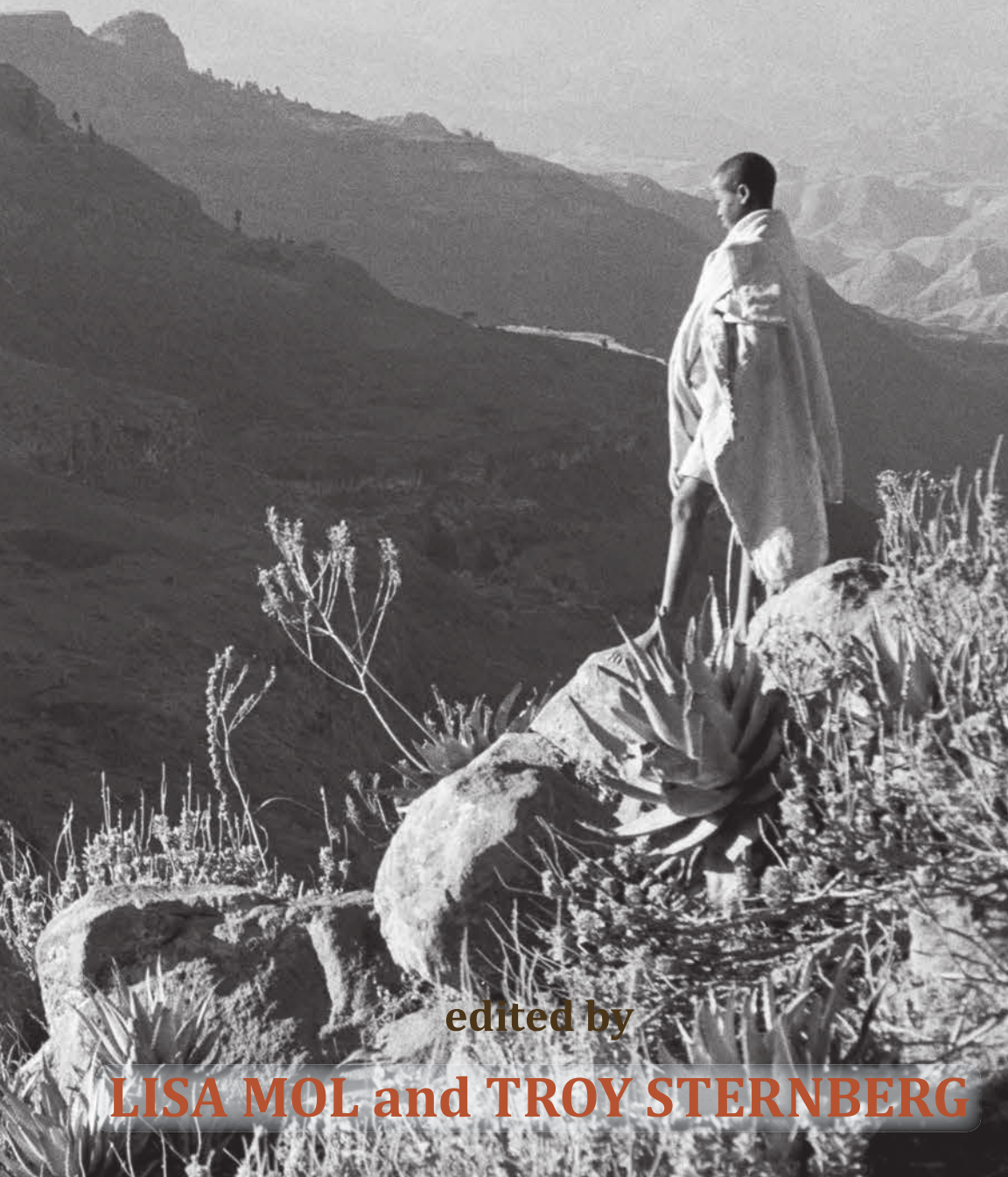


CHANGING DESERTS

INTEGRATING PEOPLE AND
THEIR ENVIRONMENT



edited by

LISA MOL and TROY STERNBERG

Changing Deserts

CHANGING DESERTS
Integrating People and their Environment

co-edited by

Lisa Mol and Troy Sternberg

The White



Horse Press

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The White Horse Press www.whpress.co.uk

The editors' names are given in alphabetical order for cataloguing purposes; the editorship was a joint enterprise.

Set in 10 point Adobe Garamond Pro

OPEN ACCESS version published 2022

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Cover illustration: View of an escarpment, looking northwards from Tanta (near Magdala) Ethiopia by Wilfred Thesiger, 1960. Pitt Rivers Museum, University of Oxford (2004.130.27508)

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 978-1-874267-69-0 (HB) 978-1-912186-31-0 (Ebook)

doi: 10.3197/9781912186310.book

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FOREWORD

Troy Sternberg and Lisa Mol

As Balzac said, ‘in the desert there is everything ... and nothing’.¹ It is the implied grandeur and emptiness of the natural landscape that distinguishes deserts from subtler environments. Their vastness and sense of uniqueness are matched by climate extremes, physical processes and lives carved out of natural limitations. We are drawn by absence rather than plenitude, endurance over comfort, unpredictability over the familiar, as deserts touch the limits of survival for man and all living things. Perhaps a sense of tranquillity draws humans into the desert’s embrace; in today’s world, research and a quest for understanding follows. Gathering those who work and live in deserts and drylands creates an opportunity to illuminate the variegated ways we engage with arid landforms, history, livelihoods and possibilities. It also provides a window on the hardships and challenges that are connected to life in constantly changing extreme environments.

Once the redoubt of the indigene, wanderer and aesthete, the poet’s idealised land of ‘god without mankind’ is framed by certainties and myths from afar. Drylands are equally home to teeming cities, scars of resource extraction and nuclear testing, skeletons born of extremes and processes that reduce a pristine conception to an ordinary reality. Into lands of contrast and contradiction people for millennia have entered, dragging the accoutrements of life and outsized hopes – grand canals, agricultural schemes and railways covered in sand litter the drylands. For archaeologists the desert environment preserves the material of their pursuit; geologists and geographers are engrossed by questions of landscape, wind and water. Whilst anthropologists and historians may see mankind past and present, social scientists find the processes, development and relations that shape our world. Deserts host as many versions and conceptions of life as people living within their limitations. A certain magnetism attaches people to dry regions and arid lands, though possibility and variety is greater in temperate zones. This affinity breeds return, even devotion, to what outsiders may characterise as empty, harsh, minimalist; in short, a wasteland.

Against this backdrop, the 2010 First Oxford Interdisciplinary Desert Conference sought to bring together people who know parts of the desert equation, aiming to better understand a greater whole rather than just our individual pieces. The goal was to juxtapose, up-end and reconfigure our knowledge and assumptions about drylands. Leaving known disciplines meant encountering new fields, approaches, interpretations and people. This breakdown and rearrangement of the ordinary led to cooperation

1. Balzac, Honoré de (1830). ‘A Passion in the Desert’. Trans. by Ernest Dowson. Available at <http://www.gutenberg.org/ebooks/1555>

and uncertainty, two things familiar to researchers. Presentations, methods, processes differed; yet curiosity and intrigue made clear the inherent connections across fields, locations and eras. In desert environments scarce resources are preserved and treasured; so it is with research knowledge that is shared across dryland zones.

Uniting a collection of researchers from different fields, the conference had the enthusiasm of place and the interest of similar yet new dryland environments. Rather than a study-specific focus, the talks presented research to stimulate discussion between subjects and participants. The cross-discipline dynamics gave spark to the proceedings, as people researching different angles in the same regions met. Exchanging ideas across fields, presenting findings to a knowledgeable yet non-specialist audience, finding common points in diverse sites or ages and debating future directions became the theme and approach of the conference. The spirit and freshness of the conference segued into future collaboration; indeed *Changing Deserts: Integrating People and their Environment* exemplifies how researchers in fields from archaeology and geography to development and biodiversity can find related ground and shared interests.

This is a time of transition across drylands. Climate change is a constant theme; population, economics, politics and governance exert a major impact on lives and land use in deserts. Current scientific projections identify arid and semi-arid regions as most at risk of rapid environmental change and potential degradation over the coming fifty years. The idea of flux and change identified in the book title is apparent throughout the chapters. How landscapes are measured, the trajectory of human use and settlement, physical impacts on nature, often intermediated by humans, are addressed in this book, exemplifying the variability and fluctuation, even transformation, that societies and landforms are experiencing. Whilst a desert may appear static, a researcher sees it as a dynamic environment to engage with at multiple timescales. Integrating physical and social sciences encourages the reader to understand drylands from several perspectives, looking to the past and the present to anticipate the future.

The book is organised in three sections to cover changing environments, changing people and changing issues. In the first section authors explore the physical world by examining past dryland environments and their potential current use, highlighting the longstanding connection between humans, migration and deserts. In more contemporary terms, dryland environments create specific challenges for livelihoods that encompass scarce resources, evolving socio-economic forces and the role of traditional lifestyles in modernising societies. These issues are discussed in the second section of the volume. The complex issues of today include conserving the past while adapting to a present increasingly defined by climate parameters and human–environment interactions. The third section reflects how nature and society become inextricably linked in drylands. Research on water, biodiversity and natural hazards exemplify how physical dimensions influence human well-being. Increasing population pressures, settlement in marginal areas and often limited access to vital resources result in community exposure to environmental forces. The volume concludes by evaluating how knowledge

Foreword

systems, and the resultant research, policy and interaction across fields and interests, have served the world's drylands with a view towards the future.

Deserts and drylands merit our attention for several reasons. Arid and semi-arid zones cover a third of the earth's surface (Figure 1) and are home to more than a billion people, a number that is set to rise dramatically in the next fifty years. The majority of dryland inhabitants live across the developing world in Africa and Asia, where young populations and dynamic economies deal with key themes such as food and water supply limits, urbanisation, conflict and migration – topics that possess global relevance. As sparse environments, drylands are at the forefront of the climate change debate. Should precipitation and temperature patterns shift as predicted, dominant livelihoods (agriculture and livestock) will face a great number of changes and challenges. Community sustainability, development trends and migration patterns will undergo significant transformation. Further, deserts are rich in natural resources essential to modern life – oil, rare earth elements, copper, gold and coal – yet lack adequate water and arable land for expanding populations. With a better understanding of arid biomes comes awareness of the role drylands have played in the past and their significance today. Whilst we may be drawn to deserts by sweeping vistas, carved landscapes and vibrant cultures, as a group of authors it is the challenges and rewards of research that give us insight into a desert perspective of vital importance to our world. By integrating diverse disciplines we can develop a much more dynamic and multi-faceted approach to dryland studies and engagement.



Figure 1. Global drylands from hyper-arid (black) to semi-arid (gray) regions. Created by Chris van Nice, 2011.

INTRODUCTION

Andrew Goudie

THE NATURE AND DIVERSITY OF DESERTS

Extremely arid areas cover about four per cent of the earth's land surface, arid about fifteen per cent and semi-arid about 14.6 per cent. Combined, these amount to almost exactly one third of Earth's land surface area. If sub-humid areas are also included, then drylands cover about forty per cent of the total. Deserts occur in five great provinces, separated by either oceans or equatorial forests. The largest of these by far includes the Sahara and a series of other deserts extending eastwards through Arabia to central Asia. The southern African province consists of the coastal Namib Desert and the Karroo and Kalahari inland dry zones. The South American dry zone is confined to two strips – the Atacama and Altiplano along the west coast and the Patagonian Desert along the east coast but with the Monte Desert linking them. The North American desert province occupies much of Mexico and the south-western United States, including the Mojave and Sonoran Deserts. The fifth and final province is in Australia. Descriptions of the landscapes and evolution of these deserts are given in Goudie (2002), while a more systematic treatment is provided by Thomas (2011).

The main characteristics of deserts are caused by the very low levels of rainfall and extremely low levels of precipitation are a particular feature of coastal deserts. For example, mean annual totals at Callao in Peru are only 30 mm, at Swakopmund in Namibia only 15 mm and at Port Etienne in Mauritania only 35 mm. In Egypt there are stations in the Libyan Desert where the mean annual precipitation only amounts to 0.5 mm. Years may go by in such areas of extreme aridity when no rain falls at all.

According to their type, deserts have a wide range of temperature conditions. Interior deserts can be subjected to extremes of temperature, both seasonally and diurnally, that are not equalled in any other climatic region, while coastal deserts tend to have relatively low seasonal and diurnal ranges. Here the climate is modified and moderated by the presence of cold currents and upwelling. Temperature ranges over the year are low – Callao in the Peruvian desert has an annual range of only 5°C. Daily ranges in such stations are also low, often around 11°C, and only about half what one would expect in the Sahara. The annual temperature values are also generally moderate (c. 19°C in the Atacama and 17°C in the Namib). By contrast, great extremes of

temperature occur in interior deserts, with maximum shade temperatures exceeding 50°C. Temperatures in excess of 37°C may occur for many days on end in the summer but, because of the clear skies, there may be a marked reduction of temperature at night and daily ranges of 17–22°C are normal. In the winter months in high-altitude interior deserts, frost can occur frequently. A good summary of weather and climate in deserts is provided by Warner (2004).

On a large scale, one can classify deserts on the basis of their geological history into shield deserts and mountain and basin deserts. The *shield deserts*, which occur in India, Africa, Arabia and Australia (and were once part of Gondwanaland) have less relief than the mountain and basin deserts; because they do not suffer from extensive tectonic activity at present, ancient land surfaces have often survived over wide areas. In contrast, the *mountain and basin deserts*, such as those of the south-west USA or Iran, have much steeper relief and, because they are often undergoing present-day mountain-building, they tend to have sharp fault junctions between mountains and plains.

THE HISTORY OF CLIMATE CHANGES

Many deserts are of great age and the Atacama (Rech *et al.* 2010), Namib and Kalahari (Miller *et al.* 2010), Taklamakan (Sun *et al.* 2010) and some of the Sahara (Schuster *et al.* 2009) may have come into existence in the Tertiary. During the Ice Age of the Pleistocene temperature and rainfall conditions fluctuated repeatedly and many deserts were subjected to increased rainfall; such periods are called *pluvials*, or lacustral phases. Some deserts have also been subjected to even greater aridity than today: such dry phases are called *interpluvials*. Table 1 lists some of the indicators that are available for reconstructing climate changes in deserts.

There are many indicators in present desert environments of higher levels of precipitation in the past: high lake levels marked by ancient shorelines around now dry, salty closed basins; expanses of fossil soils of humid type, including laterites and other types indicative of very marked chemical changes under conditions of humidity; great spreads of *tufa*; vast river systems which are currently inactive and blocked by dune fields; and animal and plant remains, together with evidence of former human habitation, in areas now too dry for people to survive.

The evidence for formerly drier conditions includes the presence of degraded, stable sand dunes in areas that are now too wet and vegetated for sand movement to occur. Optical dating is now making it possible to date periods of sand dune accumulation and preservation.

Some of the pluvial lake basins reached colossal dimensions (Table 2), especially in the south-west of the United States, where faulting had created a large number of closed basins in which lakes could accumulate during periods of greater humidity. Lake Bonneville, near Salt Lake City in Utah, now has a water area of 2,600–6,500 km² and is highly saline – in the pluvials of the Pleistocene it had an area of 51,640 km² (almost the size of present-day Lake Michigan) and was probably relatively fresh. It was 335 m deeper than it is now.

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Table 1. Evidence for palaeoenvironmental reconstruction in drylands.

| Evidence | Inference |
|---|--|
| <i>1. Geomorphological</i> | |
| Fossil dune systems | Past aridity |
| Breaching of dunes by rivers | Increased humidity |
| Discordant dune trends | Changed wind direction |
| Lake shorelines | Balance of hydrological inputs and outputs |
| Old drainage lines | Integrated hydrological network |
| Fluvial aggradation and siltation | Desiccation |
| Colluvial deposition | Reduced vegetation cover and stream flushing |
| Karstic (e.g. cave) phenomena | Increased hydrological activity |
| Frost screes | Palaeotemperature |
| <i>2. Sedimentological</i> | |
| Lake floor sediments | Degree of salinity, etc. |
| Lee dune (lunette) stratigraphy | Hydrological status of lake basin |
| Spring deposits and tufas | Groundwater activity |
| Duricrusts and palaeosols | Chemical weathering under humid conditions |
| Dust and river sediments in ocean cores | Amount of aeolian and fluvial transport |
| Loess profiles and palaeosols | Aridity and stability |
| Cave sediments | Hydrological activity |
| <i>3. Biological and miscellaneous</i> | |
| Macro-plant remains, including charcoal (e.g. in Packrat or hyrax middens, bat guano, etc.) | Vegetation cover |
| Pollen and phytolith analysis of sediments | Vegetation cover |
| Faunal remains | Biomes |
| Disjunct faunas | Biomes |
| Isotopic composition of groundwater and speleothems | Palaeotemperatures and recharge rates |
| Distribution of archaeological sites | Availability of water |
| Drought and famine record | Aridity |
| Dendrochronology | Moisture conditions |
| Chloride concentrations in dunes | Recharge |
| Isotopic composition of calcretes, etc. | Presence of C3 or C4 plants |

Table 2. Areal extent (km²) of some pluvial mega-lakes.

| Basin | Area |
|----------------------------|-----------------|
| Caspian/Aral, Central Asia | 1,100,000 |
| Mega-Chad, Sahara | 350,000–400,000 |
| Mkagdikgadi, Botswana | 120,000 |
| Mega-Fazzan, Sahara | 76,250 |
| Bonneville, USA | 51,640 |
| Jilantai-Hetao, China | 34,000 |
| Lahontan, USA | 30,000–35,000 |
| Eyre, Australia | 25,260 |
| West Nubia, Sudan | 7,000 |
| Mega-Frome, Australia | 6,500 |

Likewise, on the margins of the Sahara, Lake Chad underwent major changes in level: it may have been about 120 metres deeper than it is now and it extended for hundreds of kilometres north of its present limits. In central Asia there was another colossal lake, in the area of the present Aral and Caspian Seas, that covered over 1.1×10^6 km² and extended 1,300 km up the Volga from its present mouth.

The dates for these more humid phases are still the subject of great discussion. In general, it appears that in the American south-west the high lake levels were broadly contemporaneous with the last major expansion of the great ice caps (around 18,000 years BP) but in areas like the margins of the Sahara and in East Africa the last major lake expansion phase (probably one of many) took place just after the start of postglacial times (around 9,000 years BP). Large expanses of the tropics were dry shortly after the Last Glacial Maximum.

There was an abrupt climate event at 8,200 cal yr BP (the 8.2 ka event) that interrupted an otherwise humid period (Brooks 2006). Around 4,200–4,100 cal yr BP evidence for another major shift in climate from a number of regions of the globe has been recognised. A pronounced dry event is recorded from Red Sea sediments at around this time (Arz *et al.* 2006) and also from a core in the Gulf of Oman (Cullen *et al.* 2000), where mineralogical and geochemical analyses of the sediments revealed a large increase in windblown dust derived from Mesopotamia. A further abrupt climatic event took place in the Middle East around 3,500 to 2,500 years ago and caused devastation of some cultures and settlements (Kaniewski *et al.* 2008). In the Mojave Desert, fans and lakes responded to the climate changes of the Medieval warm period and the Little Ice Age (Miller *et al.* 2009), while in Arizona fan aggradation occurred from 3,200 to 2,300 years ago when there was an intensification of the ENSO circulation.

It is apparent from the study of meteorological records, dating back in some cases to the middle of the last century, that appreciable fluctuations may still take place. Thus, for example, in the 1930s a period of greatly reduced rainfall and higher-than-average temperatures in the United States contributed to the extreme wind erosion and dust blowing of the 'Dust Bowl' years (Anderson *et al.* 2007).

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Likewise, since the late 1960s, a great belt, extending from Mauritania in the west to the Sudan in the east, has suffered from a series of prolonged and serious droughts, with rainfall only around two-thirds of the long-term mean. This has caused extensive famines and led to great pressure on the limited vegetation available for grazing animals on the desert margins. Severe land degradation and erosion have ensued.

Climatic changes have had great impacts on humans and there is now a great deal of interest in the ways in which human populations in deserts have flourished, declined and migrated (e.g. Parker and Goudie 2008, Staubwasser *et al.* 2003).

CURRENT TRENDS

The growth in human population, its concentration in ever-larger urban centres and its increasing impact, are of great environmental significance.

In terms of population growth while the global population increased by 2.38 times between 1950 and 2000, growth in the dryland countries shown in Table 3 was considerably greater, averaging 3.74 times. Within some individual countries, dryland states grew more than the average.

Table 3. Population of selected dryland countries (millions).

| Country | 1950 | 2000 |
|----------------------|--------|--------|
| Egypt | 21.80 | 67.90 |
| Yemen | 4.36 | 18.35 |
| Saudi Arabia | 3.20 | 20.35 |
| Burkina Faso | 3.96 | 11.54 |
| Peru | 3.52 | 11.35 |
| Chad | 2.66 | 7.89 |
| Jordan | 0.47 | 4.91 |
| Libya | 1.09 | 5.29 |
| Oman | 0.46 | 2.54 |
| Kuwait | 0.15 | 1.91 |
| United Arab Emirates | 0.07 | 2.61 |
| Namibia | 0.51 | 1.76 |
| Botswana | 0.39 | 1.54 |
| Djibouti | 0.06 | 0.63 |
| Qatar | 0.03 | 0.57 |
| Western Sahara | 0.01 | 0.25 |
| Algeria | 8.75 | 30.29 |
| Syria | 3.50 | 16.19 |
| Iran | 16.91 | 70.33 |
| Pakistan | 39.66 | 141.26 |
| Total | 111.56 | 417.76 |

Source: UN data processed by author

Drylands have also seen rapid rates of urbanisation. Indeed, as Table 4 shows, there are now some enormous urban agglomerations.

Table 4. Estimated population of major dryland urban areas, 2010 (millions).

| | |
|-------------|-------|
| Cairo | 17.29 |
| Los Angeles | 14.78 |
| Karachi | 13.09 |
| Tehran | 8.17 |
| Lima | 8.00 |
| Lahore | 7.11 |
| Baghdad | 5.85 |
| Khartoum | 5.18 |
| Riyadh | 4.74 |
| Alexandria | 4.30 |
| Jedda | 3.18 |
| Jaipur | 3.05 |

The growth of cities has been substantial. As Table 5 suggests, the average size of major dryland cities expanded 7.9 times between 1950 and 2000. The footprint of such cities is enormous. They require water, fuel, building materials, food, space for construction, and room for recreation.

Desert environments may be very difficult to develop without unfortunate environmental consequences. In recent years the fear has been expressed that human actions may even be leading to the spread of desert-like conditions – a process termed *desertification*. Not everyone is agreed as to the nature or causes of the spread of desert-like conditions and the question has been asked whether this process is caused by temporary drought periods of high magnitude, is due to a longer-term climatic change towards aridity, is caused by human-induced climatic change or is the result of human action in degrading the biological environments in arid zones. Most people now believe that it is produced by a combination of increasing human and animal population levels, which causes the effects of drought years to become progressively more severe, so that the vegetation is placed under severe stress – by overgrazing, by cultivation of marginal areas, by burning shrub vegetation to increase the area of pasture and by collection of wood for fuel. The removal of vegetation sets in train the operation of such insidious processes as deflation and water erosion. These further reduce the utility of the available land. Major treatments of desertification include that of Middleton and Thomas (1997).

Table 5. Population of selected dryland cities in 1950 and 2010 (millions).

| City and country | 1950 | 2010 |
|---------------------------|-------|--------|
| Cairo, Egypt | 2.41 | 12.66 |
| Ouagadougou, Burkina Faso | 0.03 | 2.55 |
| Ndjamena, Chad | 0.04 | 1.58 |
| Lanzhou, China | 0.32 | 2.10 |
| Alexandria, Egypt | 1.04 | 5.53 |
| Jodhpur, India | 0.18 | 1.22 |
| Tehran, Iran | 1.04 | 8.71 |
| Esfahan, Iran | 0.18 | 3.92 |
| Alma Ata, Kazakhstan | 0.32 | 1.29 |
| Kuwait City, Kuwait | 0.09 | 1.51 |
| Bamako, Mali | 0.06 | 2.13 |
| Karachi, Pakistan | 1.03 | 16.61 |
| Lima, Peru | 0.97 | 8.84 |
| Riyadh, Saudi Arabia | 0.11 | 4.59 |
| Jeddah, Saudi Arabia | 0.12 | 2.75 |
| Damascus, Syria | 0.37 | 3.10 |
| Las Vegas, USA | 0.04 | 1.12 |
| Phoenix, USA | 0.22 | 2.86 |
| Los Angeles, USA | 4.05 | 13.86 |
| Dubai, UAE | 0.02 | 1.70 |
| Abu Dhabi, UAE | 0.01 | 1.09 |
| Baghdad, Iraq | 0.58 | 5.44 |
| Windhoek, Namibia | 0.02 | 0.23 |
| <i>Total</i> | 13.37 | 105.38 |

Source: UN data processed by author

ENVIRONMENTAL HAZARDS

Although deserts cover a third of the earth's surface, they are generally hostile environments for man and they are easily degraded. Some of the geomorphological problems they present are shown in Table 6. There are also severe climatological hazards including droughts, heat waves, photochemical smogs and *dzuds*.

Some of these hazards have been the subject of recent reviews. A general discussion of geomorphological hazards is provided by Cooke *et al.* (1982), while salt weathering is discussed by Goudie and Viles (1997) and dust storms by Goudie and Middleton (2006).

Table 6. Examples of geomorphological hazards in deserts.

| |
|---|
| <i>Aeolian</i> |
| Dust and sand storms |
| Dune movement |
| Soil erosion |
| Wind abrasion |
| <i>Fluvial</i> |
| Piping |
| Sheetfloods |
| Floods |
| Avulsion of channels |
| Arroyo trenching |
| Clear water erosion below dams |
| Soil erosion |
| Siltation behind dams |
| <i>Weathering and Mass Movements</i> |
| Salt attack |
| Salt heave |
| Debris flows |
| Landslides |
| Surface |
| Subsidence |
| Hydrocompaction |
| Collapsible soils |
| Ground fissuring |
| Sinkholes in evaporites and carbonates |
| Salt crusts over saturated ground giving 'quicksand' conditions |
| <i>Miscellaneous</i> |
| Lake expansion and shrinkage |
| Storm surges across coastal sabkhas |
| Coast erosion promoted by sediment starvation |

DESERTS IN A WARMER WORLD

It is evident that if global warming occurs, the Earth's whole climatic system will be transformed. Higher temperatures will in themselves cause rates of soil moisture loss to be greater, through their effect on rates of evapotranspiration. The IPCC (2007) suggested that in drylands temperatures could increase by between 1 and 7°C by 2017–2100 compared to 1961–1990 and that precipitation levels could decrease by as much as ten to twenty per cent in the case of the Sahara but increase by as much as

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ten to fifteen per cent in the Chinese deserts. In addition, it is likely that many areas that are currently dry, such as the Sahel (Sylla *et al.* 2010) may see enhanced aridity because of reductions in precipitation, though even within an area such as the Middle East, some parts may become wetter and some may become drier. The Saudi Arabian desert may, for instance, become wetter because of a more northerly intrusion by the Intertropical Convergence Zone (Evans 2010). There is also an emerging consensus that the south-western USA will become more arid (Seager and Vecchi 2010). Zeng and Yoon (2009) have suggested that, as conditions become drier and vegetation cover is reduced, there may be vegetation-albedo feedbacks which will serve to enhance any aridity trend. By 2099 their model suggests that globally the warm desert area may expand by 8.5 million km² or 34 per cent. However, some areas may experience more frequent hurricane activity and there may also be changes in ENSO frequency and intensity, though this latter aspect of climate change is still characterised by highly divergent model results (Latif and Keenlyside 2009).

Changes in climate could affect wind erosion either through their impact on erosivity or through their effect on erodibility. Wind erosion leads to dust storms. The nature of future dust activity will depend on three main factors: anthropogenic modification of desert surfaces (Mahowald *et al.* 2006); natural climatic variability (e.g. in the El Niño Southern Oscillation or the North Atlantic Oscillation); and changes in climate brought about by global warming. If soil moisture declines as a result of changes in precipitation and/or temperature, there is the possibility that dust storm activity could increase in a warmer world. If dust storm activity were to increase as a response to global warming it is possible that this could have a feedback effect on precipitation that would lead to further decreases in soil moisture (Miller and Tegen 1998). Munson *et al.* (2011) have also argued that, with increased drought brought about by reduced precipitation and higher temperatures, there will be a reduction in perennial vegetation cover in the Colorado Plateau and thus an increase in aeolian activity. In contrast, however, in northern China, there is some evidence that dust storm activity has decreased in recent warming decades, partially in response to changes in the atmospheric circulation and associated wind conditions (Jiang *et al.* 2009) and might decrease therefore still further in a warming world (Zhu *et al.* 2008).

Sand dunes, because of the crucial relationships between vegetation cover and sand movement, are highly susceptible to changes of climate, though there are huge challenges in predicting just how much dune systems may change (Thomas and Wiggs 2008). Detailed scenarios for dune remobilisation by global warming have been developed for the mega-Kalahari in southern Africa (Thomas *et al.* 2005).

Coastal flooding and the effects of sea-level rise can and could be a serious matter for arid zone coastlines, especially for low-lying *sabkha* areas. Among arid zone coastal environments that may be particularly susceptible to sea-level rise are deltaic areas subject to subsidence and sediment starvation (e.g. the Nile) and areas where ground subsidence is occurring as a result of fluid abstraction (e.g. California). Rising sea-levels can be expected to cause increased flooding, accelerated erosion and acceler-

ated incursion of saline water up estuaries and into aquifers. Sea-level rise is especially dangerous where there are coastal freshwater aquifers, as along the Batina coast of Oman or on the seaward margins of the Nile Delta.

CONCLUSIONS

Deserts are highly variable in their climatic conditions and in terms of their landscapes. They have a long history of environmental change at many time-scales and it is likely that these have had major impacts on the fortunes of human societies. At the same time, deserts can be hazardous environments for humans and it is likely that in a warmer world the intensity and distribution of some of these hazards may change. The other great drivers of future changes are changes in human societies themselves, with increases in human populations and burgeoning urbanisation.

REFERENCES

- Anderson, D., A.S. Goudie and A.G. Parker (2007). *Global Environments through the Quaternary*. Oxford: Oxford University Press.
- Arz, H.W., F. Lamy and J. Patzold (2006). 'A pronounced dry event recorded around 4.2 ka in brine sediments from the northern Red Sea'. *Quaternary Research* **66**: 432–41.
- Brooks, N. (2006). 'Cultural responses to aridity in the Middle Holocene and increased social complexity'. *Quaternary International* **151**: 29–49.
- Cooke, R. U., D. Brunnsden, J.C. Doornkamp and D.K.C. Jones (1982). *Urban Geomorphology in Drylands*. Oxford: Oxford University Press.
- Cullen, H.M., P.B. de Menocal, S. Hemming, G. Hemming, F.H. Brown, T. Guilderson and F. Sirocko (2000). 'Climate change and the collapse of the Akkadian empire: evidence from the deep sea'. *Geology* **28**: 379–82.
- Evans, J.P. (2010). 'Global warming impact on the dominant precipitation processes in the Middle East'. *Theoretical and Applied Climatology* **99**: 389–402.
- Goudie, A.S. (2002). *Great Warm Deserts of the World – Landscapes and Evolution*. Oxford: Oxford University Press.
- Goudie, A.S. and N.J. Middleton (2006). *Desert Dust in the Global System*. Heidelberg: Springer Verlag.
- Goudie, A.S. and H.A. Viles (1997). *Salt Weathering Hazard*. Chichester: Wiley.
- IPCC. (2007). *Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. S. Solomon *et al.* Cambridge and New York: Cambridge University Press.
- Jiang, Y., Y. Luo, Z. Zhao and S. Tao. (2009). 'Changes in wind speed over China during 1956–2004'. *Theoretical and Applied Climatology* doi:10.1007/s00704-009-0152-7.
- Kaniewski, D., E. Paulissen, E. Van Campo, M. Al-Maqdissi, J. Bretschneider and K. Van Leberge (2008). 'Middle East coastal ecosystem response to middle-to-late Holocene abrupt climate changes'. *Proceedings of the National Academy of Sciences* **105**: 13941–6.

Introduction

- Latif, M. and N.S. Keenlyside (2009). 'El Niño/Southern oscillation response to global warming'. *Proceedings of the National Academy of Sciences* **106**: 20578–83.
- Mahowald, N.M., D.R. Muhs, S. Levis, P.J. Rasch, M. Yoshioka, C.S. Zender and C. Luo (2006). 'Change in atmospheric mineral aerosols in response to climate: Last glacial period, preindustrial, modern and doubled carbon dioxide climates'. *Journal of Geophysical Research* **111** (D), doi:10.1029/2005JD006653.
- Middleton, N.J. and D.S.G. Thomas (1997). *World Atlas of Desertification*. 2nd Edition. London: Arnold.
- Miller, R.L. and I. Tegen (1998). 'Climate response to soil dust aerosols'. *Journal of Climate* **11**: 3247–67.
- Miller, D.A., K.M. Schmidt, S.A. Mahan, J.P. McGeehin, L.A. Owen, J.A. Barron, F. Lehmkuhl and R. Löhner (2009). 'Holocene landscape response to seasonality of storms in the Mojave Desert'. *Quaternary International* **215**: 45–61.
- Miller, R.McG., M. Pickford, and B. Senut (2010). 'The geology, palaeontology and evolution of the Etosha Pan, Namibia: implications for terminal Kalahari deposition'. *South African Journal of Geology* **113**: 307–34.
- Munson, S., J. Belnap and G.S. Okin (2011). 'Responses of wind erosion to climate-induced vegetation changes on the Colorado Plateau'. *Proceedings of the National Academy of Sciences* in press.
- Parker, A.G. and A.S. Goudie (2008). 'Geomorphological and palaeoenvironmental investigations in the southeastern Arabian Gulf region and the implication for the archaeology of the region'. *Geomorphology* **101**: 458–70.
- Rech, J.A. and 8 others. (2010). 'Evidence for the development of the Andean rain shadow from a Neogene isotopic record in the Atacama desert, Chile'. *Earth and Planetary Science Letters* **292**: 371–82.
- Schuster, M and 10 others (2009). 'Chad Basin: paleoenvironments of the Sahara since the Late Miocene'. *CR Geoscience* **341**: 603–11.
- Seager, R., and G.A. Vecchi (2010). 'Greenhouse warming and the 21st century hydroclimate of southwestern North America'. *Proceedings of the National Academy of Sciences* **107**: 21277–82.
- Staubwasser, M., F. Sirocko, P.M. Grootes and M. Segl (2003). 'Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability'. *Geophysical Research Letters* **30**, 1425, doi:10.1029/2002GL016822.
- Sun, J., J. Ye, W. Wu, X. Ni, B. Shundong, Z. Zhang, W.Liu and J. Meng (2010). 'Late Oligocene-Miocene mid-latitude aridification and wind patterns in the Asian interior'. *Geology* **38**: 515–8.
- Sylla, M.B., A.T. Gaye, G.S. Jenkins, J.S. Pal and F. Giorgi (2010). 'Consistency of projected drought over the Sahel with changes in the monsoon circulation and extremes in a regional climate model projections'. *Journal of Geophysical Research* **115** D16108, doi:10.1029/2009JD012983.
- Thomas, D.S.G. (ed.) (2011). *Arid Zone Geomorphology*. 3rd edition. Chichester: Wiley-Blackwell

- Thomas, D.S.G. and G.F.S. Wiggs (2008). 'Aeolian system responses to global change: challenges of scale, process and temporal integration'. *Earth Surface Processes and Landforms* **33**: 1396–1418.
- Thomas, D.S.G., M. Knight and G.F.S. Wiggs (2005). 'Remobilization of southern African desert dune systems by twenty-first century global warming'. *Nature* **435**: 1218–21.
- Warner, T.F. (2004). *Desert Meteorology*. Cambridge: Cambridge University Press.
- Zeng, N. and J. Yoon (2009). 'Expansion of the world's deserts due to vegetation-albedo feedback under global warming'. *Geophysical Research Letters* **36** L17401, doi:10.1029/2009GL039699.
- Zhu, C., B. Wang and W. Qian (2008). 'Why do dust storms decrease in northern China concurrently with the recent global warming?' *Geophysical Research Letters* **35** L18702, doi:10.1029/2008GL034886.

PART I. CHANGING ENVIRONMENT

SHEDDING LIGHT ON THE PAST: RECORDS OF PAST CONDITIONS IN THE NAMIB DESERT AND THE USE OF LUMINESCENCE DATING

Abi Stone

The Namib Desert may be one of the oldest deserts on earth and contains some of the largest dune forms found in any desert (Ward *et al.* 1983, Ward and Corbett 1990, Lancaster 1989). In total it stretches over 2,000 km along the west coast of southern Africa, covering three countries (Angola, Namibia and South Africa), bounded in the north by the Carunjamba River in Angola (14°S) and in the south by the Olifants River in South Africa (32° S) (Figure 1). The aridity in this west coast desert is the consequence of both the descent of dry air at this latitude (the descending limb of

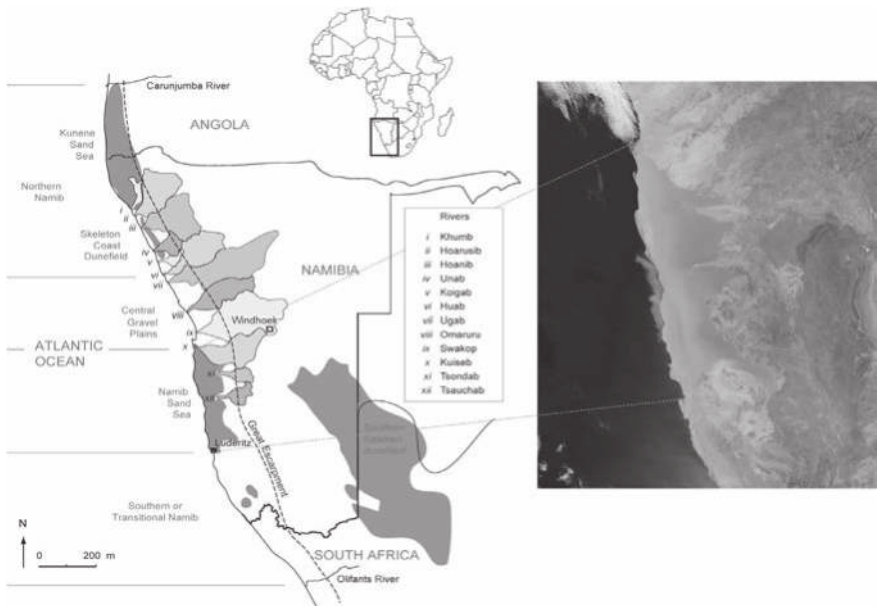


Figure 1. Map of the Namib Desert, indicating the four major regions and the twelve major ephemeral river catchments, with a satellite image of the Namib Sand Sea. Satellite image courtesy of Jacques Descloitres, MODIS Rapid Response Team at NASA GSFC, 9 January 2003.

the Hadley Cell atmospheric circulation pattern) and the cold Benguela current along the coast, which reduces the amount of moisture evaporated from the ocean (Dingele *et al.* 1996). This narrow (120–200 km wide) desert band contains a range of different landscapes from the vast and large (up to 250 m high) sand dunes in the Namib Sand Sea to the flat gravel plains of the central Namib (see the four zones in Figure 1). Despite the aridity of the region there are ephemeral rivers (experiencing occasional flow) that run from east to west across the desert. The desert is largely unpopulated, particularly in the vast Namib Sand Sea, and any settlements are found on the coast or at the eastern edge of the desert close to the Great Escarpment. It may therefore not be facetious to ask ‘why study the past conditions in this particular Desert?’; ‘of what use is this to present-day and future human populations?’

In answer to the first question there is an important link between understanding the past and being able to make predictions about the future. If we are able to understand the causes of past environmental changes in deserts (the connections between climatic forcing and environmental response) it will be easier to predict possible future changes in these diverse regions. This is important as many deserts and dryland regions are currently experiencing land and environmental degradation which pose challenges for continued sustainable human livelihoods. This is reflected in the remit of the internationally funded IGCP500 (International Geoscience Programme) *Dryland change: Past present and future*. The Programme aims to: i) ‘enhance welfare of dryland societies by contributing to a better understanding of what drives climate change and variability, environmental change and key resource availability over timescales of millennia to subdecadal’; and ii) ‘investigate the dynamics of key dryland landscape and resource elements, especially hydrological dynamics and aeolian system dynamics, and their impacts and interactions with the human use of drylands’. Therefore, whilst human population is largely absent from the Namib Desert, it is a very useful location in which to enhance our understanding of the link between changing climate and the resulting environmental response. It contains a variety of desert landscapes and, in particular, records from fluvial (river-based) and aeolian (wind-based) geomorphological systems that respond in a certain way to fluctuations in climate. The record from the past allows us to: i) establish the boundaries that the environmental system is capable of shifting between in response to climatic change, for example the range between high and low flow in rivers; and ii) how quickly the environment can respond to climatic fluctuations. Vital to this is working out *when* the changes to the environmental systems (such as rivers and aeolian dunes) occurred and how these relate to past climatic forcing. The tools for establishing *when* changes occurred are known as geochronological tools (or dating methods). Geochronology is a very important part of the research agenda of Quaternary¹ scientists to establish the order of events and the relationship between environmental response and climatic forcing. It is not trivial to highlight that in addi-

1. The Quaternary period is the most recent geological period (covering the past 2.6 million years), a time in which our own species, ‘hominins’, underwent remarkable and rapid evolution; it was marked by the advance and retreat of large glaciers from the poles, with global fluctuations

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tion to understanding the past to inform the future, the motivation for research also lies in an inherent interest in understanding the changes to the earth's environment and climate in the past.

Over the past few decades there has been rapid development in our understanding of the response of desert regions to changing climates over thousands to a few hundred thousand years ago (ka will be used as shorthand for thousands of years) of the Quaternary Period. Early ideas surrounded the expansion and contraction of desert belts (in the form of dunes and sand seas) as the global climate moved from glacial to interglacial conditions as the result of shifting boundaries of rainfall belts (Sarnthein 1978). However, a growing body of work reveals the complexity of the environmental response of desert systems to Quaternary climate change at a range of timescales. See for example the 54 papers in the volume edited by Alsharan *et al.* (1998), representing some of 120 papers presented at a conference on Quaternary Deserts and Climatic Change, held at Al Ain, UAE. Developments in understanding environmental response run parallel to developments in understanding the complexity of the climatic change itself (at global and regional scales). Reconstructing past climatic change and environmental response is a two-way, and often iterative, process. As Figure 2 illustrates, we use the evidence preserved in the environment (in sources from the ice cores at the poles to the sand dunes of the desert) to infer changes to the climate in the past. The source is often referred to as an archive and an individual parameter within that is known as a 'proxy' record. We use an understanding of the connection between present-day observed climate and the proxy records (often termed a transfer function) to refine our ability to reconstruct the past climate. This connection is not always straightforward or related to one climatic factor, such as temperature, rainfall or wind.

This chapter gives a brief outline of the range of tools (archives and proxies) that are available to investigate the past in the Namib Desert and then focuses on the information that has been gained from using luminescence dating as a geochronological tool to work out *when* changes occurred in the past. There have been a number of important developments over the past decade for both fluvial (water-lain) and aeolian (wind-blown) sediments: i) application of luminescence dating to replace previous unreliable radiocarbon age estimates; ii) application of luminescence dating alongside newly applied, detailed interpretive approaches (known as lithofacies approaches) of the fluvial sediments that clarify the environmental and climatic interpretation of the deposits; iii) a new understanding of the age and migration of large complex linear dunes in the northern Namib Sand Sea; iv) an attempt to establish the timing of dune development in the southern transitional Namib; and v) the age of fine-grained loess material in the eastern margin of the northern Namib.

between colder (glaciations) and warmer periods (interglacials) that impacted the climate and environmental conditions at all latitudes, including the earth's great deserts.

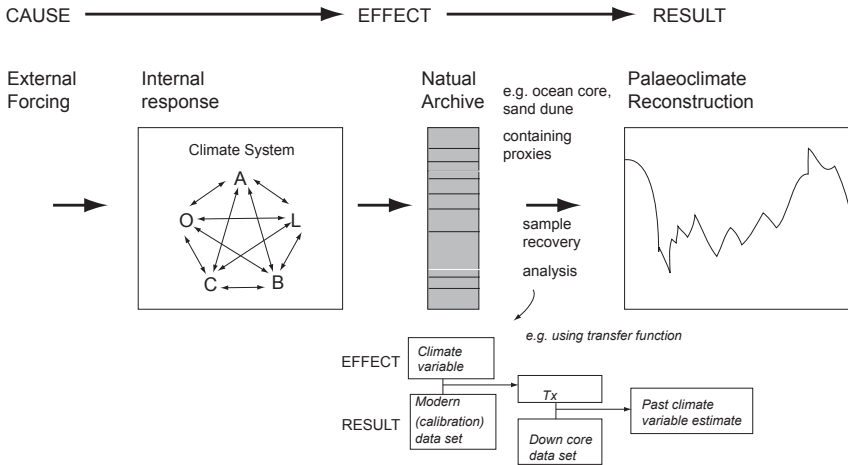


Figure 2. Schematic diagram of the relationship between climatic forcing and the signal preserved and reconstructed from the sedimentary record. After Bradley 1999.

PAST CONDITIONS IN THE NAMIB DESERT

In order to understand something about past environmental and climate change in the Namib Desert it is useful to sketch out features of the modern day climate. Figure 3a shows the rainfall pattern, with the strong west to east gradient, only 10–20 mm per year at the coast, up to ~200 mm at the very eastern edge of the desert. In addition to the descending limb of the Hadley cell and the cold Benguela current, the presence of the South Atlantic Anticyclone (SAA) (Figure 3b) produces offshore winds which contribute to aridity in this Desert (Van der Merwe 1983). The rainfall has a strongly seasonal pattern. There is a summer rainfall zone (SRZ, receiving > 66 per cent of rainfall between October and March) and a winter rainfall zone (WRZ, > 66 per cent of precipitation between April and September) (Tyson 1999). In the former, moisture comes from the east and is influenced by the position of the ITCZ (Inter-Tropical Convergence Zone) (Figure 3b, i) and in the latter it comes from the west (Figure 3b, ii).

It is understood that there have been variations in the circulation features shown in Figure 3b, such as the ITCZ in the atmosphere and the temperatures and currents in the ocean, during the Quaternary period. There have been a number of conceptual models proposed describing how these features might have changed in position and intensity (reviewed by Deacon and Lancaster, 1988). More recently, numerical models of the earth's climate (General Circulation Models, GCMs) (Broccoli *et al.* 2006, Chiang *et al.* 2003) and a range of proxy data (e.g. Koutvas and Lynch-Stieflitz 2004, Peterson *et al.* 2000) demonstrate how the drastic cooling and warming in northern hemisphere high latitudes, associated with the build up and retreat of the ice sheets, have had an

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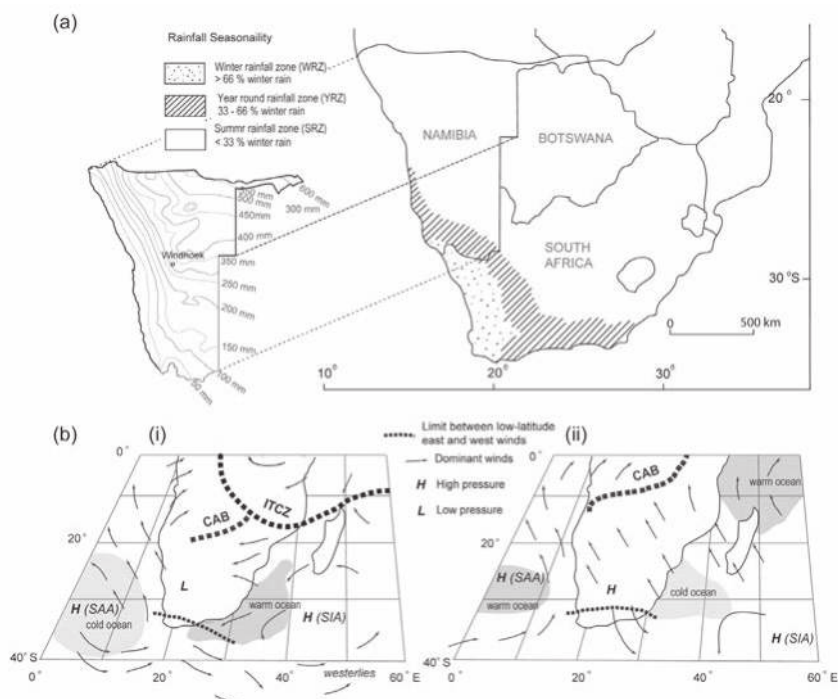


Figure 3. (a) rainfall annual totals and seasonality in Namibia and (b) illustration of major atmospheric and oceanic circulation features that affect the Namib Desert for (i) austral summer and (ii) austral winter (ITCZ is the Inter-Tropical Convergence Zone, the CAB is the Congo Air Boundary).

influence on climatic features over the southern hemisphere and the Namib Desert. Fluctuations in sea ice around Antarctica have also affected features over southern Africa, as have changes to the strength of the earth's monsoon systems that originate nearer the equator. For example, the monsoons involve movements of the position of the ITCZ and therefore receipt of rainfall in southern Africa, particularly in the SRZ (for example, this is suggested from the sediment record of the past at Tswaing Crater by Partridge *et al.* 1999).

TYPES OF EVIDENCE FOR PAST ENVIRONMENTAL CONDITIONS IN THE NAMIB DESERT

In addition to the fluvial and aeolian deposits that will be described in some detail, the Namib Desert contains sediments and chemical precipitates that relate to specific environmental conditions and can also be used to infer past changes in climatic parameters (things such as rainfall and temperature). The following gives a flavour of the

types of evidence that exist, where they are found, how old they might be and what they might tell us about the past.

Gypcretes and calcretes

These are found on the gravels and rocky surfaces of the central Namib Plain (Figure 1). It can take up to 10,000 years for a crust of a few millimetres to form (Heine 1998). Fog from the coast (Atlantic Ocean) carries dissolved salts that form surface crusts as the moisture moves downward. Heine (1998) suggests that the preservation of these gypcretes indicates no major changes to rainfall in the desert, because rainfall can erode and remove them. It is, however, difficult to establish the age of these deposits. In contrast to gypcretes, the formation of multiple layers, or generations, of calcrete (calcium-carbonate based precipitate) has been used by Eitel (1993) to suggest there have been repeated phases of dry and wet conditions. It is also difficult to establish accurate ages for calcretes. Additionally, the inferences about past rainfall are limited because the processes that form them can operate under a wide range of conditions, from as little as 50 mm to as much as 600 mm annual rainfall.

Cave deposits and spring tufa

There are not many cave sites in the Namib Desert. Inactive speleothems within the Rössing Cave on the central Namib Plains indicate higher rainfall than at present. This is because formation of these calcium carbonate cave deposits requires water to flow through the rock above the cave, to dissolve calcium carbonate and re-precipitate it inside the cave as the water drips from the cave roof. The bulk of the deposit accumulated between 800–100 ka ago, whilst the outer layer is 19–15 ka old (Heine 1998). Calcium carbonate deposits are also formed in rivers and are known as tufa. These are found in the Kuiseb River (Ward, 1984; Vogel, 1989) and inland in the tributary streams of the Tsondab River in the Naukluft Mountains (Brook *et al.* 1999, Viles *et al.* 2007, Stone *et al.* 2010a). Again, presence of these deposits indicates flowing water and thus more rainfall. The Hudoab Tufa of the Kuiseb was dated using radiocarbon but there are reasons to question the reliability of dates using this method on this type of deposit. Attempts to apply uranium series dating to the Naukluft Tufa encountered a number of significant challenges. However, there is good evidence to suggest that much of these very large (cascades 100 m high and 50 m wide) tufa systems was deposited before 350 ka, with later deposition ~ 80 ka and as recently as 4–1 ka (Stone *et al.* 2010a).

Faunal and plant remains

In an arid environment it is rare to find preserved biological evidence such as grains of pollen (known as palaeoecological proxies). However, one type of deposit in which they are well preserved is fossil middens (the preserved dung of hyrax) (e.g. Scott *et*

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al. 2004, Chase *et al.* 2009). Hyrax pollen records indicate what sort of vegetation was growing in the desert in the past. A record from the Daures Massif on the central gravel plains shows vegetation at the last glacial maximum (last peak in global ice volume, ~ 29–19 ka) contained fewer succulents, grass and woody elements than at ~ 10 ka. However, the record is low resolution (just four snapshots in time) and no clear inferences about climate shifts have been drawn (Scott *et al.* 2004). Middens also contain preserved isotopes of carbon and nitrogen. The isotopes are influenced by shifts in vegetation type and temperature in the past. At Klein Spitzkoppe on the central Namib Plains these suggest there have been fluctuations between wet and dry conditions over the past 10 ka, with wetter conditions 8.7–7.5 ka, 6.9–6.7 ka, 5.6–4.9 ka and 4.2–3.5 ka ago (Chase *et al.* 2009). Samples were taken from many more than four levels, creating a higher resolution record of past climate change; it is possible to see shifts occurring in under 200 years.

Archaeological evidence

Past human populations have left artefacts in the landscape that can also be used to infer what the environment might have been like from the very fact that people could survive there and the kind of lifestyle they were living. There are many sites in the Namib Desert containing Early and Middle Stone Age (a period of African prehistory spanning ~300–50 ka) artefacts (e.g. Corvinus 1983, Vogelsang, 1998) and particularly along the Kuiseb River valley, which would have been an important source of water. Radiocarbon dates from charcoal in the Mirabib rock shelter of ~ 8 ka and ~ 5 ka suggest this site was occupied sporadically (Sandelowsky, 1977), maybe by herders living in the Kuiseb valley (22 km to the south). A layer containing sheep hair has been dated to ~ 1.5 ka ago, suggesting early domestication of animals (Sandelowsky *et al.* 1979). There are also micromammalian bones, the assemblages of which suggest a moister habitat with greater grass coverage ~ 6.5 ka ago (Brain and Brain, 1977).

Luminescence dating

Luminescence dating is one of a group methods used to determine the age of sediments and materials. For a highly accessible introduction to this technique see Duller (2008). In short, it uses the emission of light in minerals, such as quartz, to establish the time that has elapsed since a sediment was last exposed to light. Therefore, a luminescence age represents the age of a depositional event, at which time the sediment is no longer exposed to light. In the laboratory the mineral is either heated (Thermoluminescence, TL) or has blue, or green, light shone onto it (Optically Stimulated Luminescence, OSL) to cause the mineral to release/emit a measurable signal of light in the ultra violet part of the spectrum.

LUMINESCENCE DATING THE RECORD OF THE PAST: I – THE FLUVIAL RECORD

There are twelve ephemeral rivers on the west coast of Namibia (Figure 1). These contain sequences of terrace sediments, which record past changes to river flow regimes. The oldest terraces contain boulders and gravel, whilst the younger are made of gravel, sand and silt suggesting a decrease in river flow through time (Korn and Martin 1955). However, the record is more complex with additional information provided by the spatial extent of former river courses. In addition, the specific characteristics of different depositional layers (e.g. grain size, structures within the sedimentary layers and the relationship between different units) can be used to make detailed interpretations about the type of river flow and from this infer information about the climate. OSL has been applied at sites along former river courses, in some instances revising previous chronologies, and also to individual units. In both cases this was in order to establish *when* the rivers flowed and deposited sediment.

OSL to revise the timing of Tsondab River deposition

River sediments are found at sites further west into the Namib Desert than the river reaches today. In order for the rivers to have reached these sites there must have been a considerable amount more water flowing than at present, fed by higher rainfall. OSL has been used to work out *when* this occurred. For the Tsondab River (Figure 4, river xi) OSL revises a previous chronology provided by another method, known as radiocarbon dating, that was applied to carbonate-rich water-lain material. Carbonate-free sand found between the carbonate-rich units is suitable for OSL dating.

Three sites along a former course of the Tsondab River have been dated using OSL: Narabeb, 60 km west of the current end point; Hartmut Pan, 55 km west of the end point and Ancient Tracks, just 5 km west of the end point (Stone *et al.* 2010b). To have reached the first two of these sites the river must have carried a considerable amount of water, overcoming losses into the sand and also via evaporation. Additional evidence about the moisture conditions in the past comes from preserved diatom remains at Narabeb, which suggest some permanence of water body rather than ephemeral flooding (Teller and Lancaster, 1986). OSL ages suggest the 35 m thick sequence at Narabeb is between 68.3 ± 5.7 and 132.3 ± 5.7 ka (with a single central age estimate of $\sim 110 \pm 4$ ka) (Stone *et al.* 2010b). These ages fall within the last interglacial period (known as marine oxygen isotope stage 5, MIS 5, spanning 128–74 ka) and are much older than the radiocarbon estimates of 20–30.8 ka (Teller *et al.* 1990). There are a number of reasons why dating carbonates using radiocarbon dating might be problematic (e.g. Geyh and Eitel 1998; and see the discussion in Stone *et al.* 2010b). The deposits at Hartmut Pan are dated to between 16.9 ± 0.6 and 12.7 ± 0.1 ka (not previously dated). At Ancient Tracks OSL ages bracket the water-lain units to 12.8 ± 0.8 – 12.0 ± 0.7 ka and 11.5 ± 0.5 – 10.5 ± 0.5 ka, revising radiocarbon ages of 16.2–15.4 ka. Together

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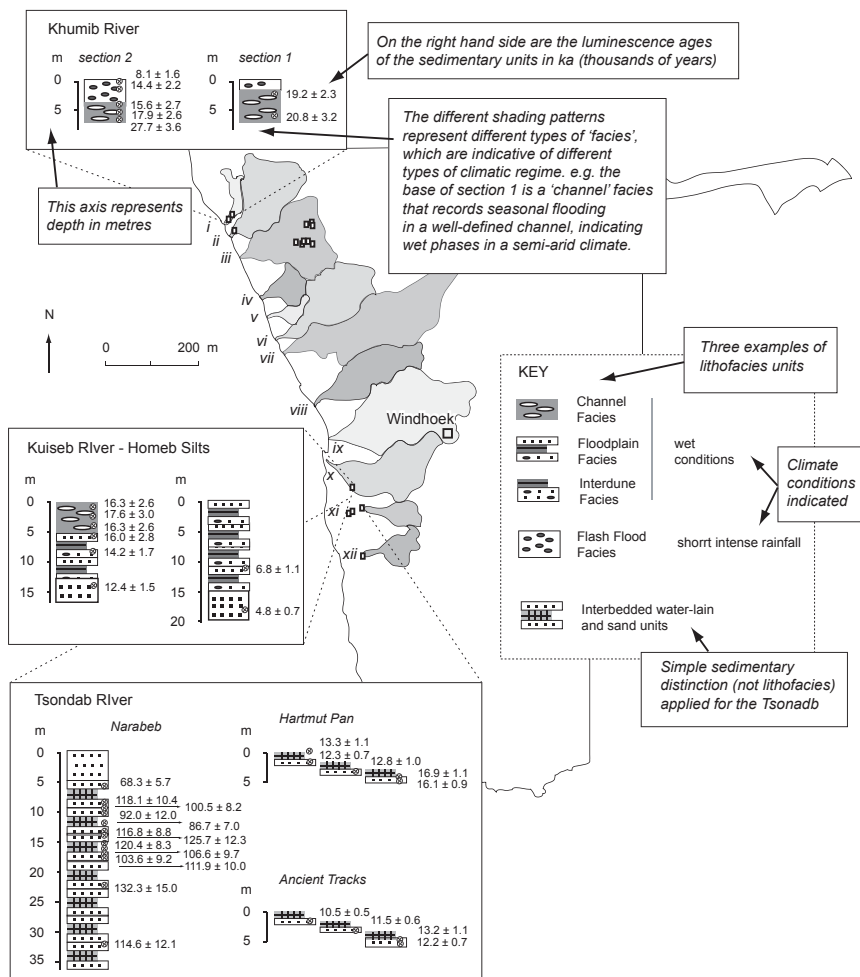


Figure 4. Sediments and OSL ages for the fluvial deposits on the west coast using simplified representations of the fluvial lithofacies associations. Source: simplified from Stone and Thomas in press, which depicts all five catchments.

the OSL chronology from these three sites revises the timing of the progressive drying up of the former Tsondab River since the last interglacial.

The next step in the process of environmental reconstruction is to look for potential correspondence in timing of these units with other proxy records from the region. Summaries of the proxy evidence and past climatic conditions in southern Africa that cover the Namib Desert have recently been provided by Chase and Meadows (2007) and Gasse *et al.* (2008). Producing these summaries is not a simple task and these two

syntheses contain some contradictory conclusions about how the past environment and climate of the region have evolved. Contradictions exist for a number of reasons: i) different interpretations of the environmental significance of particular archives and proxies; ii) a spatial complexity of weather systems; and iii) because the rivers originate to the east of the desert in the Great Escarpment they import a signal of past change from a different geographical region. Stone *et al.* (2010b) discuss how there is greater correspondence in timing of the deposition of the former Tsondeb River sediments with proxy records for increased rainfall in the interior of southern Africa (the current SRZ) than with marine proxies off the west coast. The understanding of environmental and climatic fluctuations is still incomplete for this region.

OSL and new interpretations of fluvial silt deposits

In a further five of the twelve ephemeral west coast rivers OSL has been applied to establish *when* sedimentary units were deposited by rivers alongside using a more detailed lithofacies interpretive approach. The lithofacies approach allows scientists to infer the climatic conditions that led to the deposition of particular, and distinct, types of river sediment. In technical terms this means using physical sedimentary structures, grain size and indicators of disturbance to identify units that are indicative of a particular style of river flow (Miall 1987). The practical implications are that it is easier to reliably distinguish between superficially similar sediments, for example between flood deposits (which indicate wetter conditions) and river end-points (which indicate drier conditions), and to make more certain inferences about past climate. Such distinctions have been confused and contested in the past, particularly in the case of the Homeb Silts, which have been formally interpreted as dry climate indicators (e.g. Goudie 1972, Rust and Wienke 1974, Marker and Muller 1978) and as wet climate indicators (Ward 1987, Smith *et al.* 1993, Heine and Heine 2002). The consensus is now that these sediments record a transition from dry to wetter conditions (Srivastava *et al.* 2006).

The records from the five rivers are considered briefly from north to south. The northernmost river, the Khumib, differs from the others in that the entire catchment is found within the desert zone (the Skeleton Coast dunefield). This means that the sedimentary record records changes to rainfall over the desert itself, rather than also recording changes in rainfall to the east in the Great Escarpment (from which the other rivers originate). The two lithofacies associations at this site are a lower 'channel facies', representing seasonal flooding in a well-defined channel (wet phases in a semi-arid climate) dated to between 27.7 ± 3.6 and 15.6 ± 15.6 ka, and an upper 'flash flood facies', indicating shorter, intense periods of rainfall such as storms, with two dated events at 14.2 ± 2.2 ka and 8.1 ± 1.6 ka (Srivastava *et al.* 2004) (Figure 4, river i).

The Hoaruib River contains an older record of fluvial deposition with a twenty-metre thick 'channel facies' (known as the Clay Castle Silts), OSL dated to 42 ± 8 ka (Srivastava *et al.* 2005). This facies indicates a vertically aggrading river, which needs sufficiently high rainfall input. Further upstream a 'back-flow' facies indicates water spilling over the main channel into a tributary and a 'silt and massive sand facies'

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indicates that sand from the desert was washed into the channel under higher rainfall. Dates from these units suggest two past phases of rapid sediment deposition under wetter climate conditions than present at $\sim 44\text{--}40$ ka and $\sim 33\text{--}29$ ka.

The third river record, the Hoanib, contrasts with the previous two. Whilst it is also a fine-grained deposit, it represents a river-end deposit rather than a flood deposit and therefore drier conditions than present (Eitel *et al.* 2006). The samples are taken from the upper reaches, further inland, in contrast to downstream in the other catchments. Detailed sediment descriptions give good reason to differentiate this from the flood-style deposits. For example, the sediment covers the bottom of the valley, which shows it was not deposited by repeated high energy deposition, and the structures within the layers of the sediment suggest low, rather than high, energy river flow. OSL dates from eight different sites indicate three phases of deposition, $60\text{--}40$ ka, $34\text{--}24$ ka and $9\text{--}5$ ka ago.

In the Kuiseb River, the Homeb Silts contain both a 'channel facies' (indicating river flow of < 1 m per second) and a 'floodplain facies' (sediment deposited over the banks of a river, not constrained to a channel) (Srivastava *et al.* 2006) (Figure 4, river x). These sediment characteristics together with OSL ages indicate two phases of rapid sediment accumulation in the past at ~ 15 and ~ 6 ka under a climate that was in transition from dry to wet conditions. At this site OSL revises previous radiocarbon age estimates of $27\text{--}22$ ka (Vogel 1982).

The final catchment is the Tsauchab River and this contains an 'interdune facies' (representing sheet water flow over dune slopes during high floodwater from the main river channel) and a 'channel facies' (indicative of a river with sufficient flow and energy to build 3D bedforms inside the channel) (Brook *et al.* 2006). OSL places the former in a long window of time in the past (24.6 ± 2.1 ka to 4.3 ± 0.5 ka) but with the greatest thickness of sediment deposited ~ 9.15 ka ago. The channel deposition is much younger (~ 900 to 300 years ± 100 years).

Looking at the list of dates in the above text it is evident that these rivers do not each contain the same history of events; even neighbouring catchments do not contain a comparable record. This might be a preservation issue or a sampling issue. Older events recorded in one catchment may not be preserved in another, having been eroded and removed by subsequent events, whilst younger sediments may not been found or sampled. Another possibility is that the records are complete and there were small-scale spatial variations in rainfall receipt. This may not be surprising given the modern-day situation in which there is a strong west-to-east rainfall gradient (Figure 2a). In addition, each river has a different size catchment, with the larger catchments covering inland regions, subject to potentially different climatic forcing from the coast. Apparent contradictions of wet and dry conditions during the same time slices highlight that drawing comparisons across the north-south extent of the desert is complicated. However, it is perfectly possible that changes in past climate were not gradual and unidirectional. As the global climate moved from glacial to interglacial conditions (and vice versa) there are likely to have been shorter-scale fluctuations (with both wet and dry

conditions) superimposed upon the trend. The challenge for environmental reconstruction is that the temporal resolution that is possible in dating (error of about ten per cent on a 20 ka sample represents two thousand years) cannot adequately capture the speed of depositional events during rapidly fluctuating climatic conditions (for example over a century, decade, year or season). This means that wet and dry events happening on short timescales become conflated within the resolution of dating.

LUMINESCENCE DATING THE RECORD OF THE PAST: II – THE AEOLIAN (WIND-BLOWN) RECORD

Age of linear dunes in the Namib Sand Sea

Whilst detailed descriptions of the large (up to 250 m high) dune features of the Namib Sand Sea have been undertaken (e.g. Lancaster 1989) the age of the dunes had not been well constrained. It is only recently that OSL has been applied anywhere in this vast sand sea. What is known is that the Namib Sand Sea is underlain by a Tertiary aged (Tertiary spans 65.5–2.6 million years ago) deposit called the Tsondab Sandstone, which represents an older, fossilised, Sand Sea and is part of the evidence for a long history of aridity along the west coast of Namibia (Ward *et al.* 1983). The Namib Sand Sea is thought to have formed from material derived ultimately from the Orange River in South Africa and transported northwards (Rogers 1977); however it has also been argued that the underlying Tsondab Sandstone provides some of the material that makes up the modern sand sea (e.g. Besler and Marker 1979).

OSL has been applied to two dune features in the far northern extent of the Namib Sand Sea (Figure 5) alongside a technique known as Ground Penetrating Radar (GPR) that can be used to identify layers within the dunes (known as stratigraphic units). The first is Station Dune, a short (~ 5 km long) linear dune terminating at the Kuiseb River, which was sampled across the shallow (~ 18 m high) southern edge (Figure 5a) and the second is a complex linear dune, known as Warsaw Dune, reaching sixty metres high (Figure 5b). The ages from both dunes are perhaps surprisingly young given the reports in antiquity of the Namib Sand Sea. The Station dune ages are 1.57 ± 0.07 , 0.99 ± 0.05 and 0.34 ± 0.02 ka (Bristow *et al.* 2005), whilst the oldest ages from Warsaw dunes are 5.73 ± 0.36 ka (Bristow *et al.* 2007). The youth of these dune features indicates that these dunes have moved to their present position during the past 6 ka and does not mean that dunes did not exist during older periods in the past. The pattern of the layers and ages show that linear dunes are more mobile than many researchers expected, with an east to west movement of these north–south oriented features at an average rate of ~ 0.1 m per year (Figure 5). This is an important finding, given the controversy as to how linear dunes form and grow (e.g. Rubin *et al.* 1990).

It remains unclear whether these two dated dunes are representative of other areas of the Namib Sand Sea. The far northern extent of the dunefield is considered to be 'extending' and therefore youngest part of the dunefield. Preliminary measurements

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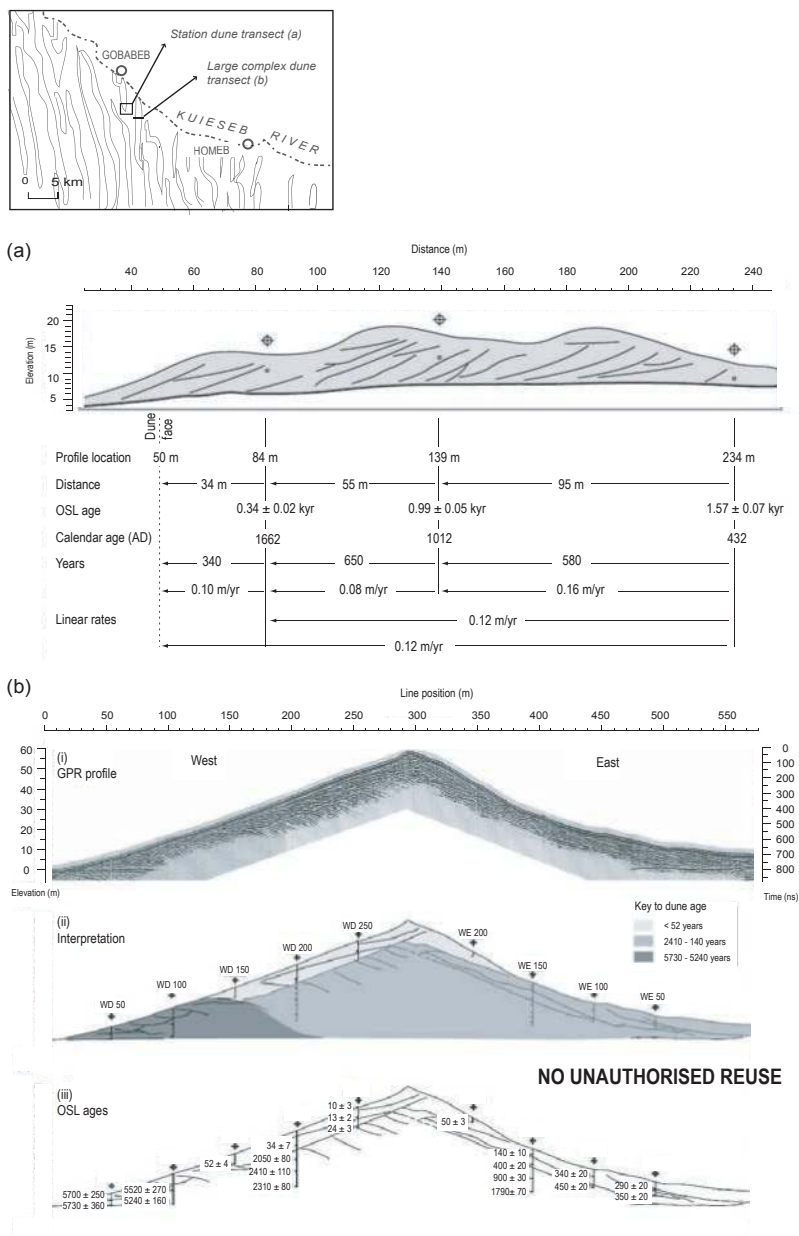


Figure 5. OSL ages and GPR (Ground Penetrating Radar) results showing age, accumulation and migration rates of (a) Station Dune, after Bristow *et al.* 2005 and (b) a complex linear dune, after Bristow *et al.* 2007. Material reprinted with permission from C. Bristow and the Geological Society of America.

by the author on samples just south of the Tsondab Flats (which is ~ 100 km east and 60 km south of Station dune) suggest there are deposits at least 40 ka old.

Accumulation of small dunes in the transitional Namib

In the southern, transitional Namib between the Olifants River and the Orange River (Figure 1) smaller dune features have been OSL dated (~ 1.6 m high accumulating coversands and migrating dunes) (Chase and Thomas 2006, 2007). The approach here was to establish the timing of dune accumulation across a larger spatial area than individual dunes. To do this samples for dating were taken progressively with depth at a number of sites without additional information about sedimentary units (unlike in the Namib Sand Sea where GPR data was collected). The OSL ages from individual sites were then combined together to try to produce a record of sand accumulation at the spatial scale of the dunefield (as has been applied in the Kalahari, e.g. Telfer and Thomas 2007). Chase and Meadows (2006, 2007) suggest there were periods of more intense dune accumulation at multiple periods in the past (74.5-61, 48.5-41, 33-31 and 23.5-16 ka for cover-sands and 17-12 and 8-4 ka for migrating dunes) and that these periods correspond best with a proxy record for wind strength from an ocean core.

However, there are methodological issues in making these claims for spatial scales as large as the dunefield. Ages were combined from individual sites by being grouped into 1 ka time slices and producing a five-point moving average line plot; and these were made from relatively small datasets (six sites and 34 cover-sand ages, and fifteen sites and 47 accumulating dune ages). The peaks in the height of this line are like higher bars on a histogram and are used to infer periods of more intense sand accumulation. The problem is that the pattern of peaks produced from any OSL dataset is not solely a reflection of sand accumulation across the dunefield (in response to climatic forcing). The pattern is also influenced by: i) where in the dunefield samples have been taken (spatial sampling strategy), ii) the number of samples taken with depth per sampling location (vertical sampling strategy) and iii) the preservation potential of the system (how much of the sand record has been removed or reworked). It has been shown that changing the sampling strategy (by removing some spatial sites or vertical samples) alters the pattern of apparent sand accumulation (e.g. Stone and Thomas 2008, Stone 2009). This suggests that we need larger sample size of OSL ages before periods of dune accumulation can be identified reliably to reconstruct the environmental response of a whole dunefield region.

Desert loess

In the northern Namib Desert there are substantial deposits of loess (a fine-grained, wind-blown deposit) at the eastern margin of the desert, now dissected (cut into) by the ephemeral rivers (e.g. Brunotte and Sander 2000, Eitel *et al.* 2001, Brunotte *et al.* 2009). The environmental interpretation is that these formed under a semi-arid climate with weak summer rains and a long dry season (Eitel *et al.* 2001). Detailed

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sedimentological descriptive work allows the environment under which this material was deposited to be inferred (it is easily told apart from both fluvial sediments and poorly-sorted colluvial deposits). These loess sediments have largely been dated using TL, rather than OSL. This may lead to an overestimation of age in samples (as a residual luminescence signal can be left in the sediment following exposure to light

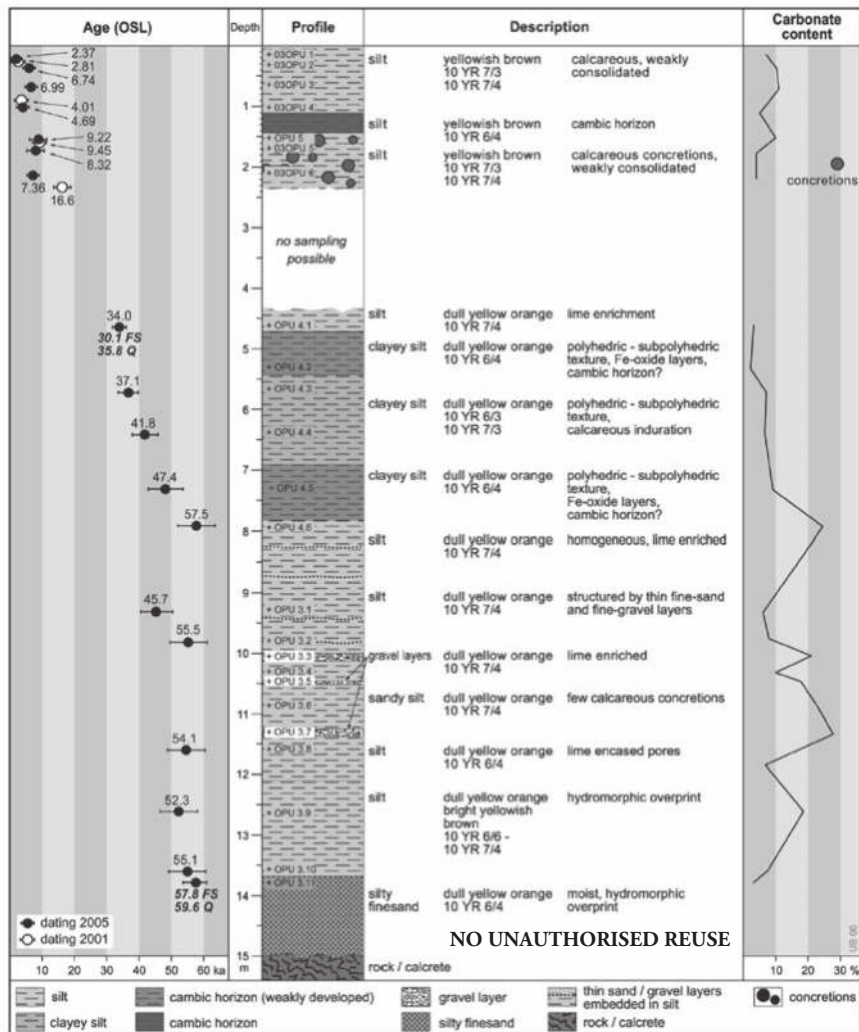


Figure 6. Loess section from Opuwo, indicating the different units observed, the ages obtained for those units and the environmental interpretation of each unit. Source: Brunotte *et al.* 2009, with permission from Elsevier.

before burial). A range of sites in three of the northern rivers have been dated. The loess in the upper Hoarusib in the Opuwo Basin is 8 ka at 2 m depth, whilst there is also material of 1.5 ka in the Omungunda Basin (Brunotte and Sander 2000). In the upper Hoanib River there is one IRSL (Infra-red Stimulated Luminescence) age of 9.1 ± 1.2 ka (Eitel *et al.* 2001). There are four TL ages for sites in the upper Huab River ranging from 29.5 ± 1.8 to 8.25 ± 0.6 ka (Eitel and Zoller 1996).

There may be a link between the thick loess deposits on the hill-slopes and the silts of the upper reaches of the Hoanib River studied by Eitel *et al.* (2006). Weak rainfall in the past would produce only weak runoff on the slopes, which erodes loessic material but can only transport it a short distance into the valley before the flowing water runs out of energy and the material is deposited (this is known as endoreic drainage). This would choke the river with sediment, and may have contributed to the formation of the river end point deposits found by Eitel *et al.* (2006).

There is a 15 m section of loess with a more detailed OSL chronology near Opuwo in the upper Hoarusib River (Brunotte *et al.* 2009) (Figure 6). Four different depositional units have been identified from base to top that yield information about past environmental conditions and climate. The lower fine-grained fluvial sands (dated to > 55 ka) suggest a humid climate without very heavy rainfall. Above this ~ 2 m of loess suggests a drier climate, with a further ~ 3.5 m of alternating sand and gravel indicating material washed from the slopes during heavy rainfall (both dated between 57 and 52 ka and thereby indicating a high rate of deposition). Above this there is a 4 m unit of loess with some clayey-silt layers that indicate slightly wetter conditions (dated between 52 and 34 ka, suggesting a lower deposition rate). The top 2.5 m unit of loess contains a cambic (weakly developed, mineral soil) horizon indicating slightly wetter conditions (dated between 9 and 2 ka). Detailed applications of OSL to clear sedimentary sections such as this will continue to be a vital tool in deciphering the complex response of the environment and landscape to climate throughout the past.

CONCLUSIONS AND FUTURE OUTLOOK

The Namib Desert contains a long environmental history of aridity. However, there is a range of evidence to suggest that there have been environmental and climatic fluctuations including wetter conditions than present during episodes of the past 120 thousand years. This evidence comes from sources known as 'proxies'. These include gypcretes and calcretes, cave deposits and tufa, faunal and plant remains, archaeological evidence, aeolian (wind-blown) dunes and sediments and fluvial (river) deposits. Luminescence dating techniques have started to play a very important role in deciphering the environmental history of the Namib Desert since their first application almost ten years ago, by establishing *when* changes occurred. Luminescence ages have led to important developments in understanding the record of the past contained within fluvial and aeolian sediments by providing:

- better estimates of the age of sediments along former river courses

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- ages for particular units with specific climatic interpretations (both wetter and drier than present), as made using detailed sedimentary descriptions (lithofacies approaches)
- the first estimate of how old the large and extensive dunes of the Namib Sand Sea are
- important insights into how linear dunes accumulate and migrate, alongside information about the layers of accumulated sand
- timing of the accumulation of small dune forms in the southern transitional Namib Desert
- a chronology for loess deposits at the eastern edge of the northern Namib Desert that indicate fluctuations in climate between dry conditions and periods of heavier rainfall.

Establishing the age of proxies is vital for reconstructing *when* changes to the Namib Desert environment occurred in the past and how quickly changes can occur, whilst the interpretation of the environmental significance of these proxies permits an assessment of how much the environment is capable of changing. Understanding the envelope and rate of possible environmental change and refining our understanding of the link between climatic forcing and environmental response in the past is a vital part of understanding how the environment might respond to future climate change.

A coherent picture of environmental change and climatic fluctuations in the Namib Desert over the past hundred thousand years is still forthcoming. However, there have been great advances in the understanding of the complexity of environmental response to climate change during this period. Luminescence dating has been a vital tool in this process of investigation, allowing scientists to establish when in the past changes occurred and how quickly these changes happened. Having a better idea of the timing and nature of environmental change in the fluvial and aeolian systems has also thrown up new questions about how these systems respond to climatic forcing. There are many more sites to which luminescence should be applied to help answer these, providing a more detailed spatial picture of past environmental change in this fascinating region. We may also have to accept that climatic changes in deserts have contained rapid transitions that may be of a shorter duration than it is possible to resolve using available dating methods. In understanding the past environments of desert regions, we will be better informed to predict the environmental consequences of future climate change in these environmentally sensitive regions.

*Time past and time future
What might have been and what has been
Point to one end, which is always present.*

T. S. Eliot. *Four Quartets*. 'Burnt Norton'.

ACKNOWLEDGEMENT

Figure 6 is reprinted from E. Brunotte, B. Maurer, P. Fischer, J. Lomax and H. Sander (2009) 'A sequence of fluvial and aeolian deposits (desert loess) and palaeosoils covering the last 60ka in the Opuwo basin (Kaokoland/Kunene Region, Namibia) based on luminescence dating'. *Quaternary International* 196 (1–2): 71–85. Copyright (2008), with permission from Elsevier.

REFERENCES

- Alsharan, A.S., K.W. Glennie, G.L. Whittle and C.G.S.C. Kendall (1998). *Quaternary Deserts and Climatic Change*. Rotterdam: A. A. Balkema.
- Besler, H. and M.E. Marker (1979). 'Namib sandstone: a distinct lithological unit'. *Transactions Geological Society of South Africa* 82: 155–60.
- Bradley, R. (1999). *Paleoclimatology: Reconstructing Climates of the Quaternary*. San Diego: Academic Press.
- Brain, C.K. and V. Brain (1977). 'Microfaunal remains from Mirabib: some evidence of palaeoecological changes in the Namib'. *Madoqua* 10: 285–93.
- Bristow, C.S., N. Lancaster and G.A.T. Duller (2005). 'Combining ground penetrating radar surveys and optical dating to determine dune migration in Namibia'. *Journal of the Geological Society* 162: 315–21.
- Bristow C.S., G.A.T. Duller and N. Lancaster (2007). 'Age and dynamics of linear dunes in the Namib Desert'. *Geology* 35: 555–8.
- Broccoli, A.J., K.A. Dahl and R.J. Stouffer (2006). 'Response of the ITCZ to Northern Hemisphere cooling'. *Geophysical Research Letters* 33 L01702.
- Brook, G.A., E. Marias and J.B. Cowart (1999). 'Evidence of wetter and drier conditions in Namibia from tufas and submerged speleothems'. *Cimbebasia* 15: 29–39.
- Brook, G.A., P. Srivastava and E. Marais (2006). 'Characteristics and OSL minimum ages of relict fluvial deposits near Sossus Vlei, Tsauchab River, Namibia, and a regional climate record for the last 30 ka'. *Journal of Quaternary Science* 21: 347–62.
- Brunotte, E. and H. Sander (2000). 'Loess accumulation and soil formation in Kaokoland (Northern Namibia) as indicators of Quaternary climatic change'. *Global and Planetary Change* 26: 67–75.
- Brunotte, E., B. Maurer, P. Fischer, J. Lomax and H. Sander (2009). 'A sequence of fluvial and aeolian deposits (desert loess) and palaeosoils covering the last 60 ka in the Opuwo basin (Kaokoland/Kunene Region, Namibia) based on luminescence dating'. *Quaternary International* 196: 71–85.
- Chase, B.M. and M.E. Meadows (2007). 'Late Quaternary dynamics of southern Africa's winter rainfall zone'. *Earth-Science Reviews* 84: 103–38.
- Chase, B.M. and D.S.G. Thomas (2006). 'Late Quaternary dune accumulation along the western margin of South Africa: distinguishing forcing mechanisms through the analysis of migratory dune forms'. *Earth and Planetary Science Letters* 251: 318–33.

Shedding Light on the Past

- Chase, B.M. and D.S.G. Thomas (2007). 'Multiphase late Quaternary aeolian sediment accumulation in western South Africa: Timing and relationship to palaeoclimatic changes inferred from the marine record'. *Quaternary International* 166: 29–41.
- Chase, B.M., M.E. Meadows, L. Scott, D.S.G. Thomas, E. Marais, J. Sealy and P.J. Reimer (2009). 'A record of rapid Holocene climate change preserved in hyrax middens from southwestern Africa'. *Geology* 37: 703–6.
- Chiang, J.C.H., M. Biasutti and D.S. Battisti (2003). 'Sensitivity of the Atlantic Intertropical Convergence Zone to Last Glacial Maximum boundary conditions'. *Paleoceanography* 18: 18–21.
- Corvinus, G. (1983). *The Raised Beaches of CDM on the West Coast of South West Africa/Namibia*. Munich: C.H. Beck-Verlag.
- Deacon, J. and N. Lancaster (1988). *Late Quaternary Environments of Southern Africa*. New York: Oxford University Press.
- Dingle, R.V., J. Girardudeau, D. Buhmann and J.M. Bremner (1996). 'Modern and palaeo-oceanographic environments under Benguela upwelling cells off southern Namibia'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 123: 85–105.
- Duller, G.A.R. (2008). *Luminescence Dating: Guidelines on Using Luminescence Dating in Archaeology*. Swindon: English Heritage.
- Eitel, B. (1993). 'Kalkkrustengenerationen in Namibia: Carbonatherkunft und genetische Beziehungen'. *Erde* 124: 85–104.
- Eitel, B. and L. Zoller (1996). 'Soils and sediments in the basin of Dieprivier-Uitskot (Khorixas District, Namibia): age, geomorphic and sedimentological investigation, paleoclimatic interpretation'. *Palaeoecology of Africa* 24: 159–72.
- Eitel, B., W.D. Blümel, K. Hüser and B. Mauz (2001). 'Dust and loessic alluvial deposits in Northwestern Namibia (Damaraland, Kaokoveld): Sedimentology and palaeoclimatic evidence based on luminescence data'. *Quaternary International* 76–77: 57–65.
- Eitel, B., A. Kadereit, W.D. Blümel, K. Hüser, J. Lomax and A. Hilgers (2006). 'Environmental changes at the eastern Namib Desert margin before and after the Last Glacial Maximum: New evidence from fluvial deposits in the upper Hoanib River catchment, northwestern Namibia'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 234: 201–22.
- Gasse, F., F. Chalié, A. Vincens, M.A.J. Williams and D. Williamson (2008). 'Climatic patterns in equatorial and southern Africa from 30,000 to 10,000 years ago reconstructed from terrestrial and near-shore proxy data'. *Quaternary Science Reviews* 27: 2316–40.
- Geyh, M.A. and B. Eitel (1998). 'Radiometric dating of young and old calcrete'. *Radiocarbon* 40: 795–802.
- Goudie, A. (1972). 'Climate, weathering, crust formation, dunes, and fluvial features of the central Namib Desert, near Gobabeb, south west Africa'. *Madoqua, Series II* 1: 15–31.
- Heine, Klaus (1998). 'Late Quaternary climate changes in the Central Namib Desert, Namibia', in A.S. Alsharan, K.W. Glennie, G.L. Whittle and C.G.St C. Kendall (eds.) *Quaternary Deserts and Climatic Change*. Rotterdam: A.A. Balkema. pp. 293–304.
- Heine, K. and J.T. Heine (2002). 'A paleohydrologic reinterpretation of the Homeb Silts, Kuiseb River, central Namib Desert (Namibia) and paleoclimatic implications'. *Catena* 48: 107–30.

- Korn, H. and H. Martin (1955). 'The Pleistocene in South-West Africa'. *Proceedings of the Third Pan-African Congress: Prehistory*.
- Koutavas, A. and J. Lynch-Stieglitz (2004). 'Variability of marine ITCZ over the eastern Pacific during the past 30, 000 years. Regional perspective and global context', in H.F. Diaz and R.S. Bradley (eds.) *The Hadley Circulation: Present, Past and Future*. Dordrecht: Kluwer Academic Publishers. pp. 334–69.
- Lancaster, Nick (1989). *The Namib Sand Sea: Dune Forms, Processes and Sediments*, Rotterdam: Balkema.
- Marker, M. E. and D. Müller (1978). 'Relict vlei silts of the Kuiseb River valley, South West Africa'. *Madoqua* 11: 151–62.
- Miall, A.D. (1987). 'Recent developments in the study of fluvial facies models', in F.G. Etheridge, R.M. Flores and M.D. Harvey (eds.) *Recent Developments in Fluvial Sedimentology*. Special Publication 39. Society of Economic Palaeontologists and Mineralogists. pp. 1–9.
- Partridge, T.C., L. Scott and J.E. Hamilton (1999). 'Synthetic reconstructions of southern African environments during the Last Glacial Maximum (21–18 kyr) and the Holocene Altitheimal (8–6 kyr)'. *Quaternary International* 57/58: 207–14.
- Peterson, L.C., G.H. Haug, K.A. Hughen and U. Rohl (2000). 'Rapid changes in the hydrologic cycle of the tropical Atlantic during the last glacial'. *Science* 290: 1947–51.
- Rogers, J. (1977). 'Sedimentation on the continental margin off the Orange River and the Namib Desert'. *Joint Geol. Survey/Univ. Cape Town Mar. Geosci. Group Bull* 162.
- Rubin, D. M. 1990. 'Lateral migration of linear dunes in the Strezlecki Desert, Australia'. *Earth Surface Processes and Landforms* 15: 1–14.
- Rust, U. and F. Wieneke (1974). 'Studies on gramadulla formation in the middle part of the Kuiseb River upstream of Gobabeb, South West Africa'. *Madoqua* 3: 5–15.
- Sandelowsky, B.H. (1977). 'Mirabib: an archaeological study in the Namib'. *Madoqua* 10: 221–84.
- Sandelowsky, B.H., J.H. Van Rooyen and J.C. Vogel (1979). 'Early evidence for herders in the Namib'. *South African Archaeological Bulletin* 34: 50–1.
- Sarnthein, M. (1978). 'Sand deserts during the glacial maximum and climatic optimum'. *Nature* 272: 43–6.
- Scott, L., E. Marais and G.A. Brook (2004). 'Fossil hyrax dung and evidence of Late Pleistocene and Holocene vegetation types in the Namib Desert'. *Journal of Quaternary Science* 19: 829–32.
- Smith, R.M.H., T.R. Mason and J.D. Ward (1993). 'Flash-flood sediments and ichnofacies of the Late Pleistocene Homeb Silts, Kuiseb River, Namibia'. *Sedimentary Geology* 85: 579–99.
- Srivastava, P., G.A. Brook and E. Marais (2004). 'A record of fluvial aggradation in the Northern Namib Desert during the Late Quaternary'. *Zeitschrift für Geomorphologie, Supplementband* 133: 1–18.
- Srivastava, P., G.A. Brook and E. Marais (2005). 'Depositional environment and luminescence chronology of the Hoarusib River Clay Castles sediments, northern Namib Desert, Namibia'. *Catena* 59: 187–204.

Shedding Light on the Past

- Srivastava, P., G.A. Brook, E. Marais, P. Morthekai and A.K. Singhvi (2006). 'Depositional environment and OSL chronology of the Homeb silt deposits, Kuiseb River, Namibia'. *Quaternary Research* 65: 478–91.
- Stone, A.E.C. (2009). 'Should we be concerned about the sampling-strategy bias on records of Kalahari aeolian activity in the late Quaternary?' *7th International Conference on Geomorphology, Melbourne*. 6–11 July 2009.
- Stone, A.E.C. and D.S.G. Thomas (accepted). 'Casting new light on late Quaternary environmental and palaeohydrological change in the Namib Desert: a review of the application of optically stimulated luminescence in the region'. *Journal of Arid Environments*.
- Stone, A.E.C., H.A. Viles, L. Thomas and P. van Calstern (2010a). 'Can ^{234}U – ^{230}Th dating be used to date large semi-arid tufas? Challenges from a study in the Naukluft Mountains, Namibia'. *Journal of Quaternary Science* 25 (8): 1360–1372.
- Stone, A.E.C., D.S.G. Thomas and H.A. Viles (2010b). 'Late Quaternary palaeohydrological changes in the northern Namib Sand Sea: New chronologies using OSL dating of interdigitated aeolian and water-lain interdune deposits'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 288: 35–53.
- Teller, J.T. and N. Lancaster (1986). 'Lacustrine sediments at Narabeb in the central Namib Desert, Namibia'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 56: 177–95.
- Teller, J.T., N. Rutter and N. Lancaster (1990). 'Sedimentology and paleohydrology of Late Quaternary lake deposits in the northern Namib Sand Sea, Namibia'. *Quaternary Science Reviews* 9: 343–64.
- Tyson, P.D. (1999). 'Atmospheric circulation changes and palaeoclimates of southern Africa'. *South African Journal of Science* 95: 194–201.
- Van der Merwe, J. H. (1983). *National Atlas of South West Africa Namibia*. Capetown: National Book Printers Goodwood.
- Viles, H.A., M.P. Taylor, K. Nicoll and S. Neumann (2007). 'Facies evidence of hydroclimatic regime shifts in tufa depositional sequences from the arid Naukluft Mountains, Namibia'. *Sedimentary Geology* 195: 39–53.
- Vogel, J.C. (1982). 'The age of the Kuiseb River silt terrace at Homeb'. *Palaeoecology of Africa* 15: 201–9.
- Vogel, J.C. (1989). 'Evidence of past climatic change in the Namib Desert'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 70: 355–66.
- Vogelsang, R. (1998). 'Archaeological survey in Kaokoveld, Namibia'. *Nyame Akuma* 50: 22–4.
- Ward, J.D. (1984). 'A reappraisal of the Cenozoic stratigraphy in the Kuiseb valley of the central Namib desert', in J.C. Vogel (ed.) *Late Cainozoic Palaeoclimates of the Southern Hemisphere*. Rotterdam: Balkema. pp. 455–65.
- Ward, J.D. (1987). 'The Cenozoic succession in the Kuiseb Valley, Central Namib Desert'. *Geological Survey of Namibia, Memoir* 9: 124.
- Ward, J.D. and I. Corbett (1990). 'Towards an age for the Namib', in M.K. Seely (ed.) *Namib Ecology: 25 Years of Namib Research*. Pretoria: Transvaal Museum. pp. 17–26.
- Ward, J. D., M.K. Seeley and N. Lancaster (1983). 'On the antiquity of the Namib Desert'. *South African Journal of Science* 79: 175–83.

SOIL ORGANIC CARBON AND SOIL RESPIRATION IN DESERTS: EXAMPLES FROM THE KALAHARI

*Andrew D. Thomas, Stephen R. Hoon, Helen Mairs
and Andrew J. Dougill*

INTRODUCTION

Soils in dryland environments typically contain less than one per cent organic matter by weight, yet this small component of carbon-rich material affects many aspects of the desert environment and how people use these ecosystems to secure a sustainable livelihood. Mineralisation of organic carbon (C) on and within soils provides a supply of essential nutrients (notably nitrogen) that nourish desert plant communities and allows crop growth. Organic matter improves water holding and ion exchange capacities, enabling soils to retain moisture and nutrients. It also provides structural stability to soils, reducing erodibility and the problems associated with wind or water erosion. The C stored in dryland soils is vital – yet the manner in which C is stored and the influence of C in drylands on global atmospheric CO₂ levels is under-researched and poorly understood.

On a global scale, the mass of C contained in soil organic matter is three times larger than that in vegetation and the former is the single largest terrestrial C store (Raich and Schlesinger 1992). The African savannah biome is seen as particularly important, currently acting as a modest C sink and storing approximately fourteen per cent of the world's terrestrial C (Ciais *et al.* 2009). Understanding the inputs, outputs and fluxes of C into and out of desert soils is therefore vitally important not just for local soil fertility and erodibility but also for the global balance of C held in soils and the atmosphere. The need for information on the processes controlling C budgets in soils and ecosystems also has global policy and economic significance as new policy frameworks (e.g. Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) and REDD+) and voluntary trading schemes (e.g. Plan Vivo) are developed. These policies and schemes seek to mitigate climate change through enhanced C storage in ecosystems and to provide monetary payments to communities practising land management that reduces soil C loss.

Soil Organic Carbon and Soil Respiration in Deserts

In the early 1990s, however, a review by Raich and Schlesinger (1992) stressed that a lack of data was hindering our understanding of soil C cycles in dryland environments. Despite an increasing number of studies investigating fluxes of C from dryland soils (e.g. Sponseller 2007, Inglima *et al.* 2009, Liu *et al.* 2009, Shen *et al.* 2009, Sheng *et al.* 2010, Thomas and Hoon 2010) the latest reviews suggest this is still the case (Conant 2009, Bond-Lamberty and Thompson 2010a). How the soil organic C store is affected by changing air temperatures and moisture availability, or changes in land use and management, and the implications of any change for ecological systems remain urgent research priorities.

In this chapter we describe the characteristics of soil organic carbon (SOC) in drylands with specific reference to the Kalahari of southern Africa. Although the Kalahari Sands cover a much larger area, we use the term Kalahari to mean the semi-arid and arid part of the Kalahari within Botswana and northern South Africa. We discuss inputs of C from surface biological soil crusts (BSCs) and losses of C as CO₂ from soils due to respiration. We demonstrate that predicting the rate at which C is added to soils from BSC organisms and lost in respired gases and how these are affected by climatic and land use change presents major challenges. Both C loss and gain are microbial processes and bridging between the micro-scale at which these processes occur and soil behaviour at regional scales forms a central theme of the chapter and is a wider challenge for the dryland environmental science community. We have used data derived from experiments conducted over a number of years in Botswana to illustrate our points. Further details on these experiments and the field methods employed can be found in Hoon *et al.* (2009), Thomas *et al.* (2008); Thomas and Hoon (2010) and Thomas *et al.* (2011).

HOW MUCH SOIL ORGANIC C IS THERE IN THE KALAHARI?

There have been several notable attempts to quantify over large scales the mass of C in soils. For example, the distribution of terrestrial C, including living biomass (Reusch and Gibbs 2008), topsoil and subsoil organic C (FAO 2007), soil inorganic C (USDA, 2000) and total C and total organic C (Batjes 1996) have all been documented and mapped at a global scale. Regional-scale SOC has also been determined for southern African drylands (e.g. Henry *et al.* 2009, Scharleman *et al.* 2009) and databases are being developed that estimate the size and composition of the soil C store on a global (ISRIC 2009) and continental scale for Africa (ICRAF 2010). However, due to the high levels of heterogeneity that characterise dryland soils (both spatially and through time) and the different measurement approaches followed in different studies (e.g. different depths of sampling, use of different analytical methods for soil C characterisation) it remains impossible to compare the data. There is an obvious need for a standardised approach so that we can make useful comparisons between locations and advance our understanding of the C cycle in drylands such that models of future change in soil C storage can be provided.

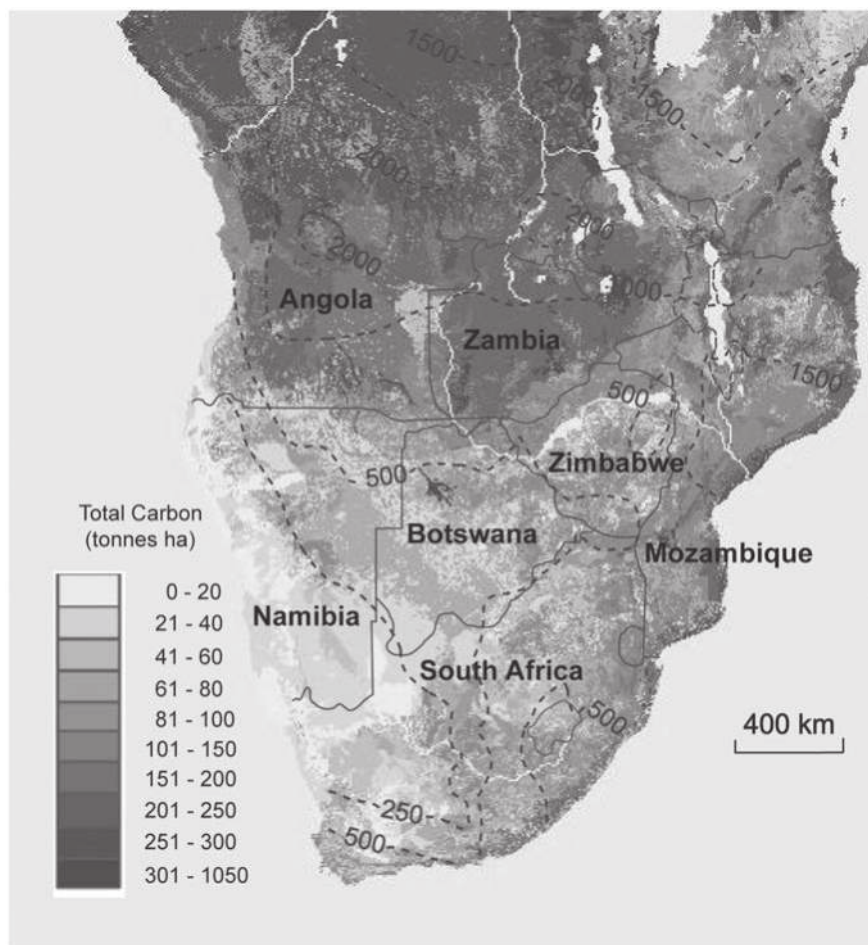


Figure 1. A section of the Updated Global Carbon Map showing total vegetation and soil organic C values for southern Africa. The dotted lines are isohyets, showing mean annual rainfall (mm). Based on Scharlemann *et al.* (2009).

The updated global terrestrial C map produced by the United Nation's Food and Agricultural Organisation (FAO) amalgamates SOC data from the harmonised world soil database (FAO/IIASA/ ISRIC/ISS-CAS/JRC 2009) together with above- and below-ground vegetation biomass (Reusch and Gibbs 2008). The map shows the distribution of vegetation and soil organic C to 1 m depth over a 1 km² resolution (Scharlemann *et al.* 2009) and is currently our best estimate of global scale terrestrial C stores. Figure 1 shows the southern African area of the map, together with rainfall

Soil Organic Carbon and Soil Respiration in Deserts

isohyets. At this scale the influence of rainfall on primary productivity and total C is clear, with greatest concentrations in the tropics through Angola, Zambia, Malawi and the Democratic Republic of Congo. The dominant control on soil organic C content is the amount of input from plants whose growth is regulated principally by moisture availability. Thus the distribution shown in Figure 1 can be expected to correlate closely with amounts of soil organic C. The semi-arid and arid areas of the Kalahari and the Namib, where net primary productivity is limited by available moisture, are also clear, with large areas estimated to contain less than forty tonnes of C per hectare. It is therefore tempting to dismiss dryland areas as being of little importance to large-scale C cycles. However, although soil organic C concentrations are low in drylands, a combination of rapid C cycling and their vast extent make them a significant component of the global terrestrial C cycle. Recent work by Elbert *et al.* (2009) estimates that globally 1.0 petagrams of C (a petagram is equivalent to 10^{15} grams or 1 billion metric tonnes) is taken up by autotrophic organisms in BSCs each year in dryland regions; thus, at the current global C price of \$20 per metric tonne, the annual dryland soil C uptake has a monetary value of *c.* \$20 billion. Despite this, the effects of changes in land use and climate on this vital C store are largely unknown and in need of further process-based studies of the form presented in this overview.

The SOC component of Figure 1 was quantified using a widely accepted and globally implemented method (van Engelen and Wen 1995, Henry *et al.* 2009) where an average SOC concentration is determined by taking homogenised samples from depths of 0–30 cm and 30–100 cm to give surface and subsoil values (IPCC 2003, FAO 2009). This works well in temperate environments where soil C varies slowly with depth and soils have distinctive and deep organic horizons overlying organic-poor lower horizons. However, in drylands the SOC content is often concentrated in the uppermost few millimetres of the surface and declines rapidly with depth. It is crucial, then, that this layer is sampled appropriately if sub-sampling is not to produce large errors. The rapid decreases in both total C (TC) and total N (TN) with depth in Kalahari Sands illustrate this point (Figure 2), with negligible organic material below 5 cm. This is typical of desert soils where organic material accumulation is limited both by plant inputs and the highly oxidising nature of the well-aerated sandy soils. Using this profile of C we obtain estimates of *c.* 6 tonnes of organic C per ha for degraded sandy Kalahari soils and poorly crusted soils near Tsaabong in the south-west Kalahari of Botswana. This is compatible with the terrestrial organic C estimate of 21–40 tonnes per ha for this region in Figure 1 (as this also includes C in vegetation and roots). However, less degraded and well-crusted soils, typically found in wildlife management zones or lightly grazed rangelands (Thomas and Dougill 2007), have much higher surface C contents. Here, a sampling framework that assesses soil C from homogenised 30 cm deep samples could significantly underestimate the amount of soil C contained in the upper soil layers.

Of equal importance is the potential for underestimating the regional store of soil organic C because of differences in soil type. Using the improved method described above, we estimated *c.* 39 tonnes per ha to 1 m of calcrete pan soils in the

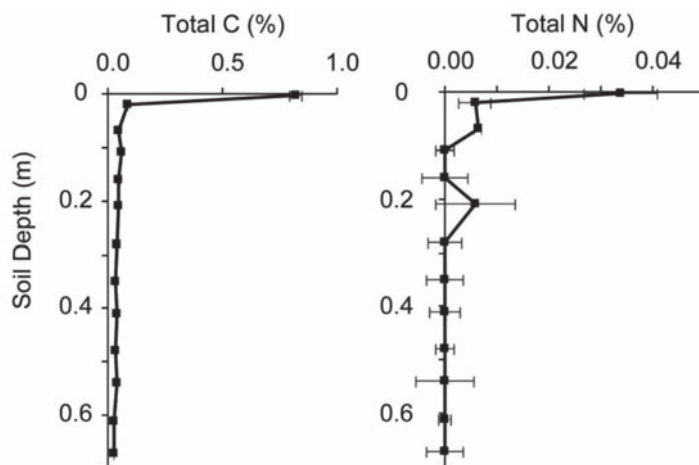


Figure 2. Total C and N with depth in Kalahari Sands.
Samples from Tsabong, SW Botswana, Feb 2010.

SW Kalahari and over fifty tonnes OC per ha to 1 m on the salt pan systems of the Makgadikgadi Pans in north east Botswana. Calcrete pans are numerous in the SW Kalahari and form a significant proportion of the landscape (Thomas and Shaw 1991). The Makgadikgadi Pan system covers 37, 000 km² and the C contained within these soils is substantially greater than in the Kalahari Sands, yet does not appear in the FAO map. This is understandable for the calcrete pans, most of which are less than 1 km² and so smaller than the sampling resolution. The omission from the FAO maps of the much greater C stored in the Makgadikgadi Pans reflects the current lack of data for African environments, particularly in drylands.

SOURCES OF SOIL ORGANIC CARBON IN THE KALAHARI

The Kalahari Sands are ancient wind-blown deposits covering over 2.5 million km² of Southern Africa, including over eighty per cent of Botswana (Thomas and Shaw 1991). Although often called a desert because of the absence of surface water, the Kalahari climate ranges from arid in the south-west (covering large parts of the Northern Cape in South Africa, the eastern fringes of southern Namibia and south-west Botswana), to semi-arid (covering northern Namibia, southern Angola and most of Botswana) and sub-tropical/tropical around northern Angola and the Democratic Republic of Congo. Even in the semi-arid areas, where SOC is at its lowest, the Sands support a diverse and extensive vegetation cover (Figure 3).

Kalahari Sands consist of over 95 per cent fine sand-sized grains of quartz (SiO₂) and are predominantly structureless and nutrient deficient (Dougill *et al.*



Figure 3. Mixed tree, shrub and grassland north east of Mabuasehube, Botswana in the semi-arid part of the Kalahari.

1998) (Figure 4). Although the characteristics of the Kalahari Sands remain relatively homogeneous over their range (Shugart *et al.* 2004), SOC is lowest in the driest areas and increases with mean annual precipitation reaching a peak in the more northerly areas with 400–500 mm / yr (Bird *et al.* 2004, Wang *et al.* 2007). In the driest areas, SOC content is limited by primary productivity due to the low moisture and thus C input in roots and litter. SOC increases with surface vegetation biomass cover and rainfall but this also leads to an accumulation of fuel, which increases fire frequency and intensity. In areas where mean annual rainfall exceeds 500 mm / yr, fires prevent greater accumulation of SOC (Bird *et al.* 2004).

Despite the relatively high vegetation cover in the Kalahari (Figure 3) and inputs of organic C via leaf litter, SOC accumulation is limited in the warm, well-aerated soils which contain high concentrations of oxidising enzymes (Stursova *et al.* 2006). Under these conditions SOC is rapidly decomposed and lost as respired CO_2 , limiting the amount of C stored in the soils (Lal 2003). The extensive biological productivity of the Kalahari is therefore facilitated not by large stores of soil C but by small amounts of C cycling rapidly through the plant-soil system. The contribution of leaf litter to SOC is limited by insect herbivory



Figure 4. Kalahari Sand surface profile.

(Crawley, 1989) and photochemical oxidation by sunlight (Austin and Vivanco 2006). Organic matter inputs have a much-improved chance of longevity if they are below the surface and away from oxidising effects of direct sunlight. Thus the most important contributors to SOC are from plant roots and BSCs. The roots of perennial grasses are particularly important because of their high root:shoot ratios and highly developed rhizospheres (the narrow zone of soil directly influenced by secretions from roots and associated micro-organisms). Annual grasses, more prevalent in areas of high grazing, have far smaller root systems and provide much lower inputs of C to the soil (Figure 5). Perennial grasses are, however, common in areas with little or light grazing, thus providing a direct link between land use and C storage.

The distribution of trees and woody shrubs is also important in affecting SOC content. Wang *et al.* (2009) found that up to ninety per cent of soil C originated from shrubs and trees in wetter areas of the Kalahari. However, in drier areas only around forty per cent of soil C was derived from shrubs, with most originating from grasses, but these inputs were dependent on the location of woody plant species. The distribu-



Eragrostis Lehmanniana
Lehmann's Love Grass



Schmidtia Kalihariensis
Sour Grass

Figure 5. Contrasting root systems of typical perennial (left) and annual (right) grass species found in the Kalahari.

Soil Organic Carbon and Soil Respiration in Deserts

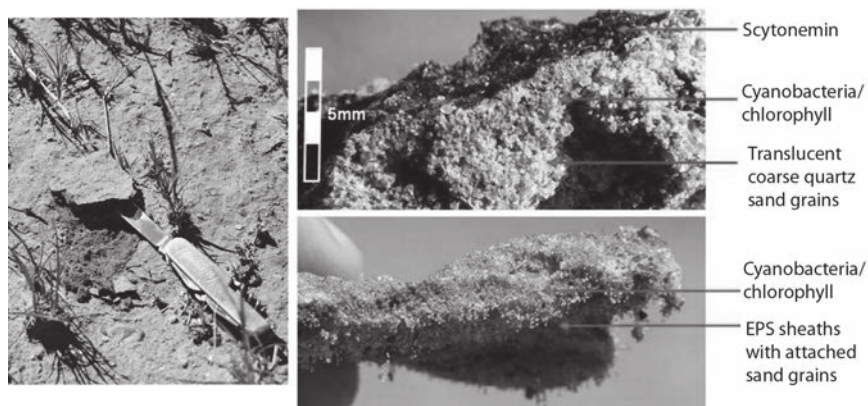


Figure 6. Cyanobacterial soil crusts in the Kalahari.

tion of woody shrubs also affects the distribution of the other major input of SOC into Kalahari Sands – namely biological soil crusts (Figure 6). Biological soil crusts form aggregates of mineral grains, cyanobacteria, lichen and fungi and are common in all drylands (Belnap and Lange 2003). They are widespread across the Kalahari, with cover in pastoral areas varying from nineteen to forty per cent compared to undisturbed wildlife management zones and game reserves, where cover can reach 95 per cent of the surface (Thomas and Dougill 2007). In grazed areas, soils under the canopy of shrubs, particularly of *Acacia mellifera* whose dense thorny canopies provide an effective deterrent to many browsers, provide an untrampled refuge for crust formation (Berkeley *et al.* 2005). Our recent analyses in the south-western Kalahari show that there are significantly greater total-C concentrations stored in surface soils in sub-canopy sites ($TC = 1.32\% \pm 0.63$) compared to open sites ($TC = 0.22\% \pm 0.12$). This displays the importance of localised ‘islands of fertility’ around shrubs, which can potentially act as a positive feedback contributing to greater bush dominance in grazed systems.

Soil crusts in the Kalahari are comprised of cyanobacteria and are typically 3–4 mm thick. They are beneficial for a range of ecosystem functions and properties, including soil erodibility, water holding capacity and the storage of nitrogen and organic C. Well-developed crusts form stratified micro-environments at the soil surface (Figure 6). Soil cyanobacteria exude C-rich sugar compounds in the form of extra-cellular polysaccharides (EPS) as sheaths which protect bacterial cells from desiccation during dry seasons and prolonged droughts. The pale green colouration of cyanobacterial chlorophyll is also visible within the EPS-bound particle layer (Figure 6). Sand grains attached to EPS sheaths may also be seen to be dangling from the underside of the crust fragment even after removal from the soil surface.

As most soil organic C is contained within BSCs at the surface (Figure 2) it experiences large diurnal and seasonal variations in temperature, including winter frost

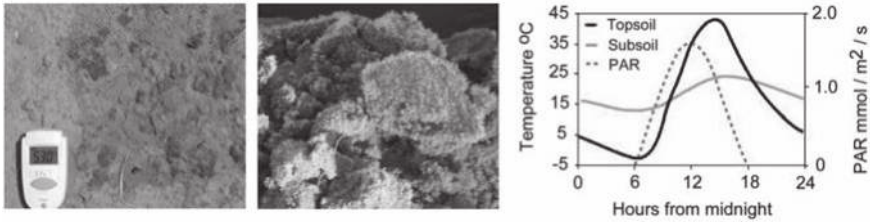


Figure 7. Left: Soil surface temperature, SW Botswana. February, 3pm local time. Centre: Frost covers disturbed Kalahari Sands, SW Botswana. July, 6.30am local time. Right: Diurnal trends in light (PAR), top and sub-soil temperatures. Data collected on a clear day in June, Tshane, Botswana.

and extreme summer heat (Figure 7). The crust rapidly equilibrates with air temperatures, coupling microbial processes with current weather conditions and making it highly sensitive to climatic changes.

For the autotrophic organisms in BSC to photosynthesise and sequester new C they need light and water. Determining light and moisture availability in the crust layer requires detailed small-scale investigations based on an understanding of soil physics and microbiology. Firstly, light in the form of photosynthetically active radiation (PAR) needs to penetrate the soil to sufficient depth to reach the autotrophic micro-organisms. As light propagates into the soil its intensity is reduced as it is absorbed and scattered. If absorption rather than scattering dominates, then the light intensity decreases exponentially with depth. Garcia-Pichel and Belnap (1996) have observed photosynthesis in BSCs down to a depth of 600 mm. Cyanobacterial sheaths are often bound to the largest translucent quartz grains (Figure 6) in the crust, indicating that cyanobacteria may well be utilising the light harvesting qualities of these grains to assist photosynthesis at depth.

Water molecules are the other essential ingredient for photosynthesis, with hydrogen atoms providing the electrons to initiate and power the photo-system chain. Water, unlike light, will be limited for a large part of the year. Thus organisms in crusts have evolved to be able to utilise very small amounts of water, even from dew, and to do so very rapidly before it evaporates. The images in Figure 8 illustrate the rapidity of photosynthesis and chlorophyll generation by BSC organisms. The greening of a crusted surface occurs within minutes of wetting but rapidly disappears after evaporation has dried the soil surface. Wetting the soil also changes its optical properties. Water films reduce the light scattering by the soil particles due to the smaller difference between the refractive indices of quartz and water compared to those of quartz and air, thus improving the soil's optical transmission. This means that in moist soil the water filled soil capillaries assist in guiding light to greater depths by acting as light guides in a manner similar to a fibre optic cable. This facilitates photosynthesis in BSC organisms when water is available. As water also cuts out damaging UV this explains why subsoil

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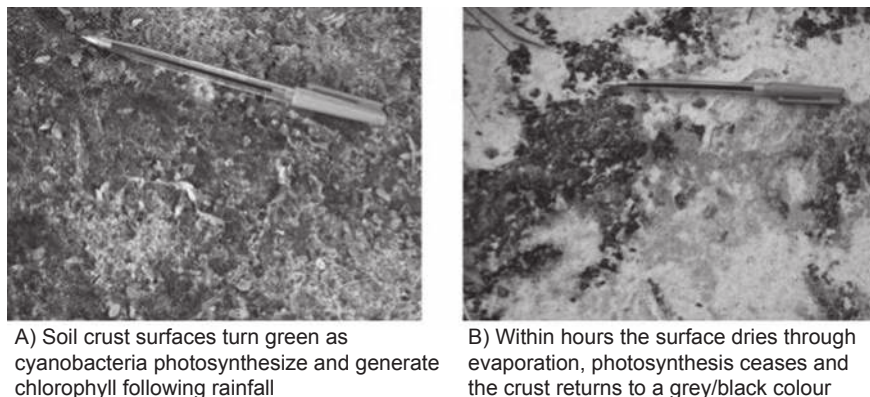


Figure 8. Cyanobacterial crust organisms generating chlorophyll after rainfall in the Kalahari (A). This phase is short-lived and is quickly followed by desiccation and the cessation of photosynthesis (B).

autotrophic bacteria lack any natural sun-screening pigments such as scytonemin. Many cyanobacteria such as the most common *Microcoleus* spp. are motile and can glide along strands of EPS (Belnap *et al.* 2003), enabling them to optimise their exposure to light and screen themselves from biologically damaging UV radiation.

BSCs are, however, spatially heterogeneous, adding variability to the distribution and composition of SOC across landscapes. They are also temporally heterogeneous, with BSC cover a product of the balance between disintegration (due to burial by wind-blown dust, impact from saltating particles and compression from animals) and rebuilding phases during windows of optimal conditions. Damage and disruption to the BSC micro-environment adversely affects the optimisation of conditions necessary for photosynthesis and C uptake. Thus the contribution BSCs make to the SOC pool varies enormously over time and space and is directly linked to patterns of land use, grazing management and ecological changes.

LOSSES OF ORGANIC CARBON IN THE KALAHARI: SOIL RESPIRATION

Soil respiration (R_s) is the major pathway of C loss from soils. Estimated global annual losses of C in respired gas vary from 68 and 100 Pg C (Musselman and Fox 1991, Raich and Schlesinger 1992, Conant *et al.* 2000). Respiration is a cellular process, resulting from the breakdown of C substrates and subsequent release of energy, water and CO_2 (Luo and Zhou, 2006). When the term is applied to soils it refers to the efflux of CO_2 from the surface to the atmosphere and is therefore the end product of numerous processes. In most soils, respiration gases (R_s) contain CO_2 derived from two principal sources: i) heterotrophic microbial respiration resulting from mineralisation of soil

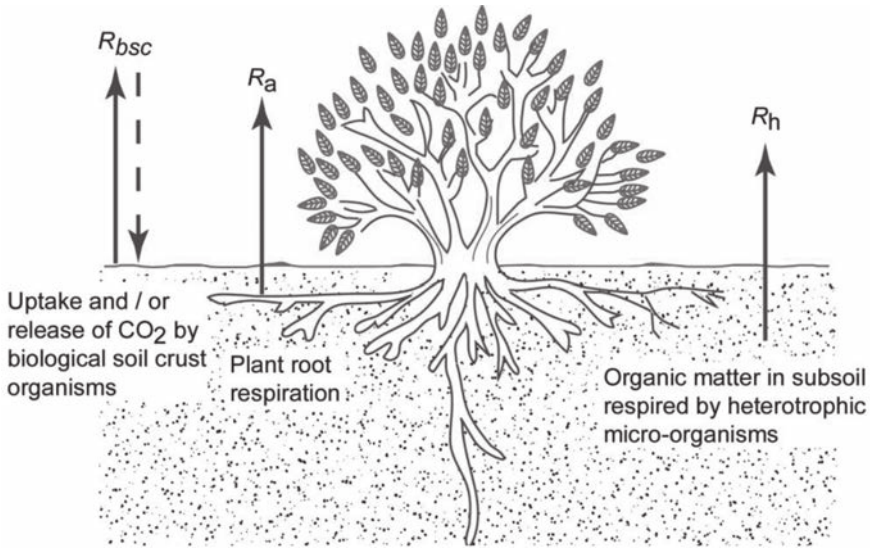


Figure 9. Components of soil respiration in drylands.

organic matter (R_h) and ii) plant roots, termed autotrophic respiration (R_a) (Equation 1 and Figure 9). R_h fluxes are of particular interest because they reflect the amount and rapidity of soil organic C mineralisation and are a major pathway of soil C loss.

$$R_s = R_h + R_a \quad (\text{Equation 1})$$

R_s in drylands will also be affected by CO₂ fluxes associated with BSC organisms and they form an important additional component of R_s (Equation 2) where R_{bsc} refers to CO₂ fluxes associated with crust organisms.

$$R_s = R_h + R_a + R_{bsc} \quad (\text{Equation 2})$$

Because cyanobacteria can derive energy either autotrophically or heterotrophically (Anthony and Fabricius, 2000) they can sequester atmospheric CO₂ and add to the soil C store as well as mineralise organic matter, respire CO₂ and deplete soil C. It is likely that there are occasions when organisms in the upper zone of the BSC are photosynthesising whilst organisms below the zone of light penetration are mineralising organic C as an energy source. CO₂ efflux from the BSC layer can therefore be either positive or negative depending on the environmental conditions and the dominant metabolic strategy of the ensemble of organisms. Despite their importance, very few studies have parameterised the conditions required for BSC photosynthesis (see Lange 2003 as a rare example) or determined R_{bsc} and simple relationships between environ-

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mental variables and R_s rates in drylands are not the norm. Soil CO_2 fluxes will reflect the balance between constantly changing rates of uptake and release in BSCs as well as R_h and R_a emissions (Thomas and Hoon 2010).

Despite uncertainty surrounding predictions of the temperature sensitivity of R_s , a recent meta-analysis of 818 different studies has demonstrated that atmospheric warming is enhancing the global flux of CO_2 respired from soils (R_s) to the atmosphere (Bond-Lamberty and Thomson 2010a, b). This could result in a potential double-negative feedback of declining soil C and increasing atmospheric CO_2 (Cox *et al.* 2000). Climatic change and warming will also lead to more frequent droughts and precipitation changes in many locations (IPCC 2007) further affecting the soil properties and processes controlling R_s rates. In dryland environments, where organic matter is already limited, the pedological, ecological and agricultural consequences of such changes would be particularly marked and yet studies from African drylands are lacking completely from the studies reviewed globally (Bond-Lamberty and Thomson 2010a, b). Given the large extent of drylands (over fifty million square km or forty per cent of the land surface including dry sub-humid areas – UNEP 1997) even a relatively small increase in CO_2 efflux could have a significant effect on atmospheric composition.

HOW MIGHT CLIMATIC AND LAND USE CHANGE AFFECT SOIL RESPIRATION IN THE KALAHARI?

The Kalahari is predicted to experience higher mean annual temperatures, changing rainfall patterns and enhanced soil moisture deficits in the future (IPCC 2007). Increasing aridification will reduce the amount of time BSC organisms are photosynthetically active, thus decreasing an important input of OC to the Kalahari Sands. At the same time there are proposals to increase the number of cattle (Dougill *et al.* 2010), which will exacerbate soil disturbance, reducing BSC cover and development. Crusts that are frequently disturbed are less well developed, have reduced species diversity and contribute less OC. Although we are currently uncertain, the combined effects of these changes are likely to be increased soil erodibility and dust storm frequency as well as less ecologically productive soils and reduced C storage.

As a preliminary assessment of these issues, the authors have investigated and quantified *in-situ* R_s using an array of chambers at five remote sites in the Kalahari with contrasting mean annual rainfall, temperature and grazing levels (full details are given in Thomas *et al.* 2011) (Figure 10). Experiments were conducted to determine the effect of 2 mm and 50 mm simulated water pulses and temperature on diurnal variations in R_s . Mean annual precipitation at each site ranges from 220 mm / yr at Khawa to 420 mm / yr at Ngami. Four of the sites (Khawa, Tsabong, Takatshwaane and Ngami) were largely undisturbed by domestic animals and BSC cover was correspondingly high (over eighty per cent). Tshane, however, had a much lower BSC cover (*c.* ten per cent) as a result of frequent grazing.

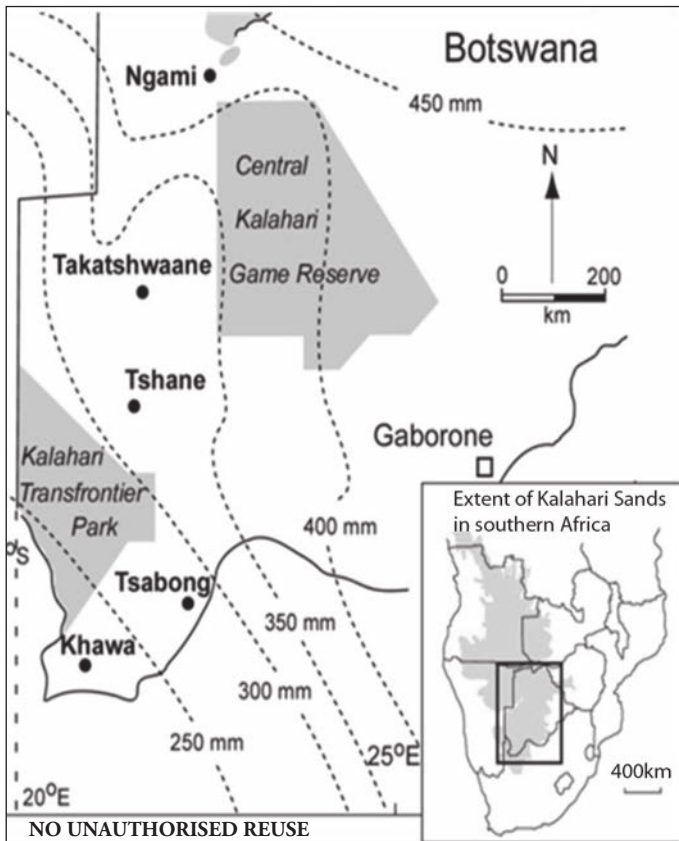


Figure 10. Location of the experiments across the Kalahari in Botswana. Reproduced with permission of Elsevier from Thomas et al. (2011).

An example of the temporal variations in R_s from three chambers, together with photosynthetically active radiation (PAR) and air temperatures from Takatshwaane, is shown in Figure 11 to illustrate the general trends found.

We can draw several conclusions from the temporal trends in R_s :

1. The peak and range of flux from dry control soils was very low at all sites but there were short periods, usually in the early morning or evening, when there was net uptake of CO_2 . A window of opportunity presents itself in mid-morning when the high pre-dawn relative humidity provides moisture and rising air temperatures warm the soil surface enough to provide energy for metabolic activity but not to completely evaporate the moisture.
2. The application of the equivalent of 2 mm rainfall wetted the upper crusted soil layer and resulted in higher peak and a greater range of R_s fluxes compared to control

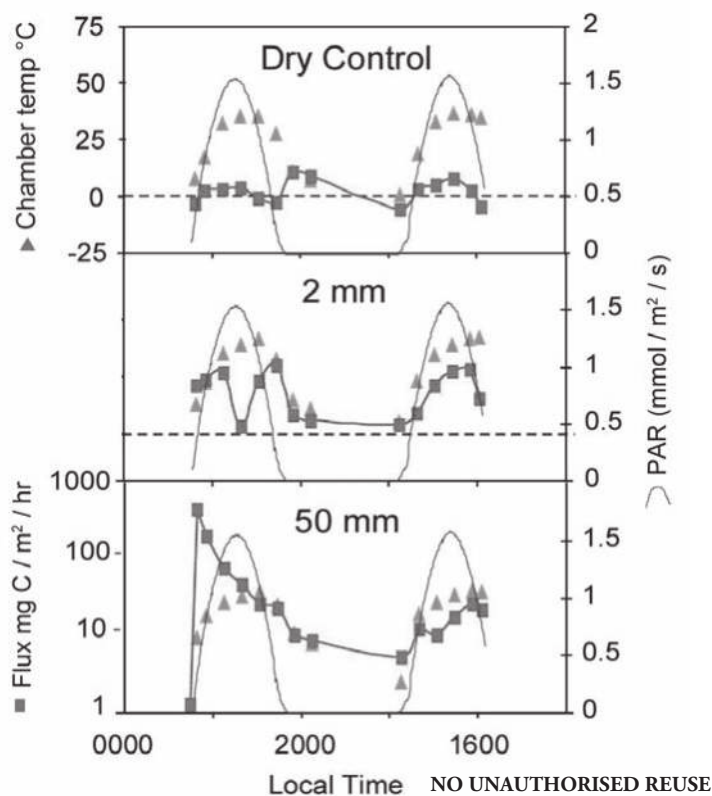


Figure 11. Temporal trends in R_s , air temperature and PAR in control (dry) soils and after artificial wetting with 2 mm and 50 mm of water, Takatshwaane, Botswana. Reproduced in modified form, with permission of Elsevier, from Thomas et al. (2011).

soils. Rainfall of 5 mm or less occurred on average 21 times a year between 1996 and 2007 in Tsabong. The frequency of these events will therefore have a large effect on the total amount of respired CO₂ over a year. Although peak R_s usually corresponds with the highest air temperatures, diurnal variations were complex and there were often double peaks, indicative of the competing processes of uptake and release coming into and out of phase. Nevertheless it is clear that moisture is a primary limiting factor to metabolic activity and that providing moisture to crust organisms stimulates R_s at least over a two-day period.

3. The 50 mm wetting treatment increased soil moisture to 10–12 per cent v/v to a depth of 20–25 cm and resulted in a short-lived but high magnitude pulse of CO₂ from the soils (note the scale change in Figure 11 for the 50 mm plot). Rainfall events of sufficient size to hydrate the subsoil are a characteristic feature of the Kalahari envi-

ronment and often comprise the majority of annual precipitation. Between 1996 and 2007 21–82 per cent of annual precipitation at Tsubong occurred in events of more than 20 mm. When preceded by long dry periods, they result in large pulses of CO_2 efflux and the highest pulse we recorded was greater than $1000 \text{ mg C / m}^2 \text{ / hr}$ in one of the chambers at Tsubong. Within hours, however, R_s rates return to levels similar to those from the 2 mm wetted soils. Although there was some displacement of the initial soil pore atmosphere it does not explain the large R_s fluxes as dry pore-space CO_2 concentrations were generally very low (less than 0.07 ppm). The transient nature of the pulse is indicative of soils with a limited and rapidly exhaustible supply of readily available C substrate. The subsoil source of CO_2 is therefore likely to be from R_h and the respiration of available C by bacteria and fungi stimulated by the increase in soil moisture. We must caution, however, that without further field experiments to isolate this pathway or corroborating isotopic signature data this remains an untested hypothesis.

Although diurnal changes in R_s provide an insight into the soil processes generating CO_2 fluxes and how they are affected by pulses of simulated rainfall, it is difficult to deduce the temperature sensitivity of the flux or what the data mean for soil C storage. To overcome this we calculated net cumulative changes in C over the duration of the experiments. The total net change was normalised to 24 hours to provide an estimate of the mean daily C losses in respired gases (Figure 12). The magnitude of the C loss after the application of 50 mm of water also increased the further north the study site and was significantly positively correlated ($r^2 = 0.99$) with mean air temperature. Losses from Tshane were significantly greater than predicted, particularly after the 2 mm rainfall event. This, we believe, is due to the lack of a BSC at this site. Unlike at the other, well crusted sites, respiration losses of C are not offset by uptake in the crust, resulting in higher C loss estimates.

To determine what impact the respired C losses will have on the SOC store it is necessary to know where the C originates from. CO_2 respired from roots (R_a) will have been recently sequestered during photosynthesis and represents 'new' soil C. Increases in R_s driven by greater R_a will have few, if any, long-term consequences for soil C or atmospheric CO_2 (Janssens *et al.* 2001, Trumbore and Czimczik 2008). In contrast, heterotrophic soil microbes mineralise organic matter of varied composition and age. The R_h flux thus contains C that has been resident in the soil for longer than C in the R_a flux. Accelerated R_h is a concern because increases can occur independently of C inputs from plants and it represents a net loss of previously stored soil C. In our study, it is likely that the large losses of C measured after the 50 mm rainfall event are due to R_h , and therefore represent a true loss of soil organic C. This is because, during the dry season when the experiments were conducted, most of the plants were in a dormant state and could not have rapidly increased their metabolic activity.

Whether or not greater R_s leads to a positive feedback to warming and deterioration in soil fertility depends not only on whether it comprises more R_a or R_h but on the source of C contributing to the R_h . A loss of soil organic C driven by mineralisation of older C compounds could have potentially huge consequences for the biological

productivity of dryland systems and the viability of their rural populations (Knorr *et al.* 2005, Trumbore and Czimczik 2008).

Under optimal conditions dryland soils can be a net sink of CO_2 , at least for short periods, as crust organisms photosynthesise (Thomas and Hoon 2010). At other times, although not a net CO_2 sink, uptake by crust organisms can offset and reduce total R_s fluxes derived from the subsoil. Net mean losses of C in respired CO_2 were $473 \pm 17 \text{ mg C m}^2 / \text{day}$ on undisturbed crusted Kalahari Sand soils over six days in February 2010. In contrast, on soils where the crust had been artificially removed losses were $544 \pm 26 \text{ mg C m}^2 / \text{day}$. The difference between the two suggest uptake of *c.* $71 \text{ mg C m}^2 / \text{day}$ due to cyanobacterial photosynthesis in the surface crust.

However, BSCs are susceptible to disturbance and damage to the BSC micro-environment adversely affects the composition and metabolic activity of the organisms and the ability of BSCs to fix CO_2 (Belnap 1996, Lalley and Viles 2006). Soil crusts that were sequestering CO_2 can rapidly become a net source of CO_2 if disturbed, making dryland soil respiration highly sensitive to animal stocking densities and cultivation methods in more humid areas. Land use management decisions are therefore crucial in maintaining the input of C from BSCs into dryland soils.

Numerous wetting and drying cycles will affect organic C mineralisation (Harris 1981) and potentially generate large 'pulses' of respiration. The balance between losses of soil C in pulses of R_h following rainfall and uptake during windows of optimal conditions for photosynthesis will be critical to the soil C store (Figure 5). Consequently soil C is particularly vulnerable to changes in precipitation and evapotranspiration rates that need investigation for scenarios of C storage under future climatic conditions.

CONCLUSIONS

Despite being present in only low concentrations, organic C is fundamental to soil processes in drylands. There remains doubt over the accuracy of our current best estimates of the total amount of organic C stored in soils across the Kalahari. We recommend that the OC content of BSCs is determined independently and that consideration is given to OC storage on calcrete and salt pans.

Major sources of soil organic C include inputs from the roots of perennial grasses and BSCs. Both are sensitive to grazing and climate. Our studies show that BSC cover and metabolic activity are adversely affected when frequently disturbed and BSCs that were sequestering CO_2 can rapidly become a net source of CO_2 , making dryland soil C highly sensitive to animal stocking densities. Similarly, the density of perennial grasses reduces with grazing, as animals will preferentially graze on the highly nutritious stems. Grazing is, however, fundamental to the rural economy of much of these regions and payment schemes valuing C stored will be essential if land management for C storage is to be encouraged further. Managed grazing regimes, which prevent excessive utilisation of land, are important if the soil C inputs from these two sources are to be maintained.

Predicting how climate and land use affect respiration, the major pathway of soil organic C loss, is less straightforward. The predicted warming of southern Africa will increase soil moisture deficits and reduce the amount of time crust organisms photosynthesise. At the same time, warming will increase the rapidity with which soil C is respired and lost from the soil. A shift to less frequent but more intense rainfall is also likely to lead to a loss of soil organic C as large pulses of CO₂ are released. Ultimately, the balance between respired losses of soil C and uptake during windows of optimal conditions for photosynthesis will be critical to the balance of the soil C store.

Before we can be more certain of the impacts of climatic change on C budgets, there needs to be more research on the sources of C contributing to the respiration flux. An increase in respiration does not necessarily mean greater C losses. More work is needed on parameterising the conditions for optimal BSC photosynthesis so we can improve predictions of this major input into the soil C store. Models are further complicated because of uncertainties associated with vegetation changes driven by the greater atmospheric CO₂ concentrations, which will enable dryland plants to improve their water and nitrogen use efficiencies. This could lead to greater net primary productivity and therefore terrestrial organic C storage. It is likely, however, to favour C₃ species and may lead to greater woody shrub encroachment, reducing grazing capacity and increasing the likelihood of fires. Disentangling these related processes and how they will change in the future is a fundamental challenge to improving our scientific understanding of the dryland ecosystem. Given the opportunities which lie ahead for 'managing agricultural lands for C storage' under the United Nations REDD+ and REDD++ programmes designed to enable payment systems for C storage there is an added urgency to improving our predictive capacity in dryland soil C cycles. This is an essential prerequisite for the opportunities for more C-friendly land management systems to be supported financially via either voluntary C markets or global Clean Development Mechanism or REDD+ initiatives.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge receipt of a Royal Geographical Society Peter Fleming Award, which made the research possible. The assistance of Jill Thomas of Berry Bush Farm in Tsabong was invaluable and we extend our thanks. The research was conducted under the auspices of a Government of Botswana Research Permit Number EWT8/36/4 VIII(4). Thomas compiled the manuscript whilst in receipt of a Leverhulme Trust Research Fellowship.

REFERENCES

- Anthony, K.R.N. and K.E. Fabricius (2000). 'Shifting roles of heterotrophy and autotrophy in coral energetics under varying turbidity'. *Journal of Experimental Marine Biology and Ecology* **252**: 221–253.
- Austin, A.T. and L. Vivanco (2006). 'Plant litter decomposition in a semi-arid ecosystem controlled by photodegradation'. *Nature* **442** (7102): 555–558.
- Batjes, N.H. (1996). 'Total carbon and nitrogen in the soils of the world'. *European Journal of Soil Science*. **47**: 151–163.
- Belnap, J. (1996). 'Soil surface disturbances in cold deserts: effects on nitrogenase activity in cyanobacterial-lichen soil crusts'. *Biology and Fertility of Soils* **23**: 362–367.
- Belnap, J. and O.L. Lange (2003). 'Structure and functioning of biological soil crusts: a synthesis', in J. Belnap and O.L. Lange (eds.) *Biological Soil Crusts: Structure, Function and Management*. Berlin: Springer-Verlag. pp. 471–479.
- Belnap, J., B. Büdel and O.L. Lange (2003). 'Biological soil crusts: characteristics and distribution', in J. Belnap and O.L. Lange (eds.) *Biological Soil Crusts: Structure, Function, and Management*. Berlin: Springer-Verlag. pp. 3–30.
- Berkeley, A., A.D. Thomas and A.J. Dougill (2005). 'Cyanobacterial soil crusts and woody shrub canopies in Kalahari rangelands'. *African Journal of Ecology* **43**: 137–145.
- Bird, M.I., E.M. Veenendaal and J.J. Lloyd (2004). 'Soil carbon inventories and $\delta^{13}\text{C}$ along a moisture gradient in Botswana'. *Global Change Biology* **10**: 342–349.
- Bond-Lamberty, B. and A. Thomson (2010a). 'Temperature-associated increases in the global soil respiration record'. *Nature* **464** (7288): 579–U132.
- Bond-Lamberty, B. and A. Thomson (2010b). 'A global database of soil respiration data'. *Biogeosciences* **7**: 1915–1926.
- Ciais, P., S.-L. Piao, P. Cadule, P. Friedlingstein and A. Chédin (2009). 'Variability and recent trends in the African terrestrial carbon balance'. *Biogeosciences* **6** (9): 1935–1948.
- Conant, R.T., J.M. Klopatek and C.C. Klopatek (2000). 'Environmental factors controlling soil respiration in three semi-arid ecosystems'. *Soil Science Society of America Journal* **64**: 383–390.
- Conant, R.T. (2009). *Challenges and opportunities for carbon sequestration in grassland systems: a technical report on grassland management and climate change mitigation*. Prepared for the UN Food and Agriculture Organization; Crop and Grassland Service, Plant Production and Protection Division.
- Cox, P.M., R.A. Betts, C.D. Jones, S.A. Spall and I.J. Totterdell (2000). 'Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model'. *Nature* **408**: 184–7.
- Crawley, M.J. (1989). 'Insect herbivores and plant population dynamics'. *Annual Reviews of Entomology* **34**: 531–564.
- Dougill, A.J., E.D.G. Fraser and M.S. Reed (2010). 'Anticipating vulnerability to climate change in dryland pastoral systems: Using dynamic systems models for the Kalahari'. *Ecology and Society* **15**:(2)17. Available online at <http://www.ecologyandsociety.org/vol15/iss2/art17/>

- Dougill, A.J., A.L. Heathwaite and D.S.G. Thomas (1998). 'Soil water movement and nutrient cycling in semi-arid rangeland: Vegetation change and system resilience'. *Hydrological Processes* **12** (3): 443–459.
- Elbert, W., B. Weber, B. Büdel, M.O. Andreae and U. Pöschl (2009). 'Microbiotic crusts on soil, rock and plants: neglected major players in the global cycles of carbon and nitrogen'. *Biogeosciences* **6**: 6983–7015.
- FAO (2007). '*Land Resources: Soils and Maps*'. Available online at <http://www.fao.org/nr/land/soils/en/>
- FAO/IIASA/ISRIC/ISS-CAS/JRC (2009). *Harmonized World Soil Database* (version 1.0). Rome, Italy: FAO and Laxenburg, Austria: IIASA.
- Garcia-Pichel, F. and J. Belnap (1996). 'Microenvironments and microscale productivity of cyanobacterial desert crusts'. *Journal of Phycology* **32**: 774–82.
- Harris, R. (1981). 'Effect of water potential on microbial growth and activity', in J. Parr, W. Gardner and L. Elliott (eds.) *Water Potential Relations in Soil Microbiology*. Madison: Soil Science Society of America. pp. 23–95.
- Henry, M., R. Valentin and M. Benroux (2009). 'Soil carbon stocks in ecoregions of Africa'. *Biogeosciences* **6**: 797–823.
- Hoon, S.R., A.D. Thomas and P.E. Linton (2009). 'Design and development of an *in-situ* closed chamber for quantification of soil photosynthesis and respiration'. *Geographical Research* **47**: 71–82.
- Inglisma, I., G. Alberti, T. Bertolini, F.P. Vaccari, B. Gioli, F. Miglietta, M.F. Cotrufo and A. Peressotti (2009). 'Precipitation pulses enhance respiration of Mediterranean ecosystems: the balance between organic and inorganic components of increased soil CO₂ efflux'. *Global Change Biology* **15**: 1289–1301.
- Inter-Governmental Panel on Climate Change (IPCC) (2007). *Climate Change 2007: The Physical Science Basis*. Cambridge: Cambridge University Press.
- Inter-Governmental Panel on Climate Change (IPCC) (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme*.
- Janssens, I.A., H. Lankreijer, G. Matteucci, A.S. Kowalski, N. Buchmann, D. Epron, K. Pilegaard, W. Kutsch, B. Longdoz, T. Grünwald, L. Montagnani, S. Dore, C. Rebmann, E.J. Moors, A. Grelle, Ü. Rannik, K. Morgenstern, S. Oltchev, R. Clement, J. Guomundsson, S. Minerbi, P. Berbigier, A. Ibrom, J. Moncrieff, M. Aubinet, C. Bernhofer, N.O. Jensen, T. Vesala, A. Granier, E-D. Schulze, A. Lindroth, A.J. Dolman, P.G. Jarvis, R. Ceulemans and R. Valentini (2001). 'Productivity overshadows temperature in determining soil and ecosystem respiration across European forests'. *Global Change Biology* **7**: 269–278.
- Kirschbaum, M.U.F. (1995). 'The temperature dependence of soil organic matter decomposition and the effect of global warming on soil organic C storage'. *Soil Biology and Biochemistry* **27**: 753–760.
- Knorr, W., I.C. Prentice, J.I. House and E.A. Holland (2005). 'Long-term sensitivity of soil carbon turnover to warming'. *Nature* **433**: 298–301.
- Lal, R. (2003). 'Carbon sequestration in dryland environments' *Environmental Management* **33**(4): 528–544.

Soil Organic Carbon and Soil Respiration in Deserts

- Lalley, J.S. and H.A. Viles (2006). 'Do vehicle track disturbances affect the productivity of soil-growing lichens in a fog desert?' *Functional Ecology* **20**: 548–556.
- Lange, O.L. (2003). 'Photosynthesis of soil-crust biota as dependent on environmental factors', in J. Belnap and O.L. Lange (eds.) *Biological Soil Crusts: Structure, Function, and Management*. Berlin: Springer-Verlag. pp. 217–240.
- Liu, W., Z. Zhang and S. Wan (2009). 'Predominant role of water in regulating soil and microbial respiration and their responses to climate change in a semiarid grassland'. *Global Change Biology* **15**: 184–195.
- Luo, Y. and X. Zhou (2006). *Soil Respiration and the Environment*. San Diego, CA: Academic Press / Elsevier.
- Musselman, R.C. and D.G. Fox (1991). 'A review of the role of temperate forests in the global CO₂ balance'. *Journal of the Air and Waste Management Association* **41**: 798–807.
- Raich, J.W. and W.H. Schlesinger (1992). 'The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate'. *Tellus, Series B: Chemical and Physical Meteorology* **44**: 81–89.
- Ruesch, A. and H.K. Gibbs (2008). *New IPCC Tier-1 Global Biomass Carbon Map For the Year 2000*. Available from http://cdiac.ornl.gov/epubs/ndp/global_carbon/carbon_documentation.html.
- Scharleman, J.P.W., R. Hiederer V. Kapos and C. Ravilious (2009). *Updated Global Carbon Map*. Cambridge: UNEP-WCRC & EU-JRC.
- Shen, W., J.F. Reynolds and D. Hui (2009). 'Responses of dryland soil respiration and soil carbon pool size to abrupt vs. Combined changes in soil temperature, precipitation and atmospheric CO₂: A simulation analysis'. *Global Change Biology* **15**: 2274–2294.
- Sheng, H., Y. Yang, Z. Yang, G. Chen, J. Xie, J. Guo and S. Zou (2010). 'The dynamic response of soil respiration to land use changes in subtropical China'. *Global Change Biology* **16**: 1007–1121.
- Shugart, H.H., S.A. Macko, P. Lesolle, T.A. Szuba, M.M. Mukelabai, P. Dowty and R.J. Swap (2004). 'The SAFARI 2000 – Kalahari Transect Wet Season Campaign of year 2000'. *Global Change Biology* **10**: 273–280.
- Sponseller, R. (2007). 'Precipitation pulses and soil CO₂ flux in a Sonoran Desert ecosystem'. *Global Change Biology* **13**: 426–436.
- Stursova, M., C. Crenshaw and R.L. Sinsabaugh (2006). 'Microbial responses to long term N deposition in a semi-arid grassland'. *Microbial Ecology* **51**: 90–98.
- Thomas, A.D. and A.J. Dougill (2007). 'Spatial and temporal distribution of cyanobacterial soil crusts in the Kalahari: implications for soil surface properties'. *Geomorphology* **85**: 17–29.
- Thomas, A.D. and S.R. Hoon (2010). 'Simulated rainfall pulses and carbon dioxide fluxes from Kalahari Sands'. *Journal of Arid Environments* **74**: 131–139.
- Thomas, A.D., S.R. Hoon and P.E. Linton (2008). 'Carbon dioxide fluxes from cyanobacteria crusted soils in the Kalahari'. *Applied Soil Ecology* **39**: 254–263.
- Thomas, A.D., S.R. Hoon and A.J. Dougill (2011). 'Soil respiration at five sites along the Kalahari Transect: Effects of temperature, precipitation pulses and biological soil crust cover'. *Geoderma* **167/168**: 284–294.

Andrew D. Thomas, Stephen R. Hoon, Helen Mairs and Andrew J. Dougill

- Thomas, D.S.G. and P.A. Shaw (1991). *The Kalahari Environment*. Cambridge: Cambridge University Press.
- Trumbore, S.E. and C.I. Czimczik (2008). 'An uncertain future for soil carbon'. *Science* **321**: 1455–1456.
- USDA (2000). *Soil Inorganic Carbon Map*. Washington D.C.: USDA. Available from <http://soils.usda.gov/use/worldsoils/mapindex/sic.html>
- UNEP (1997). *World Atlas of Desertification*. Second Edition. Nairobi.
- Van Engelen, V.W.P. and T.T. Wen (eds.) (1995). *Global and National Digital Terrain Digital Databases (SOTER). Procedures Manual*. Revised edition. Wageningen: International Soil Information and Reference Centre.
- Wang, L., P. D'Odorico, S. Ringrose, S. Coetzee and S.A. Macko (2007). 'Biogeochemistry of Kalahari sands'. *Journal of Arid. Environments* **71**: 259–279.
- Wang, L., G.S. Okin, K.K. Caylor and S.A. Macko (2009). 'Spatial heterogeneity and sources of soil carbon in southern African savannas'. *Geoderma* **149**: 402–408.

HOMININ EVOLUTIONARY HISTORY IN THE ARABIAN DESERT AND THE THAR DESERT

Michael D. Petraglia, Huw Groucutt and James Blinkhorn

INTRODUCTION

Climatic fluctuations, and the waxing and waning of desert environments, have important implications for our understanding of human evolution. Increasing aridity and the expansion of drylands results in impoverished habitats and a reduction of biodiversity. Human adaptations to arid conditions are generally thought to develop relatively late in our evolutionary history, being mostly confined to the Holocene (Barker and Gilbertson 2000, Veth *et al.* 2005), although there are hints that semi-arid adaptations may go back into the Early Pleistocene (Yeshurun *et al.* 2011). On the whole, however, the majority of the archaeological evidence indicates that human populations tended to track favourable habitats, where animals and plants could be hunted and gathered and where fresh water supplies were readily available. This begs the question as to why Palaeolithic archaeologists and palaeoanthropologists should be interested in deserts. One significant reason concerns the notion that fluctuations in arid and humid landscapes have significantly shaped evolutionary processes. That is, climatic shifts and alterations in wet and dry habitats influence human demographic responses, leading either to the expansion, contraction or extinction of populations (Foley and Lahr 1998). Yet little is known about the relationship between climate change and human population history in the great desert regions of the world. Recent mapping of palaeohydrological features and archaeological sites in the Sahara have suggested that the expansion of human settlements is closely tied to moist habitats in the Holocene and Late Pleistocene (Kuper and Kropelin 2006, Osborne *et al.* 2008, Drake *et al.* 2011) and indeed the movement of hominins out of Africa is also thought to be closely related to the presence of humid corridors (Dennell 2009, Frumkin *et al.* 2010, Petraglia *et al.* 2010). On the other hand, the expansion of arid and hyper-arid landscapes may create geographic barriers, resulting in population fragmentation and isolation and even extinction. The aim of this chapter is to examine two desert regions that likely played a significant role in the Out of Africa story: the Arabian Desert and the Thar Desert. Although very little is presently known about the relationship between environmental change and human occupation in these desert regions, it is

worth outlining what is known in order to begin the process of building a framework for future investigation.

THE ARABIAN DESERT

Environments

The Arabian peninsula is a geographic land-bridge between Africa and Eurasia, although the area is bounded by the Red Sea, the Indian Ocean and the Persian Gulf on three borders (Figure 1). The main geological features in this region are the western highlands (the 'shield') and the shelf (or 'platform') to the east of this, which tilts downwards towards the Arabian Gulf (Edgell 2006). The main highlands of Arabia are found from Yemen along the west coast of the Peninsula, rising to nearly 4,000 metres above sea level and receiving relatively high levels of precipitation. The two major sand seas of Arabia are the Rub' al Khali (covering ca. 600,000 km²) and the northern An Nafud (ca. 70,000 km²). These are connected by a narrow but 1,300 km-long erg known as Ad Dhana. The sand seas cumulatively are impressive in size and cover an area greater

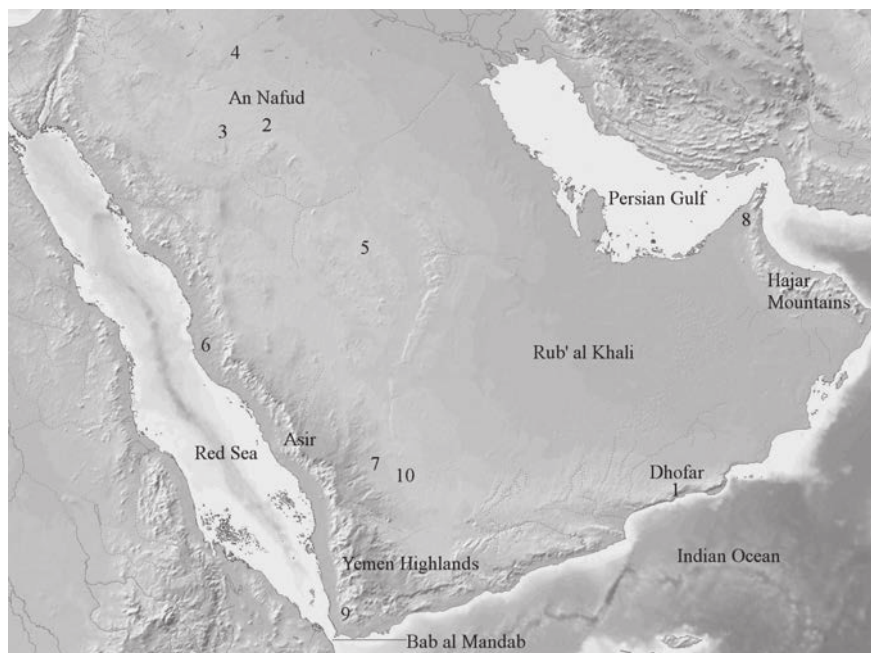


Figure 1. Key Palaeolithic sites of the Arabian peninsula: 1) Al Hatab; 2) Jubbah; 3) An Nafud faunal localities; 4) Shuwayhitiyah; 5) Dawadami; 6) Wadi Fatimah; 7) Bani Khatmah; 8) Jebel Faya; 9) Shi'bat Dihya 1; 10) Qaryat al-Faw.

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than three times the size of the United Kingdom. The main weather systems affecting Arabia are the South-west Indian Ocean Monsoon, whose rains currently only really affect the far south of the Peninsula (but see e.g. Waldmann *et al.* 2010 for a view on how this varied in the past), and north-westerly winter storms tracking across the Mediterranean. The modern inhabitation of Arabia fundamentally depends on the extraction of groundwater and desalination (Vincent 2008).

With the increasingly oscillatory climate of the Pleistocene, glacial periods, to simplify somewhat, brought aridity to the area and interglacial periods are associated with pluvial periods. The latter are recorded in features such as lacustrine sediments, alluvial fans and speleothems, while aridity is traditionally regarded as being signalled most clearly by the development of sand seas but is also evident in features such as hyperalkaline springs (Clark and Fontes 1990). An overview of the chronology and character of the last eleven marine isotope stages is shown in Table 1. It is against this oscillatory climatic background that we can begin to understand the human story in Arabia and elsewhere in the mid-latitude desert belt. Given Arabia's latitudinal position, the change of central importance, rather than change in temperature, is between relatively dry (arid) and wet (humid, pluvial) conditions.

Table 1. An overview of the chronology and character of the last eleven marine isotope stages.

| Martine Isotope Stage (MIS) | Chronology (~Ka) | General character |
|-----------------------------|------------------|---|
| MIS 11 | 420–360 | Wet |
| MIS 10 | 360–340 | Arid (?) |
| MIS 9 | 340–300 | Wet |
| MIS 8 | 300–245 | Arid? |
| MIS 7 | 245–185 | Wet |
| MIS 6 | 185–130 | Arid with wet spells |
| MIS 5 | 130–74 | Wet, particularly during sub-stages a, c, and e |
| MIS 4 | 74–60 | Arid |
| MIS 3 | 60–20 | Arid overall but unstable, with at least one short wet period |
| MIS 2 | 20–10 | Very arid |
| MIS 1 | 10–0 | Initially wet, subsequently generally arid |

Here we will primarily focus on palaeoclimate and palaeoenvironments between MIS 9 and 2 (see Parker 2009), as beyond this timescale dating techniques become problematic. Nevertheless we can reasonably hypothesise that periods such as MIS 11 provided widespread suitable habitats for hominin occupation. Likewise, periods associated with northern hemisphere glaciation probably broadly correlate with arid episodes but the chronology of desert formation is little known. It has been suggested that proto-ergs

may have started to develop in the Miocene (Whitney *et al.* 1983). In the case of the An Nafud desert, it is estimated that today less than five per cent of dunes are active, indicating substantially stronger winds in the past. The younger dates for Arabian palaeoenvironmental reconstructions are traditionally based on radiocarbon dating, which in an Arabian context are often troubled by a number of factors, notably those relating to contamination by younger carbon (e.g. Immenhauser *et al.* 2007, Preusser 2009). In recent years the development of techniques such as optically stimulated luminescence (OSL) dating has greatly improved our understanding of the chronology of environmental change in Arabia.

Evidence for increased precipitation in MIS 9 and 7 has been identified in a number of areas (e.g. Burns *et al.* 2001, Abed *et al.* 2008, Parker and Rose 2008). Following this, MIS 6 has traditionally been seen as a markedly arid phase (Anton 1984). However, emerging evidence suggests that it may have seen at least periodic humid episodes (e.g. Wood *et al.* 2003). MIS 5 saw a considerable increase in precipitation across Arabia. For example, speleothem (calcitic cave formations, such as stalactites and stalagmites) records clearly indicate an increase in precipitation (e.g. Burns *et al.* 2001, Fleitmann *et al.* 2007, Fleitmann and Matter 2009). MIS 5e represents the Last Interglacial, when the area saw peak precipitation. MIS 5c and 5a were also marked by considerable humidity according to the speleothem data. Phytoliths from MIS 5c and 5a horizons near the Jubbah palaeolake indicate the presence of grasses and some trees (Petraglia *et al.* 2011). Emerging information therefore indicates that large areas of Arabia provided habitats suitable for hominins in MIS 5.

MIS 4 appears to have been extremely arid. In contrast, the succeeding MIS 3 has generally been regarded as a humid phase, which Parker (2009) dubbed the 'Debated Pluvial'. The traditional chronology for this period rests on radiocarbon dates but, as previously mentioned, it is likely that many of these are problematic and, as detailed chronologies have been produced from speleothem records and other sources, there is a clear lack of congruence between dating techniques. Thus, claims for MIS 3 humid periods are difficult to evaluate at present and reported examples (e.g. McClure 1976) may in fact be rather older. It is known, however, that MIS 3 saw at least pulses of increased humidity (e.g. McLaren *et al.* 2009).

MIS 2 is associated with the Last Glacial Maximum when Arabia was very arid (e.g. Preusser *et al.* 2002, Parker and Goudie 2007). But even here some evidence suggests a brief humid period at 15–13 ka (which can perhaps be related to the occupation of Al-Hatab rockshelter in Oman (Rose and Usik 2009). It is notable that a marked 'Holocene Wet Phase' occurred between ca. 10–5 ka, which may provide a useful analogue for Pleistocene humid episodes (e.g. Parker *et al.* 2006, Lézine *et al.* 2007).

At a landscape level, the most profound features associated with humid periods are widespread indications of palaeolakes (dried up ancient lakes) and palaeorivers, with which Palaeolithic (old stone age) sites often appear to correspond (e.g. McClure 1976, Parr *et al.* 1978, Zarins *et al.* 1981). For much of the Pleistocene, the Arabian

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Gulf was exposed and formed a large river valley carrying the combined flow of the Tigris-Euphrates rivers and water from the Zagros Mountains and Arabia. Such areas may have provided attractive habitats, and therefore acted as refugia, during aridification of the interior (e.g. Bailey 2009, Rose and Petraglia 2009, Rose 2010; see also Faure *et al.* 2002).

Palaeolakes would presumably have acted as magnets for faunal communities, particularly under conditions of aridification. At Jubbah, in northern Saudi Arabia's An Nafud desert, for instance, a palaeolake some twenty kilometres (east to west) and five kilometres (north to south) in size preserves deep lacustrine (lake) deposits (Garrard *et al.* 1981, Petraglia *et al.* 2011). Here, thirty-metre deep stratigraphies indicate fluctuations between humid and arid conditions over the course of the late Middle Pleistocene to Holocene. Optically stimulated luminescence (OSL) ages of 211, 95, and 75 ka were recently obtained from calcretes and palaeosols near the palaeolake-shore, indicating a period of increased precipitation (Petraglia *et al.* 2011). Other Pleistocene palaeolakes in the An Nafud area indicate a generally wet area (Whitney *et al.* 1983, Schultz and Whitney 1986). These northern examples are by no means unique in Arabia (e.g. McClure 1976). Some of the few known examples of Pleistocene faunal fossils are associated with palaeolake contexts in the An Nafud desert (Thomas *et al.* 1998). These fossils are of interest for their broadly Afrotropical composition and indications of a savannah type environment. No dates have yet been published for these fossils. Mitochondrial DNA analysis of baboons (*Papio hamadryas hamadryas*) revealed range expansions into Arabia during interglacial phases of OIS 9e (330 ka) or OIS 7c (220 ka) and during the second half of interglacial OIS 5e (120–110 ka) or at the end of OIS 5a (80 ka) (Fernandes 2009). Through studying species such as baboons, we can frame the biological and environmental conditions in which human populations expanded into today's desert areas. The baboons of south-west Arabia are the only natural population found outside Africa and genetic evidence suggests they dispersed into the area synchronously with periods of increased precipitation.

Archaeological evidence

Evidence for hominin occupation of Arabia is plentiful and a number of key Palaeolithic sites have been identified across the peninsula (e.g. Parr *et al.* 1978; Zarins *et al.* 1981, 1982; Gilmore *et al.* 1982; Whalen *et al.* 1988, 2002; Amirkhanov 1994; Whalen and Schatte 1997; Rose 2006; Crassard 2007; Petraglia and Rose 2009; Armitage *et al.* 2011; Petraglia *et al.* 2011) (Figure 1). The Palaeolithic, or 'old stone age' period covers the bulk of human history, when populations survived using stone tool (or 'lithic') technology and lived as hunter-gatherers. For the Lower Palaeolithic (elsewhere, where the chronology is better known, this period extends from ca. 2.6–0.25 Ma), this includes poorly known 'Oldowan' sites (e.g. Shuwayhitiyah) and somewhat better known Acheulean occurrences. The Oldowan represents the earliest form of lithic technology, whilst the subsequent Acheulean is associated with 'bifaces'

(hand axes) and cleavers, where hominins carefully removed flakes from either side of the tool, often giving the end product a regularised morphology. The majority of the Acheulean sites occur in the western portion of the peninsula but it is unclear to what extent this reflects survey bias and the coverage of sites in the east by Quaternary sediments in the desert areas (Petraglia 2003). The Acheulean sites at Dawadmi and Wadi Fatimah, two of the most important Lower Palaeolithic localities, have been described as typologically 'Middle Acheulean' (e.g. Zarins *et al.* 1980; Whalen *et al.* 1981, 1984, 1988, 1989), with minimum U-Th ages of 204 and 61 ka (Whalen *et al.* 1984). These ages are, however, minimum ages so almost certainly do not indicate the true ages of hominin inhabitation at the sites. Palaeohydrological mapping and the location of Acheulean sites indicate that hominins probably used large river channels and their tributaries to reach inland areas of Arabia (Petraglia *et al.* 2009). Acheulean hominins were likely present along the Red Sea coast, where they used the Wadi Fatimah River and other such channels to reach interior areas. The location of the Dawadmi sites, in the central portion of the Arabian Desert, indicates that hominins travelled along river channels to penetrate the interior. Once at Dawadmi, fresh water springs and smaller river drainages supplied hominins with fresh drinking water. Unfortunately, the exact age of the Acheulean sites remains unknown but the palaeohydrological and archaeological evidence clearly indicates the correspondence between wet phases and hominin expansion processes.

Following the long period of the Lower Palaeolithic, in both western Eurasia and Africa the subsequent 'Middle Palaeolithic' developed by 250 ka. The stone tool technology of this time is based on the idea of a 'prepared core'; where the parent nodule of raw material is prepared in such a way that, when struck with a hammerstone, a stone tool of deliberate size and shape is produced. Middle Palaeolithic archaeological sites are well represented in Arabia, perhaps resulting from the expansion of *Homo sapiens* from Africa or the Neanderthals from the Levant (Petraglia and Alsharekh 2003). In the Levant both early *Homo sapiens* and Neanderthals manufactured broadly similar types of stone tools, demonstrating the difficulty of assigning stone tools to a particular species in the absence of fossil evidence. A number of sites are located near the Bab al Mandab (Whalen and Pease 1992), while others are found along the Red Sea Coast (Zarins *et al.* 1980, 1981), suggesting the possibility for water crossings and coastal dispersals (Petraglia 2003). Middle Palaeolithic sites have been identified inside the An Nafud desert, around the Jubbah palaeolake (Garrard *et al.* 1981, Petraglia *et al.* 2011). The Middle Palaeolithic site of Jebel Qattar 1 has been dated to ca. 75 ka, representing an occupation in the final stages of MIS 5a (Petraglia *et al.* 2011). The site of Bani Khatmah is located along the edge of the Rub al Khali, not far from a purportedly MIS 3 palaeolake (McClure 1994), although the actual age of the palaeolake is likely to be MIS 5 (F. Preusser and T. Rosenberg, pers. comm., 2010). Amongst a variety of tool types found here are a number of tanged points and scrapers, somewhat reminiscent of the (otherwise) North African Aterian industry (McClure 1994). This may be evidence for demographic connections with North Africa, or merely technological convergence.

In southern portions of Arabia, a number of Middle Palaeolithic sites with stone tools such as distinctive ‘bifacial foliates’ have been identified, suggesting the expansion of Middle Stone Age populations from Africa (Rose 2006, 2007). Stratified (i.e. buried, so they can be dated and placed in environmental context) Middle Palaeolithic assemblages has been discovered at Jebel Faya 1 (UAE), dating from ca. 125 to 40 ka (Armitage *et al.* 2011). The older assemblages are argued to be broadly similar to those of the African Middle Stone Age, suggesting that populations dispersed rapidly eastwards early in MIS 5, across the Nejd plateau, before environmental conditions worsened. The younger assemblages from Jebel Faya appear to follow a distinctive autochthonous trajectory, suggesting regional adaptations to local environments. Although the Jebel Faya populations appear to have been present across the most arid periods of MIS 4, the investigators argue that they contracted to refugium zones in the riverine habitats of the Persian Gulf. In Yemen, a number of sites can be attributed to the Middle Palaeolithic, with some claims that assemblages in this area share similarities with the Levantine Middle Palaeolithic, thereby potentially suggesting north–south cultural connections (e.g. Crassard 2009). Of particular note in western Yemen is the site of Shi’bat Dihya 1, a stratified locality dated to ca. 80–70 ka (Delagnes *et al.* 2008, Macchiarelli 2008). Middle Palaeolithic stone tool assemblages are found in association with faunal remains and isotopic data that suggest increasingly arid conditions at the transition between MIS 5a and 4. As at Jebel Faya, it is possible that Middle Palaeolithic populations were present in a refugium zone during heightened arid conditions. Whilst the chronology and nature of the Middle Palaeolithic in Arabia remains poorly understood, recent advances show that considerable progress is being made, providing new information on the rise of our species and, arguably, our dispersal through the Saharo-Arabian desert belt.

Upper Palaeolithic stone tool industries (typified by the production of long, thin ‘blades’ as well as, often, evidence of ‘art’ and symbolism), appear in the Levant at about 47–45 ka but seem to be rare to absent in Arabia. Maher (2009) comprehensively discusses potentially later Pleistocene sites in Arabia, most of which she identifies as being located in the north-west and south-west of the peninsula. The Qaryat al-Faw site is a possible Late Pleistocene locality, containing laminar technology reminiscent of Levantine Upper and Epi-Palaeolithic assemblages (Edens 2001). The overall lack of Upper Palaeolithic technologies either suggests that human populations were not present in MIS 3, or that Middle Palaeolithic technologies were used until more sophisticated technologies were developed in the Holocene (Crassard *et al.* 2006, Crassard 2007). In either case, the nature of environmental conditions is a critical factor in determining the character of human occupations and material culture.

THE THAR DESERT

Environments

The Thar Desert marks the eastern limit of the arid desert belt that stretches, through Arabia, across to the Atlantic margin of the Sahara. The desert occupies the north-western area of the Indian subcontinent (Figure 2). Fluctuating environmental conditions within the Thar have meant that this region can act as either an arid barrier or a humid gateway for dispersals of hominins into the mosaic environments of South Asia, which is suggested to be a significant route for hominin dispersals toward South-east and East Asia and onwards (e.g. Field and Lahr 2005, Field *et al.* 2007). To the north, the mountainous ranges of the Himalaya and Karakoram are a considerable barrier to hominin dispersals, whereas the Ganges-Brahmaputra delta and dense rainforests beyond only infrequently allow passage out of South Asia and into South-east Asia. It therefore appears that any dispersal of hominins into South Asia has been controlled by the environmental conditions of the Thar Desert and so understanding both the archaeology and palaeoenvironmental conditions of this region is crucial to investigate this topic.

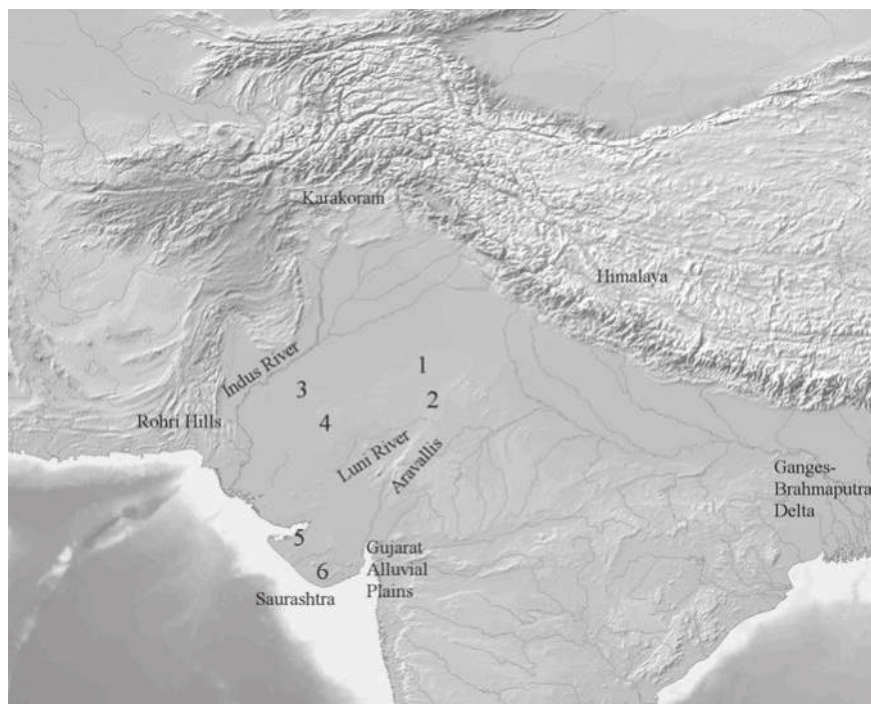


Figure 2. Key Palaeolithic sites of the Thar Desert: 1) Didwana; 2) Budda Pushkar; 3) Veesar Valley; 4) Jaisalmer; 5) Jetpur; 6) Umrethi.

The present extent of the Thar Desert is 300,000 km² (Misra 1995), occurring predominately in the Indian state of Rajasthan and the Pakistani state of Upper Sindh as well as Gujarat, Haryana and Punjab in India. The Thar is flanked by the Aravallis Range to the east, and grades into the foothills of the Himalaya to the north, whereas the eastern margin is marked by the Indus alluvial plains and the southern by the Arabian coastline. Low topographic relief is provided in places by the underlying Tertiary geology but extensive sedimentary deposition throughout the Quaternary period has occurred, predominately through fluvial and aeolian activity, with 300 m deposits over pre-Quaternary horizons in some places (Bajpai *et al.* 2001).

The South-western monsoon currently brings the majority of the precipitation in South Asia from the Arabian Sea during the summer months, which has a significant impact upon Thar Desert landforms, while a weaker North-eastern monsoon provides additional rainfall during the winter in northern South Asia (Enzel *et al.* 1999). Generally, during a glacial climatic regime, decreased albedo of the Tibetan Plateau results in a reduced difference between oceanic and land temperatures, and so there is a significant decrease in wind strength and precipitation associated with the SW monsoon (Clemens *et al.* 1991). Interglacial climates see a strengthened SW monsoon, resulting in warmer conditions and more extensive summer rainfall. Recent studies have suggested that the amount of precipitation and its regional gradient are the key factors in desert margin shift (Singhvi and Kar 2004).

Neo-tectonic factors have also had a major impact upon the Thar Desert, with a criss-cross of lineaments occurring throughout the desert (Kar 1995). Tectonic control of pre-Quaternary geology appears to have influence on a number of river courses (e.g. Roy and Jakher 2001, Ramasamy *et al.* 1991) and sub-surface features, such as graben depressions, appear to have some impact upon ground water flow and accumulation (Bajpai *et al.* 2001). While the basement topography of the alluvial plains of Gujarat, on the southern Thar margin, has been formed through reactivation of Tertiary basement faults during the early Quaternary, the current surface landscape has been formed through a mix of late Quaternary sedimentation and tectonic activity (Maurya *et al.* 1995).

The Jayal formation, a large undulating gravel ridge, exposed for over 50 km in Nagaur and Jodhpur districts, appears to have formed in the Late Neogene/Early Quaternary period as the result of a powerful fluvial system, presumably rising in the Himalayas (Misra 1995). Middle Pleistocene deposits suggest both strong aeolian and low energy fluvial activity, indicating semi-arid conditions punctuated by occasional pluvial events, resulting in some stabilisation of dune surfaces and the formation of inter-dunal depressions (Misra 1995).

Three geomorphological studies have provided dated evidence for aeolian activity during MIS 6 and close to the boundary to MIS 7. At the sites of 16R dune (Singhvi *et al.* 2010), Chamu (Dhir *et al.* 2010) and Karna (Jain *et al.* 2005), aeolian deposits have been identified, indicating arid conditions. Calcrete horizons provide evidence for phases of ameliorated climates during MIS 6 (Singhvi *et al.* 2010), although these

have not been directly dated, and may relate to significantly later palaeoenvironmental conditions.

Overall, the last interglacial period (MIS 5) was marked by periods of humidity similar to, if not more humid than, conditions during the early Holocene climatic optimum (Enzel *et al.* 1999). In the central Thar, there is evidence of strong fluvial activity, seen in the presence of braided gravel bed channels at sites in the Luni valley (Jain *et al.* 2005), whereas on the southern margin there is evidence for extensive fluvial regimes in the Orsang, Sabarmati and Mahi valleys (Juyal *et al.* 2003, 2006). Limited aeolian activity is also reported during MIS 5, suggesting intermittent periods of increased aridity in the region, such as at 16R dune (Singhvi *et al.* 2010).

Towards the end of MIS 5 there is increasing evidence for reduced fluvial activity. Fluvial courses become absent from the central Thar (Jain *et al.* 2005) and they are considerably weaker on the southern margin (Juyal *et al.* 2003, 2006). The lack of aeolian or fluvial activity during MIS 4 is likely to relate to reduced influence of the monsoonal system as the major agent of landscape change. Aeolian activity and deposition appears to occur only at the very end of MIS 4 and at the onset of MIS 3, with the resumption of monsoonal winds (e.g. Dhir *et al.* 2010).

Increased precipitation is inferred between 50–30 ka, although relatively little landscape modification occurred during this period, suggesting this period was less humid than MIS 5. Palaeoenvironmental evidence indicates some stability and pedogenesis in MIS 3 (e.g. Juyal *et al.* 2003, 2006), even within the central region (e.g. Andrews *et al.* 1998, Dhir *et al.* 2004, Jain *et al.* 2005). Aeolian activity becomes more apparent toward the end of MIS 3 (e.g. Dhir *et al.* 2010), which, alongside evidence from the start of MIS 3, suggests that the precipitation associated with the SW monsoon is more sensitive to climatic change than the winds.

Palaeoenvironmental evidence indicates a period of extreme aridity in MIS 2. Once more, there is limited geomorphological evidence for landscape modification relating to the height of this arid phase except at the southern margin, where aeolian deposition is seen for the first time, a phenomenon that is likely to relate to onshore winds and proximity to the coast (Juyal *et al.* 2003, 2006). Between the LGM and the onset of the interglacial conditions in the Holocene, palaeoenvironmental conditions appear to have been in a state of flux, with deposition of aeolian sediments interspersed with fluvial, lacustrine or pedogenised horizons throughout the Thar Desert (e.g. Chawla *et al.* 1992, Deotare *et al.* 2004, Jain *et al.* 2005).

The presence of coherent fluvial systems extending into the central region during major humid phases (e.g. the Early Quaternary period, MIS 5) is likely to have been a key factor that enabled the occupation of the Thar Desert and eastward dispersals into South Asia. The switch from arid to humid climatic regimes (e.g. MIS 4–3, MIS 2–1), led to considerable changes in the landscape and the organisation of water resources. In some cases aeolian deposition has caused significant disorganisation of drainage networks, with the effect of creating lakes in localised depressions, of which Bap Malar playa is a recent example (Deotare *et al.* 2004). During the height of arid-

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ity, few places in the Thar Desert would have been suitable for hominin occupation, although the southernmost margin may be an exception due to coastal precipitation not entirely determined by the monsoon system. In addition to this, evidence from Sambhar Lake suggests it did not dry out even during the LGM (Sinha *et al.* 2006) and would presumably have provided a considerable pull for both hominins and a variety of fauna, just as it offers a wintering ground from numerous migratory birds from northern Asia today.

As the gateway region to South Asia, it is clear that climatic change in the Thar Desert has the potential to permit or prohibit human dispersals. At its most arid (MIS 6, 4 and 2), this region would have been an impenetrable barrier, lacking sufficient water resources to entice or support migrating populations to travel eastwards. However, at its most humid (MIS 5 and 3) the Thar Desert would have provided an attractive suite of riverine corridors and lakes, stable landscapes and seasonal abundances in resources, even in the modern arid core, that could support colonisation by migrating human populations and permit expansions into the unique mosaic environments of the subcontinent.

Archaeological evidence

Archaeological discoveries in the Thar Desert were first reported by Stein (1942) and the area has since seen a number of surveys that have provided a rich array of detail regarding the distribution of Palaeolithic sites in the region (Misra 2006) (Figure 2). Excavations at the site of 16R dune on the eastern Thar margin, near Didwana, provide a chronometrically dated sequence spanning MIS 6–1 incorporating archaeological assemblages labelled Lower, Middle and Upper Palaeolithic and Mesolithic (Raghavan *et al.* 1989, Singhvi *et al.* 2010).

The Lower Palaeolithic of the Thar Desert consists of Acheulean assemblages that are broadly split into Early and Late facies (Misra 1995). The excavations at Singi Talav, near Didwana, provide the best-known Lower Palaeolithic assemblage from the Thar Desert. Two Early Acheulean horizons are recorded at Singi Talav, based upon metamorphic rocks that are found between three and twenty kilometres away from the site. Geomorphological comparisons with deposits dated to 800 ka at Amarapura quarry, three kilometres away from Singi Talav, have been made, leading to suggestions that this is the minimum age for these assemblages (Gaillard *et al.* 2010), although this has been disputed (Chauhan 2010). At Umrethi, Saurashtra, a U-Th date on miolite of 190 ka overlies an Acheulean horizon (Baskaran *et al.* 1986). A small sample of Lower Paleolithic artefacts has been recovered from the nearby site of 16R dune (Gaillard 1993), dated between ~190–130 ka (Singhvi *et al.* 2010). On the whole, the Thar evidence generally agrees with a long duration of archaic hominin habitation in the subcontinent and the late survival of archaic hominins, extending to the onset of MIS 5 (Petraglia 2010, Haslam *et al.* 2010, Pappu *et al.* 2011).

The majority of evidence for Acheulean habitation of the Thar Desert comes from the surface finds and clear spatial patterning can be seen in their distribution.

Acheulean sites are almost exclusively located on the margins of the Thar Desert, close to large rocky outcrops such as the Aravallis (Misra 2006), Saurashtra (Ajithprasad, pers. comm.) and the Rohri Hills (Shaikh *et al.* 2002–03). An Acheulean age is present in the central Thar (e.g. IAR 1979–80) but the area is mainly devoid of sites, perhaps signalling the importance of arid conditions in limiting occupations.

A large number of Middle Palaeolithic sites occur in the Thar Desert, although most have not been dated. An exceptional site is the 16R dune, which contains stratified Middle Paleolithic assemblages dated to ca 126–108 ka, corresponding with a high percentage of C4 plants, a strong monsoon and summer rains (Achyuthan *et al.* 2007). At the site of Jetpur in Saurashtra, two excavated Middle Palaeolithic assemblages are recorded beneath a miolite layer that is dated by U-Th methods to 56 ka, suggesting an earlier presence (Baskaran *et al.* 1986). The distribution of Middle Palaeolithic assemblages exhibits continuity from the preceding period, as well as pointing towards considerable expansion into previously unoccupied areas. Extensive surveys of the Luni valley have revealed a wealth of Middle Palaeolithic sites extending into the central Thar regions (Misra 2006). Middle Palaeolithic sites are also reported from the central Thar close to a number of extinct palaeochannels near Jaisalmer, Pokoran and Phalodi (Misra 2006). Middle Palaeolithic sites become much more numerous in Saurashtra and are present in the alluvial plains of Gujarat (Ajithprasad, pers. comm.) whereas in Sindh sites extend much further into the desert, with numerous sites in the Veesar valley (Shaikh *et al.* 2002–03). The evidence suggests that during improved conditions, Middle Palaeolithic hominins expanded into many areas of the Thar.

Upper Palaeolithic industries are present in the Thar but the ages of many of these sites remain unknown. An assemblage dated to ca. 26 ka has been identified as Upper Palaeolithic at 16R Dune, although the sample size is too low for easy technological comparisons to be made (Achyuthan *et al.* 2007). It can be reasonably hypothesised that many Upper Palaeolithic assemblages, containing blade and microblade technologies, date to ca. 35 ka and after (Petraglia *et al.* 2009). Microblade innovations have been tied to more efficient hunting strategies in the face of environmental deterioration and population increase at ca. 35 ka (Petraglia *et al.* 2009). Survey in the western Thar margin resulted in the identification of over one hundred Upper Palaeolithic sites containing unidirectional blade cores, wide blades and retouched scrapers (Shaikh *et al.* 2002–03). Upper Palaeolithic sites have also been identified in the region around Buddha Pushkar and systematic collection of artefacts has shown that these assemblages contain high percentages of blade cores and blades, alongside a range of scrapers and burins (Allchin and Goudie 1974). The evidence suggests that human populations were present in the marginal habitats of the Thar Desert from MIS 3 and into the Holocene, although Misra (1995) suggests that, due to the intense aridity of the Late Glacial Maximum, occupation of the Thar Desert was significantly reduced.

DISCUSSION

Examination of the Arabian and Thar desert zones provides an opportunity to outline the relationship between environmental change and hominin occupation history over the Pleistocene. One of the most interesting topics concerns the relationship between palaeohydrological features and archaeological site locations (Figure 3). Palaeorivers and palaeolakes must have played a key role in the dispersal of hominins, allowing populations to penetrate deep into the interior of Arabia and the Thar. The first secure occupations in both regions occur in the Acheulean, indicating that archaic hominins penetrated deeply into the interior of Arabia and at least to the margins of the Thar. Unfortunately, there is little chronological information on the precise date of Acheulean occupation and environmental information for sites is woefully inadequate. It is clear, however, that Acheulean hominins travelled along river channels to reach interior zones, indicating their presence in wet periods of the Middle Pleistocene. The long duration of archaic hominin occupation of India, from ca. 1.4 mya to 140–130 ka, suggests that hominins survived considerable climatic fluctuations. The presence of hominins in the Thar Desert in MIS 6 may suggest that archaic populations were able to adapt to marginal environments, consistent with Levantine evidence to suggest the

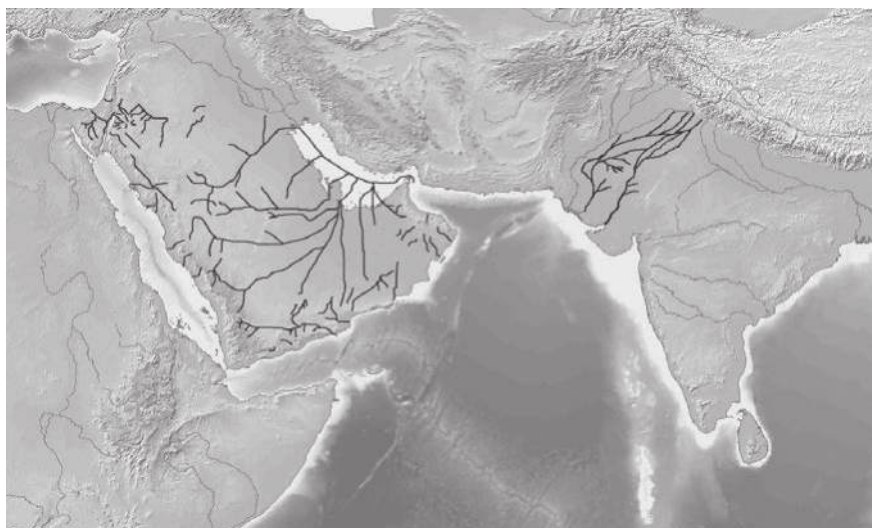


Figure 3. Map of the Arabia–Thar Desert zone. The major palaeorivers have been illustrated. The main river channels and their tributaries would have attracted animals and hominins. Hominins probably used rivers to disperse across these regions. Palaeolakes, not depicted here, are also important considerations in influencing hominin dispersals. Rivers and lakes would have provided fresh-water resources in interior areas. During arid and hyper-arid conditions, rivers and lakes dried, probably leading to population fragmentation, isolation and possible extinction events.

use of semi-arid zones by Palaeolithic hominins (Yeshurun *et al.* 2011). Given their adaptive success over the long term, the reason for the extinction of archaic hominins in India remains unknown. Acheulean sites in Arabia do not seem to be as plentiful compared to India, suggesting that arid conditions may have played a stronger role in the long-term survival of archaic hominins.

Middle Palaeolithic archaeological sites are widespread and more abundantly represented in Arabia and in the Thar Desert in comparison to Acheulean sites, thus raising the possibility for larger, and more behaviourally flexible, populations. Middle Palaeolithic populations dispersed into Arabia and the Thar with improving environmental conditions in early MIS 5. The Jebel Faya assemblages at ca. 125 ka and the 16R dune assemblages at ca. 126–108 ka, indicate population expansions into favourable habitats. Though the Jebel Faya assemblages have been considered to represent the expansion of *Homo sapiens* from Africa on the basis of stone tool typology (Armitage *et al.* 2011), there is the possibility that the hand-axe assemblages may represent an archaic form of hominin (Petraglia 2011). Likewise, the Middle Palaeolithic assemblages from the 16R dune may have been produced by expanding populations of *Homo sapiens* or by archaic hominins (Petraglia *et al.* 2010). The presence of Middle Palaeolithic populations in the later stages of MIS 5 in Arabia (Delagnes *et al.* 2008, Armitage *et al.* 2011, Petraglia *et al.* 2011) and in the Thar Desert (Mishra *et al.* 1999) indicates that populations moved widely across these regions. MIS 4 environments in Arabia and the Thar Desert were probably inhospitable, probably leading to depopulation of the dry interior zones. However, the continued presence of populations in Arabia from MIS 5–3 at Jebel Faya (Armitage *et al.* 2011) and the presence of populations at the transition of MIS 5a–4 in Yemen (Delagnes *et al.* 2008) indicates that populations contracted into refugium zones in highlands and along riverine coastlines. In India, MIS 4 would have resulted in the expansion of the Thar Desert but populations were probably present in a mosaic of habitats across the subcontinent (Petraglia *et al.* 2010). MIS 3 conditions in Arabia may not have been entirely favourable (Parker 2009), perhaps relating to the lack of Upper Palaeolithic industries in Arabia. On the other hand, the widespread presence of blade and microblade assemblages from 35 ka in India indicates the sustained presence of humans from MIS 3 and onwards. And, indeed, genetic coalescence ages, ranging between 70–50 ka, for the appearance of *Homo sapiens* in India (Endicott *et al.* 2009, Soares *et al.* 2009), indicates that populations were present from at least MIS 4 to the present.

This brief overview indicates that environmental fluctuations in Arabia and in the Thar likely played a key role in structuring the population history of these regions. The dispersal and demographic expansion of hominin populations is probably related to improved environmental conditions in these desert zones. Once the deserts opened up in wet periods, archaic hominins and humans expanded across these regions. The demographic history of these two arid regions appear to vary somewhat, however, probably owing to the different geographic nature of these desert zones. Arid periods in Arabia correspond with the drying of rivers and lakes, which would have made

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continued occupation in the interior desert difficult, if not impossible. Populations would have had to contract to refugium zones along the margins of the peninsula, although these populations would presumably have become increasingly stressed over time. On the other hand, populations could have survived on the margins of the Thar Desert and in many other grassland and woodland zones of the subcontinent. Although much more detailed information is needed to understand the evolutionary history of hominin populations in Arabia and the Thar, it is abundantly clear that these desert zones must have played a key role in influencing prehistoric demography.

Palaeoanthropologists and archaeologists remain obsessed with the dispersal of *Homo sapiens* from Africa; it is impossible to understand how humans came to occupy Eurasia, Australia and the Americas without considering how environmental fluctuations have turned deserts from impenetrable barriers to attractive corridors for migrating populations. Archaeological and palaeoanthropological inquiry in the deserts of Arabia is central to investigating the first steps out of Africa by dispersing modern humans. The Thar, as the eastern limit of the broad desert belt stretching for more than 7,000 km from West Africa, marks the final, familiar desert landscape that would have been colonised by dispersing human groups prior to encountering the diverse and unique environments found east of Africa. Therefore, it is in these desert landscapes that the first chapter of the Out of Africa story is set.

ACKNOWLEDGEMENTS

We acknowledge the Saudi Commission for Tourism and Antiquities and the Archaeological Survey of India for permission to conduct research in Saudi Arabia and India. Funding for our research has been provided by the Arts and Humanities Research Council, the British Academy, the Leverhulme Trust, the Royal Anthropological Institute, and St Hugh's College, Oxford. For useful discussions, we thank Abdullah Alsharekh, Nicole Boivin, Pete Ditchfield, Ravi Korisettar, Adrian Parker and Bert Roberts.

REFERENCES

- Abed, A.M., S. Yasin, R. Sadaqaa and Z. Al-Hawari (2008). 'The Palaeoclimate of the eastern Desert of Jordan during marine isotope stage 9'. *Quaternary Research* 69: 458–468.
- Achyuthan, H., J. Quade, L. Roe and C. Placzek (2007). 'Stable isotopic composition of pedogenic carbonates from the eastern margin of the Thar Desert, Rajasthan, India'. *Quaternary International* 162–3: 50–60.
- Allchin, B. and A. Goudie (1974). 'Pushkar: Prehistory and climatic change in Western India'. *World Archaeology* 5 (3): 358–368.
- Amirkhanov, A. (1994). 'Research on the Paleolithic and Neolithic of Hadramaut and Mahra'. *Arabian Archaeology and Epigraphy* 5: 217–228.

- Andrews, J.E., A.K. Singhvi, A.J. Kailath, R. Kuhn, P.F. Dennis, S.K. Tandon and R.P.Dhir (1998). 'Do stable isotope data from calcrete record late Pleistocene monsoonal climate variation in the Thar Desert of India?' *Quaternary Research* 50: 240–251.
- Anton, D. (1984). 'Aspects of geomorphological evolution: Paleosols and dunes in Saudi Arabia', in A.R. Jado and J.G. Zötl (eds.) *Quaternary Period in Saudi Arabia. Vol 2: Sedimentological, Hydrogeological, Hydrochemical, Geomorphological, and Climatological Investigations of Western Saudi Arabia*. Wien: Springer-Verlag. pp. 275–96.
- Armitage, S.J., S.A. Jasim, A.E. Marks, A.G. Parker, V.I. Usik and H.-P.Uerpmann (2011). 'The southern route "Out of Africa": Evidence for an early expansion of modern humans into Arabia'. *Science* 331: 453–456.
- Bailey, G. (2009). 'The Red Sea, coastal landscapes, and hominin dispersals', in M.D. Petraglia and J.I. Rose (eds.) *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory, and Genetics*. Netherlands: Springer. pp. 15–37.
- Bajpai, V.N., T.K. Saha Roy and S.K. Tandon (2001). 'Subsurface sediment accumulation patterns and their relationships with tectonic lineaments in the semi-arid Luni River Basin, Rajasthan, Western India'. *Journal of Arid Environments* 48: 603–621.
- Barker, G. and D. Gilbertson (eds.) 2000. *The Archaeology of Drylands: Living at the Margin*. London: Routledge.
- Baskaran, M., A.R. Marathe, S.N. Rajaguru and B.L.K. Somayajulu (1986). 'Geochronology of Palaeolithic cultures in the Hiran valley, Saurashtra, India'. *Journal of Archaeological Science* 13: 505–514.
- Burns, S.J., D. Fleitmann, A. Matter, U. Neff and A. Mangini (2001). 'Speleothem evidence from Oman for continental pluvial events during interglacial periods'. *Geology* 29 (7): 623–626.
- Chauhan, P. (2010). 'Comment on "Lower and early Middle Pleistocene Acheulian in the Indian sub-Continent" by C. Gaillard *et al.*' *Quaternary International* 223–224: 248–259.
- Chawla, S., R.P. Dhir and A.K. Singhvi (1992). 'Thermoluminescence chronology of sand profiles in the Thar Desert and their implications'. *Quaternary Science Reviews* 11: 25–32.
- Clark, I. and J.-C. Fontes (1990). 'Paleoclimatic reconstruction of Northern Oman based on carbonates from hyperalkaline groundwaters'. *Quaternary Research* 33: 320–336.
- Clemens, S., W. Prell, D. Murray, G. Shimmield and G. Weedon (1991). 'Forcing mechanism of the Indian Ocean monsoon'. *Nature* 353: 720–725.
- Crassard, R. (2009). 'The Middle Paleolithic of Arabia: The view from the Hadramawt Region, Yemen', in M.D. Petraglia and J.I. Rose (eds.) *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics*. Netherlands: Springer. pp. 151–168.
- Crassard, R., J. McCorriston, E. Oches, A. bin Aqil, J. Espagne and M. Sinnah (2006). 'Manayzah, early to mid-Holocene occupations in Wādī Sanā'. *Proceedings of the Seminar for Arabian Studies* 36: 151–73.
- Crassard, R. (2007). 'Apport de la technologie lithique à la définition de la préhistoire du Hadramawt, dans le contexte du Yémen et de l'Arabie du sud'. Ph.D. dissertation, Université Paris, Panthéon-Sorbonne.

Hominin Evolutionary History

- Delagnes A., R. Macchiarelli and J. Jaubert (2008). 'Middle Paleolithic settlement in Arabia: First evidence from a complex of stratified archaeological sites in Western Yemen'. Paper presented at the Palaeoanthropology Meetings, Vancouver.
- Dennell, R.W. (2009). *The Palaeolithic Settlement of Asia*. Cambridge: Cambridge University Press.
- Deotare, B.C., M.D. Kajale, S.N. Rajaguru, S. Kusumgar, A.J.T. Jull and J.D. Donahue (2004). 'Palaeoenvironmental history of Bap-Malar and Kanod Playas of Western Rajasthan, Thar Desert'. *Proceedings of the Indian Academy of Sciences (Earth and Planetary Sciences)* 113: 402–425.
- Dhir, R.P., S.K. Tandon, B.K. Sareen, R. Ramesh, T.K.G. Rao, A.J. Kailath and N. Sharma (2004). 'Calcretes in the Thar: Genesis, chronology and palaeoenvironment'. *Proceedings of the Indian Academy of Sciences (Earth and Planetary Sciences)* 113: 473–515.
- Dhir, R.P., A.K. Singhvi, J.E. Andrews, A. Kar, B.K. Sareen, S.K. Tandon, A. Kailath and J.V. Thomas (2010). 'Multiple episodes of aggradation and calcrete formation in late Quaternary aeolian Sands, Central Thar Desert, Rajasthan, India'. *Journal of Asian Earth Sciences* 37: 10–16.
- Drake, N.A., R.M. Blench S.J. Armitage, C.S. Bristow and K.H. White (2011). 'Ancient watercourses and biogeography of the Sahara explain the peopling of the desert'. *Proceedings of the National Academy of Sciences of America* 108: 458–462.
- Edens, C. (2001). 'A bladelet industry in Southwestern Saudi Arabia'. *Arabian Archaeology and Epigraphy* 12: 137–142.
- Edgell, H.S. (2006). *Arabian Deserts. Nature, Origin and Evolution*. Netherlands: Springer.
- Endicott, P., S.Y.W. Ho, M. Metspalu and C. Stringer (2009). 'Evaluating the mitochondrial timescale of human evolution'. *Trends in Ecology and Evolution* 24:515–521.
- Enzel, Y., L.L. Ely, S. Mishra, R. Ramesh, R. Amit, B. Lazar, S.N. Rajaguru, V.R. Baker, and A. Sandler (1999). 'High-Resolution Holocene environmental changes in the Thar Desert, Northwestern India'. *Science* 284: 125–128.
- Faure, H., R.C. Walter and D.R. Grant (2002). 'The coastal oasis: Ice Age springs on emerged continental shelves'. *Global and Planetary Change* 33: 47–56.
- Fernandes, C.A. (2009). 'Bayesian coalescent inference from mitochondrial DNA variation of the colonization time of Arabia by the Hamadryas Baboon (*Papio hamadryas hamadryas*)', in M.D. Petraglia and J.I. Rose (eds.) *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics*. Netherlands: Springer Press. pp. 89–100.
- Field, J.S. and M.M. Lahr (2005). 'Assessment of the southern dispersal: GIS-based analyses of potential routes at oxygen isotopic stage 4'. *Journal of World Prehistory* 19:1–45.
- Field, J., M.D. Petraglia and M.M. Lahr (2007). 'The southern dispersal hypothesis and the South Asian archaeological record: Examination of dispersal routes through GIS analysis'. *Journal of Anthropological Archaeology* 26: 88–108.
- Fleitmann, D. and A. Matter (2009). 'The speleothem record of climate variability in southern Arabia'. *C.R. Geosciences* 34 (8): 633–642.

- Fleitmann, D., S.J. Burns, A. Mangini, M. Mudelsee, J. Kramers, I. Villa, U. Neff, A.A. Al-Subary, A. Buettner, D. Hippler and A. Matter (2007). 'Holocene ITCZ and Indian monsoon dynamics recorded in stalagmites from Oman and Yemen (Socotra)'. *Quaternary Science Reviews* 26: 170–188.
- Foley, M.M. and R.A. Lahr (1998). 'Towards a theory of modern human origins: geography, demography, and diversity in recent human evolution'. *Yearbook of Physical Anthropology* 41: 137–176.
- Frumkin, A., O. Bar-Yosef and H.P. Schwarcz (2011). 'Possible paleohydrologic and paleoclimatic effects on hominin migration and occupation of the Levantine Middle Paleolithic'. *Journal of Human Evolution* 60: 437–451.
- Gaillard, C. (1993). 'Contribution à la connaissance du Paléolithique inférieur-moyen du Inde'. Unpublished PhD. Thesis, Université de Provence.
- Gaillard, C., S. Mishra, M. Singh, S. Deo and R. Abbas (2010). 'Lower and early Middle Pleistocene Acheulian in the Indian Sub-Continent'. *Quaternary International* 223–224: 234–241.
- Garrard, A.N., C.P.D. Harvey and V.R. Switsur (1981). 'Environment and settlement during the Upper Pleistocene and Holocene at Jubba in the Great Nefud, Northern Arabia'. *Atlat* 5: 137–148.
- Gilmore, M., M. Al-Ibrahim and A.S. Murad (1982). 'Preliminary report on the Northwest-ern and Northern Region Survey 1981 (Arabic 1401)'. *Atlat* 6: 9–23.
- Goudie, A.S., A. Colls, S. Stokes, A.G. Parker, K. White and A. Al-Farraj (2000). 'Latest Pleistocene dune construction at the North-eastern edge of the Rub' al Khali, United Arab Emirates'. *Sedimentology* 47: 1011–21.
- Haslam, M., R.G. Roberts, C. Shipton, J.N. Pal, J.L. Fenwick, P. Ditchfield, N. Boivin, A.K. Dubey, M.C. Gupta and M. Petraglia (2010). 'Late Acheulean hominins at the marine isotope stage 6/5e transition in North-central India'. *Quaternary Research* 75: 670–682.
- Immenhauser, A., Y.V. Dublyansky, G. Schmiedl, H.S. Niebler and C. Hemleben (2007). 'Textual, elemental, and isotopic characteristics of Pleistocene Phreatic cave deposits (Jabal Madar, Oman)'. *Journal of Sedimentary Research* 77: 68–88.
- Indian Archaeology – A Review 1979–1980*. Delhi: Archaeological Survey of India.
- Jain, M., S. K. Tandon, A.K. Singhvi, S. Mishra and S.C. Bhatt (2005). 'Quaternary alluvial stratigraphical development in a desert setting: A case study from the Luni River Basin, Thar Desert of Western India'. *Special Publications of the International Association of Sedimentologists* 35: 349–371.
- Juyal, N., A. Kar, S.N. Rajaguru and A.K. Singhvi (2003). 'Luminescence chronology of aeolian accretion during the late Quaternary in the Southern margin of Thar Desert'. *Quaternary International* 104: 87–98.
- Juyal, N., L.S. Chamyal, S. Bhandari, R. Bhushan and A.K. Singhvi (2006). 'Continental record of the southwest monsoon during the last 130 ka: Evidences from the southern margin of the Thar Desert, India'. *Quaternary Science Reviews* 25: 2632–2650.
- Kar, A. (1995). 'Geomorphology of arid west India', in S. Wadia, R. Korisettar and V.S. Kale (eds.) *Quaternary Environments and Geoarchaeology of India*. Bangalore: Geological Society of India. pp. 168–190.

Hominin Evolutionary History

- Kuper, R. and S. Kropelin (2006). 'Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution'. *Science* 313: 803–807.
- Lézine, A.-M., J.J. Tiercelin, C. Robert, J.-F. Saliège, S. Cleuziou, M.-L. Inizan and F. Braemer (2007). 'Centennial to millennial-scale variability of the Indian monsoon during the early Holocene from a sediment, pollen and isotope record from the desert of Yemen'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 243: 235–249.
- Macchiarelli, R. (2008). 'From Africa to Asia through Arabia: Models, predictions and witnesses of first phases of human settlement'. Paper presented at the Conference on the First Great Migrations of Peoples, UNESCO, Paris.
- Maher, L.A. (2009). 'The late Pleistocene of Arabia in relation to the Levant', in M.D. Petraglia and J.I. Rose (eds.) *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics*. Netherlands: Springer. pp. 187–202.
- Maurya, D.M., L.S. Chamyal and S.S. Merh (1995). 'Tectonic evolution of the Central Gujarat Plain, Western India'. *Current Science* 69: 610–613.
- McClure, H.A. (1976). 'Radiocarbon chronology of late Quaternary lakes in the Arabian Desert'. *Nature* 263: 755–756.
- McClure, H. (1994). 'A new Arabian stone tool assemblage and notes on the Aterian industry of North Africa'. *Arabian Archaeology and Epigraphy* 5: 1–16.
- McLaren, S., F. Al-Juaidi, A.C. Millington and M.D. Bateman (2009). 'Evidence for wetter events in the arid interior of Central Saudi Arabia'. *Journal of Quaternary Science* 24: 198–207.
- Mishra, S., M. Jain, S.K. Tandon, A.K. Singhvi, A.P. Joglekar, A.C. Bhatt, A.A. Kshirsagar, S. Naik and A. Deshpande-Mukerjee (1999). 'Prehistoric cultures and late Quaternary environments in the Luni Basin around Balotra'. *Man and Environment* 24: 39–49.
- Misra, V.N. (1995). 'Geoarchaeology of the Thar Desert, Northwest India', in S. Wadia, R. Korisettar and V.S. Kale (eds.) *Quaternary Environments and Geoarchaeology of India*. Bangalore: Geological Society of India. pp. 210–230.
- Misra, V.N. (2006). 'Gazetteer of archaeological sites in Rajasthan (from Palaeolithic to early Historic)'. *Man and Environment* 31: 46–78.
- Osborne, A.H., D. Vance, E.J. Rohling, N. Barton, M. Rogerson and N. Fello (2008). 'A humid corridor across the Sahara for the migration of early modern humans out of Africa 120,000 years ago'. *Proceedings of the National Academy of Sciences* 105: 16444–16447.
- Pappu, S., Y. Gunnell, K. Akilesh, R. Braucher, M. Taieb, F. Demory and N. Thouveny (2011). 'Early Pleistocene presence of Acheulian hominins in South India'. *Science* 331: 1596–1599.
- Parker, A. (2009). 'Pleistocene climate change in Arabia: Developing a framework for hominin dispersal over the last 350 ka', in M.D. Petraglia and J.I. Rose (eds.) *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics*. Netherlands: Springer. pp. 39–49.
- Parker, A.G. and A.S. Goudie (2007). 'Development of the Bronze Age landscape in the Southeastern Arabian Gulf: New evidence from a buried shell midden in the Eastern extremity of the Rub' al Khali Desert, Emirate of Ras al-Khaimah, UAE'. *Arabian Archaeology and Epigraphy* 18: 232–238.

- Parker, A., G. Preston, H. Walkington and M.J. Hodson (2006). 'Developing a framework of Holocene climatic change and landscape archaeology for the Lower Gulf Region, South-eastern Arabia'. *Arabian Archaeology and Epigraphy* 17: 125–130.
- Parker, A.G. and J.I. Rose (2008). 'Climate change and human origins in Southern Arabia'. *Proceedings of the Seminar for Arabian Studies* 38: 227–44.
- Parr, P.J., J. Zarins, M. Ibrahim, J. Waechter, A. Garrard, C. Clarke, M. Bidmead and H. al-Badr (1978). 'Preliminary report on the second phase of the Northern Province Survey 1397/1977'. *Atlat* 2: 29–50.
- Petraglia, M.D. (2003). 'The Lower Palaeolithic of the Arabian Peninsula: Occupations, adaptations, and dispersals'. *Journal of World Prehistory* 17: 141–179.
- Petraglia, M.D. (2010). 'The Early Paleolithic of the Indian subcontinent: Hominin colonization, dispersals and occupation history', in J.G. Fleagle, J. Shea, F.E. Grine, A.L. Baden and R.E. Leakey (eds.) *Out of Africa I: The First Hominin Colonization of Eurasia*. Netherlands: Springer. pp. 165–179.
- Petraglia, M.D. (2011). 'Trailblazers across Arabia'. *Nature* 470: 50–51.
- Petraglia, M.D. and A. Alsharekh (2003). 'The Middle Palaeolithic of Arabia: Implications for modern human origins, behaviour and dispersals'. *Antiquity* 77 (298): 671–684.
- Petraglia, M.D. and J.I. Rose (eds.) (2009). *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics*. Netherlands: Springer.
- Petraglia, M.D., N. Drake and A. Alsharekh (2009). 'Acheulean landscapes and large cutting tools assemblages in the Arabian Peninsula', in M.D. Petraglia and J.I. Rose (eds.) *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics*. Netherlands: Springer. pp. 103–106.
- Petraglia, M.D., M. Haslam, D.Q. Fuller, N. Boivin and C. Clarkson (2010). 'Out of Africa: New hypotheses and evidence for the dispersal of *Homo sapiens* along the Indian Ocean rim'. *Annals of Human Biology* 37: 288–311.
- Petraglia, M.D., A.M. Alsharekh, R. Crassard, N.A. Drake, H. Groucutt, A.G. Parker and R.G. Roberts (2011). 'Middle Paleolithic occupation on a marine isotope stage 5 lake-shore in the Nefud Desert, Saudi Arabia'. *Quaternary Science Reviews* 30:1555–1559.
- Preusser, F. (2009). 'Chronology of the impact of Quaternary climate change on continental environments in the Arabian Peninsula'. *C.R. Geoscience* 341: 621–632.
- Preusser, F., D. Radies and A. Matter (2002). 'A 160,000 year record of dune development and atmospheric circulation in Southern Arabia'. *Science* 296: 2018–20.
- Raghavan, H., S.N. Rajaguru and V.N. Misra (1989). 'Radiometric dating of a Quaternary dune section, Didwana, Rajasthan'. *Man and Environment* 13: 19–22.
- Ramasamy, S.M., P.C. Bakliwal and R.P. Verma (1991). 'Remote sensing and river migration in Western India'. *International Journal of Remote Sensing* 12: 2597–2609.
- Rose, J.I. (2006). 'Among Arabian sands: Defining the Palaeolithic of Southern Arabia'. Unpublished Ph.D. dissertation, Southern Methodist University, Dallas.
- Rose, J.I. (2007). 'The Arabian corridor migration model: Archaeological evidence for hominin dispersals into Oman during the Middle and Upper Pleistocene'. *Proceedings of the Seminar for Arabian Studies* 37: 219–237.

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- Rose, J.I. (2010). 'New light on human prehistory in the Arabo-Persian Gulf oasis'. *Current Anthropology* 51: 849–883.
- Rose, J.I. and M.D. Petraglia (2009). 'Tracking the origin and evolution of human populations in Arabia', in M.D. Petraglia and J.I. Rose (eds.) *The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics*. Netherlands: Springer. pp. 1–12.
- Roy, A.B. and S.R. Jakher (2001). 'Late Quaternary drainage disorganization, and migration and extinction of the Vedic Saraswati'. *Current Science* 81: 1188–1195.
- Schultz, E. and J.W. Whitney (1986). 'Upper Pleistocene and Holocene lakes in the An Nafud, Saudi Arabia'. *Hydrobiologica* 143: 175–190.
- Shaikh, N., G.M. Vesar and Q.H. Mallah (2002–2003). 'Recent discoveries of sites/industrial complexes in Thar, Rohri Hills and adjacent plains: Regional perspectives'. *Ancient Sindh* 7: 27–66.
- Singhvi, A.K. and A. Kar (2004). 'The aeolian sedimentation record of the Thar Desert'. *Proceedings Indian of the Academy of Sciences (Earth and Planetary Sciences)* 113: 371–402.
- Singhvi, A.K., M.A.J. Williams, S.N. Rajaguru, V.N. Misra, S. Chawla, S. Stokes, N. Chauhan, T. Francis, R.K. Ganjoo and G.S. Humphreys (2010). 'A ~200 ka record of climatic change and dune activity in the Thar Desert, India'. *Quaternary Science Reviews* doi:10.1016/j.quascirev.2010.08.003
- Sinha, R., W. Smykatz-Kloss, D. Stüben, S.P. Harrison, Z. Berner and U. Kramar (2006). 'Late Quaternary palaeoclimatic reconstruction from the Lacustrine sediments of the Sambhar Playa Core, Thar Desert Margin, India'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 233: 252–270.
- Soares, P., L. Ermini, N. Thomson, M. Mormina, T. Rito, A. Rohl, A. Salas, S. Oppenheimer, V. Macaulay and M.B. Richards (2009). 'Correcting for purifying selection: An improved human mitochondrial molecular clock'. *American Journal of Human Genetics* 84: 740–749.
- Stein, A. (1942). 'A survey of ancient sites along the "lost" Saraswati River'. *Geographical Journal* 99: 173–182.
- Thomas, H., D. Geraads, D. Vaslet, A. Memesh, D. Billiou, H. Bocherens, G. Dobigny, V. Eisenmann, M. Gayet, F. de Lapparent de Broin, G. Petter and M. Halawani (1998). 'First Pleistocene faunas from the Arabian Peninsula: An Nafud Desert, Saudi Arabia'. *C.R. Earth and Planetary Science* 326: 145–152.
- Veth, P., M. Smith and P. Hiscock (eds.) (2005). *Desert Peoples: Archaeological Perspectives*. Oxford: Blackwell.
- Vincent, P. (2008). *Saudi Arabia: An Environmental Overview*. London: Taylor and Francis.
- Waldmann, N., A. Torfstein and M. Stein (2010). 'Northward intrusion of low- and mid-latitude storms across the Saharo-Arabian belt during past interglacials'. *Geology* 38: 567–570.
- Whalen, N.M. and D.W. Pease (1992). 'Variability in developed Oldowan and Acheulean bifaces of Saudi Arabia'. *Atlatl* 13: 43–48.
- Whalen, N.M. and K.E. Schatte (1997). 'Pleistocene sites in southern Yemen'. *Arabian Archaeology and Epigraphy* 8: 1–10.

- Whalen, N.M. A. Killick, N. James, G. Morsi and M. Kamal (1981). 'Saudi Arabian archaeological reconnaissance 1980: Preliminary report on the Western Province Survey'. *Atlatl* 5: 43–58.
- Whalen, N., J.S. Siraj-Ali and W. Davis (1984). 'Excavation of Acheulean sites near Saffaqah, Saudi Arabia, 1403 AH 1983'. *Atlatl* 10: 94–101.
- Whalen, N.M., J. Sirasj-Ali, H.O. Sindhi, D.W. Pease and M.A. Badein (1988). 'A complex of sites in the Jeddah-Wadi Fatimah area'. *Atlatl* 11: 77–85.
- Whalen, N.M., W.P. Davis and D.W. Pease (1989). 'Early Pleistocene migrations into Saudi Arabia'. *Atlatl* 12: 59–75.
- Whalen, N.M., M. Zoboroski and K. Schubert (2002). 'The Lower Palaeolithic in southwestern Oman'. *Adumatu* 5: 27–34.
- Whitney, J.W., D.J. Faulkender and R. Meyer (1983). 'The environmental history and present condition of Saudi Arabia's northern sand seas'. USGS open-file report, 83: 749–788.
- Wood, W.W., Z.S. Rizk and A.S. Alsharhan (2003). 'Timing of recharge, and the origin, evolution, and distribution of solutes in a hyperarid aquifer system', in A.S. Alsharhan and W.W. Wood (eds.) *Water Resources Perspectives: Evaluation Management and Policy*. Amsterdam: Elsevier. pp. 295–312.
- Yeshurun, R., Y. Zaidner, V. Eisenmann, B. Martínez-Navarro and G. Bar-Oz (2011). 'Lower Paleolithic hominin ecology at the fringe of the desert: Faunal remains from Bizat Ruhama and Nahal Hesi, Northern Negev, Israel'. *Journal of Human Evolution* 60: 492–507.
- Zarins, J., A. al-Jawad Murad and K.S. Al-Yish (1981). 'The comprehensive archaeological survey program. The secondary preliminary report on the Southwestern Province'. *Atlatl* 5: 9–42.
- Zarins, J., A.A. Rahbini and M. Kamal (1982). 'Preliminary report on the archaeological survey of the Riyadh Area'. *Atlatl* 6: 25–38.
- Zarins, J., N. Whalen, M. Ibrahim, A.A. Jawad Mursi and M. Khan (1980). 'Comprehensive archaeological survey program, preliminary report on the Central and Southwestern Provinces Survey: 1979'. *Atlatl* 4: 9–36.

CAN CARBON FINANCE ENHANCE DESERT AFFORESTATION AND SERVE SMALLHOLDERS' NEEDS?

Henri Rueff and Moshe Schwartz

INTRODUCTION

For over a century, large-scale afforestation projects¹ have been carried out in the drylands, often by government agencies. The purposes were to rehabilitate degraded land, supply timber or non-timber forest products including fuel wood, prevent deserts from spreading, protect land from winds and cities from dust or provide employment and recreational sites (Rueff *et al.* 2004). Often governments have also pursued such projects to ensure control of disputed lands or to prevent alternative uses (Cohen 1991). Dryland afforestation has been carried out around the entire Mediterranean basin (Cohen 1993, Ben Said 1995, Caparrós and Jacquemont 2003, Earth Trends 2003, Gruenwzweig *et al.* 2003, Maestre and Cortina 2006, Sahara and Sahel Observatory 2008, Rueff *et al.* 2008); in South Asia (Rahim *et al.* 2010); in Sub-Saharan Africa (Sahara and Sahel Observatory 2008, Reij *et al.* 2009); in the Americas (Sedjo 1999, Olschewski *et al.* 2006, Shaikh *et al.* 2007); in Central Asia (WOCAT 2007); and in Australia (Hunt 2008). The resulting dryland forests are usually rain-fed monocultures of drought resistant and fast-growing species. Nursery-grown seedlings are planted on prepared land with pits to harvest runoff water and ease its infiltration to the root zone of trees. Once planted, the trees can withstand dry seasons and consecutive years of drought.

Some critics oppose dryland afforestation, emphasising its use for political purposes (Cohen 1993) as well as the environmental damage it can wreak on dryland ecosystems (Maestre and Cortina 2005). Monocultural forests of exotic fast-growing trees in the drylands can indeed play havoc with biodiversity (Shohat *et al.* 2001, Hawlena and Bouskila 2006, Hunt 2008, Caparrós *et al.* 2009) while consuming most

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1. The forests are rain-fed and planted from dry sub-humid to arid conditions. They have a closed canopy with the fewest trees possible, to reduce water requirements. Areas with an aridity index of 0.2 (250 mm rain per annum) seem to be the driest where large scale afforestation can be pursued. *Pinus halepensis* fits such areas and has been planted in most parts of the Mediterranean Basin.

of the precipitation water, thus hurting downstream farmers and preventing aquifer recharge (World Rainforest Movement 2003, Farley *et al.* 2005).

With the emergence of the carbon (C) market, this controversy has gained momentum. Dryland trees, like most plants, remove CO₂ from the atmosphere through photosynthesis. Moreover, they are efficient C sinks,² promising for climate change mitigation (Gruenzweig *et al.* 2003). This effect may be traded between developing and industrialised countries in the form of C credits. The Kyoto Protocol defined the Clean Development Mechanism (CDM)³, which allows industrialised countries to offset part of their greenhouse gas (GhG) emissions by purchasing C credits from mitigation activities in developing countries. Each C credit represents a ton of CO₂ removed from the atmosphere or whose emission has been avoided. Large tracts of barren drylands could be afforested to obtain C payments (Ornstein 2009). About half the developing countries have drylands and could receive C payments to afforest them. This makes afforestation and reforestation activities under the CDM scheme (A/R-CDM) potentially relevant for developing countries in the drylands.

This chapter shows that, assuming strict compliance with the Kyoto Protocol's regulations, C finance opportunities will not, at current prices, accelerate tree planting in the drylands. While this may be a welcome outcome for the opponents of large scale planting, small-scale afforestation is probably less harmful⁴ to the environment and might benefit smallholders. If so, C trading might help support smallholders' afforestation initiatives. For this to happen, however, some regulations would need to be modified and financial services extended. Afforestation in the drylands could become a pro-poor instrument, raising the livelihood of smallholders rather than serving political land control. After all, the C exchange mechanism was meant to mitigate both climate change and poverty (Chichilnisky and Sheeran 2009). Under current conditions, however, these objectives are unlikely to be met. After showing why current CDM regulations are unsuitable for dryland afforestation, the chapter discusses how smallholder-oriented alternatives may be encouraged.

The following section presents the societal services and disservices of dryland afforestation. Section three shows why, under present conditions, the C market is unsuitable for dryland afforestation. Section four discusses afforestation solutions that may reduce environmental harm while benefiting smallholders. Section five suggests

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2. See section on dryland afforestation and the carbon market
 3. The Clean Development Mechanism is the Kyoto Protocol's C exchange scheme allowing the trade of C credits between industrialised (Annex I) countries and developing (non-Annex I) countries. The CDM regulates the C accounting procedures and the exchange of C credits on the compliance markets.
 4. Patchy tree plantation is likely to alter less the native ecosystem than a large scale continuous afforestation project. The damages and benefits of dryland afforestation in relation to the scale of plantation remain however unstudied. Savannisation, which consist of planting trees at a very low density, is also an alternative to large scale afforestation. Sachs and Moshe (1999) define savannisation as 'a human-managed process, whereby, the water, nutrients, and soil flows are controlled by increased biodiversity and productivity in desertified areas'.

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ways in which C finance might be used to support small-scale tree planting, and suggests areas for further research.

DRYLAND AFFORESTATION – SOCIETAL SERVICES

Low vegetal cover due to harsh climate, overgrazing or other short-term land management forms, exposes the drylands to wind and water erosion (Zhu and Ren 2000). The impact of drops on barren soil in high intensity rain events leads to the formation of crust, which enhances runoff generation and thus water erosion (Morin *et al.* 1981). A tree canopy intercepts raindrops, which prevents their impact on the ground and the formation of crust. Forests in drylands thus prevent water and wind erosion of soils, which helps in rehabilitating degraded land, while increasing C sequestration in biomass and soils. Soil conservation, enhanced by afforestation, no-till cropping, low intensity grazing, land preparation or cropping diversification, can prevent C loss or even allow its re-sequestration (Lal 2004).

While preventing soil loss is the main societal service provided by dryland afforestation, it also reduces the risk of flash floods (Bradshaw *et al.* 2007, Van Dijk and Keenan 2007), which occur on barren land under intensive rain events, endangering population, buildings, roads and agriculture structures and crops. Additional services include recreation and non-use value,⁵ often viewed as important amenities at least in richer dryland countries (Amir and Retchman 2006). Also, some non-timber forest products are extracted by communities living on the outskirts of dryland forests (Croitoru 2007, Rueff *et al.* 2008). Finally, herders have found shade for their livestock in dryland forests, as well as grazing grounds in dry periods. Conversely, the removal of understorey vegetation by livestock has provided foresters with cost-effective fire control (Rueff *et al.* 2004).

DRYLAND AFFORESTATION – SOCIETAL DISSERVICES

Large-scale planting of trees in deserts is increasingly being challenged, in view of a number of societal disservices. One major disservice, given the scarcity of water in the drylands, is the massive consumption of water by trees, leaving none for the surrounding native ecosystem or to downstream users (Farley *et al.* 2005, Maestre and Cortina 2005, Van Dijk and Keenan 2007). Additional disservices are biodiversity alteration and habitat fragmentation (Shohat *et al.* 2001) especially when the forest is monospecific. Planted trees out-compete native species for resources that were already scarce beforehand (Ariza 2003). Introducing trees may also facilitate the nesting of generalist birds, reducing the resources available to specialist birds and exposing terrestrial species to avian predation, which they are unable to withstand (Shohat *et al.* 2001, Hawlena

5. When housing is located in the vicinity of a forest, its non-use value is reflected in the real estate market: a buyer will pay more for living near a forest, even if he is unlikely to consume this amenity directly, by spending leisure time in the forest.

et al. 2007). These drawbacks are especially serious in arid regions known for their fragile biodiversity, sensitive to the loss of even a single species (McNeely 2003). Tree planting also affects the aesthetic value of landscapes (Mattwes *et al.* 2002, Caparrós and Jacquemont 2003, Caparrós *et al.* 2009, Shaikh 2007) though this effect is a matter of controversy. Some would say that planting pine trees on maquis, scrubland, grassland or even landscapes with less vegetal cover generates pleasant leisure areas, while enhancing the value of real estate in the vicinity. For others, such planting turns natural landscapes into 'pine deserts'.⁶

DRYLAND AFFORESTATION AND THE CARBON MARKET

Despite the above drawbacks, the idea of planting trees in deserts and getting paid for it to mitigate climate change has gained attention in recent years. Gruenzweig *et al.* (2003) showed that the 'fertilization effect' of a CO₂-rich atmosphere made dryland trees more drought resistant, which gave hopes for planting deeper into deserts. Moreover, dryland trees in the northern hemisphere benefit from two sources of high CO₂ concentration in the atmosphere, which leads to a higher 'fertilization effect'. The first source is the considerable CO₂ uptake in spring and summer, when boreal and temperate areas have their photosynthetic activity. The yearly CO₂ atmospheric concentration in the northern hemisphere thus fluctuates from high concentrations in winter to low in summer. Unlike trees in temperate areas, dryland plants photosynthesise during the rainy season, throughout winter and spring. This out-of-phase photosynthetic activity makes a higher concentration of CO₂ in the atmosphere available for dryland plants. The second source of high CO₂ concentration is industrial activities, which have exponentially driven up CO₂ release in the last century, bringing it to current concentration levels above 380ppmv.⁷

Ornstein *et al.* (2009) have analysed the potential of tree planting in deserts, using C finance. According to them, raising the price of a gallon of gasoline by one dollar would cover the costs of planting trees all over the Sahara and the Australian Outback, including the hypothetical cost of desalinating seawater to irrigate the trees. Planting the Sahara and the Australian outback with trees would offset all global CO₂ emissions.

The two main stakeholders who might plant trees under a C finance scheme in developing dryland countries are government agencies and farmers. As stated, they are both unlikely to be rewarded for so doing. The agencies will find it difficult to demonstrate 'additionality',⁸ while the farmers' expected payment will be insufficient

6. In an article published in *Ha'aretz* (2008) a group of local experts discusses the controversial 'pine deserts' in the Israeli context, after more than sixty years of afforestation mainly with Aleppo Pines, claiming that the term 'pine deserts' is not relevant any more, as these forests have created the ground for plants to regenerate selectively.

7. Parts per million by volume.

8. UNFCCC's definition of additionality: 'a Programme of Activities (PoA) is additional if it can be demonstrated that in the absence of the CDM (i) the proposed voluntary measure would not be implemented, or (ii) the mandatory policy/regulation would be systematically not enforced and

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to induce them to renounce their usual agriculture activity in favour of tree planting. The two following sections show why this is the case.

**CARBON PAYMENT FOR DRYLAND AFFORESTATION ON
GOVERNMENT AGENCIES' INITIATIVES – THE ISSUE OF
'ADDITIONALITY'**

Additionality excludes projects from consideration as mitigation activities and thus from receiving C payment, unless they can demonstrate that without such payment, the projects would not have been implemented. A mitigation project demonstrates additionality if it is economically unfeasible without C payments. Government agencies having a long-term afforestation mandate are thus likely to keep afforesting regardless of C payments. As afforestation is for most government agencies their business-as-usual scenario, the mitigation scenario they would sell produces no additional GhG removal from the atmosphere and cannot, in theory, be validated.

Ferrey (2010) shows that strict additionality invalidates projects efficient at GhG removal or emission avoidance, even when they are economically feasible. According to him, and given the urgent need to abate global warming, any CO₂ removal from the atmosphere should be rewarded. It is uncertain whether additionality will remain a strict criterion or gain flexibility. In any case, under the Kyoto Protocol regime, additionality remains essential to the validation of C offsetting projects.

The Jewish National Fund⁹ (JNF) is an example of such a government agency, planting trees in Israel's drylands and seeking C payment.¹⁰ For the last few years, it has been advertising and marketing the C sequestered by the trees it is planting. It remains, however, outside the compliance scheme set by the CDM and sells its C credits on its own voluntary C offsetting program.¹¹ Standards and rules of non-regulatory schemes

that non-compliance with those requirements is widespread in the country/region, or (iii) that the PoA will lead to a greater level of enforcement of the existing mandatory policy/regulations. This shall constitute the demonstration of additionality of the PoA as a whole.' <http://cdm.unfccc.int/Reference/glossary.html> (Accessed 26 January 2012).

9. The JNF (Keren Kayemet Le'Israel in Hebrew) is the Israeli parastatal in charge of natural and planted forests in Israel, among other activities. For more information on the agency see Cohen 1993, Shilony 1998, Blougrund 2001, Rueff *et al.* 2004 and 2008.
10. Among a few other countries (Bahrain, South Korea, Oman, Qatar, the United Arab Emirates), Israel has been granted a non-Annex I country status though it has an annual income per capita above US\$20,000. As a result, these countries are considered 'developing' ones and exempted from emission restrictions, to safeguard their 'industrialisation'. These countries are allowed to host C offsetting projects and sell certified emission reductions to industrialised countries. Sources for the income per capita were taken from the World Bank, Gross National Income per Capita 2010, Atlas Method – available at <http://siteresources.worldbank.org/DATASTATISTICS/Resources/GNIPC.pdf> – Accessed 26 January 2012.
11. Voluntary market: a carbon offsetting scheme functioning outside of the compliance market set by the Kyoto Protocol and regulated by different standards.

(or voluntary markets) are set on each market¹² separately. Although voluntary markets often apply CDM regulations, some large ones, such as the Chicago Climate Exchange, require no additionality (Neeff *et al.* 2007). It is up to the buyer to decide whether the verified emission reductions (VERs)¹³ purchased meet a certain standard quality.¹⁴ C exchange presents a financial opportunity for the JNF, as long as additionality is not a limiting factor. Moreover, the JNF's contribution to climate change mitigation strengthens its appeal when campaigning for donations.

Other international organisations are initiating large-scale afforestation in the drylands, following the example of the Algerian 'Green Dam' implemented in the 1970s. Back then, a 1,500-kilometre stripe of trees was planted on the northern edge of the Sahara to stop its expansion. Today, a gigantic transnational project, called the 'Great Green Wall', aims at planting a fifteen-kilometre-wide stripe of trees from the western coast to the Horn of Africa, covering over 7,000 kilometres along the southern Saharan edge (Sahara and Sahel Observatory 2008). The project is funded by international organisations, NGOs and governments. Though the C sequestration potential of that project is acknowledged, no information is available as to whether that potential is to be used to fund the project (Sahara and Sahel Observatory 2008). Such large-scale projects are occurring, among Middle Eastern countries, in Syria, Jordan and the Palestinian Territories, whose governments have shown no intention of asking for C payments.

Given the variation in additionality restrictions described above, it is difficult to forecast whether C finance will benefit governmental agencies in the drylands, speeding up tree planting. However, as already asserted, afforestation in the drylands is unlikely to be accelerated on the compliance market regulated by the CDM scheme.

CARBON PAYMENT FOR DRYLAND AFFORESTATION ON FARMERS' INITIATIVES – THE ISSUE OF MINIMUM PAYMENT

In the drylands, farmers face higher levels of precipitation uncertainty than elsewhere and thus higher yield and income uncertainty. Their land management is affected by the need to limit soil loss, which is spurred by intensive cropping, deep tilling or excessive grazing, all of which bare the land and expose it to water and wind erosion. Choices of cropping and land management can be adjusted to minimise soil loss. No-till cropping is one such choice. While yields may remain steady if not increase under a no-till treat-

12. A few examples of non-regulatory schemes are: the Chicago Climate Exchange, the Norwegian Government Fund, the Clinton Climate Initiative, the Japanese Voluntary Emissions Trading Scheme, the Forest Carbon Partnership Facility. See Neeff *et al.* 2007.

13. Certified emission reductions (CERs) are C credits sold on the compliance market, while verified emission reductions (VERs) are C credits sold on the voluntary market. VERs are often granted for projects which have failed validation on the compliance market.

14. ClimateClean discusses the issue on its website <http://climateclean.net/about/> (Accessed 26 January 2012).

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ment compared to management with tillage (DeVuyst and Halvorson 2004), pesticide use is likely to increase, due to diseases fostered by the crop residues left on the field to obtain a mulching effect, whereby moisture is kept in the soil.

Farmers using pastures may reduce grazing intensity, resorting to feed and concentrates, so as to allow the land a longer resting period. Entering pastures later in the season prevents animals from grazing on shoots. By pursuing this course of action, a farmer raises present costs to boost future income. Alternatively, dryland farmers may renounce their customary use of land (no-till wheat and low grazing regime) and plant trees to receive C and timber payment and enhance soil conservation. At first glance, such a choice appears rational, as it reduces yield uncertainty. Indeed, the main income from afforestation would be from timber and C, both of which accumulate from year to year. A dry year may lower C uptake by trees but farmers will remain able to market the accumulated C uptake, rather than incurring a total loss that year as in the case of wheat. Also, when trees are planted, soil is being restored and thus the capital value of land maintained for the future. The next generation may remove the trees to use the restored soil for grazing or wheat cultivation.

This section analyses the minimum C price at which dryland farmers/landowners find nothing to choose between between thirty years of afforestation and thirty years of the renounced activity (thirty years being the project duration for afforestation under the CDM scheme). The analysis extends along a gradient, stretching from arid conditions, with ca. 150 mm of annual precipitation, to dry sub-humid conditions, with ca. 900 mm of annual precipitation, comparing *Pinus halepensis* plantations vs. no-till wheat on productive land, or small ruminant rearing on marginal land.

Weather and price uncertainties are integrated in this analysis, through the production functions. C yields for the afforestation activity were simulated by means of the CO2FIX v3.1 model (Schelhaas *et al.* 2004).¹⁵ Wheat yields and pasture yields were predicted on somewhat similar nitrogen-based quadratic models, using thirty years of weather data for the simulation of moisture stress in the wheat model (Korentajer *et al.* 1989) and precipitation for the pasture model (Zaban 1981). Both models were developed for dryland conditions, while calibration and validation used data collected in Israel.

No-till wheat and pasture yield values were then fitted to a gamma probability distribution function to allow iterative production simulations, gamma distributions being those that best describe precipitation patterns in drylands (Ben-Gai *et al.* 1998).

15. We determined the trees' yield classes along the aridity gradient by means of a Geographic Information System database, which provided top height data for different *Pinus halepensis* along the gradient in Israel. We selected three likely yield classes per station along the gradient. We used as baseline scenarios no-till wheat for agricultural land and pasture for marginal land. We used the expiring Certified Emission Reductions (CERs) for forestry (the issue of non-permanent carbon storage in trees and thus the need to consider expiring CERs is explained at http://unfccc.int/methods_and_science/lulucf/items/3064.php – Accessed 26 January 2012). Locatelli and Pedroni (2006) explain how the price of expiring CERs should be estimated based on permanent CERs including discount rates applied in Annex I (buyer) and Non Annex I (supplier) countries.

Input and output prices were, however, fitted to a normal distribution. Production as well as input and output prices were afterwards simulated on a Monte Carlo matrix with 10,000 iterations on a thirty-year cash flow for farmers engaged in no-till wheat cropping or in small ruminant rearing. The expected Net Present Value (NPV) obtained from the Monte Carlo simulation¹⁶ served to estimate the minimum payment for a farmer seeking C trading through afforestation. Discount rates and their effects on minimum C payment were analysed at eight stations, stretching along the above aridity gradient.

Results show that, despite the high levels of CO₂ removal from the atmosphere by dryland trees, afforestation for C trading is unprofitable anywhere along the aridity gradient. Even ignoring the revenue lost by foregoing the alternative activities, afforestation at current prices is only economically feasible under optimum soil and climate conditions in northern (wetter) areas. However, under the latter conditions the high C yields fail to compensate for the steep increase in wheat yields from dryer to wetter regions. Thus, dryland forestry remains an economically inferior choice. Trading C appears more profitable under dryer conditions below 400 mm (on productive land) as the latter drive up the production risks of wheat growing or small ruminant rearing. In any case, C prices will have to rise considerably before the drylands giving the highest C yields become worth afforesting, especially since the price of wheat is also likely to increase.

Worth mentioning is that no-till cropping is, among other agricultural practices, a future mitigation activity candidate. Should it become a valid one, farmers already growing no-till crops are even less likely to plant trees instead, since their primary activity could yield a C payment in addition to the crop.

ENABLING SMALLHOLDERS IN THE DRYLANDS TO BENEFIT FROM THE C MARKET

Smallholders are bearing the brunt of climate change, more than any other group of people (Altieri and Koohafkan 2008, IFAD 2008, Mortimore 2009, Ifejika Speranza 2010). Substantial knowledge exists about ways for smallholders to cope with uncertainty and adapt to increasing climate change and variability (Colin *et al.* 2003, Hurni *et al.* 2004, Walker *et al.* 2004, Ifejika Speranza 2010, Hazell *et al.* 2010). Nevertheless, the smallholders' prospects remain grim, especially since some of this knowledge is unapplied or, in its current state, inapplicable. Yet mitigation activities may help smallholders to become less vulnerable to climate change, strengthening their adaptive capacity (Ifejika Speranza 2010). As mentioned, planting trees has advantages such as soil conservation in addition to C sequestration. Furthermore, farmers may select tree species according to their needs. For example, fast-growing species have more C uptake in less time than fodder trees but the latter allow the rearing of more livestock.

16. The methodologies to estimate the expected Net Present Value are explained in Rueff (2009).

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In principle, the C market was created to offer developing countries an incentive to participate in global mitigation efforts, though, under present conditions and as demonstrated, the C market cannot sufficiently reward smallholders for afforestation activities in the drylands. For smallholders in the drylands to plant trees on their land, the price of C would have to be high enough to make afforestation as financially attractive as the foregone cropping. Furthermore, current transaction costs (certification and verification) are only affordable, if at all, on large farms thanks to the economies of scale provided by their larger farms. Smallholders cannot afford these costs, even under the 'Simplified Modalities and Procedures'¹⁷ as the latter have not sufficiently reduced transaction costs for small-scale mitigation projects (Locatelli and Pedroni 2006).

The smallholders' C payment could be raised through government interventions, as society would gain from the environmental services thus generated. The interventions could be carried out through governmental agencies, NGOs, local community-based organisations or other institutions. They could include extension support for afforestation practices as well as organisational and credit assistance.

Extension support may help farmers to decide whether to engage in afforestation, by predicting C uptake and payment over the thirty years of project lifespan (in the case of a tCER accounting method). Then, extension services could provide counselling on how to prepare the land with catchments built as mounds to retain runoff water and enhance its infiltration. They could also advise as to the species to be planted, according to local conditions and farmer's needs, while also establishing nurseries to grow seedlings. They might help the farmers seek the best location where trees will receive maximum runoff water, plant them at a given density to maximise growth and optimise tree canopy to maintain soil moisture. Later on, they could assist with forest maintenance – e.g. adjusting water consumption and tree growth through thinning and pruning applied at different rates during the lifespan of an afforestation project. Finally, extension support is needed to monitor the forest-generated C build-up in soils, which makes up for much of the mitigation effect.¹⁸

Organisational assistance should provide herders with the means to prepare, implement and strengthen their bargaining position. Priority should be given first to informing farmers in drylands about the existence of a C market. Since transaction costs are very high, intermediaries could reduce farmers' costs by organising them in larger units; as explained, large farmers benefit from economies of scale on these costs. The intermediaries would then represent the farmers, sell the sequestered C, receive

17. The 'Simplified Modalities and Procedures' (SM&P) were adopted at the UNFCCC CoP9. Projects are eligible for SM&P if their expected net GhG removal is lower than 8Mg CO₂e per year on average over the crediting period (Locatelli and Pedroni 2006).

18. C build up in soils may only be neglected under special circumstances. See UNFCCC. 2007. Annex 15, A/R Methodological tool – 'Procedure to determine when accounting of the soil organic carbon pool may be conservatively neglected in CDM A/R project activities', CDM-Executive Board, http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-06-v1.pdf/history_view – Accessed 31 August 2010).

payment and distribute it annually. The intermediary organisations could also represent farmers' interests, keeping abreast of the complex certification and verification procedures. Such an organisation should of course be transparent and properly monitored.

Credit assistance might relieve smallholders from bearing the costs of high up-front cash investment as well as monitoring costs while receiving payment only at the end of the crediting period, which, for tCERs, is often set at five years. Few smallholders would agree to receive payment only five years after their investment.

MULTI-PURPOSE AFFORESTATION ALTERNATIVES FOR SMALLHOLDERS IN THE DRYLANDS TO OPTIMISE LAND USE CONSIDERING CARBON FINANCE

Previous estimates of afforestation considered C payment on mutually exclusive land uses (afforestation vs. wheat or afforestation vs. pastures). Thus, the worth of afforestation was compared to that of the renounced activity. Smallholders in the drylands may also consider intercropping options, combining an annual crop with trees. Intercropping systems in such a setting can produce fuel, food and fodder. Such a combination, where surface water is being harvested and supplied to the system, is referred to as a 'Runoff Agroforestry System' (RAS) (Droppelmann and Berliner 2003). Droppelmann *et al.* (2000) show that an arid area RAS, combining high density tree planting and annual intercrop, will have more water use efficiency, provided that the trees are intensively pruned.

Intercropping with trees on an RAS allows a number of income-generating activities on the same unit of land. C payment would be just one income generated, acting as a 'bonus'. To our knowledge, intercropping RAS, with their potential to sustain smallholders' livelihood by including C payments, remain unstudied. Furthermore, the optimal combinations of crop and tree species according to local conditions remain to be determined.

CONCLUSION AND SUGGESTIONS FOR FURTHER RESEARCH

This chapter discusses the limitations and potential of dryland afforestation, by adding the C market to other services and disservices of planted dryland forests: preventing soil erosion, rehabilitating degraded land, preventing floods and contributing to the livelihoods of communities living at the outskirts of forests (through timber, grazing, non-timber forest products and jobs). However, massive consumption of water by the trees, leaving none for downstream users, as well as biodiversity alteration are evidence that the disservices might be worse in case of large-scale dryland afforestation.

We have shown that, in addition to the above services, dryland afforestation could mitigate climate change through the sequestration of C and thus planting trees in deserts has potential for developing countries. They may indeed host such projects and sell the C credits – reflecting the equivalent CO₂ removal from the atmosphere – to

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industrialised countries. This flexible mechanism is authorised by the Kyoto Protocol under the CDM scheme. However, under present conditions, the CDM cannot motivate stakeholders in developing countries to afforest the drylands. There are three main reasons why the C market is presently insufficient for further afforesting the drylands.

First, C prices are much too low to turn afforestation into a competitive land use for private dryland farmers when compared to their customary agricultural land use (wheat or small-ruminant husbandry). Second, government agencies, another stakeholder that has been planting trees in the drylands all over the world, are unlikely to have their afforestation projects qualify for additionality on the compliance market. Additionality, excludes projects from consideration as mitigation activities and thus from receiving C payments unless it can be demonstrated that without such payments they would not be carried out. Finally, transaction costs of A/R-CDM are very large. Thus, even though they have been reduced for small projects with an uptake of $8\text{Mg CO}_2\text{e yr}^{-1}$ or less, A/R-CDM projects in the drylands remain unfeasible for small farmers. Even for large projects, C prices would have to climb steeply to make them profitable. The C market, under current conditions, cannot serve the needs of smallholders and be used as a pro-poor tool in developing countries.

It is unlikely that the forecasted rise in C prices will be enough to turn dryland afforestation into a worthwhile enterprise. However, if the goal is to turn C trading between developing and industrialised countries into a source of income for poor farmers the following steps are needed. Smallholders will need financial assistance (for upfront cash investment and yearly payment), extension services (land preparation, nurseries, C sequestration monitoring) and organisational support, allowing them economies of scale similar to those that remain the advantage of large farmers. Such assistance to small farmers may help the C market achieve the pro-poor objectives which informed its establishment, while at the same time leading to small scale forest planting, potentially less harmful to the environment than large scale afforestation.

We suggest further investigations in a number of fields. First, the voluntary market may be less restrictive than the compliance (CDM) market and thus offer more potential. Second, RAS agro-forestry shows interesting intercropping options, combining high density tree planting and annual intercrop, which would allow a number of income-generating activities on a same unit of land. Such agro-forestry can be undertaken in rather arid conditions if sufficient runoff can be harvested and the right crop and land management is applied. C payment would be just one income generated acting as a 'bonus' in addition to the crop, fodder and fuel-wood collected from trees. The optimal combination is nevertheless site specific, which is why more studies are needed, both on the physical implications of RAS and on its economic implications for the farmers using it. After all, if RAS turn out to be capable of achieving economic profitability for desert agriculture through the accumulation of these income generating activities, it will combine environmental benefits and a pro-poor contribution. Third, an important addition to the know-how required to successfully implement forest-based CDM would be to analyse market access for small farmers in different agricultural contexts

and climates. Such a study would be an important input for the post-Kyoto era. In particular, one would learn whether the forest-based CDM has reached its pro-poor objectives and what it would take to help it reach those objectives.

ACKNOWLEDGEMENTS

This study was conducted within the framework of the Swiss National Centre of Competence in Research (NCCR). Mr. Robert Equey, through the Albert Katz International School for Desert Studies, has also provided financial support with a four-year graduate study scholarship. No-till wheat data was provided by Dr. David Bonfil from the Agricultural Research Organization in Gilat, Israel. Climate data was provided by Prof. Pedro Berliner from the French Associates Institute for Agriculture and Biotechnology of Drylands, now Director of the Blaustein Institutes for Desert Research in Sede Boqer, Israel.

REFERENCES

- Altieri, M. and P. Koohafkan (2008). *Enduring Farms. Climate Change, Smallholders and Traditional Farming Communities*. Penang: Third World Network. Environment and Development Series 6.
- Amir, S. and O. Rechtman (2006). 'The development of forest policy in Israel in the 20th century: Implications for the future'. *Forest Policy and Economics* 8: 35–51.
- Ariza, C. (2003). 'Vegetation monitoring in a semi-Arid afforestation Project, Ben Gurion University of the Negev', Sede Boqer: Blaustein Institutes for Desert Research, Israel, M.Sc. thesis (unpublished).
- Ashkenazi, E. (2008). 'Clearing the pine tree's name'. *Haaretz*. 6th February 2008.
- Ben-Gai, T., A. Bitan, A. Manes, P. Alpert and S. Rubin (1998). 'Spatial and temporal changes in rainfall frequency distribution patterns in Israel'. *Theoretical and Applied Climatology* 61: 177–190.
- Ben Said, S. (1995). 'Bilan critique du Barrage Vert en Algérie'. *Sécheresse* 6: 247–255.
- Blougrund, D. (2001). 'The Jewish National Fund'. *Policy Studies* 49: 1–37.
- Bradshaw, C., N. Sodhi, K. Peh and B. Brook (2007). 'Global evidence that deforestation amplifies flood risk and severity in the developing world'. *Global Change Biology* 13: 2379–2395.
- Caparrós, A. and F. Jacquemont (2003). 'Conflicts between biodiversity and carbon sequestration programs: Economics and legal implications'. *Ecological Economics* 46: 143–157.
- Caparrós, A., E. Cerdá, P. Ovando and P. Campos (2009). 'Carbon sequestration with reforestation and biodiversity – scenic values'. *Environmental and Resource Economics* 45: 49–72.
- Chichilnisky, G. and K. Sheeran (2009). *Saving Kyoto. An Insider's Guide to How it Works, Why it Matters and What it Means for the Future*. London: New Holland Publishers Ltd.

Can Carbon Finance Enhance Desert Afforestation?

- Cohen, S. (1993). *The Politics of Planting: Israeli–Palestinian Competition for Control of Land in the Jerusalem Periphery*. Geography Research Paper No. 236. Chicago: The University of Chicago Press.
- Colin, P., D. Schröter, A. Patt, S. Gaffin, M. Long Martello, R. Neff, A. Pulsipher and H. Selin (2003). 'Assessing vulnerabilities to the effects of global change: an eight-step approach'. Research and Assessment Systems for Sustainability Program Discussion Paper 2003-05. Cambridge: Environment and Natural Resources Program. Belfer Center for Science and International Affairs. Kennedy School of Government. Harvard University.
- Croitoru, L. (2007). 'Valuing the non-timber forest products in the Mediterranean region'. *Ecological Economics* 63: 768–775.
- DeVuyst, E. and A. Halvorson (2004). 'Economics of annual cropping versus crop/fallow in the northern Great Plains as influenced by tillage and nitrogen'. *Agronomy Journal* 96: 148–153.
- Droppelmann, K., J. Lehmann, J. Ephrath and P. Berliner (2000). 'Water use efficiency and uptake patterns in a runoff agroforestry system in an arid environment'. *Agroforestry Systems* 49: 223–243.
- Droppelmann, K. and P. Berliner (2003). 'Runoff agroforestry – a technique to secure the livelihood of pastoralists in the Middle East'. *Journal of Arid Environments* 54: 571–577.
- Earth Trends (2003). *Country Profiles: Forest, Grassland and Drylands – Israel*. Washington, DC: World Resources Institute.
- Ferrey, S. (2010). 'Post-Copenhagen: The “new” math, legal “additionality” and climate warming'. *The Electric Journal* 23: 6–18.
- Farley, K., E. Jobba and R. Jackson (2005). 'Effects of afforestation on water yield: a global synthesis with implications for policy'. *Global Change Biology* 11: 1565–1576.
- Gruenzweig, J., T. Lin, E. Rotenberg, A. Schwartz and D. Yakir (2003). 'Carbon sequestration in arid land forest'. *Global Change Biology* 9: 791–799.
- Hawlena, D. and A. Bouskila (2006). 'Land management practices for combating desertification cause species replacement of desert lizards'. *Journal of Applied Ecology* 43: 701–709.
- Hazell, P., S. Wiggins and A. Dorward (2010). 'The future of small farms: Trajectories and policy priorities'. *World Development* 38: 1349–1361.
- Hunt, C. (2008). 'Economics and ecology of emerging markets and credits for bio-sequestered carbon on private land in tropical Australia'. *Ecological Economics* 66: 309–318.
- Hurni, H., U. Wiesmann and R. Schertenleib (eds.) (2004). *Research for Mitigating Syndromes of Global Change. A Trans-disciplinary Appraisal of Selected Regions of the World to Prepare Development-Oriented Research Partnerships*. University of Berne, Vol. 1. Berne: Geographica Bernensia.
- IFAD (2008). 'Climate change and the future of smallholder agriculture: How can rural poor people be a part of the solution to climate change?' Discussion paper prepared for the Round Table on Climate Change at the Thirty-first session of IFAD's Governing Council. Rome: IFAD.
- Ifejika Speranza, C. (2010). *Resilience to Climate Change in African Agriculture*. Bonn: DIE.
- Kliger, E. (1989). 'Planting techniques in the semi-arid and arid Negev Regions'. *Allgemeine Forstzeitschrift für Waldwirtschaft und Umweltvorsorge* 24–26: 636–637.

- Korentajer, L. and P. Berliner (1988). 'Effects of moisture stress on nitrogen fertilizer response in dryland wheat'. *Agronomy Journal* 80: 977–981.
- Korentajer, L., P. Berliner, F. Dijkhuis and J. Van Zyl (1989). 'Use of climatic data for estimating nitrogen fertilizer requirements of dryland wheat'. *Journal of Agricultural Science* 113: 131–137.
- Lal, R. (2004). 'Carbon sequestration in dryland ecosystems'. *Environmental Management* 33: 528–544.
- Locatelli B. and L. Pedroni (2006). 'Will simplified modalities and procedures make more small-scale forestry projects viable under the clean development mechanism?' *Mitigation and Adaptation Strategies for Global Change* 11: 621–643.
- Maestre, F. and J. Cortina (2005). 'Are *Pinus halepensis* plantations useful as a restoration tool in semiarid Mediterranean areas?' *Forest Ecology and Management* 198: 303–317.
- Matthews, S., R. O'Connor and A. Plantinga (2002). 'Quantifying the impacts on biodiversity of policies for C sequestration in forests'. *Ecological Economics* 40: 71–87.
- McNeely, J. (2003). 'Biodiversity in arid regions: Values and perceptions'. *Journal of Arid Environments* 54: 61–70.
- Morin, J., Y. Benyamini and A. Michaeli (1981). 'The effect of raindrop impact on the dynamics of soil surface crusting and water movement in the profile'. *Journal of Hydrology* 52: 321–335.
- Mortimore, M. (2009). *Dryland Opportunities: A New Paradigm for People, Ecosystems and Development*. Gland: IUCN, London: IIED and Nairobi: UNDP/DDC.
- Neeff, T., L. Eichler, I. Deecke and J. Fehse (2007). *Update on Markets for Forestry Offsets*. Turrialba: Centro Agronómico Tropical de Investigación y Enseñanza.
- Olschewski, R., P. Benitez, G. de Koning and T. Schlichter (2005). 'How attractive are forest carbon sinks? Economic insights into supply and demand of certified emission reductions'. *Journal of Forest Economics* 11: 77–94.
- Ornstein, L., I. Aleinov and D. Rind (2009). 'Irrigated afforestation of the Sahara and Australian outback to end global warming'. *Climatic Change* 97: 409–437.
- Portnov, B. and U. Safriel (2004). 'Combating desertification in the Negev: Dryland agriculture vs. dryland urbanization'. *Journal of Arid Environments* 56: 659–680.
- Rahim, I., D. Maselli, H. Rueff and U. Wiesmann (2010). 'Indigenous fodder trees can increase grazing accessibility for landless and mobile pastoralists in Northern Pakistan'. *Pastoralism: Research, Policy and Practice* 2 (1). Available online at <http://www.pastoralism-journal.com/content/1/1/2> doi:10.1186/2041-7136-1-2
- Reij, C., G. Tappan and M. Smale (2009). 'Agro-Environmental transformation in the Sahel: Another kind of "Green Revolution"'. Discussion Paper 00914. 2020 Vision Initiative. Washington: CGIAR – IFPRI.
- Roehle, H. (1991). *Yield Tables for Aleppo Pine (Pinus halepensis) in Israel*. Munich: Forest Yield Science, University of Munich.
- Rueff, H., G. Kressel and M. Schwartz (2004). 'Forest fire control and Bedouin pastoralism in Israel's afforested drylands: a cost benefit analysis'. *Nomadic Peoples* 8: 113–137.

Can Carbon Finance Enhance Desert Afforestation?

- Rueff, H., C. Parizot, A. Ben Israel and M. Schwartz (2008). 'Dryland afforestation and poverty alleviation: Bedouin and Palestinian non-timber forest product collectors in contrasting economic environments'. *Human Ecology* 36: 923–930.
- Rueff, H. (2009). 'Optimizing dryland afforestation: Prospects and limitations: Minimum carbon payment for Non-Annex I dryland countries on an aridity gradient with stochastic weather and prices'. University of Aix-Marseille III, France. PhD Thesis (unpublished).
- Rueff, H., I. Rahim and T. Hirschbuehl (2010). 'Carbon Finance and Dryland Afforestation. NCCR North-South: Research Evidence for Policy'. Regional Edition Central-Asia.
- Sachs, M. and I. Moshe (1999). 'Savannization: an ecologically viable management approach to desertified Regions', in T. Hoekstra and M. Shachak (eds.) *Arid Land Management: Towards Ecological Sustainability*. Champaign: University of Illinois Press.
- Sahara and Sahel Observatory (2008). *The Great Green Wall Initiative of the Sahara and the Sahel. Introductory note no. 3*. Tunis: OSS. Available at <http://www.oss-online.org/pdf/imv-en.pdf> (Accessed 31 August 2010).
- Schelhaas, M., P. van Esh, T. Groen, B. de Jong, M. Kanninen, J. Liski, O. Masera, G. Mohren, G. Nabuurs, T. Palosuo, L. Pedroni, A. Vallejo and T. Vilen (2004). *CO2FIX V 3.1 A Modelling Framework for Quantifying C Sequestration in Forest Ecosystems. Rapport 1068*. Wageningen: Alterra.
- Sedjo, R. (1999). 'Potential for carbon forest plantations in marginal timber forests: the case of Patagonia, Argentina'. Discussion paper 99–27. Washington DC: Resources for the Future.
- Shaikh, S., L. Sun and G. van Kooten (2007). 'Are agricultural values a reliable guide in determining landowners' decisions to create forest carbon sinks?' *Canadian Journal of Agriculture Economics* 44: 97–114.
- Shilony, Z. (1998). *Ideology and Settlement: The Jewish National Fund, 1897–1914*. Jerusalem: Magnes Press.
- Shohat, E., Z. Abramsky and B. Pinshow (2001). 'Breeding bird species diversity in the Negev: Effects of scrub fragmentation by planted forests'. *Journal of Applied Ecology* 38: 1135–1147.
- UNFCCC (2007). 'A/R methodological tool. Procedure to determine when accounting of the soil organic carbon pool may be conservatively neglected in CDM A/R project activities. EB33. Annex 15'. Available at: http://cdm.unfccc.int/EB/033/eb33_repan15.pdf (Accessed 31 August 2010).
- Van Dijk, A.I. and R. J. Keenan (2007). 'Planted forests and water in perspective'. *Forest Ecology and Management* 251: 1–9.
- Walker B., C.S. Holling S.R. Carpenter and A. Kinzig (2004). 'Resilience, adaptability and transformability in social–ecological systems'. *Ecology and Society* 9 (2): 5.
- World Rainforest Movement (2003). *Plantations are Not Forests*. Montevideo: World Rainforest Movement.
- WOCAT (2007). *Where the Land is Greener – Case Studies and Analysis of Soil and Water Conservation initiatives Worldwide*. Hans-Peter Liniger and William Critchley (eds.).
- Zaban, H. (1981). 'A study to determine the optimal rainfed land-use systems in a semi-arid region of Israel'. PhD Thesis. University of Reading (unpublished).

Zhu, X. and M. Ren (2000). 'The Loess Plateau – its formation, soil and water losses, and control of the Yellow River', in J. Laffan, J. Tian and C. Huang (eds.) *Soil Erosion and Dryland Farming*. Boca Raton: CRC Press LLC.

PART II. CHANGING PEOPLE

‘SAHARAN WATERSCAPES’: TRADITIONAL KNOWLEDGE AND HISTORICAL DEPTH OF WATER MANAGEMENT IN THE AKAKUS MOUNTAINS (SW LIBYA)

*Savino di Lernia, Isabella Massamba N’siala
and Andrea Zerboni*

If the clouds come, they come together

Mohammed ‘Skorta’ Hammadani, Kel Tadrart

‘SAHARAN WATERSCAPES’: INTRODUCING THE PROJECT

On 22 March 2009 World Water Day, organised by the United Nations, reminded us that *today* more than 800 million humans do not have regular access to drinkable water. Two and half billion do not have use of basic hygiene facilities. For these reasons, more than two million children die every year from illness connected to scarcity of water (<http://www.worldwaterday.org/>).

This devastating calamity is largely due to a non-sustainable human pillaging of Earth resources, and not exclusively related to environmental or climate constraints. Rather, in hot deserts, such as the Sahara, water access and water exploitation have been environmental challenges for human groups, to be culturally managed (e.g., McAllister *et al.* 2011). It is interesting to study the courses of action and the choices – technological, cultural or social – adopted today by human groups to cope with increasing environmental deterioration. Changes in the environment, and increasing uncertainty due to growing dryness, are major features of Holocene Sahara history (e.g. Brooks 2006, Kuper and Kröpelin 2006, Anderson *et al.* 2007) and human adaptations have usually been seen as responding more passively, with a few exceptions (e.g. di Lernia 2002, Brooks *et al.* 2006). Studying the interface between deteriorating environmental conditions and human perception is a difficult task (e.g. Hassan 2002, Brooks 2006) but is probably the only way to better understand the social organisation of groups living in fragile, marginal environments. Geo-ethnoarchaeological and ethnohistorical indications might greatly increase our capacity to deal with the delicate issues represented by the strategies and actions directed towards a sustainable use of water in marginal or even desert environments.

In this chapter, we present the first phases of the project 'Saharan Waterscapes', a multi-disciplinary research programme based on geoarchaeological, ethnoarchaeological and ethnobotanical surveys, carried out in recent years in the Akakus Mts. (SW Libya), today inhabited by Kel Tadrart Tuareg (Figure 1). This sandstone massif is renowned for its majestic rock art and archaeological contexts: systematic Holocene human occupation of the area dates back to the Pleistocene/Holocene transition and has been affected by several severe dry spells and environmental differences, easily traceable in the changing faunas depicted in the rock art of the region (e.g. Mori 1965, Barich 1987, Cremaschi and di Lernia 1998, di Lernia and Zampetti 2008).

The aims of the project are: i) analytically to assess the available water resources and their relations with seasonal rainfall; ii) to create an ethnographic record of access, exploitation and forms of water storage adopted by the Tuareg Kel Tadrart; iii) to explore in an ethnoarchaeological perspective the relations between water and people in the later phases of the Holocene – with a focus from the end of the Neolithic until the Garamantian age – especially as regards cultivation systems.

The ethnographic work has been the basis for the assessment of water resources today – as they are embedded in the Tuareg 'social memory' – in order to provide the first repertory of natural and artificial water features in the study region. This evidence has been matched against settlement distribution of the Kel Tadrart, recently investigated (Biagetti 2008, Biagetti and Chalcraft, In press), to better understand physical constraints and adopted strategies of adjustment.

The local and traditional knowledge of Kel Tadrart herders might have benefited from a kind of ancient legacy, possibly rooted in late prehistoric times, as evident in the main water reservoir, where rock markings – signs, rock art, inscriptions – date back to the Late Pastoral (from around 5,000 uncalibrated years BP onward). During the fieldwork, a particular focus was directed towards the *etaghās*, specific areas suitable for flood-recession cultivation, in fact practiced by the Kel Tadrart until recently. We present the initial data on these water-related features, unknown until today and totally unexpected in this area. Even if the *etaghās* are known in other Saharan areas by different names (e.g. Dubief 1953, Bernus 1979, Turri 1983) and quoted in colonial ethnohistorical sources (e.g. Bourbon del Monte di Santa Maria 1912, Zoli 1926, Scarin 1934), their presence and their relevance in the food security strategies of Tuaregs – and much further back in time, according to associated materials and rock art – open a new perspective on the relations between mountains and lowlands.

Another aim of the project, surely difficult to explore and test against hard data, is the attempt to understand how the relations between rainfall and water resources are today apparently incorporated in the individual and social memory of the Tuaregs. The interviews reveal a quite complex pattern but some overlapping does exist: this is the case with the '*awatei wamshin*', the 'hard period', roughly corresponding to the droughts of the 1970s. Rainfall, quantity and distribution of water resources, mechanisms of perception, individual agency and social memory are all parts of a dramatic competition: that for survival in arid, nearly rainless regions, where resilient behaviours

'Saharan Waterscapes'

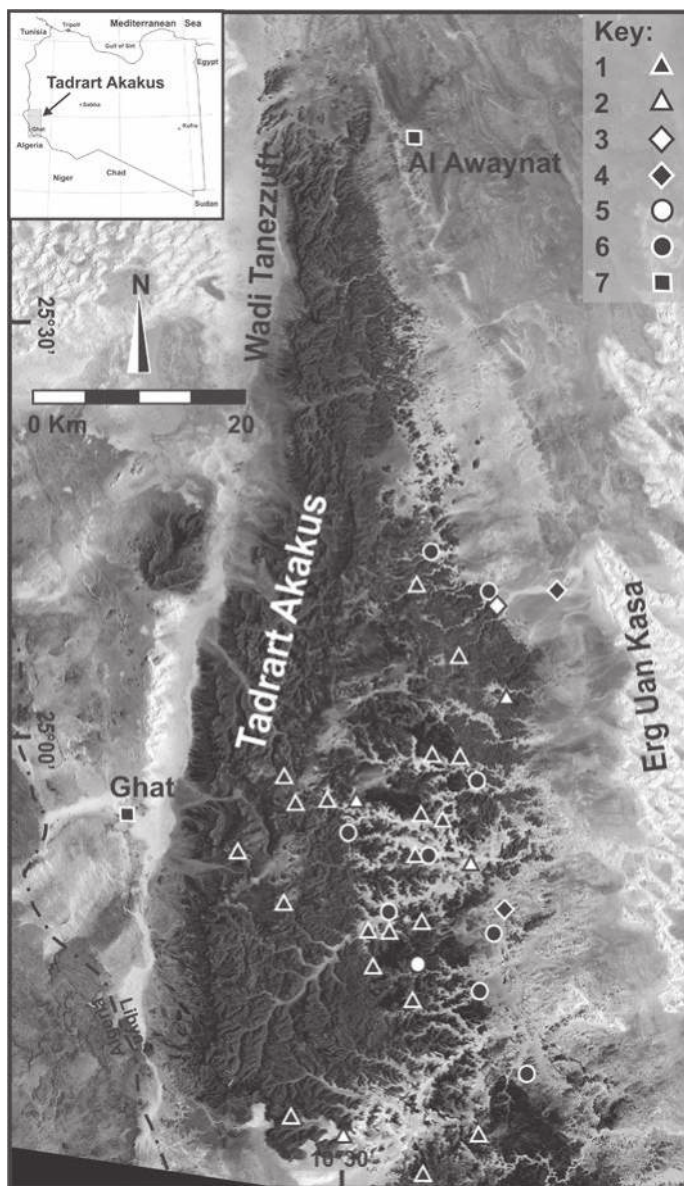


Figure 1. Landsat7 satellite imagery, indicating the distribution of the principal water-related features presented in the text; kel Tadrart base camps in the Akakus Mts., main villages and localities cited in the text are also reported. The insert shows the position of the investigated region in its geographical context. Key: 1) *guelta*; 2) *etaghas*; 3) traditional well; 4) modern well; 5) *abonkor*; 6) kel Tadrart base camp; 7) village.

towards water management appear since prehistoric times to have been the rule, rather than the exception.

ENVIRONMENT OF THE AKAKUS MOUNTAINS

The Akakus Mountains are located in south-west Libya, between latitudes 26° and 24° N. Geologically, this region belongs to the western fringe of the geosyncline of the Murzuq Basin (El-ghali 2005), whose base, mainly composed of Palaeozoic sandstone and marls, lies upon the intrusive formation of the Tassili massif, located in Algeria. The main geologic structural pattern consists of a monocline, characterised by an E–NE tilted cuesta landscape in the Tassili and Tadrart Akakus areas (Cremaschi 1998).

The Akakus Mountains cover an area of ca. 5,000 km² with a maximum elevation of 1,100 m asl in the western part and are dissected by a fossil drainage network whose NE–SW, E–W, and N–S trending pattern is controlled by tectonic structure (Galečić 1984, Cremaschi 1998). The mountains consist of lower-middle Silurian shales, apparently conformably overlying upper Silurian and lower Devonian sandstones. These formations display different hydrological behaviour: the Tanezzuft Fm. has a very low hydraulic conductivity and transmissivity and acts as an aquiclude, whereas the Akakus and Tadrart formations are highly permeable also being highly fractured (Cremaschi *et al.* 2010). The hydrogeological setting allows the formation of numerous springs, both active and fossil. While active springs are few, characterised by the presence of dripping water, the latter are identifiable by the presence of calcareous tufa that developed in the past along the contact between different rock formations (Cremaschi *et al.* 2010).

The present climate of the SW Fezzan is hyperarid, due to, as in Northern Africa, low altitude pressure and winds over the continent, surface expression of the upper air circulation. Scarce meteorological data is recorded in the region (the closest meteorological station is in the village of Ghat); the mean annual temperature is between 25 and 30° C and the mean annual rainfall is between 0 and 20 mm (Fantoli 1937, Walther and Lieth 1960). Precipitation is mostly distributed in spring and summer, and regional average annual relative humidity is 17 per cent; strong wind activity is registered through out the whole year, and especially in spring; occasional rainstorms are also recorded in the winter season (Fantoli 1937). The precipitation rates in the Tadrart Akakus might be slightly different from those registered in Ghat, as a consequence of an orographic effect, contributing to enhanced rainfall. Moreover, rains generally do not reach the whole massif at once but are concentrated in limited areas and with different intensity.

WATER RESERVOIRS: THE *GUELTAS*

Definitions and methods of fieldwork

No permanent water is present in the area – but for a spring on the westernmost part of the scarp, wadi Akakus, which is barely accessible – and water resources are limited to natural rocky reservoirs, where precipitation is trapped and can last for several months. These are locally called *guelta* (in Arabic) or *agelma* in Tamasheq (the spoken language of Tuareg). A *guelta* is a desert river-bed pool which occurs in mountain regions, situated at the foot of a former or sporadic waterfall or at a site where the sandy or rocky river-bed was deepened by fluvial or solutional processes (Davies and Gasse 1988).

Many intrinsic and extrinsic variables determine the capacity of these features to maintain water – for example, sun exposure, wind intensity, orientation, geological context, depth and shape. The basic difference, in an emic perspective (i.e. the Tuareg definition), is between *agelma* and *taourdei*: in the former, animals can drink without human intervention (and therefore may go there alone or only with children) whereas in the latter the herders have to physically pull the water up (and then adult presence, be it male or female, is mandatory). There is no difference in water quality across the Akakus and the inhabitants can rely on *guelta* water when moving their huts.

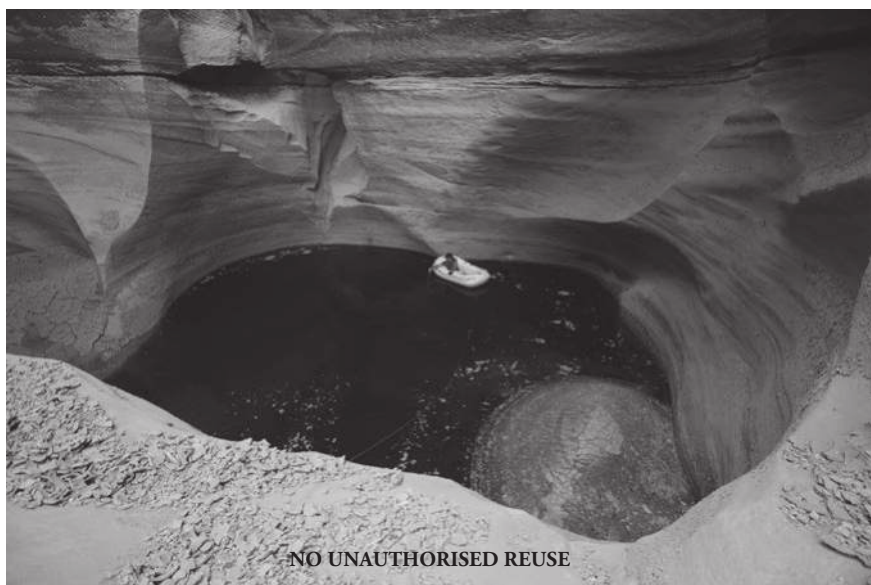


Figure 2. Guelta Taluaut, during the mapping. Photograph: F. Gallino.

During the fieldwork, a questionnaire-form was used to interview the few Tuaregs still living in the area: this information has been matched against the interviews and data collected by Biagetti and Chalcraft (In press) in recent years. Among the enquiries, particular emphasis was placed on: i) period of activity; ii) duration; iii) seasonality; iv) cyclicity; v) last rain (year, season); vi) feeding (rainfall, spring); vii) social access (female, male, adults, youths, children); viii) animal accessibility (in decreasing order of 'relevance': camel, donkey, goat); ix) distance from dwellings; x) activities (hunting, gathering, special herbs).

As concerns geomorphological, environmental and cultural data, we have mapped and recorded for each *guelta*: i) geomorphological and sedimentological context; ii) access path (including its profile); iii) GPS coordinates and tracks; iv) sun exposure and main orientation; v) size and depth; vi) water features (surface and bottom temperature, pH, oxygen concentration); vii) vegetation; viii) animal traces; ix) rock markings; x) associated archaeology. Mapping of *gueltas* and recording of water features has been done using a small inflatable boat, a quite unusual view in these desert environments (Figure 2).

DISTRIBUTION OF *GUELTAS*

The true number of *gueltas* distributed in the Akakus Mountains is not available (several hundreds, possibly) but during the fieldwork we mapped tens of pools, which represent, according to our informants, the most important in the region (Figure 1). However, rainfall in these regions can be torrential and discharge in a few hours an immense quantity of water; in these cases, every shallow depression is filled with water and the entire landscape dramatically shifts (for hours up to a few weeks) towards a savannah-like landscape. Given this peculiarity, the understanding of the 'local' perception of water reserves as embedded within Tuareg people, rather than geomorphologic criteria, is likely more significant.

The primary features to identify a 'main *guelta*', according to local informants, are easy accessibility for all animals (goats, camels, donkeys) and primarily their frequent refilling (due to a larger catchment area) and their capacity to keep water for more than one year and in a few cases for over three years. If we add that, in some cases, occasional rainfall can refill the reservoirs and further extend their duration or that there are some places where the sandy bottom can be excavated to get a little more water, then it appears clear that some of these *gueltas* are of crucial importance for the Tuareg living in the area and became part of their social memory.

It is no surprise that only a few *gueltas*, over a surface of around 5,000 km², match these requirements and hold a special significance. Within this restricted set, the most important appear to be primarily distributed in the central and southern Akakus Mountains (Figure 1): Ibduen (G3) and Intriki (G5) in the very south; In Farden (G13) and Tibestwen (G10) in the area of wadi Teshuinat; Illelen (G6) and

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Agmir (G14) around Senaddar and Rahrmellen; finally, Taluaut (G17) and Tingarifan (G19), situated farthest north but still in the central range of the massif.

Water availability, human access and use

The Akakus *gueltas* are part of a complex cultural landscape, based on a deep local and traditional knowledge, whose origins are rooted in late prehistory. The presence of modern wells has heavily impacted on the ways adopted by Kel Tadrart to manage water resources. Today, there is apparently no strict connection between distribution of the living sites of Kel Tadrart and water access (Figure 1), probably because wells are largely used for water procurement, even if during the interviews we recorded a tendency to emphasise the importance of *gueltas* in settlement choices: according to Biagetti and Chalcraft (In press), the presence of a *guelta* in the vicinity is a decisive element in location choice. During our survey, we mapped several camps abandoned due to lack of water in the *gueltas*: in some cases, the camps lasted only a few weeks (such as the stone structures of Mohammed Hammadani, built in the summer of 1961).

According to our recording, the 'main *gueltas*' can last for several months and only a few more than two years. It is essential, in this sense, to consider the possibility of water recharge due to occasional rainfall: the Kel Tadrart we interviewed do not seem able to assess the 'whole' duration of a *guelta*. It is clear, however, that the picture of water availability in the Akakus is much more complex than we expected.



Figure 3. Goats watering at Tibestewen. Photograph: F. Gallino.

Today, the Kel Tadrat consider the *gueltas* of great relevance for i) hunting of waddan (*Ammotragus lervia*); ii) animals watering (Figure 3); and iii) special herb gathering. It is clear, at least from the words of our informants, that the *gueltas* are no longer considered the primary source of water. But this was not the case until a few years ago: as a matter of fact, until 1984 no deep wells were present in the mountains. Shortage and/or absence of water were coped with, as usual, by mobility, even to the level of the total evacuation of the Akakus area (as happened a couple of times in the last forty years).

Access to *gueltas* is open: they are not private property, even if the location of camps in the vicinity of a *guelta* produces a kind of priority. Goat herds can go to the *gueltas* alone but more frequently they are escorted by children, women or men (Figure 3): there is no gender- or age-specific definition. Most of the *gueltas* are accessible to all animals: in rarer cases only goat can reach the location because of steep and barren paths.

Given the geological nature of these water reservoirs, the ponds located at the *wadi* level and excavated in the sandy river-bed are usually the first to dry out: they are usually *agelmas*, so that all animals can directly access the water. The complex hydraulic system of a *guelta*, composed of ponds, pipes and canyons, actually goes up to the highest ranges of the mountains, where water can last for longer periods. Not all the systems are known to the Kel Tadrart today and when a *guelta* located at the *wadi* level is dry they move towards another one. Again, this is a matter to be thoroughly investigated, because it has evident effects on both their settlement pattern and strategies of mobility. However, it is surprising to learn how much water is in fact unknown because they do not usually take advantage of the highest ranges of the mountain. Questioned on this specific point, the answer is 'nobody goes there, too hard, no way to bring back the water'. This contrasts with the evidence of steps, stone and wooden arrangements and other human interventions that actually characterise the paths going from the *wadi* level up to the mountains (Figure 4). It is difficult to assess the age of these facilities but they must date back to decades or centuries ago: in a few cases, steps carved in the rock bear a black varnish, possibly formed around 5,000 years BP (Cremaschi and di Lernia 1998).

Plant life and *gueltas*: habitat and traditional use

During the fieldwork, we analysed at a district scale the structure of the vegetation in the vicinity of *gueltas*, together with floristic and ethnobotanical analysis. Different types of habitats were sampled: i) below and ii) upon the water surface, iii) rock terraces and iv) flat areas interconnecting two pools in succession. Plant distribution varies greatly depending on altitude, water availability and wind protection. The *guelta* environment is a good refuge for plants, providing water, defensive shade and possibly protection from animal grazing, which is a significant limitation for the development of vegetal communities in deserts. More than thirty plant species have been identified, and ethnobotanical data (traditional Kel Tadrart names, plant parts used and dosages – see

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Figure 4. Stone arrangements on the path toward Guelta Intriki. Photograph: F. Gallino.

also Hammiche *et al.* 2006) have been collected from informants on site (Mercuri *et al.* 2007); plant specimens have also been gathered.

Species with Saharan-Mediterranean affinities were frequently recorded; plant assemblages are dominated by elements related to wet environments and rocky areas. Among them, *Ficus salicifolia* (Telokat) and *Myrtus nivellei* (Tefeltas) are species well adapted to rocky habitat, indicating the presence of percolating and dripping water (Figure 5). They are able to grow on both vertical and subvertical rock slopes, favouring exposure in the northern or naturally shaded quadrants. According to our informants, leaves and fruits are still used as traditional food and medicine. The occurrence of several algae species is closely linked to larger water availability; for instance we collected species belonging to the Characeae family and a fern, *Adiantum capillus-veneris*. Kel Tadrart consider these plants as a sort of disgusting pollution because they grow in or very near to water reservoirs, thus causing bad smells when the level of the pond drops and tissue decay begins. Finally, most of the specimens described (many are species growing in the immediate surroundings of water like *Lavandula antineae*, *Forsskaolea tenacissima*, *Euphorbia unaequilatera*, *Heliotropium ramosissimum*, *Trichodesma gracile*)

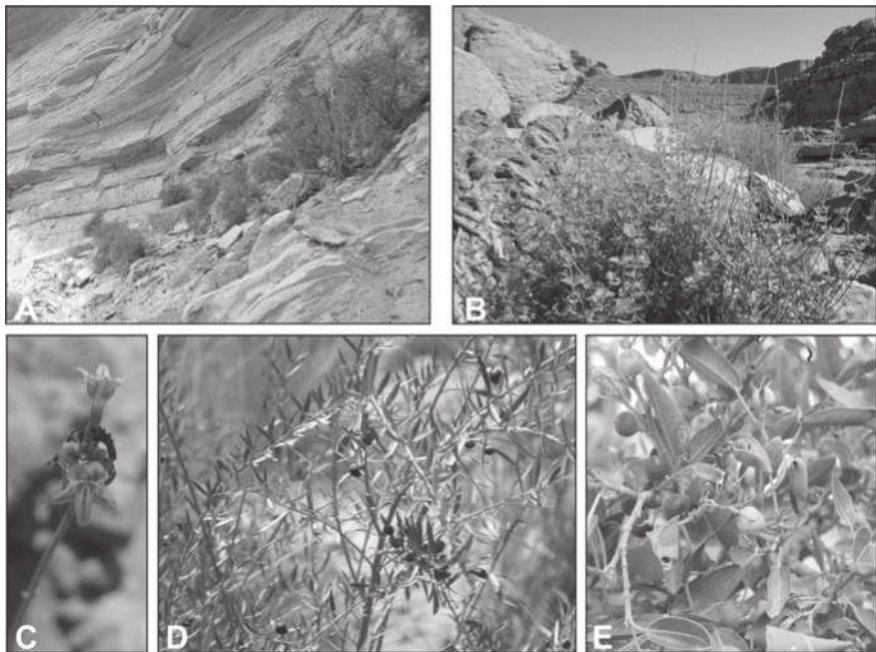


Figure 5. Some examples of plants living in the vicinity of *gueltas*. (A) *Myrtus nivellei* and *Ficus salicifolia* growing on a rock step; (B) *Lavandula antineae* plant and (C) a detail of the flower; two examples of fruits used by kel T' adrart: (D) *Myrtus nivellei* and (E) *Ficus salicifolia*. Photographs: I. Massamba N'siala. NO UNAUTHORISED REUSE

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are distributed from less than a metre to up to a kilometre from the perimeter of the ponds, growing along the *wadi*-bed originating from a *guelta*. The pattern of distribution of plants seems to be heavily influenced by seasonal overflow from the ponds as consequence of intense rains: the intensity and duration of flooding play a first level control in spreading seeds far from the *gueltas*.

Engravings, Tifinagh and other rock markings

Considering the relevance of *gueltas* in the daily life of Akakus herders, it was rather unexpected to observe that not all *gueltas* host rock markings and other signatures. According to our local informants, reasons might be different: ‘the rock is not good, the water does not stand for very long periods’ and so on. Actually, the systematic mapping of *gueltas* reveals an uneven distribution of engravings and other rock markings (Figure 6). Tifinagh (the alphabetic system used throughout Northern Africa and the Sahara since the middle of the first millennium BC) inscriptions are the most frequent, although recent research in the area clearly elucidates that these writings show the highest concentrations close to mountain passes and traditional paths (e.g. Kaci 2007, di Lernia and Zampetti 2008). Admittedly, few and isolated Tifinagh markings are the norm in the region and *gueltas* are not an exception. However, in our record, only a few contexts show articulated and organised rock engravings, indicating a long human frequentation and a possible special relevance of the water pool: Waltanneuet (G2), Bubbu (G4), Tibestwen (G10), Tjeleteri (G16), In Azawan Rahrmellen (G18), Ekniwen (G19). Most of them bear Tifinagh inscriptions but some earlier engraved representations are present. At Tibestwen some light traces depict one delicate human figure: both rock wall and engravings are water-eroded and then do not bear any varnish but a Late Pastoral style attribution seems plausible. Tjeleteri shows a high concentration of Tifinagh inscriptions and a series of camels, plus hundreds of other markings. A few camels are represented close to humans with spears: given their reddish varnish, darker than any other signs near the *guelta*, these warriors with their camels could be dated to the mature phases of the Garamantian age, roughly 2,000 years BP or possibly earlier. In Azawa Rahrmellen (G18) is the only *guelta* in Akakus, according to our informants, really bearing rock art: besides many Tifinagh, we have here a series of engravings of different styles and dissimilar degrees of varnishing, all distributed on a flat and long rock wall very close to the water pool (Figure 6). There are some bovines, varnished, a giraffe and many other engravings depicted in different styles and bearing different rock varnish (from dark-reddish, to reddish, yellow and yellow-whitish), including palm trees, bitriangular human figures and Tifinagh. It is likely that human frequentation here – obviously connected to the water reservoir, a true *cul-de-sac* in terms of accessibility – has to be dated to the Middle-Late Pastoral, due to the black varnish that was formed around 5,000 years BP (Zerboni 2008). Ekniwen (G19) is also very interesting, because of the presence of several varnished engravings, plus Camel style markings and Tifinagh: in particular, we recall here the presence of two giraffes, one apparently drinking from the *guelta* itself (Cremaschi *et al.* 2008). In

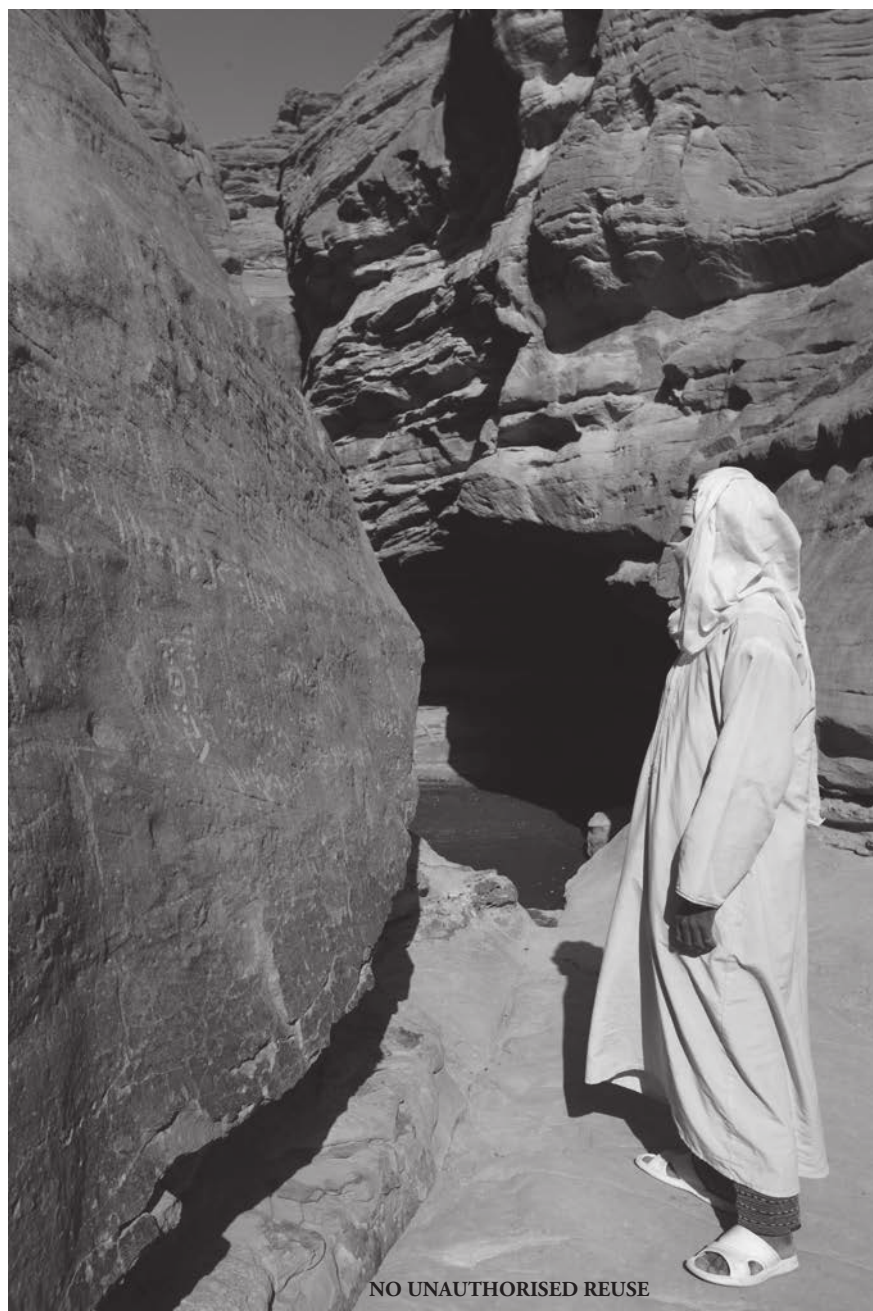


Figure 6. The engraved wall of In Azowa Rahrmellen. Photograph. F. Gallino.

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this case, however, the *gueltas* are located in an open environment and the reasons for human frequentation of these contexts might be different from the functional use of the *guelta* and possibly related to the occurrence of wild animals.

Interestingly, the *gueltas* considered today by Kel Tadrart the most important ones in the Akakus (Agmir and Intriki) show scanty evidence of rock art. This could mirror recent or less recent changes in the Kel Tadrart groups, either in the modalities of water procurement or in their settlement organisation. This is also supported by the existence of a few *gueltas*, not of primary importance in the present perception of Akakus herders, with abundantly engraved walls, especially Tifinagh with different rock varnish. This elucidates the composite pattern of historical memory, archaeological evidence and water exploitation codified in the engraved walls near the *gueltas*, yet to be fully analysed.

Even if dating of rock art in open air contexts is a quite critically debated issue (e.g. di Lernia and Gallinaro 2010), it is of the utmost importance to underline as some *gueltas* host engravings probably dating to the later phases of the Neolithic. We can postulate that, at least in some cases, rock art and markings clearly mirror the use of *guelta* through time: no evidence of older rock art styles (Round Head and Pastoral) has been recorded in the vicinity of water reservoirs, highlighting the *habitus* of marking (and then using?) the water pools only from the Late/Final Pastoral onwards, consistent with the picture of a less humid environment than in the past. This evidence is paralleled by environmental evidence for the area, where a climatic transition towards greater aridity has been recorded since ca. 5,000 years BP (e.g. Cremaschi 1998, Cremaschi and di Lernia 1999, Cremaschi and Zerboni 2009). Not surprisingly, *gueltas* became crucial segments of the perceived landscape during the last millennia of the Holocene, characterised by increasing dryness, and are today part of the Kel Tadrart social memory.

ARTIFICIAL WATER: *ABONKOR* AND WELLS

The ‘secret water’

The water stored in the *gueltas* is of course limited in quantity and time: during phases of progressive desiccation, probably also to minimise exploitation, some Kel Tadrart used to create their own small water reservoirs, digging small holes in specific parts of the mountain. These *abonkor* (sing. *ibankar*) are small cavities excavated in the slope debris, able to capture water from limited underground drainage, capillarity and thermal disequilibrium. According to one of our informants, around forty years ago and because of a strong drought (all the Akakus was dry and the only available water was brought there by the military), a man from his family dug three holes in the ground and then closed them with stone and shales: the deepest excavation was about a metre, the others slightly less (Figure 7). These features always have water and their vicinities are often marked by the presence of *Telokat* and *Tefeltas*. *Abonkor* are located far from the *wadi*-bed, close to the most remote pasture spots, used only during the harshest

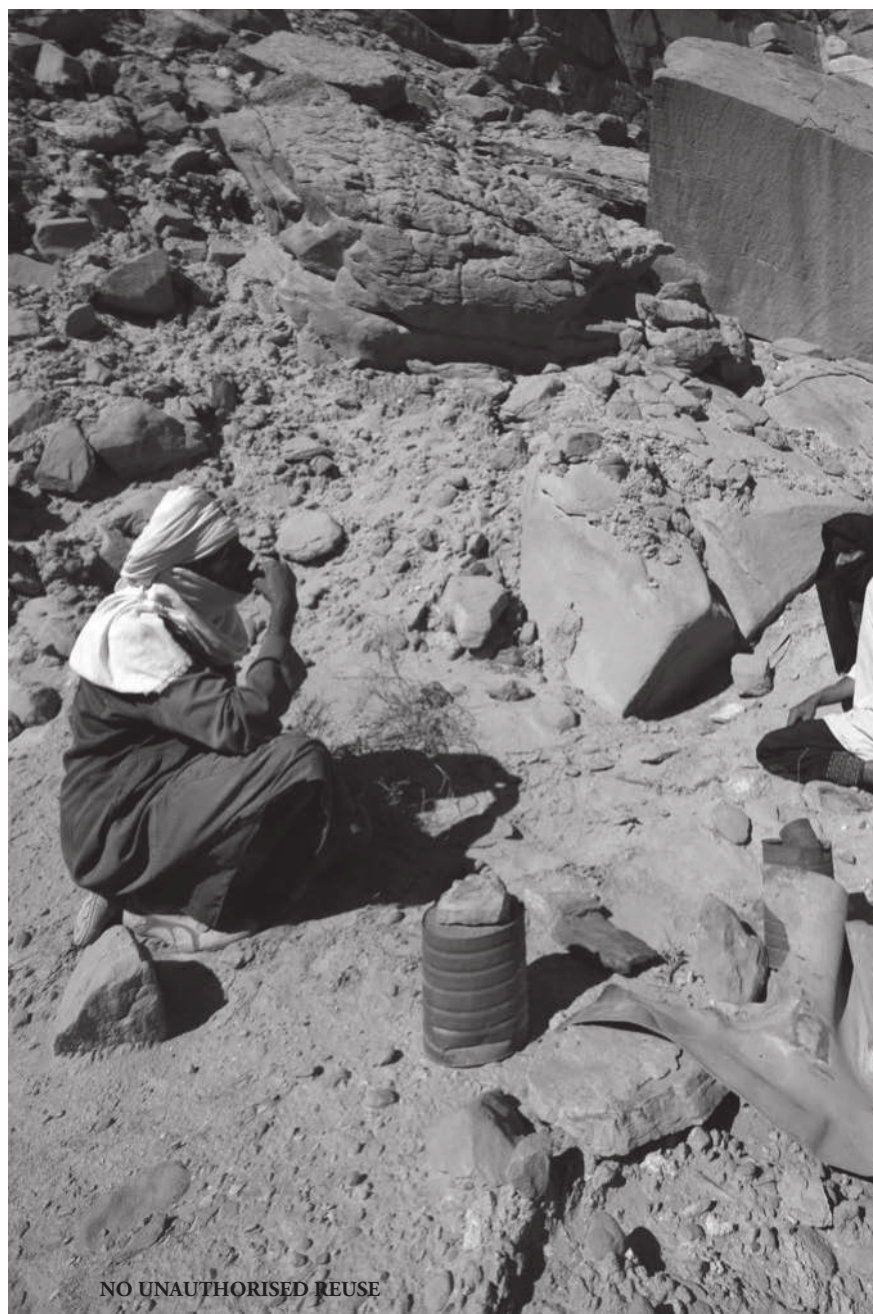


Figure 7. Ramadan Hammadani inspecting the *ibankar*. Photograph. F. Gallino.

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seasons; the water is sufficient for the herder and a few animals (up to five goats), once a week. During the winter season, the cavity is more rapidly refilled by water (it takes two or three days): great caution must be paid to the closure and sealing of the holes, in order to limit the rate of water evaporation.

These features are very rare in the Akakus – probably only two sites (the other one in the area of Teshuinat, called *Umaf*) – but they are not unknown in the Sahara (Desio 1937, Foucault 1951, Nicolaisen 1963, Bernus 1979, Camps 1985, Calegari and Soldini 1993). Elsewhere, they are quite a common feature and, given their low recharge and tendency to desiccate, human groups tend to dig as many *abonkor* as possible. It has still to be assessed if the scarcity in our study area is due to specific local traditions, different water availability or distinct mobility strategies.

The *ibankar* – the 'secret water', as some Tuaregs call it – is a rare and formidable tool to mitigate the harshest moments of the year and, seen in a deeper chronological perspective, critical to minimising the settlements' moving herders.

Traditional and modern wells

Until the mid-1980s, *gueltas* and *abonkor* were the only form of natural water storage and management in the Akakus Mountains. The building by the Libyan authorities of two main wells, *Bir Imenaneia* and *Bir Taluat*, greatly changed ways of accessing and using the water. Today, the few Tuareg families living in the Akakus regularly use *Bir Imenaneia*, also largely exploited by tourist and police (Figure 8). The well operates by pumping fossil water from more than 300 metres (an immense resource in southern Libya, largely exploited by the Great Man Made River Project – www.gmmra.org). The great depth requires a powerful engine to pump the water, unfortunately not always working: the failure or breaking of the engine at *Bir Imenaneia* is one of the most frequent causes for the return of Kel Tadrart to the villages near Al Awaynat.

Interestingly, the other deep well, built around thirty years ago at *Bir Taluat* is not very far from the only traditional well known in the Akakus Mountains, in a locality called *Sughd*;¹ moreover, they lie along the same *wadi*. This reservoir (Figure 8) can keep water up to three years but is more often refilled, when compared to *gueltas*, due to its hydrogeological mechanism (not depending only on rainfall). It was restored in 1984, with use of reinforced concrete, during the period of governmental interventions in the area (not by chance after the dramatic droughts of the 1970s). The well has an artificial vertical tube to a few metres depth and at its bottom a circle of bushes was placed; the well collects the water flowing underground along the *wadi* and sediments are roughly filtered by vegetal features. Finally the *bir* is covered by an iron slab as a defence against evaporation.

It is worth noting that one of the few 'sedentary' villages of the Akakus is located quite close to *Bir Sughd*, where we had the chance to record the main historical

1. Another 'traditional' well, ethnohistorically known, is referred to in a locality called Bakki, formally outside the Akakus Mts., some kilometres east (Gigliarelli 1932).

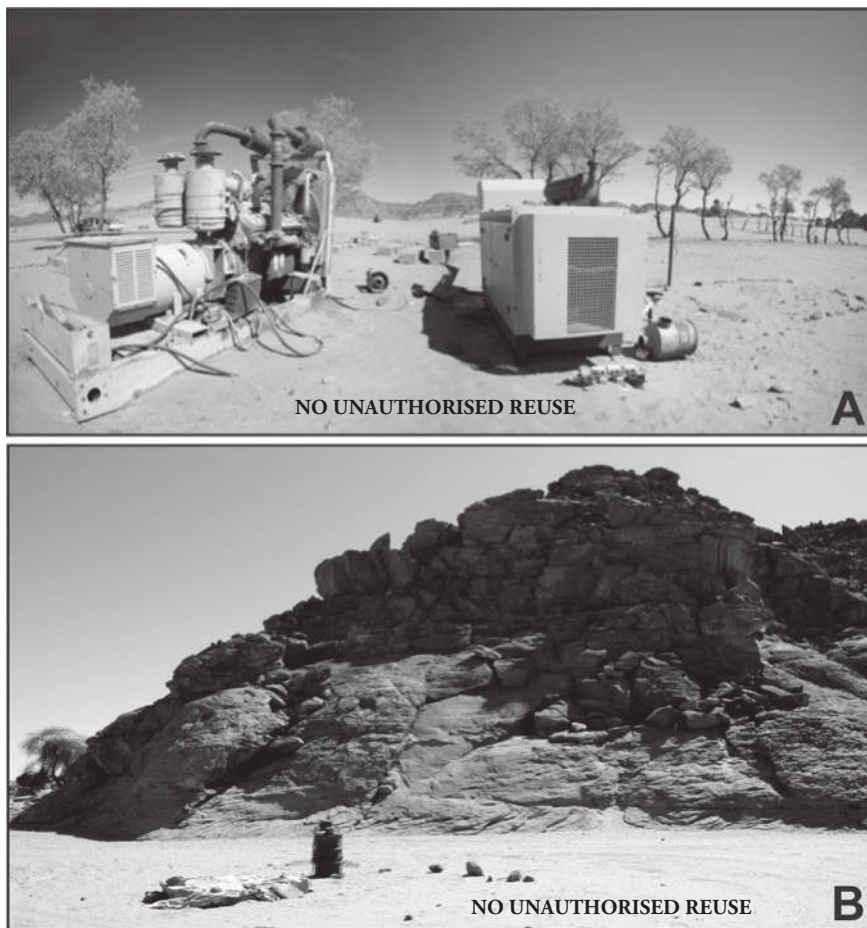


Figure 8. (A) Bir Imenaneia, a modern well located some tens of km away from the traditional (B) Bir Sughd. Photographs: F. Gallino.

narratives linked to this well. At the time of the interviews (October 2008), there was scarce water, probably less than thirty litres – a quantity barely sufficient for an adult for a couple of days. While waiting for new rainfall, they were using the modern well at Bir Taluat, around ten kilometres eastward. Before the building of Bir Taluat, the scarcity of water at Bir Sughd was dealt with by using a *guelta*. The closest is called Taluat (Figure 2): according to our informants, there is no difference in water quality between the *guelta* and the *bir*, even if the water from the *bir* is ‘water of the *wadi*’ (this possibly means that it contains sediments in suspension).

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The relevance of this well is testified by the incredible concentration of Tifinagh writings and other different and diversified rock markings, showing diverse degrees of patination. Some engravings are moderately varnished, probably dating back to the very beginning of the Late Pastoral phase. The elders apparently decipher some of the ‘enigmatic’ markings: the vertical lines supposedly indicate the place where the well should have been excavated and their numbers (eight) signal the distance (around fifteen metres): of course, the validity of this information cannot be verified. However, the exceptionality of this site is self-evident and makes it a remarkable place of memory within the Tuareg community of the Akakus.

CULTIVATION IN THE AKAKUS MOUNTAINS: EXPLOITING THE *ETAGHAS*

Geomorphology and distribution

Rainfall in desert regions is unpredictable but, when abundant and not destructive, it may generate ponds and marshes, which can stand for several weeks (e.g. Fantoli 1937, Turri 1983, Davies and Gasse 1988). A form of traditional cultivation, not known in the area until the time of our research and surely based on historically-rooted local knowledge, is represented by the exploitation of these temporary ponds, locally called *etaghas* (also known as *tesahag* or *tmed*: Desio 1937). These are well-defined areas whose geomorphologic features make recession (*decrue*) cultivation possible and allow people living in the Akakus Mountains to obtain directly, today as in the past, cereals and other plants. In a theoretical framework dominated by the oasis-desert vs. agriculture/pastoralism dichotomy, the existence at these latitudes and in this kind of environment of this type of resource – much better known further south (e.g. Nicolaisen 1963, Turri 1983) – came as a real surprise.

Thanks to their high reflectance, *etaghas* are highly identifiable by means of satellite imagery, especially the surfaces where flooding connected to occasional rains can stagnate for longer periods of time. In the field, they are covered by a silty to clay crust, sealing the sandy substratum. *Etaghas* show recurrent geomorphological and geo-archaeological features: such areas are of medium size, with quite flat surfaces along the *wadi*, covered by crust for at least 20 cm, and possibly protected by wind and by *wadi* banks, to at least minimise the effects to sun exposure. *Etaghas* are also characterised by the scarcity of stones, probably connected to human activity and must have both their ends potentially closable, by means of ditches or fences. Human presence connected to the *etaghas* is mostly typified by small (and seasonal) campsites, fields facilities (walls, ditches, fences, stone markers), low density presence of artefacts (potsherds, grinding equipment, lithic tools), rock art markings and, at least in the cases of ethnographic interest, presence of areas for plant processing.

Our fieldwork was based on informants’ indications, which identify and memorise four main *etaghas*: Itkeri, Lancusi, Ti-n-Lalan and Ousarak, all located in

the central-southern range of the Akakus Mountains (Figure 1). The distribution of the most important areas for *decrue* cultivation, combined with the location of the more permanent *gueltas*, might support the idea of the central-southern ranges of the Akakus as the most critical segments of the Kel Tadrart landscape.

Ethnographic narratives of technical features and social organisation

The Akakus Mountains possess many areas potentially suitable for *decrue* cultivation but only a few have been exploited (at least) in the last century, as indicated by our informants and as also testified by rock art and Tifinagh inscriptions. The reasons are to be found in the very rare combination of the required different features in the same spot: as an example, the *etaghas* of *Tanetheli* – today marked by a ‘forest’ of *Calotropis procera* – have never been used for cultivation, according to our informants, because they are too open and thus exposed to strong winds and easily accessible by grazing animals.

In general terms, the *etaghas* are used after abundant and prolonged rainfall, allowing the saturation of water several centimetres below the ground surface. There is no favoured period (confirming locally the unpredictable and erratic nature of rains): Kel Tadrart can sow after summer or winter rains and crops are chosen accordingly. Seeds are sown in the wet soil (as a maximum, the water will last for one month), usually after digging a small hole (easily visible in the silty crust after a few decades), traditionally with a stick made of *Tamarix aphylla*, nowadays iron tools. The favoured crops are sorghum and millet but in certain periods the cultivation is more diversified, including barley and beans. Sorghum is sown in January, to be harvested after three months (if rain is sufficient). Barley and wheat, together with beans, can be sown in early autumn as, in winter conditions, they do not grow very much. The information collected in the field appears fragmentary and, as far as timing of planting season and exploited vegetables, partially contradictory: we are currently investigating nature of and reasons for these gaps (for example, sorghum is also sown in summer, as expected), whose more likely explanation is the decreasing use of these landscape features by Kel Tadrart today.

The cultivation is a collective effort, with families coming from different parts of the Akakus (and sometimes from outside, including the regions of Tassili and Mes-sak). It is of social relevance and each *etaghas* is coordinated by the *Amghar* (head): normally the elder, he is usually appointed by the political chief. The presence of an influent person, ‘old and wise’, seems to be requested in order to minimise the risk of conflicts and discussion between different families, especially as regards the yields. After the flooding, the area to be cultivated is fenced, in order to prevent the entrance of animals (donkeys, camels): today Kel Tadrart use barbed wire but until a few decades ago the ropes were made of goat hair. In one case, at Ti-n-Lalan, the main ends of the field were delimited by ditches (Tam. *aharum*, ar. *andak*) and patrolled by a guardian living in the immediate vicinity. Once the seeds were planted, only a few people remained in the surroundings – either living in the huts (Itkeri, Ouzarak, Ti-n-Lalan), or exploiting the rock-shelters when present (Ti-n-Lalan, Lancusi), until the harvest.

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Depending on crop yields, the process of seed separation could take several days. The plants are placed on small carpets (today provided by the government) and camels trample on them in order to separate the seeds.

There is still ethnographic evidence of these areas of plant processing at Ti-n-Lalan and Itkeri (Figure 9): these functional sectors are sub-circular in shape, with the edges slightly raised due to stone clearance, done to facilitate the work of the camels. These areas still preserve residues of 'ancient' trampling floor and ongoing micromorphological analyses are providing indications about soil management. Grinding equipment is very rare, sometimes present together with other tools (hoes, sticks, etc.) and fireplaces: according to local informants, querns and grinding stones were usually taken away from the area of cultivation, to the huts in the vicinity or back to the main camps.

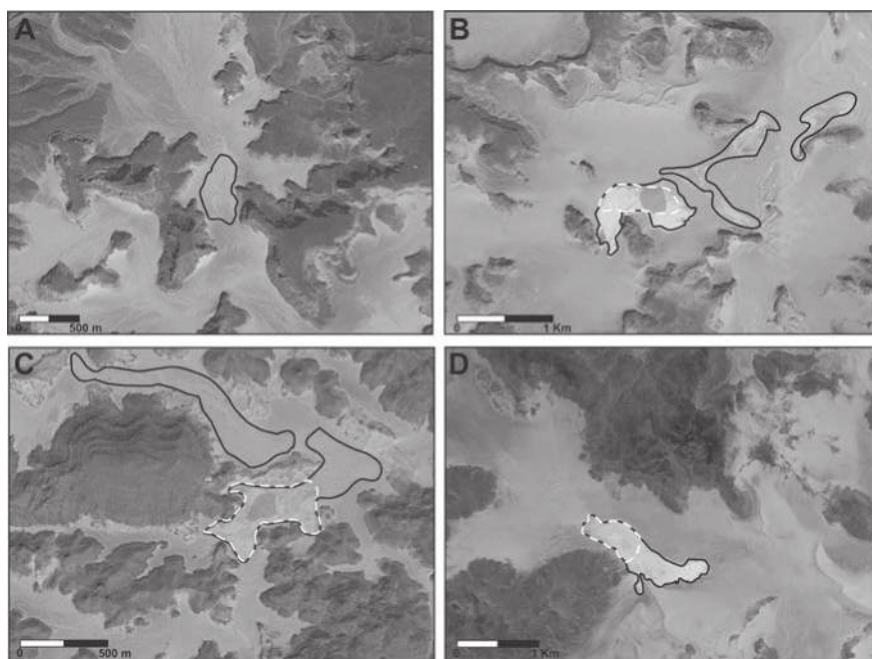


Figure 9. The *etaghas* of the Akakus (Google Earth). (A) Ti-n-Lalan; (B) Lancusi; (C) Itkeri; (D) Ouzarak. The solid lines are the limit of the silty surfaces; dashed lines indicate the areas used for cultivation as described by our informant; shadows represent the areas with cultivation holes.

Mapping the *etaghas*

Ti-n-Lala

The area of Ti-n-Lalan (Figure 9A) has been well known since the 1950s for the presence of abundant rock art (Mori 1965), recently vandalised with spray paint (di Lernia *et al.* 2010). We mapped the *etaghas* after a short rainfall and the view was quite impressive (Figure 10). The limits of the crust-covered area identified in the field are consistent with satellite images. This *etaghas* is of particular interest for a series of features, such as

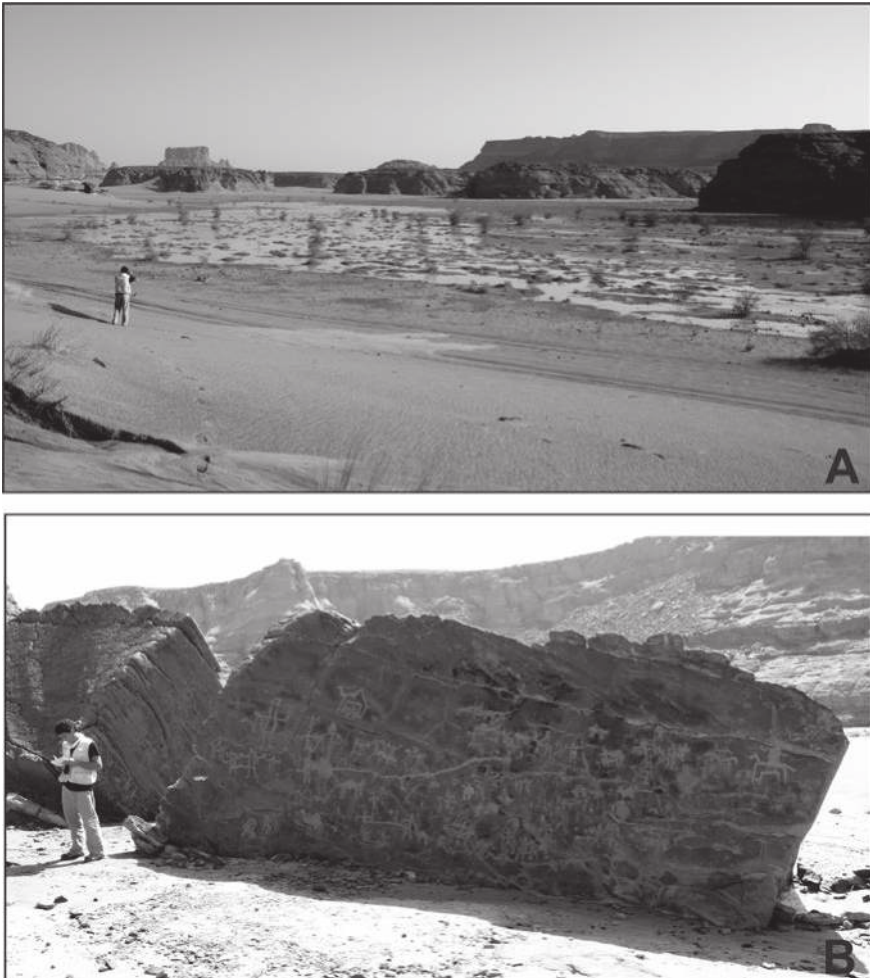


Figure 10. Etaghas Ti-n-Lalan. (A) Flooding on 25 October 2009; (B) an engraved wall at the margin of the cultivated area. Photographs: Andrea Zerboni.

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the remains of closing walls and ditches. The building of the ditches is collective work: taking from two to three weeks, with at least twenty people digging the two trenches. These are close to each other and have different widths and depths: the external ditch is around two metres deep and a metres wide; the one on the cultivated side is a half metre deep; both have vertical walls and were dug with stone hoes – the last time more than 45 years ago. Ti-n-Lalan shows a series of archaeological contexts surrounding the marsh; the main 'corners' are marked by high concentration of rock engravings, with different layers of superimpositions (Figure 10). Even if the association between rock art and *etaghas* use is difficult to ascertain, it is tempting to suggest an initial use of these seasonal ponds for cultivation since the Late/Final Pastoral phases (and possibly earlier).

Lancusi

The area of Lancusi (Figure 9B) is geomorphologically more articulated. Plotting the limits of the main features found in the field on the satellite imagery we notice that the surface dedicated to cultivation does not correspond to the whole extension of the *etaghas*; furthermore, the area where recent cultivation holes are still evident (Figure 11) is much more restricted. Nearby, we mapped other areas potentially suitable for recession cultivation but probably not used in recent times due to sand accumulation.

There are visible remains of cultivation holes – probably dating back to around seventy years ago – and some of them have been sampled for geoarchaeological and botanical analysis. One of the problems of Lancusi (very rarely flooded) is also caused by its morphology, which is quite open: only in limited (and possibly more protected) areas did we find evidence of recent cultivation. The rock-shelter in the vicinity, well



Figure 11. Etaghas Lancusi. Detail of the holes used for cultivation. Photograph: Andrea Zerboni.

known for its rock art and archaeology (Cremaschi and di Lernia 1998, Mori *et al.* 2006), was used as a temporary dwelling by the people guarding the *etaghas*.

Itkeri

The *etaghas* of Itkeri is of great relevance in the Kel Tadrart perspective, probably because more often flooded than other areas. Also in this case the ends of the fine texture crust-covered area do not coincide with the cultivation limits reconstructed on the basis of the memory of our informants (Figure 9C). Their memory is confirmed by the occurrence of cultivation marks (stone alignments and wood posts) surrounding cultivation holes.

This context shows several anthropic signs, in particular the remains of field partitioning made of stones and fences, as well as walls with Tifinagh and Arabic inscriptions (the last is dated to 1962), grinding stones, fireplaces and pottery. There is also a specialised area for plant processing, sampled for micromorphological and botanical analysis (Figure 9). The few observed potsherds are thin, yellowish to reddish in colour, with incised lines near the rim: all these features point to Final Pastoral contexts. It has to be underlined that the area of Itkeri does not show rock-shelters or caves, so it is likely that surface material might be connected to the *etaghas* function, therefore setting the beginning of cultivation activities during (at least) Final Pastoral times.

Ousarak

The southernmost *etaghas* is called Ousarak (Figure 9D): we were told that people come from the surrounding villages, up to the Tassili, to grow their own plants. It is particularly large, more than eighty hectares, and probably usable only when rainfall is abundant and continuous. Again, there is an important gap between the areas potentially suitable for cultivation as identified in the satellite imagery, against the actually cultivated areas.



Figure 12. Etaghas Itkeri. (A) Circular areas at the margin of the cultivated surface and dedicated to seed processing; (B) cariossoid of *Triticum aestivum*. Photographs: (A) Savino di Lernia and (B) Isabella Massamba N'Siala.

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One of the peculiarities of this area is the presence of a small, ephemeral Middle Pastoral campsite, composed of nine hearths with a few potsherds and lithics. In this case, the relation between the cultivation area and the site is only speculative but it has to be underlined that the only site in a quite large area is located close to the *etaghas* edge. A few stony Kel Tadrart huts are located in the immediate vicinity, with a few artefacts but no evidence of plant processing.

Assessing the relevance of *etaghas*

We are now aware of different and articulated cultivation practices in the Akakus based on a variety of crops, common at these latitudes, such as sorghum, wheat, barley and millet. Depending on the actual rainfall, wheat and barley can be planted in October, whereas sorghum, with sufficient rain, is planted in late winter. Estimates of yields depend on several factors, from the type of crop to seasonal variations: wheat and barley might produce between ten and fifteen quintals/hectare. Considering the low number of people living in the Akakus – ethnohistorical and ethnoarchaeological sources supply figures between fifty and eighty, corresponding to a maximum of ten to twelve families (Gigliarelli 1932, Scarin 1934; for a recent reassessment: Biagetti and Chalcraft, In press) – the yields of the *etaghas* might have represented an important additional resource, even if barely predictable and strictly related to erratic and occasional rainfall.

The term *etaghas* itself is ethnohistorically known, present in ethnographic and colonial sources from the mid-nineteenth century. The town of Ghat, west of the Akakus, shows not only orchards and well-irrigated cultivation, but also areas for recession cultivation along segments of the *wadi* system (Bourbon del Monte di Santa Maria 1912). *Etaghas* and cultivation without irrigation, done with wooden stick rather than plough, are known in many areas of the Sahara but their historical duration is still barely known.

In our study area, the presence of *etaghas* and associated archaeological (pottery, lithics) and rock art contexts has provided consistent evidence of an ancient use of these areas since at least Late Pastoral times. Even if the relation between the local archaeological record and the *etaghas* is speculative (lacking hard evidence, so far, of cultivation activities dating back to the same period as rock art and surface materials), it is likely that, especially in the Ti-n-Lalan region, the distribution of art sites reflects a particular use of the area. The abundant rock art (many sites with large panels, from Late Pastoral to Arabic writing) is of the utmost relevance, considering the scant presence in the area of rock-shelters with preserved archaeological series and/or large quantities of artefacts, which are quite common in the Akakus Mountains. (Cremaschi and di Lernia 1998, 1999). The understanding of the implications of cultivation activities in the area also makes clear the nature and meaning of rock art contexts. Finally reinserted in their cultural landscape, they were markers of important areas where human groups, even if not regularly, gathered and cultivated the fields, probably along a main road of the central Akakus.

RAINFALL, ARIDITY AND DROUGHTS: ANALYTICAL DATA AND KEL TADRART SOCIAL MEMORY

Ethnographic narratives and ethnohistorical proxy

Even if rainfall is quite rare, apparently the Kel Tadrart always speak about it, 'so everyone is aware of where there is water', even if it fell kilometres away. The questionnaire on the 'period', 'frequency' and 'abundance' of rainfall proved to be very unproductive. Memory seems to fail, years are not clearly identified. According to our informants, however, rains are not cumulative and are perceived as erratic and unpredictable. The 'normality', it seems, is to have dry conditions for a few years. Two *gueltas* hold a special place in Kel Tadrart perception, Intriki and Agmir: 'if they are desiccated, then all Akakus is dried out'. But even focussing only on these two water reservoirs, it is difficult to assess precisely when they were dry (many times) and if they were contemporaneously dry (they were). The longest and more abundant rainfall embedded in the Kel Tadrart social memory likely occurred around 1952 (to be further assessed): until that year, the elders say, rain in the Akakus was 'enough' but from that period onward it started to decrease.

Even if this is difficult to substantiate, it appears that aridity and especially droughts – rather than rains – are memorised and socially transmitted within the families we have interviewed. This is the case with the great drought called '*Awatea Wamshin*', the 'hard period', which lasted around twenty consecutive years, roughly corresponding to the 1970s sahelian droughts. All Kel Tadrart then went to Ghat and Awaynat and only a few families (who lived near the villages) remained in the mountains. According to our informants, the vast majority of *Acacia* trees died and only a few *Ficus* survived. The idea of dryness as the phenomenon memorised in a desert environment might be surprising but, looking at ethnohistorical sources, droughts are, in fact, more commonly recorded.

The first meteorological observation in our study area was done by Capt. Lyon (1819–20), then Heinrich Barth and other travellers collected some information; a longer and more homogenous data-set was produced by Nachtigal (1869–70). During the Italian occupation, many expeditions bring together data on rains and other climatic conditions in the Fezzan. Abundant, catastrophic rainfalls have been sparsely recorded (Fantoli 1937): in the area of Murzuq, lasting one week (1841–42); in the area of Ghat, with the Tanezzuft valley totally flooded (1850); Duveryrier describes abundant rains in 1860, 1861 and 1862; later, rains were recorded in June 1932 (Ghat and Ubari), January 1933 (Al Awaynat and Ghat), May 1934 (Ghat), all characterised by cyclonic nature and abundant flooding (Desio 1937).

Henri Duveryrier was, however, the first to express the feeling that rains were becoming rarer and rarer in the central Sahara: a nine-year drought, from 1851 to 1860, followed a series of dry periods, lasting from ten to twelve years (Zoli 1926). In the area of Murzuq, Zoli reported a drought lasting for several decades: the last

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rain fell in 1866 and it was still lacking during his trip (1914). Notwithstanding the importance of these reports, we could not establish a direct time-dependent relation between flooding or extreme drought as recorded by explorers and scholars and the effects on water resources in the Akakus range. This is due to the strong spatial limitation of rainfall: for instance, rains in Ghat do not necessarily correspond to rains in the Akakus. Moreover, the Akakus represent an isolated basin, while other regions are hydrographically connected to wider basins: the Tanezzuft, for instance, shows several flooding events but its flow is mainly controlled by its wider hydrographic net, roughly corresponding to the eastern part of the Tassili.

Combining the scant ethno-historical data, though, it seems that a long drought should have been recorded in the second half of the nineteenth century and another one in the second half of the twentieth. The idea of a correspondence between historical data, social memory and analytical information should probably be explored in more detail.

Climate oscillation in past centuries

Scarce information is available for recent decades: the lack of a continuous numerical record for precipitation in the central Sahara does not allow the confirmation of the memory of our informants. However, if we compare the results of interviews within the Kel Tadrart with the Sahel rainfall index 1900–2009 (http://jisao.washington.edu/data_sets/sahel/), we can find several positive correlations. Of course, results are not directly linked to the intensity of precipitation in the Akakus region but general trends towards increasing or decreasing aridity may be postulated for the central Sahara too.

As already discussed, the first evidence concerns the *Awatei Wamshin*, which corresponds to the Sahel drought occurring around the 1970s. The famine that affected sub-Saharan Africa had a local effect in the Akakus: the disappearance of trees and the complete desiccation of *gueltas*, *abonkor* and traditional *bir*. Before this tragic event, well fixed in the social memory of Kel Tadrart, came the intense precipitation occurring at the beginning of the 1950s; in the Sahel the first years of the 1950s are marked by intense precipitation and can be defined as the most rainy years of the century. Going back to the first half of the century, the memory of our informants became less clear and alternating dry and wet years do not find a fixed chronological position.

FINAL REMARKS

The first steps of the 'Saharan Waterscapes' project revealed a complex and articulated system of knowledge, whose roots must be dated back to the later phases of the Neolithic, as testified by archaeology and rock art. *Gueltas* are not an ephemeral water feature, episodically filled and therefore used. Their utilisation was systematic and – together with other forms of water reserves – must have ruled the settlement organisation at least since the end of the Neolithic. The relationships between water availability, anticipated mobility and settlement pattern are likely visible in the material record of both archaeological and contemporary sites and future systematic ethnoarchaeologi-

cal research could add crucial information for the understanding of the present Kel Tadrart organisation and, at the same time, might provide powerful tools to better analyse earlier contexts.

The presence of *etagh*as and the evidence of organised cultivation practices in the Akakus Mountains in past centuries (if not millennia) is of paramount importance, because it overturns a traditional historical perspective, based on a system of exchange between oasis and mountains: the former thought to provide cereals and other staple food to groups living in the mountains. The mobility strategies and settlement organisation of Final Pastoral and Garamantian groups should also be reviewed accordingly, taking into consideration these subsistence practices.

Taken together, all these water-related features of the Akakus Mountains clearly indicate that the choice to live in the mountains, rather than move and settle in the oasis, mirrors a deliberate cultural choice; and they should be considered as fundamental components of a wider resilient strategy to cope with an unpredictable environment

ACKNOWLEDGEMENTS

This research is part of the activities of 'The Italian–Libyan Archaeological Mission in the Akakus and Messak', directed by Savino di Lernia. Funds come from *Grandi Scavi* (Sapienza University of Rome), DGPCC (Minister of Foreign Affairs) and C.N.R.-I.D.P.A. (Milan). Di Lernia designed the research and directed the fieldwork. This chapter is by di Lernia with contributions by Andrea Zerboni (geological and environmental data) and Isabella Massamba N'Siala (botanical information); the final discussion reflects a common view. We would like to thank Dr Saleh Aghab, Chairman of the Department of Archaeology, Tripoli, and Dr Saad Abdul Aziz, Germa, for their support. Our work would have not been possible without the help and advice of Mohammed 'Skorta' Hammadani; we also thank Ali Khalfalla, Ebrahim Yussuf, Ramadam Ahmed and Seghair Assabun and all the Kel Tadrart still living in the Akakus. This paper is in memory of late Amghar Hammadani, the 'guardian' of wadi Teshuinat.

REFERENCES

- Anderson, D.G., K.A. Maash and D.H. Sandweiss (2007). *Climate Change and Cultural Dynamics. A Global Perspective on mid-Holocene Transitions*. London: Academic Press.
- Barich, B.E. (1987). *Archaeology and Environment in the Libyan Sahara. The Excavations in the Tadrart Acacus, 1978–1983*. Oxford: B.A.R. International Series, 368.
- Bernus, E. (1979). 'Exploitation de l'espace et desertification en zone sahélienne'. *Travaux de l'Institut de Géographie De Reims* 39–40: 49–59.
- Biagetti, S. (2008). 'I kel Tadrart, oggi', in S. di Lernia and D. Zampetti (eds.) *La Memoria dell'Arte*. Firenze: Edizioni All'Insegna del Giglio. pp. 273–280.

‘Saharan Waterscapes’

- Biagetti, S. and J. Chalcraft (In press). ‘Imagining aridity: human environment interaction in the Acacus Mountains’, in T. Ingold and M. Janowski (eds.) *Imagining Landscapes. Anthropological Studies of Creativities and Perception*. Aldershot: Ashgate Publishing Limited.
- Brooks, N. (2006). ‘Cultural responses to aridity in the Middle Holocene and increased social complexity’. *Quaternary International* 151: 29–49.
- Brooks, N., I. Chiapello, S. di Lernia, N. Drake, M. Legrand, C. Moulin and J. Prospero (2006). ‘The climate–environment–society nexus in the Sahara from prehistoric times to the present day’. *The Journal of North African Studies* 10: 253–92.
- Bourbon del Monte di Santa Maria, G. (1912). *L'oasi di Ghat e sue adiacenze*. Città di Castello: Tipografia dell'Unione Arti Grafiche.
- Calegari, G. and G. Soldini (1993). ‘Punti d'acqua e invenzione del territorio’, in G. Calegari (ed.) *La religione della sete. L'uomo e l'acqua nel Sahara*. Milano: Centro Studi Archeologia Africana. pp. 77–92.
- Camps, G. (1985). *Encyclopédie berbère*. Aix-en-Provence: Editions Edisud.
- Cremaschi, M. (1998). ‘Late Quaternary geological evidence for environmental changes in south-western Fezzan (Libyan Sahara)’, in M. Cremaschi and S. di Lernia (eds.) *Wadi Teshuinat – Palaeoenvironment and prehistory in south-western Fezzan (Libyan Sahara)*. Roma-Milano: CNR, Quaderni di Geodinamica Alpina e Quaternaria, 7. pp. 13–47.
- Cremaschi, M. and S. di Lernia (1998). *Wadi Teshuinat – Palaeoenvironment and Prehistory in South-western Fezzan (Libyan Sahara)*. Roma-Milano: CNR, Quaderni di Geodinamica Alpina e Quaternaria, 7.
- Cremaschi, M. and S. di Lernia (1999). ‘Holocene climate changes and cultural dynamics in the Libyan Sahara’. *African Archaeological Review* 16: 211–38.
- Cremaschi, M. and A. Zerboni (2009). ‘Early to middle Holocene landscape exploitation in a drying environment: two case studies compared from the central Sahara (SW Fezzan, Libya)’. *C. R. Geoscience* 341: 689–702.
- Cremaschi, M., A. Zerboni, C. Spötl and F. Felletti (2010). ‘The calcareous tufa in the Tadrart Acacus Mt. (SW Fezzan, Libya). An early Holocene palaeoclimate archive in the central Sahara’. *Palaeogeography, Palaeoclimatology, Palaeoecology* 287: 81–94.
- di Lernia, S. (2002). ‘Dry climatic events and cultural trajectories: adjusting Middle Holocene pastoral economy of the Libyan Sahara’, in F.A. Hassan (ed.) *Droughts, Food and Culture*. New York: Kluwer Academic/Plenum Publishers. pp. 225–250.
- di Lernia, S. and D. Zampetti (2008). *La Memoria dell'Arte*. Firenze: Edizioni All'Insegna del Giglio.
- di Lernia, S. and M. Gallinaro (2010). ‘The date and context of Neolithic rock art in the Sahara: engravings and ceremonial monuments from Messak Settafet (south-west Libya)’. *Antiquity* 84 (326): 954–75.
- di Lernia, S., M. Gallinaro and A. Zerboni (2010). ‘Unesco World Heritage Site vandalized. Report on damages to Acacus rock art paintings (SW Libya)’. *Sahara* 21: 59–76.
- Davies B. and F. Gasse (1988). *African Wetlands and Shallow Water Bodies - Bibliography*. Paris: Editions de l'ORSTOM, Collection Travaux et Documents 211.

- Desio, A. (1937). 'Geologia e Morfologia', in Regia Società Geografica Italiana (ed.) *Il Sahara Italiano. Parte I: Fezzan e Oasi di Ghat*. Roma: Società Italiana Arti Grafiche. pp. 39–94.
- Dubief, J. (1953). *Essai sur l'hydrologie superficielle au Sahara. Direction du service de la Colonisation et de l'Hydraulique*. Paris: Serv. Etud. Sci. 4.
- El-ghali, M.A.K. (2005). 'Depositional environments and sequence stratigraphy of paralic glacial, paraglacial and postglacial Upper Ordovician siliciclastic deposits in the Murzuq Basin, SW Libya'. *Sedimentary Geology* 177: 145–73.
- Fantoli, A. (1937). 'Clima', in Regia Società Geografica Italiana (ed.) *Il Sahara Italiano*. Roma: Società Italiana Arti Grafiche. pp. 97–119.
- Foucault De, C. (1951). *Dictionnaire Touareg–Français*. 4 Volumes. Paris: Basset.
- Galeôti, M. (1984). *Geological Map of Libya, Explanatory Booklet, Sheet: Anay, NG 32-16, scale 1:250000*. Tripoli.
- Gigliarelli, A. (1932). *Il Fezzan*. Tripoli: Ufficio Studi Governo della Tripolitania.
- Hamliche, V. and K. Maiza (2006). 'Traditional medicine in Central Sahara: Pharmacopoeia of Tassili N'ajjer'. *Journal of Ethnopharmacology* 105: 358–67.
- Hassan, F.A. (2002). *Droughts, Food and Culture: Ecological Change and Food Security in Africa's Later Prehistory*. New York: Kluwer Academic/Plenum Publishers.
- Kaci, A. (2007). 'Recherche sur l'ancêtre des alphabets libyco-berbères'. *Libyan Studies* 38: 13–37.
- Kuper R. and S. Kröpelin (2006). 'Climate-controlled Holocene occupation in the Sahara: motor of Africa's evolution'. *Science* 313: 803–7.
- McAllister R.R.J., S. Holcombe, J. Davies, J. Cleary, A. Boyle, P. Tremblay, D.M. Stafford Smith, D. Rockstroh, M. LaFlamme, M. Young and M.F. Rola-Rubzen (2011). 'Desert networks: A conceptual model for the impact of scarce, variable and patchy resources'. *Journal of Arid Environments* 75 (2): 164–173.
- Mercuri A.M., G. Trevisan Grandi, I. Massamba N'siala and L. Olmi (2007). 'Polline e piante alimentari: inventario dai siti archeologici del Tadrart Acacus'. *Atti della Società dei Naturalisti e Matematici di Modena* 137: 431–44.
- Mori, F. (1965). *Tadrart Acacus. Arte rupestre e culture del Sahara preistorico*. Torino: Einaudi.
- Mori, F., R. Ponti, A. Messina, M. Flieger, V. Havlicek and M. Sinibaldi (2006). 'Chemical characterization and AMS radiocarbon dating of the binder of a prehistoric rock pictograph at Tadrart Acacus, southern west Libya'. *Journal of Cultural Heritage* 7: 344–9.
- Nicolaisen, J. (1963). *Ecology and Culture of the Pastoral Tuareg*. Copenhagen: National Museum of Copenhagen.
- Scarin, E. (1934). *Le oasi del Fezzan*. Bologna: Zanichelli.
- Turri, E. (1983). 'Uomini e pozzanghere: la geografia evanescente del Sahel', in G. Calegari (ed.) *La religione della sete. L'uomo e l'acqua nel Sahara*. Milano: Centro Studi di Archeologia Africana. pp. 109–119.
- Walther, H. and H. Lieth (1960). *Klimadiagramm. Weltatlas*. Jena: G. Fisher.
- Zerboni, A. (2008). 'Holocene rock varnish on the Messak plateau (Libyan Sahara): Chronology of weathering processes'. *Geomorphology* 102: 640–51.
- Zoli, C. (1926). *Nel Fezzan. Note e impressioni di viaggio*. Milano: Alfieri & Lacroix.

KAREZ VERSUS TUBEWELL IRRIGATION: COMPARATIVE SOCIAL ACCEPTABILITY AND PRACTICALITY OF SUSTAINABLE GROUNDWATER DEVELOPMENT IN BALOCHISTAN, PAKISTAN

Daanish Mustafa and Usman Qazi

INTRODUCTION

Are technological transitions from traditional to modern desirable? Inevitable? And/or part of the inexorable process of development? These questions lie at the heart of the sustainable development enterprise. Water as a core resource not only for survival but for livelihoods, environmental quality and social and cultural cohesion can be a useful conduit for engaging with the above larger questions in the field of environment and development. The semi-arid highland regions of Balochistan province in Pakistan are in the midst of a transition from the ancient *karez*-based mode of tapping groundwater for irrigation to groundwater pumping with diesel and electric tubewells. The diffusion of tubewells in Balochistan is not only leading to rapid decline of water tables but also to gradual replacement of *karez* irrigation and the social systems developed around the ancient technique (van Steenberg and Oliemans 2002). This article presents the results of a field study to understand the reasons and the social and environmental impacts of the transition from *karez* to tubewell irrigation in Balochistan, with an eye towards addressing the question of whether *karez* irrigation really is an anachronism, or can it and should it be saved? The article is further concerned with the role played by social power in affecting the transition from *karez* to tubewell irrigation and the experience of that transition.

Karez irrigation is prevalent over vast swathes of the semi-arid regions of the world ranging from Balochistan to Central Asia to West Asia to North Africa. Some *karez*-like systems have also been documented in Mexico, Peru and even Japan (Lightfoot 1996). The system is known as *qanat* in the Middle East, *foggara/khattara* in North Africa and *galleria* in Spain and Latin America. *Karez* relies upon passive tapping of the groundwater through underground channels linking a series of wells to the 'mother well' dug into the water table (Figure 1). The water flows by gravity to the daylight

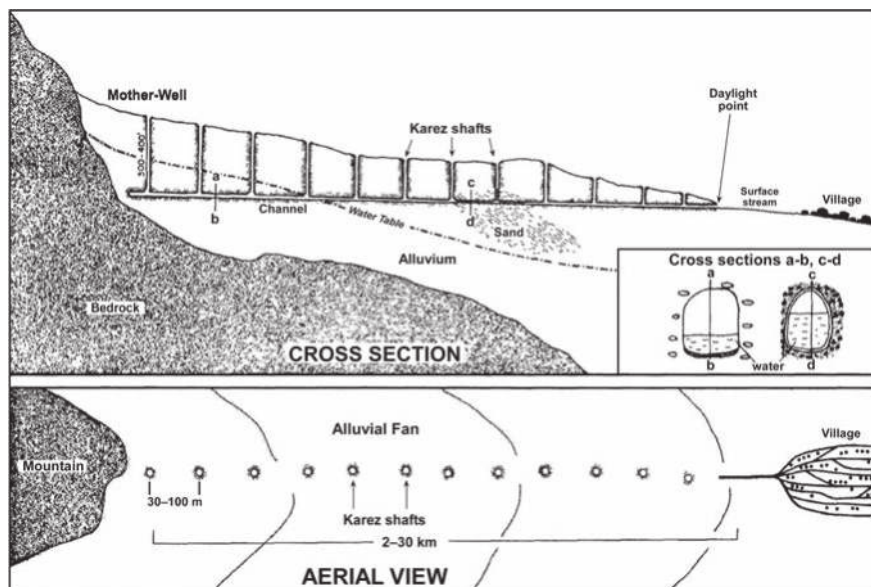


Figure 1. Schematic diagram of a typical *karez*.

point, whence it can be used for irrigation and domestic water use. Since the system relies upon passive tapping of groundwater it has little to no impact on water tables. The technique is therefore environmentally friendly but water yields from *karez*es are highly dependent upon water table fluctuations in addition to availability of labour and capital for periodic *karez* channels maintenance and cleaning (Beaumont 1968, Beaumont *et. al.* 1989, Lightfoot 1996a & b, Rehman 1981).

In the following article, after describing the conceptual framework and the field study methodology, we will review the traditional social organisation around *karez* irrigation in the highlands of Balochistan. We will then discuss the causes and impacts of tubewell diffusion in Balochistan on *karez* irrigation, agricultural productivity, social equity and cohesion as well as environmental quality. In the following sections we will present the results of the field study regarding public and policy perspectives on the ongoing transition from *karez* to tubewell irrigation, with a particular emphasis on comparing *karez* with tubewell irrigation. We will conclude by reviewing the policy options for sustainable groundwater management in Balochistan, especially with reference to prospects for *karez* rehabilitation in the province.

CONCEPTUAL FRAMEWORK

The analyses presented in this article are concerned with how social power across spatial scales mediates the actual transition and the experience of the transition from *karez* to tubewell irrigation in Balochistan. During the past decade there has been considerable attention to the role of social power in influencing wider human environment interactions. The conceptualisation of social power has been through the lens of political economy, particularly in the now well-established political ecological literature: e.g. see Blaikie and Brookfield (1989), Robbins (2000), Watts and Bohle (1994), Wisner (1993), and Peet and Watts (1996 and 2003). Within water resources literature, however, besides the grand theories on the role of water technologies in civilisation evolution (Wittfogel 1955 and 1957), the attention to social power in impacting water management and development was relatively late.

Swyngedouw (1999) and Mustafa (1999) are earlier examples of water resources researchers' engagement with the issue of water and social power. Subsequently, where Akram-Lodhi (2001) discussed the interaction between land, water and social power in northern Pakistan from an economic perspective, Swyngedouw (1997 and 1999), demonstrates how historical water development and management in Ecuador and Spain materially inscribed power relations on the urban geography of Guayaquil in Ecuador and in the national landscape or 'waterscapes' of Spain. Budds (2004) calls attention to how social power of large farmers is mediated by the Chilean water code in rural Chile. Mustafa (2001) similarly draws attention to how a key piece of colonial water legislation, through its lack of sensitivity to the geographies of power in Pakistan, in fact, becomes complicit in producing and reproducing them. Each of the above treatments of water and social power is nested within the political ecological tradition of human geography, where discourse analysis, political economy, language and culture are key conceptual tools for apprehending the role of social power in water resources management.

Mustafa (2002a), directly engaging the social power problematic in a critical realist mode, develops a schema for conceptualising the sources of power and its impact on access to irrigation water and vulnerability to hazards in rural Pakistan. He identifies three empirical types of power: naked power of social actors to ensure compliance through violence or threat of violence; compensatory power, which ensures compliance through control over economic resources and the means of production; and knowledge as power, which ensures compliance through socialisation, ideologies and collective pressure. The naked, compensatory and knowledge types of power flow respectively feudal, bourgeois and communal social structural modes, according to Mustafa (2002a). We will use Mustafa's (2002a) conceptualisation of power to apprehend the role of social power in influencing the policy context and the experience of transition from *karez* to tubewell irrigation in Balochistan, Pakistan. We will be particularly interested in identifying the specific types and modes of social power that influence the context of transition from *karez* to tubewell irrigation.

RESEARCH SETTING AND METHODOLOGY

Field research for this article had three major components. Household level survey, survey of government and non-government water related decision-makers at the federal and provincial levels of Pakistan and review of gray literature related to groundwater development and economic development in Balochistan.

The household level survey was conducted in seven villages – Karez Noth, Kunghar, Bangi Karez and Chakul Kaloza in the Mastung district; and Pesha Morezai, Yaqub Karez and Soghail Allahdadzai in the Qilla Saifullah district of Balochistan (Figure 2). Both the districts lie in the highlands of north-western Balochistan with cool and dry summers and intensely cold and more moist winters. Mastung district is inhabited by Persian speaking Dehwar people and Brahvi speaking indigenous population while Qilla Saifullah has Pashto speaking Pashtun/Pathan people dominating the cultural landscape. The Dehwar region of Mastung is closer culturally to the other Balochi and Brahvi speaking ethnic groups in Balochistan while Qilla Saifullah is the heartland of Pashtun culture in Balochistan.

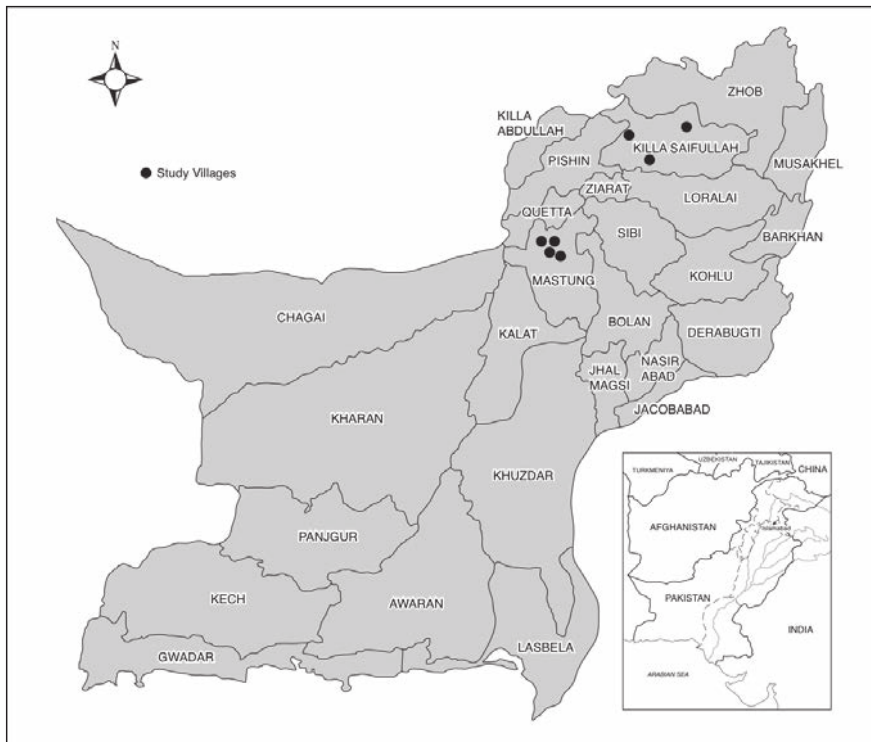


Figure 2. District map of Balochistan province in Pakistan.

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The social set up of the region is quite conservative, requiring, among other things, strict segregation between the sexes. This is more so in the Pashtun dominated areas like the Qilla Saifullah district. The research team had tremendous difficulty, especially the female enumerators, in conducting their work in the Pashtun areas. Repeatedly the research team was refused cooperation by village leadership in village after village. The team was able to find three villages in the Pashtun areas where the leadership was willing to extend cooperation to the research team but in one of the villages – Soghai Allahdadzai the cooperation was withdrawn once the local mullah found out about the presence of the enumerators. In another village – Yaqub Karez the female enumerator was harassed by local Islamist elements for doing her job. This rise in hostility towards outside researchers is a relatively recent phenomena, because of the US bombing of neighbouring Afghanistan, increased Talibanisation of Pashtun areas and the anti-NGO and anti-western rhetoric of the local religious leadership as well as of the Islamist parties in the coalition provincial government of Balochistan province (Figure 3).



Figure 3: A wall calendar in one of the study villages in Qilla Saifullah. The large text from the top states, 'two storms of two countries: Mullah Umar and Fazul-ur-Rehman' (the leader of the opposition in Pakistan's national assembly and head of the ruling party in Balochistan). 'Long live Tehrik-e-Islami Taliban'. Above the American flag it says 'America'. At the bottom it states: 'We are not afraid of America. I am on a mission to free the Islamic world from the clutches of America. Nobody can stop me. Osama bin-Laden.' The poster was printed in Sargodha under the auspices of Jamiat-e-Ulama-e-Pakistan and Jamiat-e-Tulaba-e-Islam. Photograph: Authors.



Figure 4. *Karez* channel in Pesha Morezai, Qilla Saifullah district, summer 2005. Photograph: Authors.

The household survey constituted administering 149 questionnaires to the male and female residents of the villages. A team constituting a male and a female enumerator worked in the Mastung district, while the other team worked in the Pashtun villages of Qilla Saifullah district. In the villages of Karez Noth, Kunghar, Yaqub Karez and Pesha Morezai Participatory Rural Appraisal exercises (PRAs) were also conducted separately with males and females. Furthermore, the target number of questionnaires could not be completed in the Pashtun areas, particularly among the women, because of the reasons outlined above, and hence women are under-represented in the overall sample.

The criterion for selection of each of the villages was the mode of irrigation prevalent in the village. In Karez Noth the *karez* has been dry for more than a decade and the village is almost entirely dependent upon the one collectively-owned electric tubewell in the village, though larger landowners in the village have private tubewells on their lands in adjacent villages. In the villages of Chakul Kalozai, Bangi Karez and Pesha Morezai, the *karez* is still alive but barely (Figure 4). The water flow in the *karezes* of the three villages is barely sufficient for domestic water use but not for any substantial irrigation. In Yaqub Karez there is a diesel-powered tubewell that has been the main source of irrigation water since the onset of the drought (ca 1998–2005). Since the higher than normal precipitation in the winter of 2005, the *karez* in the village has again

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started flowing, normally removing the need for operating the expensive diesel pumps (Figure 5). The *karez*es in Kunghar and Soghai Allahdadzai are fully operational, though with a diminished flow compared to the past, according to the local populace (Figure 6). Despite the presence of privately owned tubewells, *karez* flows are the mainstay of irrigation in the two villages.

The main criterion for inclusion in the questionnaire survey was primarily willingness to be interviewed. This was particularly so because of the cultural and political environment in Balochistan, referred to above. Among the willing participants, every

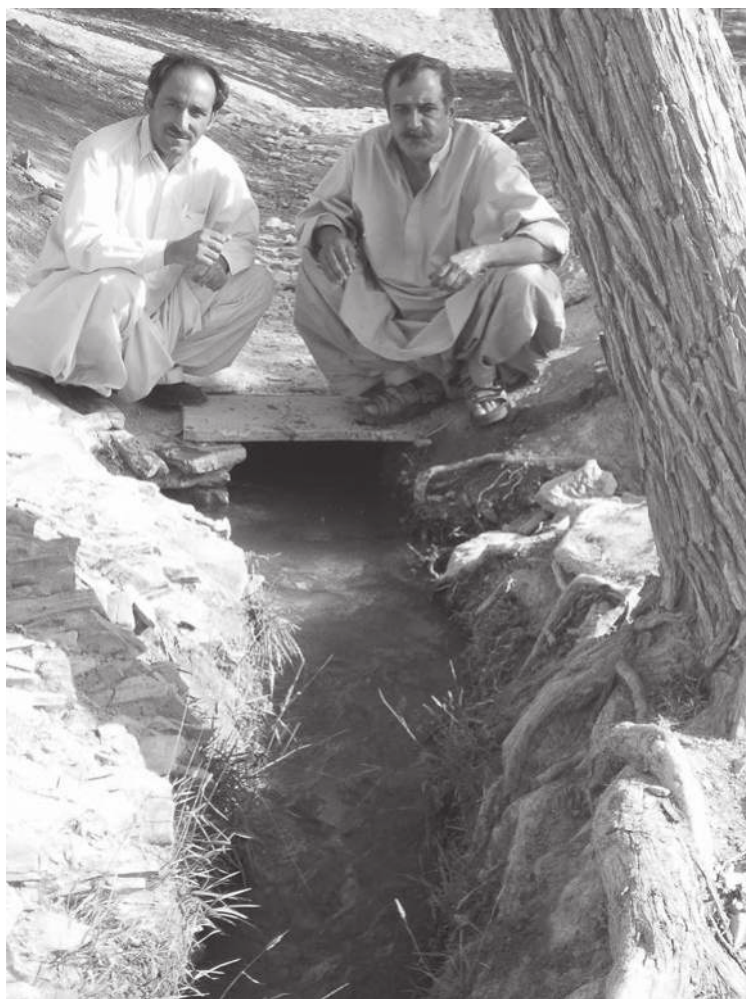


Figure 5. Daylight point of Yaqub Karez, summer 2005. Photograph: Authors.



Figure 6. *Karez* channel in Kunghar, summer 2005. Photograph: Authors.

attempt was made to include respondents from each of the following categories: those who were currently or had been shareholders in the village *karez*; those who had never been *karez* members; those who used tubewell irrigation if applicable; were landowners; or were sharecroppers. The result was a pool of respondents which, despite its limitations, is fairly representative of the different stakeholders in *karez* and tubewell irrigation. In addition to questionnaire survey, PRA exercises were also conducted in Karez Noth, Kunghar, Yaqub Karez and Peshawar, to access group perceptions regarding the transition from *karez* irrigation to tubewell irrigation and also to cross-check the findings of the questionnaire survey.

GEOGRAPHICAL CONTEXT OF TRANSITION FROM *KAREZ* TO TUBEWELL IRRIGATION

*Karez*es by virtue of their physical makeup, are highly labour intensive. The long underground tunnels and deep manholes warrant a large-scale use of the rudimentary technology of humans, animals and hand digging implements for both *karez* development and periodic repair and maintenance. The implication from a social organisation perspective is that it was beyond the power of any individual to single-handedly

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embark upon the development of this sole source of water, necessitating the forging of a collective to provide investment in the form of labour.

The water distribution in a *karez* is most often based on time division, whereby a shareholder is entitled to the full flow of the channel for a fixed period of time during a water cycle that revolves over seven to thirty days, depending upon the cropping pattern. The magnitude of an individual water share is pro-rata to the investment made by the shareholder (or his forefathers¹) in *karez* development. Similarly, the distribution of the onus of recurrent obligations for periodic repair and maintenance of the *karez* is also proportionate to the initial entitlement.

A single person or a committee of village dignitaries is responsible for the organisation of labour for *karez* maintenance, levying of penalties on the defaulters, taking the lead in resolving water related disputes and managing other aspects of water management. This person, known as *rais*, *hisabgar* or *mir-i-aab*, may inherit the office or be elected. The incumbent of the office may be compensated through the allocation of some extra water share or exemption from *karez* maintenance.

A remarkably equitable feature of *karez* system is the land distribution associated with it. Commonly, *karez* shareholders have landholdings distributed along the head, middle and tail reaches of the main irrigation channel downstream from the daylight point. This ensures that, in addition to every shareholder retaining an equal stake in maintaining the entire length of the channel, all shareholders also equitably share in water scarcity. This was also confirmed during the cognitive mapping exercises conducted as part of the PRAs in the four communities of Yaqub Karez, Peshawar, Peshawar, Kunghar and Karez Noth.

This mutual dependence of the community in keeping a shared resource intact knits them into an intertwined fabric of cooperative enterprise where the communal mode of power (Mustafa 2002a) is the defining character of the social organisation.

Balochistan was accorded the status of a province in 1970 and the national electricity grid was expanded to the province. This heralded an era of state-sponsored modernisation of the agricultural sector. In the case of arid zones of Balochistan, this was manifested in the proliferation of tubewells for ground water exploitation and the popularisation of water intensive cash crops such as apples and onions. The first tubewells were installed in the early 1970s with heavy subsidies for both their installation and operation (van Steenberg, 1997a). Under the continued subsidy on tubewell operation in the form of a flat monthly electricity tariff, the number of officially recorded tubewells had leapt from around 2,000 in 1970–71 to more than 14,000 in 2001–02 (Government of Pakistan (GoP), 2002). To this should be added the substantial number of private electric tubewells without a legal connection, as well as more than 11,000 diesel-driven wells in the valleys not yet connected to the electricity grid (GoP 2002).

The year 1998 saw the setting in of a very severe drought in large parts of central and western Asia, including Balochistan, that persisted till 2003. The lack of precipitation put further pressure on groundwater levels already rapidly declining at

1. *Karez* shareholders are invariably male.

a rate of 0.25 to 1.10 m/annum as recorded as early as 1992 (WAPDA, 1992). The already-stressed aquifers came under immense pressure due to an acute absence of recharge and this led to sharp reductions in flow and subsequently the drying up of *karez*s. The richer farmers invested in installation of new – and further deepening of existing – tubewells as a drought coping mechanism. The ones who could not afford to invest more in ground water extraction went off to other places in search of alternative sources of livelihood such as day labour, mining, casual urban jobs etc. This withdrawal of shareholders from an interest in *karez*s, in many cases, led to disintegration of the social organization around the *karez*. In these cases the fate of the *karez* was sealed, with little likelihood of people contributing in its rehabilitation even if the rainfall patterns improved.

Tubewell installation in the highlands of Balochistan was not just motivated by the positive reason of promoting ‘modern’ irrigation technologies but also by the perceived inefficiency of the *karez* irrigation. Kemper *et. al.* (1979) was one of the earlier donor funded studies on *karez* irrigation, identifying the twenty-four-hour flow of water in a *karez* as wasteful and something which an arid region like Balochistan could ill afford. Kahlowan and Hamilton (1994) identify high seepage losses and seasonal variations in water levels as additional problems with *karez* irrigation. The focus on such problems with *karez* irrigation was an additional motivating factor for the initial promotion of tubewell irrigation in official policy. It is to the micro-scale experience and perceived consequences of the transition from *karez* to tubewell irrigation that we now turn.

PUBLIC DISCOURSE ON *KAREZ* VS. TUBEWELL IRRIGATION

The contours of the public discourse outlined in this section were gleaned from the household level questionnaire surveys and elements of PRAs conducted in four of the seven study villages. In terms of overall profile of the survey population, the reported average household size was twelve. The most highly educated males in the survey households on average had 7.6 years of schooling while women on average had 2.4 years of schooling. Sixty-seven per cent of the survey respondents did not report any literate females in the household, while only eighteen per cent reported lack of literate males in the household.

In terms of sources of income, 29 per cent reported agriculture as the primary source of household income, though sixty per cent of the survey respondents reported agriculture as a secondary source of income. Among other primary sources of income were out of village employment, reported by 28 per cent of the respondents, and working as day labourers, reported by 34 per cent of the respondents. Among other secondary sources of income fifteen per cent and seven per cent of the respondents respectively reported out of village employment and working as a day labourer. In the study area animal husbandry was a primary source of income for only three per cent of the respondents and a secondary source for no more than four per cent. The sources of income present a picture of an agricultural economy in a state of transition and/or

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stress, where the core economic activity of agriculture is no longer a primary source of livelihood for a majority of the people.

Despite the lowering of the water table from the recent drought, compounded by the rapid diffusion of tubewells, many communities in the survey sample were resisting the temptation to install a tubewell. Figure 7 summarises the responses when survey respondents were asked about reasons for continued viability of *karez* irrigation in their communities. Community interest, communal harmony, water availability and protection of water rights were some of the chief reasons for the continued success of *karez* irrigation. The communal harmony aspect of the continued survival of *karez* irrigation was intricately tied to the issue of social equity and apprehensions about awarding too much social power to economically stronger elements within the community, since they were the only ones who could afford to install tubewells and to benefit from them. The following quotes illustrate the point:

Large landowners have benefited the most from tubewells. They have the resources and land to put down tubewells on individual or shareholder basis. A small landowner like myself has two to three acres of land. How much am I going to get out of that land and how much profit will I earn? (Rais Dawood, Kunghar)

Landowning farmers have benefited from the tubewell and have provided work for poor people. We [small farmers] are the ones who have suffered because our *karez* water is reduced, our lands are lying fallow, and unemployment has increased beyond all limits (Zulekha, Bangi Karez).

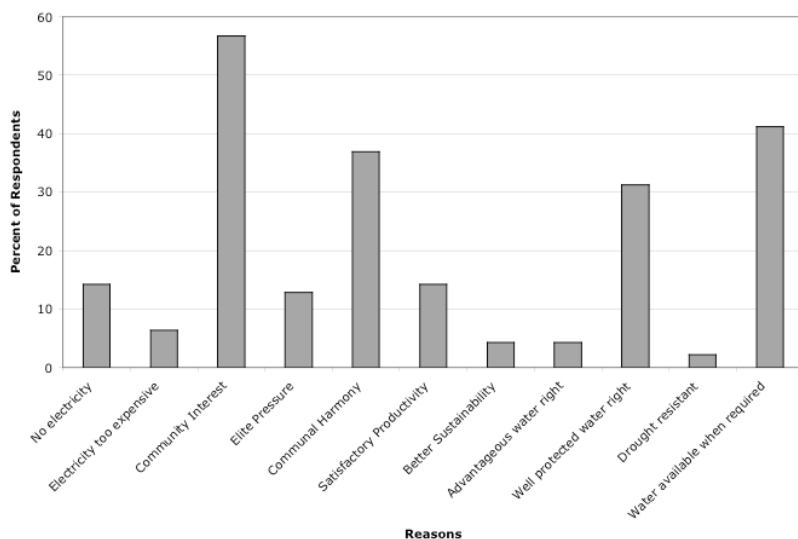


Figure 7. Percentages of survey respondents reporting various reasons for the desirability of *karez* irrigation.

In fact, 87 per cent of the survey respondents deemed *karez* irrigation to be advantageous compared to tubewell irrigation, even though many of them had switched completely from *karez* to tubewell irrigation. Only four per cent of respondents thought tubewell to be better than *karez* and the remainder did not have an opinion on the matter. The main reason for abandoning *karez* irrigation was given as decline in *karez* water flows (36 per cent), while fourteen per cent cited the positive reason of a desire to expand cropped area as a reason for abandoning *karez* irrigation. Less than ten per cent of the respondents listed other reasons such as social freedom (since they had exclusive rights to water from their tubewells) and drought coping as reasons for abandoning *karez*.

Since tubewells are fast becoming the dominant form of tapping ground water in the highlands of Balochistan, it was deemed important to understand the advantages that people perceived with tubewells. Figures 8 and 9 outline the advantages and disadvantages of tubewell irrigation reported by survey respondents. Although there is no majority opinion on the advantages of tubewell irrigation, a plurality considered expansion in cropped area, higher productivity, social freedom and drought coping as the major advantages. Surprisingly, traditional reasons cited in favor of tubewell irrigation (see Chilton *et. al.* 2000) – e.g. on-demand water and reducing waste – were barely even mentioned among the advantages of tubewell irrigation. Surprisingly, the people who had no experience with tubewell irrigation, particularly women, seemed to have the most positive view of tubewell irrigation:

The farmers and people have benefited [from tubewells]. Farmers get more productivity and people can get water for domestic use. Poor people can lease their land out to tubewell owners and get a sixth of the produce. It is a little something for the poor. Nobody has lost from tubewells (Haleema, Bangi Karez).

Women who did have direct experience with tubewells did not think of them as more advantageous than *karez* for irrigation but they were certainly positively disposed towards tubewells for drinking and domestic water supply. There was a perception among many women that tubewell water was cleaner and caused fewer diseases. Men generally did not address the issue of water quality in their opinions.

In terms of disadvantages, there was a much greater diversity of opinions among the plurality of respondents. Most of the disadvantages referred to cost, reliability and environmental sustainability of the technique. While the numbers do echo the general themes that emerged from the survey, there were however, many nuances of opinions regarding tubewell and *karez* irrigation that hide behind the numbers.

Despite the rapid diffusion of tubewell, the picture that emerged from interviews during the fieldwork did not show the technology in a very positive light. Even the water users who have completely switched to tubewells were not very happy with the technology, as hinted in the aggregate numbers. Although, cost was a major overall cause of dissatisfaction, the cost factor was perceived to be tied up with class. Figure 10 shows

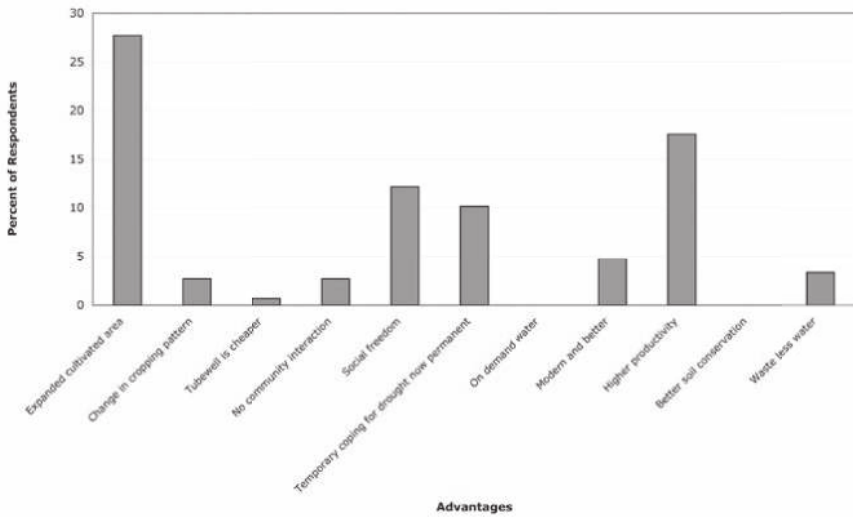
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Figure 8. Percentages of survey respondents reporting various advantages of tubewell irrigation.

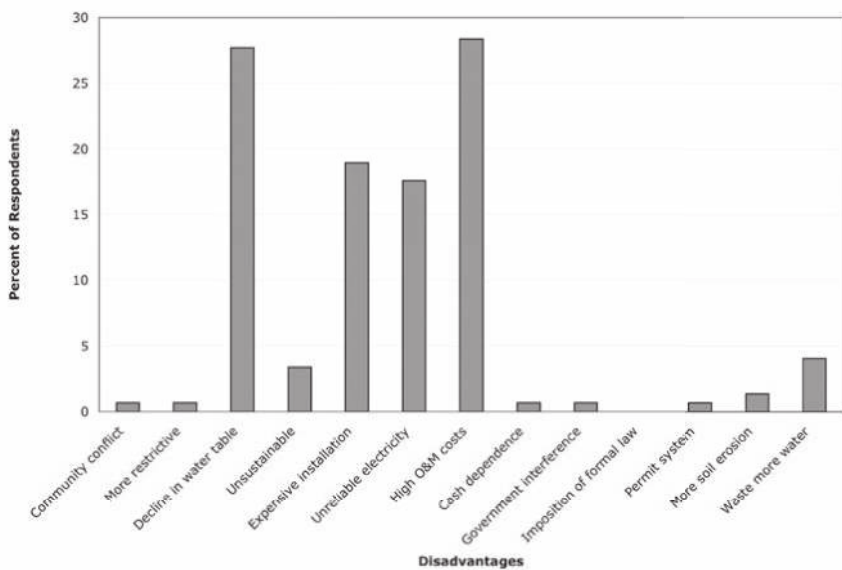


Figure 9. Percentages of survey respondents reporting various disadvantages of tubewell irrigation.

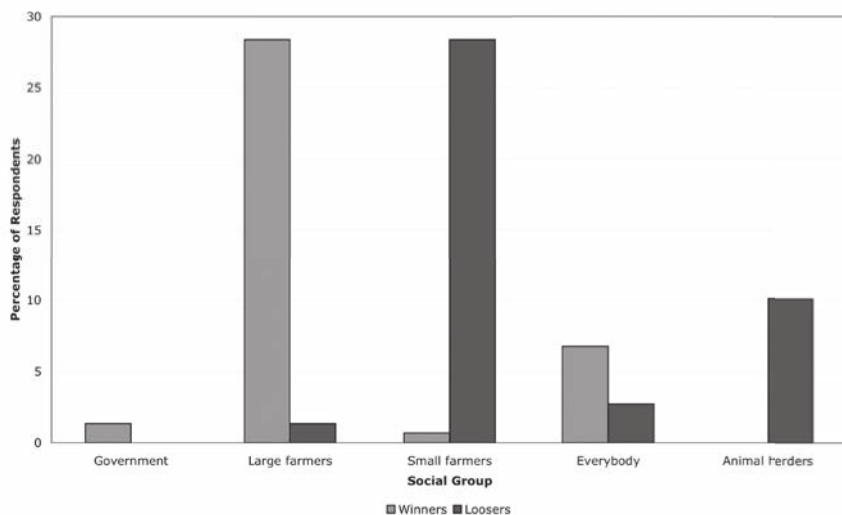


Figure 10. Percentages of survey respondents reporting various winners and losers from the transition to tubewell irrigation from *karez*.

the overall responses to the question of who won and who lost from the transition to tubewell irrigation. Some of the following quotes further confirm the overall picture:

Those who have fruit orchards benefit [from tubewells]. Those who just plant wheat and onions lose. The only benefit [of tubewells] is that if you have money [which most do not] you can get water and the women can do laundry with tubewell water (Shaadi Khan, Karez Noth).

The small shareholders have really lost out because they do not have the resources to install their own tubewells. They are now forced into sharecropping arrangements with the tubewell owners (Sakina, Kunghar).

The rich have grown richer and the poor have grown poorer. The rich have installed tubewells and saved their orchards and crops. The poor farmer, on the other hand, does not have the wherewithal to save his few trees (bibi Asseea, Yaqub Karez).

The frustration with the class aspect of the diffusion of tubewells then spills over beyond the immediate issue of the rich getting richer, toward the government's policy of subsidy for tubewell electricity, which promotes excessive use of water and therefore jeopardises the long-term sustainability of rural communities.

If the drought ends, there might be a future for *karez*. But it is also a reality that the huge number of tubewells installed has really hurt the *karez*. Between Dasht and Kadikucha [from one end of Mastung district to another] there are more than 6,000 tubewells, which have eliminated the *karezes* in Mastung. Everybody is concerned with increas-

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ing his income and is focused on next year's crop instead of the future of our region. Also, the governments never considered that there should be micro-projects to increase groundwater recharge. I would go so far as to say that we are spending away our future generations' water today—leave alone the future of Karez irrigation! (M. Ayub, Kunghar).

The concern with long-term sustainability is in addition to very deeply felt angst about the loss of culture and community, which follows in the wake of the diffusion of tubewell technology.

In these modern times people are abandoning the ancient and traditional irrigation, and trying to maximise cropped area. Ever since the tubewells have arrived, a competitive trend has emerged amongst the people and farmers. The installation of tubewells for modern irrigation succeeded in increasing agricultural productivity, but it also gravely damaged the ancient *karez* system. *Karez*es were a great source of social and communal life for us village folks. People would sit on their sides and discuss their issues and find solutions to their problems. But modern times, new technologies, and tubewells have dried out the *karez*es and their resurrections is no longer possible, nor is there any future for the existing ones (Ghaus Bux, Kunghar).

Traditional methods of irrigation have almost gone extinct since the drying of *karez*es ... When tubewells slowly started damaging/replacing the *karez*es, people started taking less interest in *karez*es as well. When people loose interest, what could be the future of *karez* in this region? Individuals have benefited from tubewells, but nobody thought about *karez* from which 600–700 people derived their livelihood. Also *karez* was a source of sense of community for the people. People would often sit besides a *karez* and find solutions to their problems. But with the drying of the *karez* these things have also gone extinct (Muhammad Umar, Bangi Karez).

Upon surveying the contours of the public discourse on transition from *karez* to tubewell irrigation, a number of questions arise. The core question that arises is, why is the transition from *karez* to tubewell continuing in Balochistan despite acute public awareness of its negative impacts on social equity, community cohesion, culture, long-term sustainability and livelihoods of the majority? To find an answer we propose engagement with the issue of social power. Just as Mustafa (2002a) discussed the role of different types of social power in influencing access to irrigation water in the Punjab, we propose that social power is again at play in this situation to promote diffusion of the tubewell technology. At the micro-scale of the household and village level, as presented in this section, we argue, in light of the above evidence, that the communal mode of power exercised by the community to ensure compliance among its members is steadily being eroded by the bourgeois mode of power of the larger farmers.

The larger farmers' social power in the study villages was under check from the communal mode of power when *karez* was the dominant livelihood-related technology available. The larger farmers did have large shares in *karez* water but that also meant that they had greater obligation towards its upkeep. Furthermore, the large or small farmers were not necessarily locationally disadvantaged, as is so often the case in other types of irrigation systems (e.g. see Ali 1988, Vander Velde and Svendsen 1994, van

Steenbergen 1997, Mustafa 2002b), because of the even distribution of land parcels along the head, middle and tail reaches of a *karez* channel. Now, with the advent of tubewells in those villages where they had replaced *karez*, the communal mode of power for compliance and rule making was replaced by the greater compensatory/financial power of the larger farmers, who, with their independent source of water in the semi-arid environment of Balochistan, had less of a reason to subscribe to community rules *vis-à-vis* water management. This was also true in the study villages where neighbouring villages had established tubewells, causing the village *karez*es to go dry. Because of the inter-connected nature of groundwater it is not essential for the tubewell to be in the specific community in order to have the impacts discussed above. Van Steenbergen and Shah (2002) observed a similar trend in transition from *karez* to tubewell irrigation in the neighbouring Quetta district.

Of the study villages, in Pesha Morezai, where there was no tubewell nearby or in the village, the communal mode of power remained dominant. This was also true to a lesser extent in the cases of communities like Yaqub Karez and Kunghar, where there were tubewells but the *karez* was also not completely dead. In villages like Chakol Kalozai, Bangi and Karez Noth, where the *karez* had ceased to be of economic importance and/or had been complete abandoned, as in the case of Karez Noth, the larger farmers had much greater freedom from community obligations, either because of their ownership of tubewells in or around the community or their greater financial power when it came to maintenance and operation of collectively owned tubewells. Poor shareholders in a *karez* could offer labour if they could not give cash. In case of a tubewell the requirement is invariably for cash for parts, expert labour and electricity charges, which the poorer shareholders cannot offer. Furthermore, the water distribution schedules superimposed on collective tubewells from *karez* are often disrupted by power failures or lack of money to buy diesel on part of the shareholders, leading to increased conflict. In either case the communal mode of power is stressed to the limits.

The transition from *karez* to tubewell irrigation clearly impacts on the nature and mode of power relations in communities at the micro-scale. The transformation in power relations was, however, nested within the macro-scale of Balochistan, where different types of social power were converging with the micro-level transitions in social power relations detailed above. It is to discussing the role of social power in impacting the policy level in Balochistan that we now turn.

POLICY CONTEXT FOR GROUNDWATER DEVELOPMENT IN BALOCHISTAN

As mentioned above, the over-exploitation of groundwater started off as a major enterprise in the 1970s when Balochistan was connected to the national electricity grid. This modernisation policy was typical of the prevalent orthodoxy of replacing ancient indigenous practices with modern and 'scientific' structures (van Steenbergen 1997a). Even during the 1970s, some cognisance of impacts of mining on the aquifer

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existed in official circles. The first official effort at regulating groundwater extraction in Balochistan was the issuance of the Groundwater Rights Administration Ordinance (1978). The objective of the ordinance was 'to regulate the use of groundwater and to administer the rights of the various persons therein'. The law allowed for the formation of district-level committees, consisting of bureaucrats and two notables nominated by the district authorities who were mandated to grant permits for groundwater withdrawals after hearing objections from the neighboring water users. Pakistani water managers have consistently stressed development of the surface and groundwater resources along modern lines. Balochistan was no exception to this countrywide thinking (Wescoat *et al.* 2000). Keeping in view the incentives to the powerful sections of society for groundwater mining, contradictory government policies and the inability of the government to enforce its writ, it is no surprise that the law was no match to the impetus for tubewell development (van Steenberg and Oliemans 2002, IUCN 2004). Tubewell development was therefore also partially the outcome of a coupling between the compensatory power of large landowners and the differential power of the discourse of modernisation and technical advancement at the policy scale.

The 1980s saw the pumping of substantial international development aid into Balochistan against the backdrop of the war in neighbouring Afghanistan, in which Pakistan was a frontline ally of the west. The popularisation of the sustainable development paradigm in the international development community had also just begun in earnest in the same era. A sizeable portion of this aid and the attached technical assistance was in the water sector and two major initiatives for improvement of gravity flow perennial systems (including channels fed from *karez*es) were funded by The World Bank, German Bank for Reconstruction (KfW) and Kuwait Fund (Government of Balochistan (GoB) 1992, GoB, 1990). In parallel to these, some investment was made in the construction of 'delayed-action dams' for groundwater recharge (Figure 11). The groundwater over-exploitation however, continued unabated throughout this era and the above efforts were only partial and scattered responses to the issue.

Although the institutions for measuring and monitoring groundwater levels are weak in Balochistan, a decrease in the cropped area under the command of gravity flow systems can be used as a proxy indicator for reduction of flows from springs and *karez*es. A steady decline in the area irrigated by gravity flow systems was recorded from 240,000 hectares in 1970–71 to around 40,000 hectares in 1996–97 (GoB 1999).

The flat rate of electricity charge for tubewell operation and the resulting incentives for farmers to develop tubewells, however, continued all this while in Balochistan. This resulted in an average annual increase in tubewell-irrigated area in the province at the rate of 8.1 per cent per annum between 1980–2002 (GoP 2002). The highest annual growth rate (21 per cent) was recorded during 2001–2002 – the peak of drought period (GoP 2002).

Ongoing current donor-funded and government initiatives in the water and agricultural sector of Balochistan are accentuating the historic pattern of promoting unsustainable exploitation of groundwater with benefits accruing mostly to large



Figure 11. A delayed-action dam in Pishin district. Photograph Arbab Nizam.

farmers. The interviews with the stakeholders and information generated through PRAs indicate that that awareness of the alarming decline in groundwater levels and its physical causes exists at all levels. It is, however ironic that the ongoing initiatives for water development continue to follow the modernisation orthodoxy of developing even more tubewells. The Government of Balochistan with the assistance of the Asian Development Bank (ADB) initiated a project called ‘Drought Impact Mitigation and Recovery Assistance Component (DIMRAC)’ aiming to install 1,215 new tubewells in the province. In addition, under the Drought Emergency Relief Assistance (DERA), the World Bank pledged assistance for the installation of more tubewells (Emma Hooper, ADB, 2005, personal communication).

During the past forty years there has not been any notable institutional support in terms of financial or technical assistance for *karez*s, except for occasional politically-oriented doles to the supporters of myriad parliamentarians in the name of *karez* rehabilitation. This was also confirmed during the fieldwork, where the *karez* in Kunghar and in some other communities had received government patronage because of the intervention of area representatives.

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Despite the above government and donor biases, there are, however, smaller projects, which are attentive to the benefits of *karez* irrigation. Only recently, the Taraqee Foundation, a non-governmental organisation has started providing financial and technical assistance to the communities for rehabilitation of *karezes* that has led to the rejuvenation of a number of collapsed *karezes*. (Muhammad Arshad, Manager, Taraqee Foundation, 2005, personal communication)

The official apathy towards supporting the collective management of resources is also largely to blame for the erosion of communal power, replacing it with compensatory power, as discussed above. In the short run, by providing subsidies for individualised resource exploitation, the state has nurtured localised coercive power structures whereby the hitherto respectably earning peasants and small farmers have been made subservient to richer farmers, even for their domestic water needs.

The supporters of continued state subsidy for tubewells present two main arguments in their favour. First, the quintessential role of subsidy in keeping the agricultural economy of Balochistan afloat and, second, the importance of tubewells for livelihood support for the poor. The first argument implies that mining of groundwater for agriculture would not remain a profitable enterprise if the state subsidy on electricity were withdrawn. It is to be noted that the province had around 14,000 electricity-powered tubewells in 2002 that received subsidy in the form of flat monthly rates for electrical power consumption, while there were more than 11,000 diesel powered tubewells that received no support from the state (GoP 2002). Intriguingly, the diesel-operated pumps are also increasing in number with an annual growth rate of 7.5 per cent in 2001–2002 (GoP 2002), despite the ever-increasing prices of diesel. This may imply that the diesel tubewell users are either more efficient, more desperate in the absence of electricity and/or are using tubewell water to keep their fruit trees alive instead of engaging in commercial fruit and cash crop production. In either case the argument of electricity subsidy as critical to the agricultural future of Balochistan is disingenuous at best.

The second argument in favour of the subsidy for tubewell electricity consumption must be engaged with by contextualising the role of tubewells in the wider agricultural economy of Balochistan. The total cultivated area in Balochistan is 2.09 million hectares, out of which 0.98 million hectares (47 per cent) fall under the category of irrigated agriculture (GoP 2002). The remaining 53 per cent is cultivated by seasonal floods and rainfall. The flood- and rain-fed agriculture employs the poorest subsistence farmers of the province who receive minimal institutional support from the government (Lawrence and van Steenberg, 2005).

A disaggregated analysis of the 47 per cent irrigated area provides some insight into the poverty-related implications of the electricity subsidy to tubewells. Figure 12 represents the distribution of irrigated areas by irrigation technique in Balochistan. The 34 per cent area irrigated by tubewells includes both electric and diesel powered tubewells and these have been counted at 14,363 and 11,371 respectively (GoP 2002). The proportionate area irrigated by electric tubewells may be approximately 18 per cent of the total irrigated area of Balochistan, mostly concentrated in northern highlands

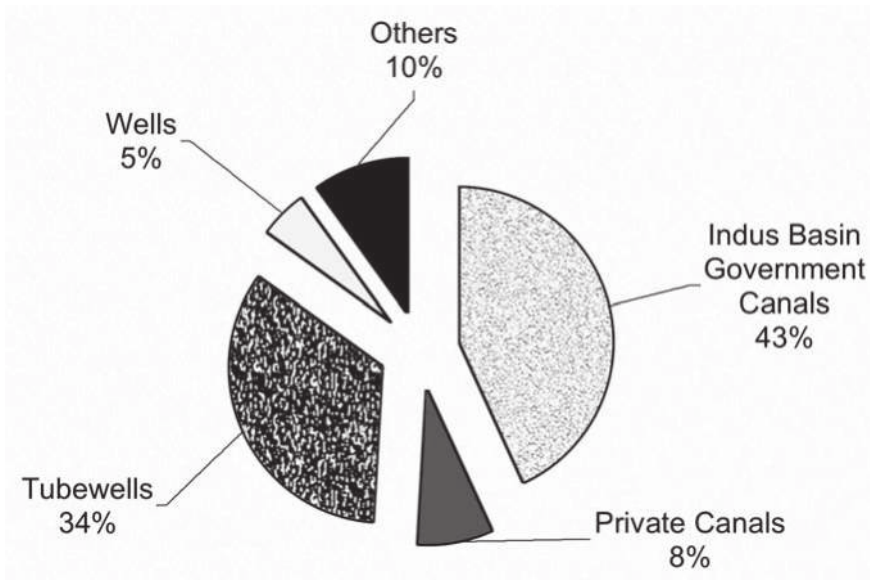


Figure 12. Percentage of irrigated land in Balochistan by irrigation technique.

and Brahvi midlands.² The same land is largely dedicated to growing high value cash crops such as deciduous fruit orchards (GoB 1999). Furthermore, only three per cent of the estimated 243,000 farms in Balochistan benefit from electric tubewells. The main point here is that only a very small minority of mostly large farmers benefit from the subsidy on tubewell electricity. Since electricity subsidy facilitates over-exploitation of groundwater and drying up of *karez*s, upon which many smaller farmers depend, the argument about electric subsidy contributing to the livelihoods of poorer farmers can be safely dismissed.

The narrative illustrates that the policy context for the transition from *karez* to tubewell irrigation is indeed defined by the coupling of the compensatory power of the large farmers and the differential power of the modernisation discourse in water resource management. The micro-level communal knowledge-based power is ironically undermined by the convergence of the knowledge-based power of the policymakers and the compensatory power of the large farmers.

2. This is of course making a rather problematic assumption that a diesel and an electric tubewell unit irrigates the same amount of land. The final number is not as important as illustrating that tubewell is not a dominant mode of irrigation in Balochistan.

CONCLUSION: POLICY OPTIONS FOR SUSTAINABLE GROUNDWATER DEVELOPMENT

The micro- and meso- level pictures of groundwater development and management in Balochistan presented in this paper point to important social, economic and environmental implications for the highlands of Balochistan. The core insights to be gleaned from the above evidence are that (1) replacement of *karez* with tubewell irrigation is not an outcome of a natural evolution or development in groundwater technology in the province but rather largely a consequence of conscious policy decisions; (2) replacement of *karez* with tubewell is leading to negative outcomes in terms of social equity and environmental quality; and (3) the transition from *karez* to tubewell is leading to a realignment of social power relations from a historically collective communal mode of power to the ascendancy of the compensatory mode of power of the large farmers. Each of the above insights has important and largely negative implications for long-term ecologically and socially sustainable development in Balochistan.

In light of the above we would suggest some of the following initiatives as part of any future policy initiatives directed towards preserving and restoring the role of the *karez* system in the social and ecological context of Balochistan. First, the bias of 'newer is better' – what we also call the differential power of the modernisation discourse in water management – will have to be confronted and reversed among the decision-makers in Balochistan. Part of the reason for the bias is the dominance of technically trained engineers and bureaucrats in the water policy domain in Balochistan. Many of these decision makers, because of their monochromatic technical view of the water problems in Balochistan, tend to lose sight of the wider social, economic and cultural aspects of water management. Greater inclusion of cross-disciplinary perspectives in water policy formulation will go a long way towards redressing the technological and modernising bias in groundwater policy.

Secondly, along the same lines as above, recognition of social power as a factor in water resource management is critical. The prospective realignment of social power relations, as a result of technological and management transitions is a little-understood aspect of water management. The transition from communal to compensatory modes of power in the water communities of Balochistan is a particularly worrisome trend with important consequences for equity and social cohesion in the water communities.

Thirdly, some very low cost measures along the lines of knowledge generation and institutional innovation could go a long way towards reversing the fortunes of the *karez* system in highland Balochistan. The *karez* communities are in need of capital investment as well as some technical improvements in the original *karez* design to make the periodic maintenance easier as well as lessening the need for it. Outside of *karez* communities there is an absence of technical knowledge regarding *karezes*. Some rudimentary research has been done, as documented by Kahlown and Hamilton (1994) but a lot more attention needs to be directed to the civil engineering, water quality and hydrological aspects of *karez* construction and management. Furthermore, groundwater mapping exercises and dissemination of the results of the exercises will be very useful in

informing *karez* operations, future *karez* construction and alignment, as well as future tubewell installation and regulation.

Karez water, as mentioned above, is divided up into 24-hour cycles called *shabannas*. A community may have anywhere between seven and thirty *shabannas* divided up between the water users on a *karez*. There are already well-developed water markets for these *shabannas* in every community in Balochistan. A governmental or non-governmental entity could insert itself into these water markets either by buying a *shabanna* or two, and seasonally auctioning them to *karez* shareholders. From the income derived from the auction of the water share, the outside entity could fund technical assistance as well as loans for *karez* maintenance. This would also allow the entity to actually have a stake and accountability to the *karez* shareholders because the price of the water share is directly proportional to the potential productivity to be derived from the *karez*. Consequently, it will be in the interest of the outside entity to ensure smooth functioning of the *karez* in collaboration with the local communities to derive maximum income from its water share. The intent of engaging an outside entity in this case is to pull the *karez* system into the knowledge-based epistemic communities of engineers, policymakers and technocrats, operating at the provincial, federal and international scales. As mentioned earlier, since the differential power of the modernising discourse was partially to blame for the fortunes of the *karez* system, giving a stake in the future of the system to outside meso- and macro-scale power holders will be the best guarantee of its sustainability.

The above set of proposals will have to be coupled with water demand management to ensure judicious use of the scarce groundwater resources. Agricultural extension services in Balochistan will have to redefine their priorities from production maximisation to building resilience and long-term productivity. In that vein they must be encouraged to promote water-efficient crops with local farmers.

Last but not least, all of the above is contingent upon removing the policy distortion of subsidised electricity for tubewell operation in Balochistan. Everybody is mindful of the impact that flat-rate electricity is having on over-exploitation of groundwater to benefit a minority of large farmers. The government will have to find the political will to remove the subsidy on tubewell electricity for the future of Balochistan.

Phasing out of *karez*es and their replacement with the 'modern' tubewell technology is neither desirable nor inevitable and it is certainly not an outcome of the inexorable process of 'development'. Development is not some naturalistic biological phenomenon. It is a human-directed phenomenon and, hence, human ideologies and choices bear upon its consequences. Local communities and even the policymakers are quite aware of the utility and relevance of the *karez* system to the human ecology of Balochistan. Given the public support that the *karez* system enjoys and its social and economic utility for communities in Balochistan, it is something that can and should be protected and even rehabilitated. Pakistan, and the province of Balochistan, will have to find an appropriate balance between the old and the new. The *karez* system has sustained community life, economic wellbeing and ecological balance in Balochistan

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for millennia. It would be a travesty to throw away a rich legacy for an uncertain future with modernity.

ACKNOWLEDGMENTS

Field research for this article was funded by the National Geographic Society: Committee on Research and Exploration grant no: 7663-04. The fieldwork would not have been possible without the efforts and perseverance of Abdul Hameed, Aftab Aziz, Arbab Nizam, Essa Khan, Kausar Parveen, and Naz Gul. Above all we must thank the community members who cooperated with us during the course of the research and allowed us to participate briefly in their lives.

REFERENCES

- Ali, Imran (1988). *The Punjab under Imperialism, 1885–1947*. Princeton, NJ: Princeton University Press.
- Akram-Lodhi, A. H. (2001). 'Like an act of God': land, water and social power in northern Pakistan'. *Contemporary South Asia* 10 (3): 319–342.
- Beaumont, P. (1968). 'Qanats on the Varamin Plain, Iran'. *Transactions of the Institute of British Geographers* 45: 169–179.
- Beaumont, P., M. Bonin and K. McLachlan (1989). *Qanat, Kariz and Kheftara*. Wisbech: Menas Press.
- Budds, J. (2004). 'Power, nature and neoliberalism: The political ecology of water in Chile'. *Singapore Journal of Tropical Geography* 25 (3): 322–342.
- Chilton, J., F. Cardy, M. Schiffler, M. Moench and S. Foster (2000). *Groundwater in Rural Development: Facing the Challenges of Supply and Resource Sustainability*. Washington DC, The World Bank.
- Gilmartin, D. (1994). 'Scientific empire and imperial science: colonialism and irrigation in the Indus Basin'. *The Journal of Asian Studies* 53 (4): 1127–1149.
- Government of Balochistan (1990). PC-3 for Irrigation System Rehabilitation Project (Kuwait Fund). Quetta, Pakistan.
- Government of Balochistan (1992). PC-2 for Balochistan Minor Irrigation and Agricultural Development Project (Phase-II). Quetta, Pakistan.
- Government of Balochistan (1999) *Agricultural Statistics of Balochistan*. Quetta, Pakistan: Directorate General of Agriculture.
- Government of Pakistan (2002). *Agricultural Statistics of Pakistan*. Islamabad, Pakistan: Agricultural Census Organization of Pakistan.
- IUCN–The World Conservation Union (2004). CLEA Regional Conference 2004: 'Legal education in developing and under-developed countries to meet the challenges of 21st century'. <http://www.iucn.org/places/pakistan/news/002May04.htm> Accessed 27 September 2005.

- Kahlown, M. Akram and J.R. Hamilton (1994). 'Status and prospects of Karez Irrigation'. *Water Resources Bulletin* 30 (1): 125–134.
- Kemper, W. D., Mazher-ul-Haq and A. Saeed (1979). *Farm Water Management in Upland Areas of Balochistan*. Fort Collins, CO: Engineering Research Center, Colorado State University.
- Lawrence, P. and F. van Steenbergen (2005). *Improving Spate Irrigation*. Oxford: HR Wallingford.
- Lightfoot, D. R. (1996a). 'Moroccan Kheffara: traditional irrigation and progressive desiccation'. *Geoforum* 27 (2): 261–273.
- Lightfoot, D. R. (1996b). 'Syrian qanat Romani: history, ecology, abandonment'. *Journal of Arid Environments* 33: 321–336.
- Mustafa, D. (2001). 'Colonial law, contemporary water issues in Pakistan'. *Political Geography* 20: 817–837.
- Mustafa, D. (2002a). 'To each according to his power? Access to irrigation water and vulnerability to flood hazard in Pakistan'. *Environment and Planning D: Society and Space*. 20 (6): 737–752.
- Mustafa, D. (2002b). 'Linking Access and Vulnerability: Perceptions of Irrigation and Flood Management in Pakistan'. *Professional Geographer* 54 (1): 94–105.
- Peet, R. and M. Watts (eds.) (1996). *Liberation Ecologies: Environment, Development, Social Movements*. London: Routledge.
- Peet, Richard and Michael Watts (eds.) (2004). *Liberation Ecologies: Environment, Development, Social Movements*. 2nd Edition.
- Rehman, M. (1981). 'Ecology of karez irrigation: a case for Pakistan'. *GeoJournal* 5 (1): 7–15.
- Robbins, P. (2000). 'The practical politics of knowing: state environmental knowledge and local political economy'. *Economic Geography* 76 (2): 126–144.
- Swyngedouw, E. (1997). 'Power, nature and the city. The conquest of water and the political ecology of urbanization in Guayaquil, Ecuador: 1880–1990'. *Environment and Planning A* 29 (2): 311–32.
- Swyngedouw, E. (1999). 'Modernity and hybridity: nature, regeneracionismo, and the production of the Spanish waterscape, 1890–1930'. *Annals of the Association of American Geographers* 89: 443–65.
- van Steenbergen, Frank (1995). 'The frontier problem in incipient groundwater management regimes in Balochistan (Pakistan)'. *Human Ecology* 23 (1): 53–74.
- van Steenbergen, Frank (1997). 'Understanding the sociology of spate irrigation: cases from Balochistan'. *Journal of Arid Environments* 35: 349–365.
- van Steenbergen, Frank (1997a). *Institutional change in local water resource management: cases from Balochistan*. Utrecht, The Netherlands: Netherlands Geographical Studies, 220.
- van Steenbergen, F. and W. Oliemans (2002). 'A review of policies in groundwater management in Pakistan 1950–2000'. *Water Policy* 4 (4): 323–344.
- Van Steenbergen, F. and T. Shah (2002). 'Rules rather than rights: Self-regulation in intensively used groundwater systems', in R. Llamas and E. Custodio (eds.) *Intensive Use of Groundwater: Challenges and Opportunities*. Brookfield, VT: A.A. Balkema. pp. 241–256.

Karez versus Tubewell Irrigation

- Vander Velde, E. J. and M. Svendsen (1994). 'Goals and objectives of irrigation in Pakistan: a prelude to assessing irrigation performance'. *Quarterly Journal of International Agriculture* 33 (3): 222–242.
- WAPDA (1992). *Uncontrolled Mining of Groundwater in Balochistan and Possible Remedial Measures*. Quetta, Pakistan: WAPDA Hydrogeology Project.
- Wescoat, J. L. Jr., S. Halvorson and D. Mustafa (2000). 'Water management in the Indus Basin of Pakistan: A half-century perspective'. *International Journal of Water Resources Development* 16 (3): 391–406.
- Wisner, B. (1993). 'Disaster vulnerability: scale, power, and daily life'. *Geojournal* 30 (2): 127–140.
- Wittfogel, K.A. (1955). 'The hydraulic civilization', in W.L. Thomas, C. O. Sauer, M. Bates and L. Mumford (eds.) *Man's Role in Changing the Face of the Earth*. Chicago, IL: University of Chicago Press. pp. 152–164.
- Wittfogel, K.A. (1957). *Oriental Despotism; a Comparative Study of Total Power*. New Haven, CT: Yale University Press.

LIVING OFF UNCERTAINTY: THE INTELLIGENT ANIMAL PRODUCTION OF DRYLAND PASTORALISTS

Saverio Krätli and Nikolaus Schareika

INTRODUCTION

That the definition of pastoralism has always been problematic is a matter that should perhaps have received closer attention as the signal of a fundamental misfit between pastoralists' actual practices and the system of reference used for their analysis. The understanding of pastoralism as an economic activity has paid little attention to the most specialised producers – those who are scattered and mobile, difficult and expensive to locate, reach, follow and keep in touch with. Instead, efforts to understand and improve 'pastoralism' have concentrated on the least specialised conditions, often on people in economic difficulty, who appeared more easily interested in a Western approach to animal production. The consequences of this legacy can hardly be overestimated. After substantial advancement in the study of rangeland ecology, descriptions of pastoralism remain characterised by narratives of deficit: resource scarcity, difficulty in adapting, struggle against droughts, diseases and insecurity. These narratives still shape the perspectives of development and policy-making as well as much of academic discourse. An alternative focus on the most specialized and successful dryland producers, leads to a different understanding of pastoralism, calling for a reconsideration of deficit narratives and the principles behind them.

A recent challenge to equilibrium models in financial economics – from a mathematical perspective – questions the utility of analytical tools based on average values when dealing with conditions of unpredictable variability. The argument is plain and fundamental enough to have wider applicability: the 'bell-curve' models of standard statistics (Gaussian models) assume that the largest possible values in the series under analysis are either so rare as to be negligible or not too far away from the average. However, when the most likely breakdown of an average is 'asymmetric' – as in the case of systems characterised by non-uniform distribution – average values cease to be meaningful simplifications and become highly misleading. Average values are therefore inadequate to represent the behaviour of systems characterised by asymmetric

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(non-uniform), distribution (Mandelbrot and Hudson 2004; a more popularised form of this argument is in Mandelbrot and Taleb 2006; and Taleb 2007). In this paper we argue that specialist dryland pastoralists produce by exploiting non-uniform distribution – in the form of what we call the ‘intelligent’ harvesting of unstable concentrations of nutrients on the range.

We make this general point on the basis of the literature and of primary data from our respective research on the production/breeding system controlled by the nomadic Wodaabe¹ of Niger, a substantial part of which has been published. While concentrating on this particular example of dryland pastoralism, we are aware that this approach has its limitations. The term ‘pastoralism’ represents a large spectrum of realities and we do not claim to embrace them all in our description. Nevertheless, the extreme operating conditions and high levels of specialisation of the Wodaabe present a magnified view of a way of using livestock and environment for production that is meaningful throughout the entire spectrum, if not always as obvious and crucial.² Our contribution to generality therefore consists in offering such a view as a point of reference for the analysis of dryland pastoralism as a system of animal production.

Within this perspective, although we describe what actual pastoralists do in real life, we only highlight the aspects of the pastoral system that, as we argue, are key for production. We refer to the key role played by mobility in enhancing production but we are aware that there are also other types of pastoral mobility not equally related to production (Schareika 2003b, Krätli 2008a, IIED and SOS Sahel 2009). Similarly, we do not claim that the ‘intelligent’ harvesting of unstable concentrations of nutrients on the range explains all the dimensions of pastoral livelihood. Not all what we describe necessarily takes place always in the most functional way throughout the lifecycle of every herding household. Pastoralists, like anybody else, operate within complex social and political systems: insecurity, poverty, access to services, markets, social capital or development resources all influence decisions about production. However, when dryland pastoralists are successful producers they do so by exploiting asymmetric distribution, not stability and uniformity.

On the other hand, average values and models of standard statistics designed to seek out stability and uniformity as the underlying condition for capturing economies of scale, are fundamental to all dimensions of pastoral development, from natural resource management to service provision. Conventional models of animal production

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1. Implosive consonants characteristic of the Fulfulde language are conventionally given as upper case letters. For the sake of readability we have not applied this rule to the spelling of the frequently used name ‘Wodaabe’, which should be read as ‘WoDaaBe’.
 2. There is a great variety of agro-pastoral systems where peak animal performance achieved though extreme mobility is traded in for the opportunity of growing field crops. In relatively good years, the generally smaller productivity of the herd (e.g. Amanor 1995) is balanced by the fact that no or few animals have to be sold for buying food. Prolonged droughts or increased environmental unpredictability would rapidly and dramatically turn the trade-off in favour of more specialised pastoralists.

also rely on a standardised environment.³ Production in dryland pastoralism might therefore be at odds with some of the most basic items in the tool bags of both pastoral development planners and policy makers.

It is almost three decades since Sandford (1983) problematised the ecological paradigm in pastoral development and Ellis and Swift (1988) suggested that pastoral ecosystems are better understood as driven by stochastic events rather than homeostatic mechanisms. Both works pointed out that pastoral development solutions that were considered self-evident were indeed dependent on a particular analytical model of ecological systems. From the new perspective, as formalised by Behnke and Scoones (1993):

The producer's strategy within non-equilibrium systems is to move livestock sequentially across a series of environments ... *exploiting optimal periods in each area they use* ... Herd management must aim at responding to alternate periods of high and low productivity, with an emphasis on exploiting environmental heterogeneity *rather than attempting to manipulate the environment to maximise stability and uniformity* (Behnke and Scoones 1993, pp. 14–15, emphasis added).

Although this perspective combined an ecological dimension with an economic one, it was mainly the former that captured the attention. Current resource-scarcity models of dryland environments, and implicitly the explanation of pastoral mobility as a 'coping strategy', still frame unpredictable ecological variability as unfavourable to production: environmental variability is a fundamental problem that pastoralists 'solve' by moving. The current wave of claims on the increasing vulnerability of pastoralism in the face of global climate change (presumed to increase environmental variability) goes unchallenged on the basis of this assumption.⁴ Deficit views of dryland environments (ultimately as lacking stability and uniformity) imply that agricultural production systems must rely upon uniformity and stability. Even when these views accept that unpredictable variability is structural to dryland ecology, they still represent it as a disturbance as far as the economic dimension is concerned (i.e. animal production), be it a problem to 'cope' with or a risk to be avoided.⁵

We focus on the economic side of Behnke and Scoones's argument and follow up on its implication that environmental heterogeneity – or the 'asymmetric distribution' (in Mandelbrot's terminology) of nutrients on the range – is what dryland

3. Whilst we back up this generalisation with regard to the models that appear to inform policy-making and mainstream pastoral development thinking, we acknowledge the important exception of a substantial strand of research on rangeland heterogeneity using the stratification of multiscale diversity in fodder resources and the effort to develop models based on livestock feeding behaviour (Boudet 1979 and 1984, Breman and de Ridder 1991, Hiernaux *et al.* 1994; Tongway *et al.* 2001, Hiernaux *et al.* 2009, Ayantunde *et al.* 2009). We are grateful to Pierre Hiernaux for drawing our attention to this work.
4. For example, most of the papers presented at the conference 'Pastoralism and Climate Change Adaptation in Africa', 25–28 May 2010, Egerton University, Kenya (<http://www.ccaa.iccamnet.org/index.html>).
5. On the survival and adaptation of risk-aversion heuristics even within pro-mobility perspectives in pastoral development, see Roe *et al.* (1998).

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pastoralists rely upon for production. We look at how pastoralists produce, including human–environment interaction and, crucially, human–animal interaction in herd management. We see two advantages in this approach: firstly, it shifts the focus away from the many problematic implications of using ecology and natural adaptation as the key explanatory framework for pastoralism; secondly it avoids the difficulties associated with defining ecosystems as equilibrium or non-equilibrium⁶ as a preliminary step to understand pastoralism.⁷

The paper starts from an overview of the key literature, presents the empirical evidence and concludes by spelling out the crucial implications for pastoral development planning. Given our transdisciplinary perspective, our use of the literature is necessarily limited to the most strictly relevant works.

WHEN UNIFORM DISTRIBUTION CANNOT BE RELIED UPON

As is well known, dryland pasture exhibits a characteristically patchy growth pattern, which, however, represents only the most macroscopic form of heterogeneity. The asymmetric distribution of nutrients applies to a whole range of scales: between ecological zones, swards, plant species, plants of the same species and even parts of the same plant. Nutrient content also accumulates and then decreases throughout the plant's life cycle (Breman and de Wit 1983, Alimaev 2003) and, on a smaller scale, within the 24-hour cycle (Kim 1995, Orr *et al.* 1998, Mayland 2000). Unpredictable precipitation in the drylands can 'start' a plant at any time of the 'rainy season', whilst the arrival of the dry season can 'stop' it at any stage of development – therefore at different levels of nutritional value.

Despite the effort of several range ecologists to quantify both spatial and temporal heterogeneity of nutrient distribution and advocate its use in animal nutrition (see note 3), unpredictable environmental variability in the drylands is still commonly seen as an obstacle to pastoral production (see note 4). Roe *et al.* (1998), by contrast, have described pastoralism as a high reliability system, hence as a *sui generis* system of production, 'native' to structurally unpredictable environments and operating not by avoiding risk but by harnessing it as the very base of production. This line of thinking, which we will follow closely, invites us to conceptualise nomadic pastoralism as geared towards the exploitation of asymmetric distribution (which is prevalent), rather than seeking uniformity and stability (which is exceptional). In other words, the unstable heterogeneity of dryland environment is not an obstacle to pastoralists: it is what they

6. See Sullivan and Rohde (2002) for an excellent analysis of this issue and Vetter (2005) for a review of the debate.

7. The understanding of pastoralism through ecological lenses is so deeply entrenched in the history of pastoral development that it proves very difficult for operators not to drift back into old habits even when acknowledging the relevance of the paradigm shift introduced by the 'new range ecology' (see Hogg 1997). This is even more important today as concerns about climate change are granting new authority to ecological heuristics of pastoralism (old and new orthodoxy).

produce with. As we will see, this is done by systematically targeting and intelligently harvesting the transient concentrations of nutrients on the range.

This implies that pastoralists or, better, their herds, should be versed in the 'art' of feeding selectively. Strands of animal nutrition science specialising in tropical and subtropical regions have for a long time grappled with issues of grazing dynamics and feeding selectivity. Periodic waves of dissatisfaction with the conventional heuristics of the discipline when applied to these issues have yet to develop into a systematic challenge. For example, an early review highlights the link between heterogeneity of tropical pastures and feeding selectivity and concludes that 'the ultimate test of any index of the nutritional value of herbage is in its relationship to animal performance' (Stobbs 1975: 148). Twenty years later, the cutting-edge had not moved much further:

grazing ruminants select a higher quality diet from Sahelian rangelands than can be predicted on the basis of pasture evaluation alone. Therefore, the foraging behaviour of the animals needs to be considered in the evaluation of Sahelian rangelands for animal production. (Ayantunde *et al.* 1999: 261).

When the counterintuitive opportunities offered by non-uniform distribution of nutrients in the drylands are spelled out, this is done with uneasiness and often with an attempt to wrap it up in the familiar perspective: '*Although problematic*, spatial and temporal variability *paradoxically* allows animals to successfully exploit unpredictable and *low quality* rangeland environments' (O'Reagain and Schwartz 1995, p. 16; italics added). Scholars writing on these issues as recently as 2005 point out that

Little progress was made on the grazing ecology of tropical and sub-tropical pastures during the 1980's and 1990's, and it became generally accepted that tropical pastures only produced stemmy, low density, poor quality herbage, suitable only for low levels of animal performance ... This seems a rather simplistic generalisation of a complex problem. ... The tropical/sub-tropical environment is unique, requiring creative and site-specific solutions to overcome production constraints in order to realize its potential. (Da Silva and Carvalho 2005, pp. 4, 11).

Whilst these studies openly recognise the instability and non uniform-distribution of nutrients on the tropical range, they tend to treat feeding selectivity itself as a stable and uniform feature in ruminants, a standard response (or set of responses) triggered by different sward conditions.

Research on ruminants' feeding behaviour from an applied ethology perspective challenges the determinism of equilibrial models like the optimal foraging theory and finds that selective feeding is inextricably entangled with cognitive variables (Provenza and Balph 1987, Launchbaugh *et al.* 1999b, Provenza 2003).⁸ Selectivity is neither stable nor uniformly distributed within species. The efficiency of competent feeders

8. Provenza and Cincotta (1993, p. 78), pointed out that: 'Functional models (e.g. optimal foraging theory), ... do not ... explain empirical observations such as why: 1. individuals within species select different kinds and amounts of forages ...; 2. wild and domesticated herbivores over-ingest plants that contain toxins ...; 3. herbivores do not necessarily select foods of the richest nutritional quality (e.g. most energy-rich foods) when given a choice.'

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can be enhanced by its combination with other skills – for example, experience in managing thermal stress (Brewer 2005) – or jeopardised by external factors leading to distraction, fatigue or stress – for example, antagonistic behaviour from conspecifics, fear or traumatic events in handling, noise or smells on the range (Rushen *et al.* 1997; Seabrook 1972, Waiblinger *et al.* 2002, cf. for a general overview Waiblinger *et al.* 2006). A robust strand of experimental research shows that sheep, goats and cattle can be trained to feed selectively on certain plants or according to desired patterns.⁹

When the harvesting of non-uniformly distributed nutrients by non uniformly distributed selective feeding patterns is analysed with the standard models designed to highlight stability and uniformity, problems arise:

models predicting intake and animal performance ... based on averages ... do not cope with the structural, spatial and temporal heterogeneous nature of forage production [nor] with constraints to intake as influenced by the 'state' or physiological condition of the animal. (Hardy *et al.* 1997, p. 49).¹⁰

EXPLOITING ASYMMETRIC DISTRIBUTION

In this section we substantiate our claims, mainly with reference to the production and breeding system of the Wodaabe herders in Niger. We only touch upon those aspects of the system that are critical to our argument. The Wodaabe are a Fulfulde-speaking group of extremely mobile pastoralists found in the arid savannah zones of Niger, Nigeria and Chad. They are well known in the ethnographic literature for their lineage-based social organisation, their secluded and scattered style of life in the bush and their outstanding knowledge in the raising of their mahogany, long-horned Bororo zebu (Stenning 1959, Dupire 1962 and 1970, Bonfiglioli 1981 and 1988, Schareika *et al.* 2000, Schareika 2001, 2003a/b, 2007 and 2010, Krätli 2007 and 2008a).

Systematic targeting: the production strategy

Wodaabe dryland pastoralism cannot simply be interpreted as a coping strategy for 'harsh' and 'marginal' environments. There are, of course, important elements of coping (and indeed instances of failure to cope) in Wodaabe pastoral life but this must not distract from the fact that the Wodaabe production system is basically proactive, methodical and geared at value creation and maximisation, rather than mere survival.

The Wodaabe clearly express their production goal as maximising cattle reproduction: getting cows ready for mating (*nagge ho'osina*) and this with as short calving

9. For example Banner (2008). Dozens of studies and applications of this kind have been carried out by the research and outreach program of the School of Range Management at the Utah State University (<http://www.behave.net/projects/index.html>).

10. Current work in tropical animal nutrition openly acknowledges the inadequacy of the 'traditional and simplistic view of production, in which control of the grazing process is made by means of fixed stocking rates, herbage allowances, grazing intervals and grazing methods'. (Da Silva and Carvalho 2005, p. 11).

intervals as possible. The Wodaabe state equally clearly that this goal is to be achieved by a system of methodical animal nutrition that optimises the animals' metabolism on the one hand and provides them with high quality fodder resources that are selected at each point of the yearly cycle according to a long-term programme of weight building. The concern for improving animal nutrition (hence maximising weight building and animal performance) is deeply embedded in the Wodaabe social and economic organisation of herding. They critically question each pastoral decision by the maxim 'look for the better' (*raara to Buri*). Besides, they constantly compare the performance of various herds and engage in a conventionalised competition of evaluating and praising different herders' pastoral choices (*mbeefi*). The Wodaabe do not bother with the attainment of 'optimal' production targets; rather they exhibit a context-specific understanding of herd performance, where the measure of success is relative to competing fellow herds and where the limit of success is open to continuous experimentation in 'search of the better'. Nomadic movement, therefore, is not only the means by which drylands' unstable heterogeneity is put to use; it is also the experimental framework for the evaluation of the feeding value of that heterogeneity.¹¹

It is important for our argument to underline the Wodaabe's proactive stance of maximising feeding quality through nomadic movement rather than just bringing their cattle to where the pasture is. When they say, 'there is no grass' (*geene ngalaa*), this should not be taken literally. Grass can be plentiful but not the grass that optimises the metabolism of their cattle. The Wodaabe generally move in order to reach better feeding conditions (*geene Buri toon* – 'grass over there is better'). The evaluation of fodder quality rests on two sources of knowledge. Firstly, on a permanent inspection of the animals' condition by the individual herder. The animals' coat, shape, respiration, behaviour, the colour and consistency of their faeces as well as milk yield and taste signal a healthy metabolism and the prospect of increase in weight. Any dissatisfaction in this regard immediately leads to herd and family moving to another place.¹²

11. To avoid misunderstanding, we wish to underline the fact that pastoral mobility is not entirely explained by the ecological aspects of raising animals in arid environments. Research on the Wodaabe (Bonfiglioli 1988, Schareika 2003b, Stenning 1959) substantiates the abundant literature on the social and political motivation of nomadic movement (e.g. Gulliver 1975, Burnham 1979). Our descriptions of nomadic movement, however, are no ideal types. They are based on detailed observation of Wodaabe real-world behaviour. We would also like to remark that social and ecological considerations in nomadic decision-making do not simply correspond to different choices of movement. Within a general choice of movement that aims to avoid, say, requests for taxpaying there will be room for further choices that target optimising animal nutrition.
12. Herders are well aware of the energy costs of mobility. When the animals are weak, at the end of the dry season, the returns expected from improved nutrition through mobility are carefully balanced against these costs. Even so, whenever possible, the herders invest in feed (bought with money from the sale of livestock), in order to give their animals the strength to move to better quality pasture. That mobility is part of a broader strategy of reliable production is also evident from the fact that herders discuss at length the danger of getting 'locked' into areas of dry season pastures that, if initially attractive, might remain isolated and therefore hinder or even prevent further movement.

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Secondly, appraisal of fodder quality rests on a sophisticated cultural knowledge system that facilitates prediction of what is good or bad for cattle.

As far as production is concerned, the herders decide their movements according to two general indicators: the presence of green matter and the nature of the soil. Fresh green matter (*kessum*) is seen to feed better than dry matter (*jo'oruDum*). In order to provide their cattle with green fodder for as long a period of the year as possible, the Wodaabe herders exploit regional variation of the starting and ending points of the vegetative growth cycle of grass. In eastern Niger, for example, they move in a long seasonal migration towards sandy soil areas that lie west of their habitual grazing zone in the argillaceous plains of Lake Chad. There, grass (particularly *Cenchrus biflorus*) sprouts early and quickly at the beginning of the rainy season when it is critical for the animals to quickly begin feeding on a more nutritious diet. Only later on, when the rains are well established, do the herders move to clayey soil that stores water more efficiently and hence produces more green grass and herbs even when the sandy-dune areas have already dried out.

The Wodaabe recognize the importance of soil quality to their cattle's wellbeing. Through the notion of 'power' (*mbaawu*), they describe and explain the fact that soils differ with respect to the nutritional value they generally produce in plants. Clayey soils are said to have more power than sandy soils because they contain valuable salts (*lamDam*). Where they are available, as in eastern Niger, they are generally preferred (except, as aforementioned, during the early dry season). A detailed analysis of the vegetative cycle of grass is very important to Wodaabe herding decisions. They value grass that has 'escaped', as they say, from the ground, so that cattle can take it in without sand (which can be fatal), but that has not yet reached the stage of 'ear emergence', since it is in that period of their development that many grass species give the best feeding result. By moving to sandy-dune areas in the early rainy season, Wodaabe herders realise the practical potential of this analysis. On sandy soil, grass (particularly *Cenchrus biflorus*) sprouts earlier within the rainy season and faster after each rain shower. The nomads thus turn the erratic distribution of rain and therefore grass to their advantage. As the rains vary spatially and temporarily, grass starts running through its vegetative cycle in different places at different times. Therefore, the nutrient content of grass does not peak and then go down everywhere at the same time, thus allowing extraction for a fairly short time span only. Rather, this peak is found in different places at different times; by 'following the rains' (*tokka duule*), the Wodaabe ensure that their cattle spend as much time as possible feeding on the maximum quality of grass available.

The asymmetric distribution of rain (in time, location and intensity) and the nature of the vegetative cycle of grass are exploited in yet another form. In some places the rains break off before the grass has completed its vegetative cycle. When it stops growing at the stage of tillering it remains short, carries no ear and gleams reddishly. The Wodaabe consider it fodder of supreme quality and call it *kunDeeri*. During the early dry season they explore the bush for this kind of grass and keep ready to move to get their cattle in touch with it. Although the Wodaabe, as all Sahelian people, hope for

abundant rains, they appreciate the fact that the relatively low and erratic precipitation in their pastoral zone allows the development of *kunDeeri* on the somewhat elevated argillaceous plains. They say that, generally, with too much water they get only grass that is long and therefore of poor quality (the point raised in Breman and de Wit 1983).

Herders distinguish between fodder plants according to several criteria. The most general distinction is between tree (*lekki*), herb (*leggel*), and grass (*geene*), with each category being attributed specific functions in animal nutrition. Grass is cattle's staple food (*nyaamdu*) and cannot be replaced by anything else long term. Herders distinguish, of course, between various species of grass and evaluate their suitability as feed for cattle. Soft grass with no disturbing spikes is usually sought after. The Wodaabe are aware that cattle eat more (that is the herders' goal) when they like what they feed on. Therefore the herders are always seeking to stimulate their animals' appetite by leading them to fodder that, in their experience, the herd will particularly appreciate (the herders talk about favoured fodder with reference to 'tastiness' and to how much the animals look 'at ease' when feeding on it). They prefer certain species for these characteristics and target them consistently. Moreover they enhance feeding performance by avoiding half-dry grass during the rainy season or pasture soiled or malodorous from cattle droppings. Browse from trees is considered a tasty supplement (*DahatorDum*) to the main diet of grass. The Wodaabe compare it to the sauce that accompanies the humans' main staple of millet porridge. *Salvadora persica* (*kasassi*), *Cadaba farinosa* (*karatiyyel*) and *Maerua crassifolia* (*sensen*), are described as very interesting *DahatorDum* species. The absence of such complementary trees, even in an otherwise abundant dry grass savannah, is regarded as a critical shortcoming (cf. Stobbs 1975: 144 on the need for nutritional supplements for grass).

Herbs are seen to serve various critical functions (although like trees they are not by themselves a replacement for grass). In the early rainy season herders look for leguminous herbs, notably *Zornia glochidiata* (*dengeere*) and *Alysicarpus ovalifolius* (*gadaji'irehi*). They attribute to these two herbs the quality of 'fixing' the animals after the deprivations of the dry season. The late rainy season brings a number of herbal plants such as *Indigofera hochstetteri* (*jaa'oomaahi*), to which the Wodaabe attribute good milk production and fattening the cattle. This herbal plant can help to get cattle over a period when good grass is becoming scarce. Other highly valued herbs are *Cucumis melo* (*yamBuruuwol*), *Heliotropium ovalifolium* (*yaharehi*), *Ipomoea verticillata* (*amaseekel*), *Ipomoea spec.* (*yagalawol*) and *Ipomoea spec.* (*buluuwol*).¹³

Based on a profound knowledge system, on permanent experimentation, on an imperative to look for the better and on extreme spatial mobility, the Wodaabe manage the dryland environment so as to turn its unstable heterogeneity of plant growth into a resource for their cattle. However, these cattle must be capable of making efficient and reliable usage of the opportunities offered by the herd management system. This capacity is far from being naturally given, as we show in the next section.

13. The botanist could only identify the genus, not the species.

Intelligent harvesting: breeding functional behaviour

The herders explore the range and make decisions on timing and direction of movements. However, these decisions are made on the basis of feedback from the animals: a herder's past experience of their performance in certain feeding conditions (type and combinations of fodder plants and possible disturbances), as well as present observation of changes in the animals' conditions. The efficient targeting of transient concentrations of nutrients therefore relies on human–animal interaction.

This dimension, human–animal interaction, is also critical to what we have called 'intelligent harvesting'.¹⁴ While efficient targeting involves reaching the most nutritious patches at the best time, intelligent harvesting is the capacity to leave, once on target, what fodder is unnecessary or undesirable to engage with. It is effective micro-operational aiming as opposed to low-discernment, large-scale engagement. The latter strategy, of course, is more convenient in the presence of uniform distribution of nutrients. But in the case of non-uniform distribution, a good diet is a balance between what is eaten and what is not eaten: the Wodaabe want their animals to eat only 'the right things' and leave the rest. As we know from the ethological research on feeding behaviour in ruminants, this requires a sophisticated selectivity that is not granted but must be learned and is subject to impairment by operating conditions.

A system to secure intelligent harvesting

By timing, directing and monitoring the movement of the herd on the range, the herders can engineer their animals' experience of the ecological environment in order to maximise opportunities for selective feeding and minimise disturbances. Ecological opportunities are maximised by exposing the herd to the most favourable feeding conditions for the longest possible grazing time. Minimising disturbances ensures that opportunities can be taken advantage of most efficiently.

Stress from external factors can inhibit an animal's capacity for feeding selectively and for learning to do so.¹⁵ It is therefore crucial to an animal nutrition strategy resting on intelligent harvesting that stress-triggering events be reduced to a minimum. The

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14. This concept of 'intelligent harvesting' refers to effective targeting of nutrients and carries no implication of a naturally benign influence of grazing. On the other hand, in systems geared towards exploiting small and short-lived concentrations of nutrients, the productivity of the animals increases with feeding selectivity and decreases with indiscriminate biomass intake. It follows that, at its maximum level of productivity, specialised dryland pastoralism can be expected to be inherently sustainable.
 15. Stress associated with management practices, and even with particular stockpersons, can severely abate feeding motivation and learning ability, slow down growth, interfere with reproduction, reduce the yield and quality of milk and increase the animals' susceptibility to disease (Seabrook 1972, Knierim and Waran 1993, de Hemsworth *et al.* 1996, Passillé and Rushen 1999, Lensink *et al.* 2000, Breuer *et al.* 2000, Pajor *et al.* 2000; for a recent overview, see Waiblinger *et al.* 2006). There is also evidence that stress can spread along social structures. In the presence of stressed conspecifics for example, both the heifers' feeding behaviour and their capacity for learning have been found to be inhibited (Boissy *et al.* 1999, Bouissou *et al.* 2001).

Wodaabe do this by influencing the social structure of the herd. This aim is already inbuilt in their cattle-naming system (shared across all Wodaabe clans). The Wodaabe name all newborn calves (males and females) after their mothers and manage them accordingly, leading to an organisation of the herds into matriarchal lineages, a structure that keeps dominant–subordinate relationships stable.¹⁶ Sires are castrated or marketed as soon as they start fighting. The system of the calf-rope, where the calves are attached every night always in the same relative position, habituates pairs of animals to one another. Social bonds between calves are also promoted by separating them from their dams for a few hours per day from less than a month after birth.¹⁷ The Wodaabe openly refer to preferential relationships between cattle, with the same word (*higo*), used for human friendship. Favouring social bonds within the herd works towards improving herd nutrition, as both the practice of selective feeding and the generation and transmission of feeding competence are favoured in herds with a stable and well-developed social structure.

With regard to minimising stress from human handling, the most obvious way is to be gentle. The Wodaabe herd management system is characteristically ‘soft’, preferring persuasion and habituation to coercion. Management practices are very close to patterns of social behaviour that ethologists have found amongst feral cattle. Examples of this would be leading the animals from the front as a group (when herding), rather than threatening them from the rear or disciplining an animal by hitting it on the horn (rather than the body), as another cattle would in asserting rank.¹⁸ Indeed, the Wodaabe go well beyond gentle handling, managing to turn stress itself (the propensity for it in their cattle), into a resource for production. Their exceptionally shy and alert Bororo zebus are also known for their characteristically selective attachment to their human household (the attitude called *geeti*). As a result of this combination of factors, the herds of the Wodaabe really only relax in the presence of their own herder. Increasing the *geeti* attitude within the herd (something done through both selection and particular management practices) makes the intensive human monitoring, characteristic of the

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16. The social organisation of cattle in feral conditions is based on clusters of small matriarchal families interconnected by preferential relationships between their members. Social interaction is ordered by dominant–subordinate relationships and by preferential relationships. As dominance relationships amongst adult females are very stable and long-lasting, aggressive behaviour is rare (Reinhardt and Reinhardt 1981, Lazo 1994; on African buffalo, cf. Prins 1996 and Sinclair 1977).
 17. Studies of calf–dam separation for artificial weaning with calves of 8–9 months showed that ‘such abrupt weaning seems to increase temporarily the social motivation since the weaned animal strengthens bonds with peers’. (Boissy *et al.* 2001: 90).
 18. As a way of reducing productivity losses from stress, authors writing about animal production in western settings recommend handling practices designed to imitate ‘species-specific’ behavioural patterns (Grandin 1987, Seabrook and Bartle 1992, Seabrook 1994). The affinity of this approach with aspects of cattle management amongst the Wodaabe is evident. Waiblinger *et al.* remark that the reliance on ‘species-specific’ patterns is what ‘may provide the basis for the success of Fulani herdsman in the control of cattle’. (2006: 191).

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Wodaabe animal nutrition strategy, not only possible but sought out by the animals themselves in order to calm down.¹⁹

Selection (and more generally the breeding system) is also important to securing the required feeding performance. The Wodaabe actively seek out particular morphological, physiological and cognitive features in their animals. They strictly control animal reproduction (near a hundred per cent of births) through selective mating based on memorised matrilineal genealogies (feeding competence being largely learned from the dam). The breeding system, however, is not aimed at maximising a single production factor or a particularly productive lineage. There is culling within lineages but not selection between lineages. On the contrary, there is deliberate effort to secure a variety of lineages within the herd. The breeding focus is on round performance over time, meaning a cow's capacity to thrive year after year, generating a strong line of descendants. Lineages that have shown reliable performance, thriving within the system for several herding generations (*na'i iririiji*) are considered of particular value.

The Wodaabe networks of breeders are careful to maintain the continuity of these lineages within the cattle population under their control. It is worth noting however, that these special lineages are valued because of their continuity of performance and not for reasons of purebred origins. Although *iririiji* lineages are always Bororo, they can in principle begin even with non-Bororo cows. To find *iririiji* lineages bearing names that the Wodaabe only give to cattle of different breeds – for example betraying a distant matriarch from the Azawak breed – is not uncommon. The focus on *na'i iririiji* is evidence of the Wodaabe's effort to breed for reliability in overall performance, and the key to reliable overall performance within their production strategy is intelligent harvesting. Thus, we can say that the Wodaabe ultimately breed their Bororo zebus for reliability in the complex task of intelligent harvesting.

Selective feeding patterns specific to the production system

The differences in livestock feeding patterns across pastoral production systems can be macroscopic even when they operate within the same ecological settings. The difference in feeding patterns between the Bororo herds kept by the Wodaabe and the herds of Azawak zebus kept by the Tuareg is a case in point.²⁰ The Azawak are well known for 'eating anything' unselectively whilst the Bororo (from the herds of the Wodaabe), are known to be exceptionally selective. According to both Wodaabe and Tuareg herders, while the Azawak would graze all the grass from a sward, the Bororo would

19. The propensity to selective attachment (*geeti*) is one of the most appreciated features in reproduction bulls. The *geeti* attitude is further strengthened artificially, by separating the calves from their dams for a few hours per day (the afternoon), well before weaning and socialising them into the human household through interaction with children (who water, groom and de-tick them). Boivin *et al.* (1992), note that calves' compensating drive to socialise, following calf–dam separation in weaning, can be exploited for habituating them to interact with humans.

20. This difference directly reflects the lower degree of specialisation (as cattle keepers) of the keepers of the Azawak breed, therefore confirming our description of 'intelligent harvesting' as the production strategy peculiar to specialised dryland pastoralism.

only lightly browse through it, picking the best bites.²¹ The Azawak's poor attitude to selectivity – undiscerningly docile with anybody but unattached to the herder (lack of the *geeti* attitude) and unselectively feeding on anything instead of focussing on the most nutritious parts of the range – is at the root of the Wodaabe's limited appreciation for these animals.²²

Differences in feeding patterns can be significant even between herds produced within the same breeding network. Amongst the agro-pastoralist Peul in the south of Niger, some herds of Bororo can put on weight on the rainy season pastures in the north even during the cold dry season but others cannot (despite being animals from the same breeding population, from the same villages and even from the same extended families). The herders themselves explain this phenomenon by saying that, in order to gain weight on the northern range after the dry season has started, the cattle need to be 'accustomed' to feed on it (Krätli 2008b).

Differences in feeding patterns (within shared bandwidths of functionality) are acknowledged by the herders as part of what distinguishes one lineage from another. The Wodaabe's acute awareness of the characteristics of the environment they take their animals to feed in is focussed on the nature of their animals' interaction with it. This interaction is closely and constantly monitored through a number of indicators, for example, the organoleptic properties of their milk (susceptible to changes in a cow's health and diet). Although the Wodaabe link milk production to the influence of the sire, the quality of the milk is considered specific to the matrilineal lineage.²³ The Wodaabe are profoundly aware of the link between the qualities of milk in their cattle and the animals' diet. They know for example that the consumption of certain fodder plants at a certain stage of development make the milk taste good, while others give it a bad smell, some make it thick, some frothy, some thin, etc.²⁴ All statements about differences in the quality of milk between animals (for example between the Bororo and Azawak breed or between different Bororo lineages) indicate an underlying awareness of both breed-specific and lineage-specific characteristics in diet preferences and eating behaviour. They also express an intimate link between the 'breed superior-

21. A French veterinarian, writing about the browsing habits of Bororo herds in Cameroon, noticed that 'foraging is so selective that at the end of the season the animals are in the grass up to their bellies' (Brouwers 1963, quoted in Boutrais 1995, p. 281).

22. This does not stop them from purchasing Azawak cows, when necessary, developing new Bororo lineages from them by systematically cross-breeding the females with top-quality Bororo bulls.

23. In conditions of relative prosperity, herders have been known to indulge the passion for refined milk degustation, to the point of exclusively drinking the milk of particular lineages (cf. Bocquené 1986, p. 40).

24. Cattle who have fed on certain plants are said by their herders to produce a milk with characteristic bad smells (e.g. *pottalhil*/ *Crotalaria podocarpa*), or unpleasant tastes (e.g. *gajaloll*/ *Panicum turgidum*). On the contrary, after foraging on *nyaanyataare* (*Peristrophe bicalyculata*), or *ndiriiri* (*Sporobolus festivus*), milk is known to take on a characteristic good taste. Grazing on *tuppere* (*Tribulus terrestris*), particularly after its early stage of development, makes milk watery and low in fat, whilst grazing on *nguDe-nguDeeri* (*Dactyloctenium aegyptiacum*), *saraho* (*Aristida gracilis* or *Gynandropsis gynandra*) makes it thick and rich (Bonfiglioli 1981).

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ity' granted to certain cattle lineages and their performance as feeders under Wodaabe management conditions.

Animals can be actively trained to feed on certain plants but the most reliable way of securing feeding competence within a herd is by aligning new cattle with a group of animals that are already competent, ensuring that new arrivals have plenty of opportunities to learn from 'veterans'.²⁵ The Wodaabe allocate one or more heifers to a newborn child in order to constitute the initial set of matriarchs of the child's future herd. These allocated cattle lineages remain in the herd of the father and, ideally, grow into a viable herd, inheriting from the father's herd both social structure and competence (feeding competence but also, for example, the knowledge of the territory).

To sum up, the Wodaabe production system is geared towards the tracking and exploitation of asymmetric distribution (of plant growth but not only this). Methodical exploration of the pastoral landscape by direct inspection precedes each move. The herd is moved on as soon as the next pasture area available is qualitatively better than the one they currently use (later on in the seasonal cycle, the once abandoned pasture area can again become 'first' choice in relation to others; that is why the nomads are monitoring and moving through the range constantly). Through close and constant monitoring of grazing conditions, the herders direct their animals so that they can get timely access to short-lived concentrations of nutrients through combinations of fodder species that, by experience, are known to trigger in these very animals comparatively high intake. The Wodaabe are aware that their system relies on the presence in their herds of particular sets of skills for feeding efficiently in conditions of asymmetric distribution of nutrients (what we call 'intelligent harvesting'). They are also aware that behavioural patterns functional to intelligent harvesting are substantially acquired (enough at least to make the difference between putting on weight or losing it on the same range, everything else being the same). Key aspects of their breeding system and herd management practices are functional in acquiring, fostering and preserving such patterns in the breeding population.

CONCLUSION: BEYOND PLANNING WITH AVERAGES

Using the example of Wodaabe production/breeding strategies, where a high level of specialisation makes our point particularly visible, we have argued for the specificity of dryland pastoralism as an agricultural production system that exploits asymmetric distribution rather than stability and uniformity in the environment.

25. The Gabra/Boran in Kenya train camels by providing them with cuttings when they are still very young: 'Animals will feed on what you taught them. Camel calves [for example], before they are being released with the larger herd, they are being fed at home. So when they are released to the field, they will go for the place that you taught them while they were in the enclosure. If you feed them on the other grass, they will look for that once they are released. If you feed them on leaves, they will look for leaves'. (contribution of Molu Kulu Galgalo, Kenya, The University of the Bush 23–27 March 2009, organised by DFID Democracy Growth and Peace for Pastoralists project, supported by the Oromia Pastoralists Association, Oromia State, Ethiopia.)

This argument rests on two points: 1) the analysis of relevant aspects of Wodaabe pastoral system showing how production is centred on the exploitation of asymmetric distribution; and 2) the critique of Gaussian models showing that they are inadequate to analyse phenomena characterised by asymmetric distribution. The first point is supported by our empirical data. The second point is based on the literature that highlights the limit in the applicability of Gaussian statistics (a critique from a mathematical perspective and extraneous to the debate over qualitative vs quantitative methodologies). While we draw attention to its relevance for dryland pastoralism, we limit our claim of applicability to the analysis of processes that rely upon asymmetric distribution: prosperous dryland animal production does but not all aspects of pastoral behaviour do.

The most straightforward implication of our argument is the problem of designing pastoral development solutions with analytical tools that highlight stability and uniformity (i.e. what can be least relied upon for production in the drylands) and ignore asymmetric distribution as disturbance (i.e. what can be most relied upon).

As we have seen, asymmetric distribution not only concerns the unstable concentrations of nutrients on the range but many crucial aspects of the production system itself. Herds, of course, are asymmetrically distributed across the range. Mobility is asymmetrically distributed over the year and over the longer period including a drought event. Functional performance (as a result of intelligent harvesting) is asymmetrically distributed across cattle lineages and within the breeding population, as well as over time, in the life-cycle of a herd/herder, as a result of changing composition at different stages of development or because of substantial shock-driven loss of animals through death or forced sales.

Tropical animal nutrition science has made some progress towards the understanding of animal–environment interaction with regard to selective feeding, but fundamental aspects of the production system remain beyond the horizon of pastoral development. These include short- and long-term human–animal interaction as well as the economic role of man-made selective feeding patterns, especially the broader combinations of functionalities behind what we call ‘intelligent harvesting’. Analytical models relying on uniformity and stability are dominant in so many academic and administrative contexts that it is difficult even to find a cognitive space for accommodating a reality that escapes their power of representation.

A framework for conceptualising models of production working with (and exploiting), non-uniform distributions has been provided by the analysis of critical infrastructures requiring high reliability (for example air traffic control or electrical grid systems). Pastoralism itself has indeed been described as a high reliability system (Roe *et al.* 1998). This approach is useful in showing that a production system does not need to work with uniformity and stability (i.e. fit an equilibrium model) in order to be ‘modern’ (be it in the sense of ‘rational’ or ‘technologically advanced’). As long as their specific requirements are respected, high reliability systems can be modern and perfectly integrated into the market economy.

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Recently, the focus of this research has shifted towards high reliability management, following new findings on the crucial role of real-time operators in securing reliability (Roe and Schulman 2008). More than the early formulation of 'high reliability pastoralism', this new focus on the management of high reliability can provide a relevant entry point towards the development of analytical and planning tools that are more in tune with the operational reality of the herders.

High reliability systems are fundamentally different and work according to different sets of rules from more familiar models that depend on stability and uniformity. They escape the standard notion of efficiency (production/cost ratio), as reliability cannot be traded for money. The familiar rationale of streamlining the system in order to make it more efficient does not apply, as reducing reliability in order to reduce costs leads to incalculable costs at the first system failure. Therefore, 'successful reliability management focuses less on safeguarding single-factor performance than on maintaining a set of key organizational processes within acceptable bandwidths' (Roe and Schulman 2008, p. 159).

As high reliability systems are largely real-time operations, they depend chiefly on management. There is a dimension of high reliability management that is critical to the system's existence and yet that unavoidably escapes design: the best design cannot account for all that makes the system work. One important consequence is that when policy-making and macro-design are extended to regulate all areas of the system (a command-and-control approach), this effectively undermines the system's capacity to work. This is most likely to be the case also for pastoralism.

The use of average values applies to most of the common loci of pastoral development, from mobility and land tenure to water management, destocking/restocking and drought early warning systems. We are not suggesting that pastoral development planners and policy makers should (or could), stop using average values and standard statistics. However, the risk of grossly misleading analysis following from the routine use of these tools is potentially very costly. For one thing, they build into any pastoral development analysis the implication that agricultural production systems must rely upon stability and uniformity. To the extent to which pastoralism does not (because instead it exploits asymmetric distribution), pastoralists are excluded from the category of producers by the analytical framework that supposedly targets them for development interventions.

It seems pertinent, therefore, to foster the awareness of this issue, recommending specific caution to those operators whose profession calls for the use of statistical tools, and raising a permanent warning flag for all pastoral development analysts. That a model for analysing dryland pastoral production as a system relying on asymmetric distribution is not yet fully developed does not make it reasonable, or acceptable, to carry on unquestioningly with the application of analytical tools designed to measure stability and uniformity.

REFERENCES

- Alimaev, I.I. (2003). 'Transhumant ecosystems: fluctuations in seasonal pasture productivity', in C. Kerven (ed.) *Prospects for Pastoralism in Kazakhstan and Turkmenistan: From State Farms to Private Flocks*. London: Routledge-Curzon.
- Amanor, K.S. (1995). 'Dynamics of herd structures and herding strategies in West Africa: a study of market integration and ecological adaptation'. *Africa* 65: 351–94.
- Ayantunde, A.A., P. Hiernaux, M. Briejer, H. Udo and R. Tabo (2009). 'Uses of local plant species by agropastoralists in south-western Niger'. *Ethnobotany Research and Applications* 7: 53–66.
- Ayantunde, A.A., P. Hiernaux, S. Fernández-Rivera, H. van Keulen and H.M.J. Udo (1999). 'Selective grazing by cattle on spatially and seasonally heterogeneous rangeland in Sahel'. *Journal of Arid Environments* 42 (4): 261–279.
- Banner, R. (2008). 'Sheep as integrated sagebrush managers'. Paper presented at the 2008 BEHAVE Annual Meeting 'Behavior-based Management: Embracing Change from Genes to Landscapes', 28–30 October, Park City, Utah.
- Behnke R.H. and I. Scoones (1993). 'Rethinking range ecology: implications for rangeland management in Africa', in R.H. Behnke, I. Scoones and C. Kerven (eds.) *Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas*. London: Overseas Development Institute.
- Bocquené, H. (1986). *Moi, Un Mbororo: Autobiographie de Oumarou Ndoudi, Peul Nomade du Cameroun*. Paris: Éditions Karthala.
- Boissy, A., R. Nowak, P. Orgeur, and I. Veissier (2001). 'Les liens sociaux chez les ruminants d'élevage: Limites et moyens d'action pour favoriser l'intégration de l'animal dans son milieu'. *Productions Animales* (INRA) 14: 79–90.
- Boissy, A., C. Terlouw and P. Le Neindre (1998). 'Presence of cues from stressed conspecifics increases reactivity to aversive events in cattle: Evidence for the existence of alarm substances in urine'. *Physiology and Behaviour* 63: 489–495.
- Boivin, X., P. Le Neindre and J.M. Chupin (1992). 'Establishment of cattle–human relationships'. *Applied Animal Behaviour Science* 32: 325–335.
- Bonfiglioli, A.M. (1988). *Dudal: Histoire de Famille et Histoire de Troupeau Chez un Groupe de Wodaabe du Niger*. Editions de la Maison des Sciences de l'Homme. Cambridge: Cambridge University Press.
- Bonfiglioli, Maliki A. (1981). 'Ngaynaaka. Herding according to the WoDaaBe'. Niger Range and Livestock Project, Discussion Paper no. 2, Tahoua: Republic of Niger, Ministry of Rural Development and USAID/Niger.
- Boudet, G. (1979). 'Quelques observations sur les fluctuations du couvert végétal sahélien au Gourma Malien et leurs conséquences pour une stratégie de gestion sylvo-pastorale'. *Bois et Forêts des Tropiques* 184: 31–44.
- Boudet, G. (1984). 'L'exploitation des parcours et la conduite des troupeaux dans les systèmes d'élevage'. *Cahiers de la Recherche Développement* 3–4: 97–101.

Living off Uncertainty

- Bouissou, M. F., A. Boissy, P. Le Neindre and I. Veissier (2001). 'The social behaviour of cattle', in L. Keeling and H. Gonyou (eds.) *Social Behaviour in Farm Animals*. Wallingford, Oxon: CAB International.
- Boutrais, J. (1995). *Hautes Terres d'Élevage au Cameroun*, 2 vols. OSTROM Éditions, Institut Français de Recherche Scientifique pour le Développement et la Coopération. Paris: Collection Etudes et Thèses.
- Breman, H. and C.T. De Wit (1983). 'Rangeland productivity and exploitation in the Sahel'. *Science, New Series* 221 (4618): 1341–1347.
- Breman, H. and N. de Ridder (1991). *Manuel sur les pâturages des pays sabéliens*. Paris: Editions Karthala.
- Breuer, K., P.H. Hemsworth, J.L. Barnett, L.R. Matthews, L.R. and G. Coleman (2000). 'Behavioural response to humans and the productivity of commercial dairy cows'. *Applied Animal Behaviour Science* 66 (4): 273–288.
- Brewer, T.K. (2005). 'Livestock grazing distribution patterns: Does animal age matter?' available at http://www.cnr.uidaho.edu/range556/App1_BEHAVE/projects/livestock_distribution.html
- Burnham, P. (1979). 'Spatial mobility and political centralization in pastoral societies', in Équipe écologie et anthropologie des sociétés pastorales (eds.) *Pastoral Production and Society*. Cambridge: Cambridge University Press. pp. 349–360.
- Da Silva, S.C. and P.C.F. Carvalho (2005). 'Foraging behaviour and herbage intake in the favourable tropics/sub-tropics'. Paper presented at the XX International Grassland Congress, 'Grassland a Global Resource'; 26 June–1 July, University College, Dublin, Ireland.
- de Passillé, A.M.B. and J. Rushen (1999). 'Are you a source of stress or comfort for your cows?' in J. Kennelly (ed.) *Advances in Dairy Technology* Vol 11: Proceedings of the 1999 Western Canadian Dairy Seminar. Edmonton: University of Alberta. pp. 347–360.
- Dupire, M. (1962). *Peuls nomades: étude descriptive des WoDaabe du Sahel Nigérien*. Travaux et Mémoires 64. Paris: Institut d'Ethnologie.
- Dupire, M. (1970). *Organisation Sociale des Peuls. Etude d'ethnographie comparée*. Paris: Livrairie Plon.
- Dyson-Hudson, N. (1958). *The Present Position of the Karimojong: A Preliminary General Survey, with Recommendations, Produced for the Government of Uganda*. Oxford: Institute of Social Anthropology, Oxford University.
- Ellis, J.E. and D.M. Swift (1988). 'Stability of African pastoral ecosystems: alternate paradigms and implications for development'. *Journal of Range Management* 41: 450–459.
- Givens, D.I., E. Owen R.F.E. Axford and H.M. Omed (eds.) (2001). *Forage Evaluation in Ruminant Nutrition*. Wallingford, UK: CAB International.
- Grandin T. (1987). 'Animal handling'. *Veterinary Clinics of North America: Food Animal Practice* 3 (2): 323–338.
- Gulliver, P.H. (1975). 'Nomadic movements: causes and implications', in T. Monod (ed.) *Pastoralism in Tropical Africa*. London: Oxford University Press. pp. 369–386.

- Hardy M.B., H.H. Meissner and P.J. O'Reagain (1997). 'Forage intake and free-Ranging ruminants: A tropical perspective', in: J.G. Buchanan-Smith, L.D. Bailey and P. McCaughey (eds.) *Proceedings of the 18th International Grassland Congress, 8–9 June 1997*. Winnipeg, Manitoba, and Saskatoon, Saskatchewan, Canada.
- Hemsworth, P. H., E.O. Price and R. Borgwardt (1996). 'Behavioural responses of domestic pigs and cattle to humans and novel stimuli'. *Applied Animal Behavior Science* 50: 43–56. Accessible at <http://www.wcds.afns.ualberta.ca/Proceedings/1999/chap30.htm>
- Hiernaux, P., M.I. Cissé, L. Diarra and P.N. De Leeuw (1994). 'Fluctuations saisonnières de la feuillaison des arbres et des buissons sahéliens. Conséquences pour la quantification des ressources fourragères'. *Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux* 47 (1): 117–125.
- Hiernaux, P., E. Mougin, L. Diarra, N. Soumaguel, F. Lavenu, Y. Tracol and M. Diawara (2009). 'Sahelian rangeland response to changes in rainfall over two decades in the Gourma region, Mali'. *Journal of Hydrology* 375: 114–127.
- Hogg, R. (ed.) (1997). *Pastoralists, Ethnicity and the State in Ethiopia*. London: Haan Publishing.
- Hughes R.N. (ed.) (1993). *Diet Selection: an Interdisciplinary Approach to Foraging Behaviour*. Oxford: Blackwell.
- IIED and SOS Sahel (2009). *Modern and Mobile. The Future of Livestock Production in Africa's Drylands*. Edited by Helen de Jode. London: International Institute for Environment and Development, and SOS Sahel International UK.
- Kim, D. (1995). 'Effect of plant maturity, cutting, growth stage, and harvesting time on forage quality'. Ph.D. Dissertation, USU, Logan, UT.
- Knierim, U. and N.K. Waran (1993). 'The influence of the human–animal interaction in the milking parlour on the behaviour, heart-rate and milk yield of dairy cows', in M. Nichelmann, H.K. Wierenga and S. Braun (eds.) *Proceedings of the International Congress on Applied Ethnology*. Berlin: Humboldt Universität, Institut für Verhaltensbiologie und Zoologie.
- Krätli, S. (2007). 'Cows who choose domestication: Generation and management of Domestic animal diversity by WoDaaBe pastoralists (Niger)'. PhD thesis, Institute of Development Studies, University of Sussex, Brighton, UK.
- Krätli, S. (2008a). 'Cattle breeding, complexity and mobility in a structurally unpredictable environment: the WoDaaBe herders of Niger'. *Nomadic Peoples* 12 (1): 11–41.
- Krätli, S. (2008b). *Future Scenario Planning with WoDaaBe Herders in Niger. Final report*. London: International Institute for Environment and Development (IIED).
- Launchbaugh K.L., J.C. Mosley and K.D. Sanders (eds.) (1999a). *Grazing Behavior in Livestock and Wildlife*. Pacific Northwest Range Short Course, Station Bulletin No. 70. Moscow, ID: University of Idaho.
- Launchbaugh, K.L., J.W. Walker and C.A. Taylor (1999b). 'Foraging behavior: experience or inheritance?' in K.L. Launchbaugh, J.C. Mosley and K.D. Sanders (eds.) *Grazing Behavior in Livestock and Wildlife*. Pacific Northwest Range Short Course, Station Bulletin No. 70. Moscow, ID: University of Idaho.

Living off Uncertainty

- Lazo, A. (1994). 'Social segregation and the maintenance of social stability in a feral cattle population'. *Animal Behaviour* 48 (5): 1133–1141.
- Lensink, J., X. Fernandez, X. Boivin, P. Pradel, P. LeNeindre and I. Veissier (2000). 'The impact of gentle contacts on ease of handling, welfare, and growth of calves and on quality of veal meat'. *Journal of Animal Science* 78: 1219–1226.
- Mandelbrot, B.B. and R.L. Hudson (2004). *The Misbehaviour of Markets: A Fractal View of Financial Turbulence: A Fractal View of Risk, Ruin, and Reward*. New York: Basic Books.
- Mandelbrot, B. and N.N. Taleb (2006). 'A focus on the exceptions that prove the rule'. *Financial Times*, 23 March 2006.
- Mayland, H.F. (2000). *Diurnal Variation in Forage Quality Affects Preference and Production*. Available at <http://www.uwex.edu/ces/forage/wfc/proceedings2000/mayland.htm>
- O'Reagain P.J. and J. Schwartz (1995). 'Dietary selection and foraging strategies of animals on rangeland. Coping with spatial and temporal variability', in M. Journet, E. Grenet, M.-H. Farce, M. Theriez and C. Demarquilly (eds.) *Recent Developments in the Nutrition of Herbivores. Proceedings of the 4th International Symposium on the Nutrition of Herbivores. Clermont-Ferrand (France), 11-15 September 1995*. Paris: Institut National de la Recherche Agronomique. Available at <http://www2.hu-berlin.de/agrar/ntoe/asia/lectures-hjs/livest-ecol/04-Lit.pdf>
- Orr, R.J., S.M. Rutter, P.D. Penning, H.H. Yarrow, L.D. Atkinson and R.A. Champion (1998). *Matching Grass Supply to Grazing Patterns for Dairy Cows under Strip-grazing Management*. Report of the Institute of Grassland Environments Research, North Wyke, Okehampton, Devon, EX20 2SB, UK.
- Pajor, E.A., J. Rushen and A.M.B. de Passillé (2000). 'Aversion learning techniques to evaluate dairy cattle handling practices'. *Applied Animal Behavior Science* 69: 89–102.
- Prins, H.H.T. (1996). *Ecology and Behaviour of the African Buffalo: Social Inequality and Decision Making*. London: Chapman & Hall.
- Provenza F.D. and R.P. Cincotta (1993). 'Foraging as a self-organizational learning process: Accepting adaptability at the expense of predictability', in R.N. Hughes (ed.) *Diet selection: an Interdisciplinary Approach to Foraging Behaviour*. London: Blackwell Science.
- Provenza, F.D. (2003). *Foraging Behavior: Managing to Survive in a World of Change*. Logan, UT: Utah State University.
- Provenza, F.D. and D.F. Balph (1987). 'Diet learning by domestic ruminants: Theory, evidence and practical implications'. *Applied Animal Behaviour Science* 18: 211–232.
- Reinhardt, V. and A. Reinhardt (1981). 'Cohesive relationships in a cattle herd (*Bos indicus*)'. *Behaviour* 77: 121–151.
- Roe, E. and P.R. Schulman (2008). *High Reliability Management: Operating on the Edge*. Stanford, CA: Stanford Business Books, Stanford University Press.
- Roe, E., L. Huntsinger and K. Labnow (1998). 'High-reliability pastoralism versus risk-averse pastoralism'. *Journal of Environment and Development* 7 (4): 387–421.
- Rushen, J., A.M. De Passillé and L. Munksgaard (1997). 'Fear of people by cows and effects on milk yield, behavior and heart rate at milking'. *Journal of Dairy Science* 80, suppl.1: 202.

- Sandford S. (1983). *Management of Pastoral Development in the Third World*. Chichester, UK: John Wiley & Sons.
- Schareika N., F. Graef, F. M. Moser and K. Becker (2000). 'Pastoral migration as a method of goal-oriented and site-specific animal nutrition among the Wodaabe of south-eastern Niger'. *Die Erde* 131: 125–41.
- Schareika, N. (2001). 'Environmental knowledge and pastoral migration among the Wodaabe of south-eastern Niger'. *Nomadic Peoples* 5: 65–88.
- Schareika, N. (2003a). *Know to Move, Move to Know: Ecological Knowledge and Herd Movement Strategies among the Wodaabe of South-eastern Niger*. Rome: FAO Inter-departmental Working Group on Biological Diversity for Food and Agriculture.
- Schareika, N. (2003b). *Westlich der Kälberleine: Nomadische Tierhaltung und naturkundliches Wissen bei den Wodaabe Südostnigers*. Berlin, Münster: Lit-Verlag.
- Schareika, N. (2007). 'Söhne des Feuers, Brüder der Milch: Politische Prozesse bei westafrikanischen Nomaden am Beispiel der Wodaabe in Südostniger'. Habilitationsschrift. Johannes Gutenberg-Universität Mainz.
- Schareika, N. (2010). 'Rituell gezeugt: Verwandtschaft als symbolische Interaktion bei den Wodaabe Südostnigers', in E. Alber, B. Beer, J. Pauli and M. Schnegg (eds.) *Verwandtschaft heute*. Berlin: Reimer.
- Seabrook, M. F. (1994). *Psychological Interaction between the Milker and the Dairy Cow Dairy Systems for the 21st Century*. St. Joseph, MI: ASAE.
- Seabrook, M.F. (1972). 'A study to determine the influence of the herdsman's personality on milk yield'. *Journal of Agricultural Labour Science* 1: 45–49.
- Seabrook, M.F. and N.C. Bartle (1992). *Farm Animal and the Environment*. Wallingford, UK: CAB International.
- Sinclair, A.R.E. (1977). *The African Buffalo: A Study in Resource Limitations of Populations*. Chicago: Chicago University Press.
- Stenning, D. (1959). *Savannah Nomads*. London: Oxford University Press.
- Stobbs, T.H. (1975). 'Factors limiting the nutritional value of grazed tropical pasture for beef and milk production'. *Tropical Grassland* 9 (2): 141–150.
- Sullivan, S. and R. Rohde (2002). 'On non-equilibrium in arid and semi-arid grazing systems'. *Journal of Biogeography* 29 (12): 1595–1618.
- Taleb, N.N. (2007). *The Black Swan: The Impact of the Highly Improbable*. London: Allen Lane, Penguin Books.
- Tongway, D.J., C. Valentin and J. Seghieri (eds.) (2001). *Banded Vegetation Patterning in Arid and Semiarid Environments. Ecological Processes and Consequences for Management*. Ecological Studies 149. New York: Springer-Verlag.
- Vetter, S. (2005). 'Rangelands at equilibrium and non-equilibrium: Recent developments in the debate'. *Journal of Arid Environments* 62: 321–341.
- Waiblinger, S., X. Boivin, V. Pedersen, M.-V. Tosi, A.M. Janczak, E.K. Visser and R.B. Jones. (2006). 'Assessing the human–animal relationship in farmed species: A critical review'. *Applied Animal Behaviour Science* 79: 195–219.

Living off Uncertainty

Waiblinger, S., C. Menke and G. Coleman (2002). 'The relationship between attitudes, personal characteristics and behaviour of stockpeople and subsequent behaviour and production of dairy cows'. *Applied Animal Behaviour Science* 79: 195–219.

AUTHENTICITY IN THE DESERT LANDSCAPES OF OMAN: THE JIDDAT-IL-HARASIIS, OMAN

Dawn Chatty

For centuries, one nomadic pastoral tribe have been the sole human inhabitants of the central desert of Oman, designated the Jiddat-il-Harasiis by the reigning sovereign in the 1930s. This remote tribe, one of six in the desert regions of the country, is organized around a subsistence economy based on the raising of camel and goat. Mobility over the vast and largely inhospitable rock and gravel plain of the Jiddat-il-Harasiis has been the principle feature of its livelihood and identity has focussed on camel transport and latterly on trucks. The authenticity of this way of life was based on a nomadic relationship with the desert, where movement of both people and herds was the core element in identity. Recent decades in the Sultanate of Oman have seen growing pressure by central government to settle the Harasiis as well as increasing competition by international conservation agencies and multi-national extractive industries with different visions of ownership and belonging regarding the landscapes of the desert. This paper examines these developments, both national and international, and explores the ways in which the Harasiis have responded to this contestation of their authenticity in national development policy as well as in the increased foreign presence and disruptions in the landscape of the Jiddat-il-Harasiis.

AUTHENTICITY IN THE DESERT

The desert-dwelling inhabitants of the Oman, organised in tribes are recognised as *bedu*, while tribes and extended families in the mountain and coastal settlements of the country are regarded as *hadar*.¹ The different landscapes associated with the *bedu* and *hadar* have important cultural and social dimensions in the understanding of human activity. Landscapes are complex phenomena encompassing physical, social and political notions of belonging. In addition to the physical features of geography, there is today a widely accepted contemporary understanding that landscapes reflect human activity and are imbued with cultural values. Landscapes combine notions of time and space as well as political and social constructs. They evolve over time, are changed through

1. The term *bedouin* is a French language derivative of the Arabic *badia*, meaning the semi-arid steppe or desert. Those who live in the *badia* are described as *bedu*.

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human activity and acquire many layers of sometimes contested meanings and versions of reality. Connections with landscapes form part of cultural and political identity; people feel they belong to certain places or regions (see Aplin 2007, Jackson 1984). People form meaningful relationships with the locales they occupy and thus transform these spaces into places. Eric Hirsch suggests that landscape in an anthropological sense has two meanings, one as a framing device used 'objectively' to bring people into view, the other as a social construct to refer to the meanings people impute to their surroundings (1995, p. 1). Furthermore as political power becomes consolidated and hegemonic in a particular stratum of society, the adage that 'possession' is nine tenths of the law is turned on its head. Here, and Oman is a case in point, the powerful few can metaphorically dispossess and impose their own vision of landscape upon sitting or authentic indigenous inhabitants.

In Oman, the divide between an urban and settled notion of human life versus a rural and nomadic has become, over time, a deeply ingrained idealisation of social categories, which are no longer clearly defined or distinguished. Furthermore, though the term *hadar/hadari* is hardly referred to any longer in Oman, the term *bedu* remains in contemporary use. For the *bedu* such self-identification is a statement of tribal identity and solidarity as well as attachment to the desert landscape, which is a physical background and social and cultural foreground. This desert is constantly shaped and reshaped by social processes and interactions with the physical environment; it is a physical space and a socio-cultural place as well as a form of ambience and a perceptual surround (Hirsch and O'Hanlon 1995, p. 23). However, when non-*bedu* use the term, particularly contemporary government officials and international civil servants, it is often a statement of contempt, highlighting the presumed backwardness, primitiveness and peripatetic quality of this social category, with no reference to the desert landscape. In general, *bedu* tribes and tribal views of events are relegated to the 'moral margins' by settled bureaucrats, government officials and international experts (Dresch 1989, p. 188).

Nationalism and identity are two concepts at the heart of the processes described above. The Sultanate of Oman had its modern 'birth' in 1970 after a 'near-bloodless' palace coup brought the Sultan Qaboos to the throne. From that moment the Sultan and his advisors have struggled to create an imagined political community of a unified nation (see Anderson 1983). The first few decades after the birth of this new nation saw campaigns to attract educated and professional Omanis in exile to return to create the modern state (Peterson 1978). This paper posits that once these outsiders and expatriates had integrated and transformed themselves into 'insiders', they set about creating an 'imagined' nation that was homogenous and modern. Thus the authentic inhabitants in 'background landscapes' such as the deserts (Hirsch and O'Hanlon 1995) became the 'outsiders'. The tension between the outsider 'traditions' and new insider 'modernities' appears to be resolved in a representation that encapsulates the political and cultural fiction of a unified nation at the expense of the *bedu* tribes of the interior deserts; *bedu* claims to authenticity are thus increasingly rejected or cast aside

as insignificant. Those in power, however, are able to carve out very different 'places' in their vision of the desert landscape – a reintroduced animal sanctuary and reserve or an oil concession area – and blank out the very inhabitants of the physical space.

Identity, national or otherwise, is closely tied to language and the spoken word often becomes an iconic marker of national belonging. The Omani national language, in this case Arabic, is not a neutral tool of communication. It represents the language of the 'hegemonic' ethnic group in power, the Ibadi of Oman, rather than the once preferred language, Swahili, of many of the returning expatriate Omanis from Zanzibar and East Africa. The gradual emergence of Arabic as the sole formal language of government in the modern state, replacing Swahili, Baluchi, Urdu and English is a reflection of the consolidation of power in one ethnic group (Bloch 1971). Many minority groups in exile reinvest in their 'native' language to an extent never practiced prior to leaving their homeland or places of origin (see Chatty 2010, Goody 1986). In other cases, traditional, local languages are part of a specific cultural setting and therefore have difficulty surviving independently from the maintenance of the social ties and networks, the resources and their allocation as well as the modes of production on which such settings depend (Crawhill 1999). In Oman both linguistic realities co-exist. Some expatriate minorities manage to maintain their 'traditional' languages having returned from exile; while other minorities *in situ* struggle to keep their languages alive.

Currently, Oman's official language is Arabic. But Swahili, Urdu and Farsi as well as eight local and perhaps aboriginal languages are also spoken in the country. They are Bathari, Harsusi, Hobyot, Jibbali, Khojki, Kumzari, Mahri and Zidgali. Of these, five are unique south Arabian languages spoken in Oman's desert – Bathari, Hobyot, Jibbali, Mahri and Harsusi.² The uniqueness of these possibly pre-Arabic languages is not recognised by the government; perhaps in the current political climate such recognition might be seen to suggest prior claims to land and resources. As a cultural heritage, moreover, these languages and their oral traditions are not formally appreciated in the country. Unlike Jordan, for example, where the Jordanian Commission for Oral and Intangible Cultural Heritage has presented its *bedu* oral traditions and culture in the regions of Petra and Wadi Rum to UNESCO for formal recognition as part of the world's Intangible Cultural Heritage, Oman officials remain mute about the country's linguistic treasures (UNESCO 2009). Although the Sultan himself has personally requested and funded a detailed and long-term study of the six south Arabian languages spoken in the country, educationalists and development planners continue to ignore this unique character of Oman's diverse population, making no place in the nations' school curriculum for these language.

Authenticity is deeply associated with place and space. For the nomadic tribes of Oman, their authenticity is defined by movement. Their frequent migrations and 'light footprint' characterised themselves to others like them and suggested a particular internal state; the external self was generated by internal qualities associated with authen-

2. A sixth south Arabian language found in Oman, Socotri, is not on the UNESCO list of endangered languages.

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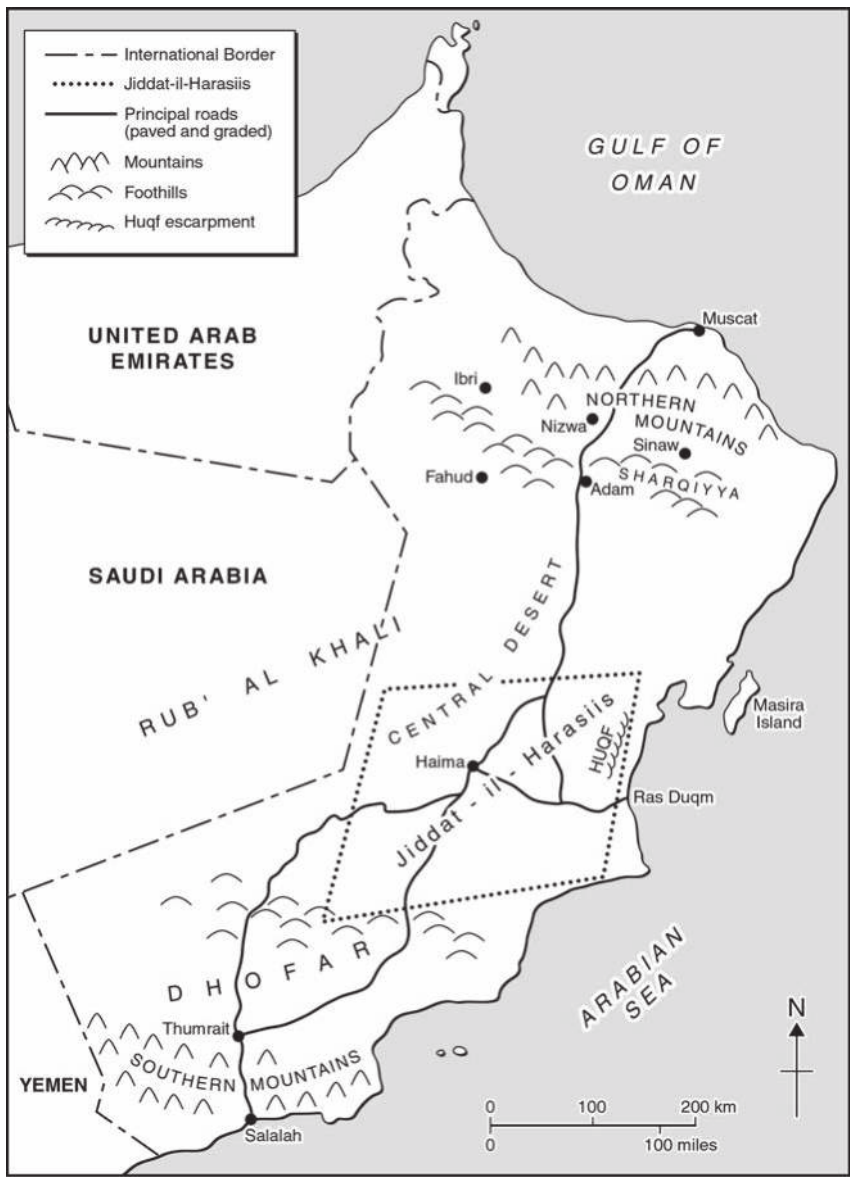
tic desert people. Lionel Trilling (1971) calls this principle 'authenticity'. Authenticity implies that one should be able to read information about a person's internal state and qualities from his or her self-presentation. Taking this one step further, consistency of action and behaviour constitutes important evidence of authenticity (Goffman, 1958). Hence, once some members of the Harasiis tribe accepted government housing adjacent to a government centre and became seasonally less mobile, the authenticity of the tribe as a whole came to be challenged by those in power and those with competing claims to its resources. These challenges to Harasiis authenticity became more pronounced as individual tribesmen grabbed business opportunities, opened transport companies, set up local shops and motels and hired Baluchi and Sindhi camel herders to watch over their livestock in their long absences from the desert. This lack of consistency in behaviour and activity came to be regarded by government and others as a weakening of authenticity and fair grounds to claim competing rights.³

HISTORICAL BACKGROUND

Like so many states of the Middle East, Oman has been inhabited by successive waves of peoples. Settlement in Oman from the desert fringe came from two directions: one along the southern coast of Arabia from Yemen and the other through the northern gateway of Al-Buraymi. The northern part of Oman is distinctly influenced by the northern migrations via Al-Buraymi and is clearly Arab, Muslim and tribal. The southern region, Dhofar, also Muslim and tribal, has much closer cultural ties with Yemen and is home to a number of Himyaritic or south Arabian language speakers. These pastoral tribes in the middle of the country are the most remote and marginal peoples in Oman physically; culturally they form distinct heterogeneous groups seemingly at odds with contemporary government efforts to create a unified state. Other migrations into Oman include the Baluch and Persian from Southwest Asia, African and Zanzibari from the East coast of Africa and Hydrabadis from the Indian Subcontinent. The latter have settled in the coastal regions and the mountain valleys mainly of the north of the country (for greater detail of ethnic composition see Peterson 2004a, Peterson 2004b).

Until 1970, the Sultanate of Oman could justifiably be described as the 'Tibet of Arabia' (Eickelman 1989: 368), so complete was its isolation from the rest of the world. This remoteness and sense of separateness of the state was largely created during the long reign of Sultan Said Al Said (1932–1970). It was a time when many urban Omanis fled the country seeking education and livelihood opportunities. During this period the tribes of the desert interior maintained their largely subsistence livelihoods including local trade and barter with coastal settlements. What little transformation

3. Changes in desert tribal lifestyles were regarded as inconsistent with authenticity by those in power seeking to expand their hegemony. Thus hiring of Baluchi and Sindhi camel herders was regarded as inconsistent with desert tribal culture but similar changes in urban society, such as the universal dependence on foreign cleaning and service staff and children's nannies, were not.



Sultanate of Oman

Figure 1. Map of Oman

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took place in the coastal and mountain settlements in the north of the country had little, if any impact, on the desert tribes.

Ever fearful that 'his people' were not ready to move into the twentieth century, Sultan Said prohibited the general importation of cars and severely restricted the enrolment of boys in schools. He took a direct interest in all matters regarding changes to long-held traditions. He banned sunglasses and torches and insisted that the gates of the capital, Muscat, be closed at sunset. Those caught outside had to wait until the next morning to enter the town. He permitted only three schools to operate over the entire country admitting a hundred boys a year, whom he personally chose. Yet Sultan Said himself was cultured and cosmopolitan. Throughout the 1950s and 1960s he made annual trips to the United Kingdom, generally in the summer.

In 1964, oil was discovered in the central desert of Oman and by 1967 it began to be exported. Projected revenues jumped dramatically but even then Said remained cautious about spending money he did not yet have. Thus, although he commissioned plans for a new port at Muscat and a hospital in Ibri among other projects, he took his time giving the go-ahead to implement these works, waiting first to accumulate the cash reserves to pay for them. Until his overthrow by his son, Qaboos, Said continued to act and behave with the shrewdness and calculation of someone always on the edge of financial ruin.

Omanis had been fleeing the country for decades during his rule (1932–1970) due to economic hardship, political oppression and lack of educational opportunities. By the summer of 1970, British forces quietly instigated and supported a *coup d'état* led by his son, Qaboos. After the palace coup, the new Sultan prioritised the modernisation and development of his country. Qaboos embraced 'progress' wholeheartedly and set about commissioning schools, clinics, hospitals, roads and other infrastructural development. Unlike that of many of the Gulf states, Oman's indigenous population was relatively large and markedly heterogeneous. In the north of the country it included an elite urban merchant class with strong cultural ties and trade links with India and the coast of East Africa. Along the coast, subsistence fishing settlements were common and in the mountains and intervening valleys, terraced farming communities survived by maintaining ancient systems of water collection and distribution (Wilkinson 1977). The towns of the interior of the country were the centres of local and regional trade as well as of religious learning. These settlements mirrored Oman's long history of successful colonial empire and incorporated East African, Baluchi, Persian and Indian elements into the dominant culture.

Once he had established his reign, Sultan Qaboos reached out to all Omanis living abroad and encouraged them to return to the country as quickly as possible. This they did in large numbers, from Bombay, Mombasa, Liverpool and other Western centres. Along with this returning 'citizenry' came skilled European, particularly British, and South Asian expatriate workers to help build a government infrastructure nearly from scratch. The armed forces, the police force, the internal security service, the civil service and government ministries of health, education, social affairs and labour, agriculture

and fisheries, water and electricity, communications and roads, among others, were rapidly set up. The trappings of a modern state were put into place almost overnight. Thousands of miles of roads were tarmacked, and Muscat was connected for the first time by a modern road network to Salalah. The social and economic transformation of the coastal areas and the mountains behind in both the north and the south of the country, funded mainly by petroleum wealth, was enormous. The same was not true of the interior desert areas of the country or for its nomadic pastoral peoples.

THE HARASIIS TRIBE IN CONTEMPORARY OMAN

The Harasiis, the Wahiba, the Duru and the Jeneba are the four main nomadic pastoral tribes in the central desert of Oman. The Wahiba tribe of about 7,000 people occupy the southern coast of Oman and the desert interior known as the Wahiba Sands. They are Arabic-speaking tribes with strong economic links to the towns and villages of the Sharqiyya region. To the West of the Wahiba Sands are the Duru camel-raising tribe. They, too, are Arabic-speaking and have close links with the towns and villages of the Dakhiliyya region; they number about 9,000. Spread out along much of Oman's southern coast and adjacent interior are the Jeneba, a large and widely dispersed tribe practicing pastoralism in places and fishing in others. They are also Arabic-speakers and their numbers are easily in excess of 12,000. To the south of the Duru and Wahiba are the Harasiis tribe. Moving over what was – until the 1950s – a vast, waterless plain of more than 42,000 square kilometres, the Harasiis are a 'refuge' tribe. They are people, largely of Dhofari origin, who have been pushed into this most inhospitable core area of the central desert of Oman. They are the most remote and isolated of already marginal peoples. The region they inhabit separates north Oman from Dhofar and is the backwater of both regions. As such, the region has attracted individuals and groups expelled from their own tribe as punishment for major infractions of traditional codes of conduct and honour. The Harasiis tribe speaks a southern Arabian language related to Mahri, an indicator of their lack of contact and relative isolation certainly in the past few centuries (Johnstone 1977). The tribe's usufruct or rights to access graze and browse found in the Jiddat-il-Harasiis were established in the 1930s when the Sultan and his political advisor, Bertram Thomas, decided to confer the name Jiddat-il-Harasiis⁴ upon the territory which had fallen to them as much by occupancy as by the lack of desire of any other tribe to be there (Thomas 1938).

The Harasiis tribe clearly represent the most excluded element of the Omani peoples. The leadership of the tribe as a whole lies with the Beit Aksit, whose ancestral forbearer is acknowledged to have united the disparate units into one tribe in the mid-

4. The Jeneba tribe, it seems, protested that this territory was theirs and the Harasiis were simply being accommodated there because they had no land of their own. However, the Sultan decided that if the Jeneba wanted to go and live in the region it could be renamed 'Jiddat-il-Jeneba' but as long as the Harasiis were the sole occupiers of the Jiddat, it would carry their name (Thomas 1938).

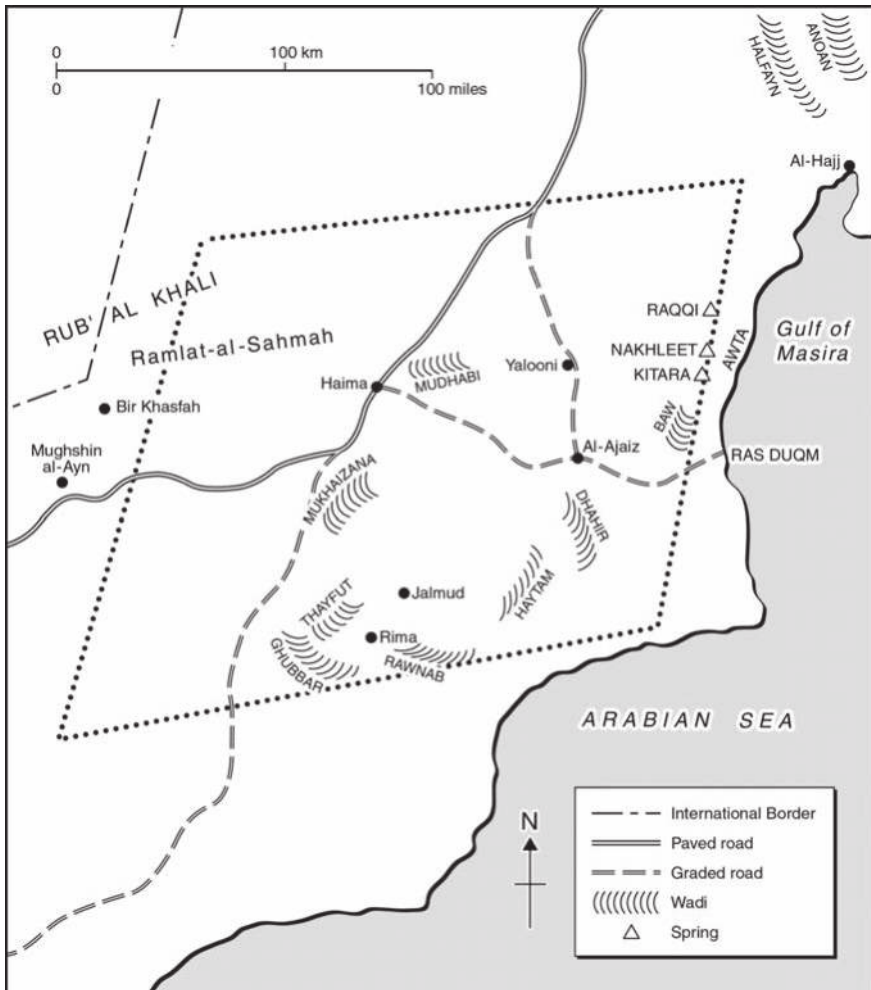
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Figure 2. Jiddat-il-Harasiis

dle of the nineteenth century. From about the mid-1930s the Harasiis tribal leader has made annual trips, generally to Salalah, in order to receive cash gifts – like the other Omani tribal leaders – from the Sultan.

The tribe is small, numbering about 5,000 people. Although their claim to the Jiddat has been, on occasion, contested by other groups, no other tribe has actually attempted to move into this most desolate of landscapes with little if any seasonal grass, no natural water sources and unfit for human habitation during the scorching

summer months. It was only with the oil activity of the 1950s that the fortunes of the Harasiis and their grazing lands on the Jiddat were transformed. In 1958 an exploratory party came to a point called Haima in the middle of the Jiddat-il-Harasiis and sank a water well there to support its oil activity. Another well was sunk at a point seventy kilometres towards the coast, called al-Ajaiz. These two wells were the first water sources on the Jiddat-il-Harasiis, an area approximately the size of Scotland. Al-Ajaiz became something of a magnet, attracting pastoral families to its well and its seasonal browse. The Haima well was also used but not to the same extent as that at Al Ajaiz, as the area surrounding Haima was a salt flat with very little grazing or browse for the herds of camels and goats.

The traditional economy of the Harasiis was based on the raising of camels and goats by natural grazing for the production of milk rather than meat. At the core of their way of life was migration determined by a combination of seasonal and ecological variables in the location of pasture and water. Survival of both herds and herders made movement from deficit to surplus areas vital. Households were, and are still, generally extended family units, the average family being composed of nine members.

At the core of the household is the nuclear family of husband, wife and children. Generally two or three adults, of one degree of kinship or another, make up the rest of the household. On average a household keeps a hundred goats, which are owned by and the responsibility of women and older girls. The average household also has 25 camels, of which five or six are generally kept near the homestead – these are the heavily pregnant or lactating ones. The remainder of the camels are left free to graze in the open desert. The whereabouts of these animals is very carefully monitored and an elaborate camel information exchange system operates among all the tribesmen. When they meet, tribesmen first exchange news about the conditions of pastures, then the whereabouts of various loose camels and finally news items of various family members. Homesteads are generally moved a significant distance three or four times a year.⁵

Basic to the organisation of all pastoral people is the existence of sedentary communities in adjacent areas and access to their agricultural products. For the Harasiis tribe, their trading towns have been along the northern desert foothills of the Sharqiyya, particularly Adam and Sinaw. The cash economy of the village was reinforced by the continual influx of 'capital on the hoof'. Transactions were completed and money exchanged hands. Significantly though, when the final purchases were made, the bulk of the money had simply moved from one end of the market to another – from the animal buyer's pocket to the merchants till. For the Harasiis, the relationship with the villages reinforced not a cash economy but a subsistence one. Until the late 1970s,

5. In 1980 the Omani government cooperated with the United Nations to implement a two-year anthropological study and needs assessment of the Harasiis tribe. I led this project and as a result was able to promote the opening of a boarding school in 1982 for boys and later a special day school for girls. Increasingly over the past two decades Harasiis families have either camped near to Haima or have taken up residence in 'low-cost' housing units on the edge of the centre while the schools are in session.

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this economic interaction was unchanged among the Harasiis and extended no further than these border desert villages and towns.

TRANSFORMING AND CONTESTING AUTHENTICITY

In the early months of 1980, I was offered an opportunity to join a small convoy of vehicles across the desert of Oman. The trip was to start in Salalah, the capital of Dhofar, the southern region of Oman, and to cross the deserts of Oman and end up in Muscat. It was not quite the retracing of the steps of the early twentieth century explorers, Bertram Thomas (1930s) and Wilfred Thesiger (1940s), but it still felt a rare opportunity and unique adventure. The purpose of the journey was partially to track several lapsed tuberculosis patients from tribes in the Dhofari interior and, at the same time, to provide immunisation vaccines to any children we came across from these communities. Half way through our journey we came across a small group of nomadic pastoral Harasiis women and children preparing for a wedding. We took the opportunity to stop and to seek their permission to begin the course of immunisation against some of the six WHO targeted childhood diseases (Poliomyelitis, Diphtheria, Tetanus, Measles, and Rubella). 'Why', we were asked, 'did we want to do this?' Our answer was, 'The Sultan of Oman wishes to see all Omanis immunised against these diseases'. 'Why', they continued, 'should he want to do this for us?' We were initially lost for an answer, having assumed that the sense of belonging to one nation had reached these parts of the country. That did, in fact, develop over time; however, the tie to the desert landscape of the Jiddat, the social construction of belonging to that locale, was not undermined in the process.

The following year, I began a fourteen-year close association with this small nomadic pastoral tribe. My role was to assist the government of Oman in extending social services to this remote community. A Royal Decree had been issued indicating that government services were to be extended into the interior desert 'without forcing migratory people to settle'. A policy had been formulated by the Sultan, which needed to move through a descending hierarchy of bureaucracy and emerge as a set of discretionary decisions made locally and on the ground.⁶ Sultan Qaboos had encouraged the government ministries to push 'development' forward into the remote interior of the country to offer its people the same services that the government had extended to the rest of the country during the first ten years of his reign. His perception of the desert landscape as a 'created' physical, social, and cultural environment inhabited by nomadic pastoralists, was undoubtedly informed by his own mother's origins as a Qara tribeswoman in Dhofar.

6. Allen Rew has described the constraints regarding policy and practice in development as a pyramid landscape. There is the hilltop where policy is formulated; then the plateau where bureaucratic hierarchy prevails; and at the base a broad expanse of discretionary practice and local coping strategies (Rew *et al.* 2000).

Over a two-year period, as a 'Technical Assistance Expert' with the United Nations Development Programme (UNDP), and with the help of two Peace Corps volunteers, I was allowed by the Minister of Health and the Minister of Education to set up both mobile and sedentary health services as well as a weekly boarding school for boys with day-enrolment for girls (Dyer 2006). Other government services with a relevance to these mobile pastoralists were more difficult to organise. It seemed that the 'hilltop' policy formulations of the Sultan had been re-interpreted by the descending bureaucratic hierarchy as aimed at creating a landscape in the desert that attempted to reproduce the settled, 'civilised' landscapes they were familiar with in the coastal and mountain valley settlements. For example, opening a government office in the remote tribal centre of Haima and staffing it with Omani government employees generally meant borrowing all the rules and regulations of a civil service developed around *ha-dari*, settled, needs. Thus government welfare benefits became possible for unmarried, widowed and divorced women, the handicapped and disabled. But, to the surprise of the Harasiis community, elderly widowers or bachelors with no family to support them were excluded from government support.⁷

Shelter and housing were particularly problematic, as government officials and ministers could not conceive of the desert being occupied in any other way than in permanent village settlements. The urban concepts of settled space ruled supreme. Thus the government civil servant's outsider view of the desert landscape became more powerful than that of the insider inhabitant. The reality of the widespread dispersal of small household camps over the 40,000 square kilometres of the Jiddat was inconceivable to government bureaucrats, whatever the Royal Decrees might have suggested. Hence our 1982 highly-successful UNDP programme of canvas tent distribution among the Harasiis households met with obstruction and eventual failure when we tried to set it up as a recurrent government programme after the formal end of the UN project the following year. In an interview with the Minister of Housing in Muscat in 1984 to plead for a continuation of the tent distribution programme, I was told that the Ministry had to be seen to be doing something useful in the interior and tents were not progressive. The Minister added that he needed to show that the Ministry was active and that could only be done with permanent 'mortar and cement'; canvas cloth was temporary and undignified. His conclusion was that the government had to build cement housing – units of twenty to thirty British-designed two-storey town houses; no matter that such architectural space was more suitable to an English suburb than an Arabian desert.⁸ The units were built in 1985 and stood empty for more than a decade, except when they were used to shelter Harasiis goat herds, or hired out to expatriate labourers imported by local traders and oil company sub-contractors.

7. Harasiis concepts of welfare and aid extended to elderly men and women alike. There was recognition that, in the extreme environment of the Jiddat-il-Harasiis, generation was as important as gender in determining need.

8. Interview with Minister of Housing, Ahmed Al Ghazali (Al Ghazali 1984).

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The distribution of potable water was another area of critical concern to the Harasiis tribe but not fully understood by government, where rules of auctioning time for watering of agriculture were well established (see Wilkinson 1977). The tribal elders petitioned the government to finance a carefully-constructed decentralised plan to distribute water to households spread out over the Jiddat-il-Harasiis, based on a horizontal organisation in which all seven of the tribe's lineages were involved. The mid-level government bureaucrats however, found it easier and more in line with the way Oman's towns and villages were organised to hand over the keys to the water bowser trucks to the tribal leaders recognised by the government and the oil company. For many years thereafter, water distribution rested in the hands of a few powerful individuals rather than with a syndicate as the tribal elders had hoped for.

Even the request for agricultural extension – a national programme widespread along the coast and in the interior towns of the country and well funded by various international agencies such as USAID and the oil company – failed to be transferred to the desert interior. Despite numerous requests for assistance from Harasiis tribal elders to improve breed stock and experiment in growing salt-resistant fodder, government ignorance of and uninterest in tribal subsistence and its potential for marketing meant that all livestock extension programmes in the country were restricted to the coast and interior towns.⁹

For decades the oil company was perceived locally as the government in the desert. Its exploration activities had resulted in three water wells being left open and maintained for the use of the local Harasiis, a service that was widely appreciated. As the major employer in the region – albeit generally for unskilled and short-term work – it had a grasp of the social makeup and organisation of these nomadic pastoralists. Thus, when the international demand for greater social responsibility resulted in the requirement that environmental and social impact assessments be conducted prior to any further oil extraction in the Central Desert of Oman, much could have been expected with regards to the complex nature of the Jiddat 'landscape'. However, in numerous conversations with local and expatriate petroleum engineers, a technical view of place emerged; the desert in their opinion was a landscape full of promising mineral resources [gas and oil] and devoid of people. These company engineers maintained that people emerged opportunistically from other regions whenever the oil company set up camp.¹⁰ This particular representation of the desert was mirrored in the expert

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9. The Sultan asked the oil company to set up an experimental farm using artesian water in the desert to show how the 'desert could bloom'. Rahab Farm was successfully set up near Marmul in the southern province of Oman and proceeded to sell its alfalfa and other grasses locally. But its goat breeding programme, which fascinated the local tribes, was closed down without any effort being made to introduce these animals into local herds.
 10. These views are common globally in the dispute over petroleum exploration in areas of human habitation. In the Amazonian belt, where tribes have sought to remain in isolation, efforts to stop petroleum exploration have resulted in the denial of their existence. Recently the president of Peru, Alan García, was quoted as saying 'the figure of the jungle native' is a ruse to prevent oil exploration. Daniel Saba, former head of the state oil company in Peru added more scornfully, 'It is absurd

reports commissioned by the oil companies regarding social impact assessments. As late as 2006, Occidental carried out a preliminary environment impact assessment of an important tribal grazing area, Wadi Mukhaizana (Fucik 2006). The 'findings' of that report were that the area was devoid of people and thus no social impact assessment was necessary. Although Mukhaizana may have been physically empty of people at the time of the brief visit of the European consultant, the absence of people and herds at that moment was related more to the lack of rain in that season rather than an absence of tribal use rights to the Wadi. Only five years earlier the largest oil company in Oman had commissioned a social impact assessment of the same Wadi and found significant numbers of authentic local Harasiis there (Rae and Chatty 2001). Those findings were ignored and Occidental has since developed a spaghetti junction of oil and gas infrastructure in the Wadi, devastating the grazing area for a large number of Harasiis families. Their rights to this land have been denied and no adequate compensation or restitution has been considered. Overall, the major oil companies in the central desert of Oman take the view that these concession areas are *terra nullius* or empty land (Gilbert 2007). They lay their pipelines across important tribal migration routes, causing disruption if not obstruction for Harasiis herders trying to transport or move their herds from one grazing area to another.¹¹ A slow and gradual process of dislocation is taking place, based on the oil companies' unwillingness to recognise the authenticity of the Harasiis seasonal presence on their traditional grazing lands. This is followed by a process of displacement that is gradually forcing some Harasiis off their lands altogether and into shabby and crowded government low cost housing at Haima.

Furthermore, conservationists – both national and international – have regarded the central desert of Oman as their own back yard, ignoring the presence and authenticity of its local human inhabitants. Conservationists generally do regard the desert as a constructed landscape as well but one shaped by plants and animals, not people. Their concern was to restore a balance to this landscape by first returning to it an animal that had been hunted to extinction in the 1970s. Planned in the late 1970s, the international flagship conservation effort, the Arabian Oryx Re-introduction Project, was set up and put into effect in the Jiddat-il-Harasiis. This process was envisaged from abroad and created in the offices of the Sultan's Advisor for the Environment without any consultation with the local Harasiis tribesmen in the desert. Between 1980 and 1996, 450 Arabian oryx were either returned to 'the wild' or were born in the Jiddat-il-Harasiis, with Harsusi males hired to track these animals. In 1994 Oman succeeded in getting this conservation project recognized formally as the UNESCO World Heritage Arabian Oryx Sanctuary. But ongoing and constant friction between the Western managers of the conservation project and the local Harasiis tribesmen

to say there are uncontacted people when no one has seen them. So, who are these uncontacted tribes people are talking about?' (Carroll 2009).

11. For a brief period of time in the early 1990s, one oil company did agree to bury any new pipelines at five kilometre intervals across the desert to facilitate the requirement of the Harasiis and other nomadic pastoral tribes to move themselves and their animals around the desert floor.

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regarding their 'rights' to graze their domestic herds in large parts of their territory – then officially a UNESCO nature reserve – eventually resulted in a distancing from the project by the Harasiis and a lack or diminution of any sense of 'ownership' or commitment to the conservation project.

Two representations of the desert landscape came to a head: a Western conservation protectionist vision of a pristine landscape of plants and animals and a local tribal vision of a landscape where there were sets of cultural and historical concepts relating people and domestic animals to desert spaces and places. When, between 1996 and 1998, poaching and illegal capture of the oryx by rival tribes resulted in the loss of more than 350 animals, the Harasiis could do little to stop this downward spiral. Other tribes were actively acting out their disaffection. For the Harasiis, their youth had become alienated and the elders were no longer interested in the transformed landscape in the part of their traditional territory that had been taken from them without their consent. In 2007, The Arabian Oryx Sanctuary became the first World Heritage site to ever be deleted from the UNESCO list of World Heritage Sites. The justification for this unprecedented step was the rapid decline in oryx number (from 450 to 65) and the supposed degradation of its grazing area.

In 2009 the government consolidated its vision of the desert landscape by physically separating out the Harasiis tribe and their livestock from an extensive area of the desert that was for centuries their home. The government is now creating a new authenticity in the desert, a pristine landscape that excludes the local tribes and their domesticated animals by fencing off a large area of more than a hundred square kilometres to keep the reintroduced Arabian Oryx in. Unfortunately other similar schemes in Arabia to create new authentic desert landscapes devoid of people have led to mass mortalities of these ungulates (Islam *et al.* 2010).

CONCLUSION

The authenticity of the Harasiis and other nomadic pastoral tribes has been challenged by national government and multi-national bodies which have their own views on the landscapes of Oman. The tensions that exist between the traditional and modern, as well as the *bedu* and the *hadar*, are not equitably addressed. This has meant that representations of landscapes are subject to the power of the hegemonic state. But space and place are not resolved in a singular representation that encapsulates the political fiction of a united state. There is no one absolute landscape but rather a series of related and also contradictory perspectives. Omani policy formulations recognise elements of the authenticity of the Harasiis vision of their desert landscapes. But bureaucratic hierarchy prioritises and puts into practice landscape perspectives that are quite contrary: *hadar* landscapes imposed upon *bedu* territories; multinational extractive industry's perspectives of landscapes with no human imprint, but replete with natural resources under the surface; and conservation landscapes of pristine import momentarily unbalanced by humans' disregard for the equilibrium of flora and fauna. These visions explain the

lack of interest in the authenticity of Harasiis culture, the lack of government interest in developing or promoting the Harasiis livestock raising economy; and the oil companies' lack of interest in Harasiis claims to spaces and places they have inhabited for centuries.

The Harasiis are increasingly becoming dislocated by the current prospecting and extractive activity of the oil and gas industry. Their restricted access to areas adjacent to the former Arabian Oryx Sanctuary has also impacted heavily on their sense of mobility and grazing rights. Contemporary government unwillingness to recognise the importance of mobility in their way of life is threatening their freedom of movement as families are increasingly finding themselves tied to government centres in order to access education, health and welfare for the vulnerable weak, the young and the old.

For the first three decades of Oman's modern nation-building history (from 1970 to the present) a truly integrationist approach seemed to hold, where all Omanis from whatever background were called upon to work together to build a new 'modern' nation. Now, however, with much of the building in place, an assimilationist outlook and approach seems to have taken hold, which is curiously out of step with global trends. Oman, in its recent failures to recognise the authenticity of its minority tribes, seems to have replaced an open-minded, ahead-of-its time, integrationist vision of the development of the modern state with a backward-looking assimilationist perspective, at the expense of the country's unique *bedu* heritage and linguistic tradition.

REFERENCES

- Al Ghazali, Ahmed (1984). Interview, Ministry of Housing, Muscat.
- Anderson, Benedict (1983). *Imagined communities: Reflections on the Origin and Spread of Nationalism*. London: Verso.
- Aplin, Graeme (2007). 'World Heritage cultural landscapes'. *International Journal of Heritage Studies* 13: 427–446.
- Bloch, Maurice (1971). 'Why do malagasy cows speak French?!' *Kung*, the Magazine of the LSE Anthropological Society.
- Carroll, Rory (2009). 'Rumble in the jungle', *The Guardian Weekend*. London.
- Chatty, Dawn (2010). *Dispossession and Displacement in the Modern Middle East*. Cambridge: Cambridge University Press.
- Crawhill, Nigel (1999). 'Going to a better life: Perspectives on the future of language education for San and Khoe South Africans'. *International Journal of Education Development* 19: 323–335.
- Dresch, Paul (1989). *Tribes, Government and History in Yemen*. Oxford: Clarendon Press.
- Eickelman, Dale F. (1989). *The Middle East: An Anthropological Approach*. Englewood Cliffs: Prentice Hall.
- Fucik, Ken (2006). Environmental Impact Assessment in Wadi Mukhaizana.
- Gilbert, Jeremie (2007). 'Nomadic territories: A human rights approach to nomadic peoples' land rights'. *Human Rights Law Review* 7: 681–716.

Authenticity in the Desert Landscapes of Oman

- Goody, Jack (1986). *The Logic of Writing and the Organization of Society*. New York: Cambridge University Press.
- Goffman, Erving (1959). *The Presentation of Self in Everyday Life*. New York: Anchor Books.
- Hirsch, Eric and Michael O'Hanlon (eds.) (1995). *The Anthropology of Landscape: Perspectives on Place and Space*. Oxford Studies in Social and Cultural Anthropology. Oxford: Clarendon Press.
- Isam, M. Zahar, Kairi Ismail and Ahmed Boug (2011). 'Fence leads to mass mortalities of threatened ungulates in Mahazat As-Sayd protected area in arid Central Arabia'. *Wildlife Middle East* 5 (1): 3.
- Jackson, John (1984). *Discovering the Vernacular Landscape*. New Haven: Yale University Press.
- Johnstone, Thomas M. (1977). *Harsusi Lexicon*. Oxford: Oxford University Press.
- Peterson, John (1978). *Oman in the Twentieth Century*. New York and London: Croom Helm.
- Peterson, John (2004a). 'Oman's diverse Society: Northern Oman'. *Middle East Journal* 58: 32–51.
- Peterson, John (2004b). 'Oman's diverse Society: Southern Oman'. *Middle East Journal* 58: 255–269.
- Peterson, John (2007). *Oman's Insurgencies: the Sultanate's Struggle for Supremacy*. London: Saqi.
- Rae, Jonathan and Dawn Chatty (2001). *Participatory Project Appraisal for the Mukhaizana Field Development : A Social Impact Study*. Petroleum Development Oman LLC.
- Rew, Alan, Eleanor Fischer and Balai Pandey (2000). *Addressing Policy Constraints and Improving Outcomes in Development-Induced Displacement and Resettlement Projects*. Refugee Studies Centre, University of Oxford.
- Thomas, Bertram (1938). *Arabia Felix: Across the Empty Quarter*. London: Reader's Union.
- Trilling, Lionel (1971). *Sincerity and Authenticity*. London. Oxford University Press.
- UNESCO (2009). *Safeguarding Intangible Cultural Heritage*. Paris: UNESCO.
- Wilkinson, John (1977). *Water and Tribal Settlement in South-East Arabia: A Study of the Aflaj of Oman*. Oxford: Clarendon Press.

PRISTINE WILDERNESS, PARTICIPATORY ARCHAEOLOGY AND THE CUSTODIANSHIP OF HERITAGE IN MURSILAND

Marcus W. R. Brittain and Timothy A. R. Clack

Some five camels died within the next two days, and many more within a fortnight; five donkeys were lost, not one of my two dozen sheep and goats ever reached camp alive, and many boxes were injured. I was obliged to throw away much valuable kit. Besides this, the men became so disheartened that they never afterwards recovered from their apathy. (Donaldson Smith 1900: 615).

It is a dangerous thing for man to try to contend with Nature in Africa. She finds a thousand means to frustrate his purposes. (Powys 1925, p. 150).

INTRODUCTION

Deserts capture the popular imagination as places of extremes. They are wilderness environments *par excellence*. Yet they exhibit little of the monolithic uniformity that underpins this popular image. In reality deserts embody considerable variation in topography, geology, hydrology and flora and fauna (Middleton and Thomas 1997, Hiscock and Wallis 2005, Smith *et al.* 2005). Nonetheless, under certain contexts there remains a distinct characterisation of desert landscapes as *terra nullius*, a pristine ‘wilderness’, ‘emptiness’ or ‘wasteland’. Central to this perspective is the absence of human agency in these landscapes, either in the past or in the present, whereby contemporary occupants may be viewed as recent ‘encroachers’ on, and potential ‘destroyers’ of the wilderness. The legal, social and economic implications of this perspective are potentially considerable for marginal communities in a globalised world. We suggest that archaeology and neighbouring disciplines working in partnership with inhabitant communities are well positioned to challenge the erroneous view that the global value of these landscapes lies in their supposed ‘naturalness’ and ‘humanlessness’. Archaeology can often reveal empirical foundations for extensive and recurrent, if not continuous, inhabitation across desert or dryland landscapes (see Barker and Gilbertson 2000, Veth *et al.* 2005). This enhancement of knowledge is targeted through research on specific *objects* of interpretation. By contrast, in this chapter, as archaeologists working with communities in arid

environments, we intend to explore the *practice* of interpretation. Using an example of ongoing research in the Lower Omo Valley of south-west Ethiopia, we argue that a participatory research approach, working at multiple levels of stakeholder partnership, presents fieldworkers with unusual opportunities and challenges. In particular, we suggest that aspects of knowledge arising from this type of research attitude may serve to empower peoples and their pasts in desert environments that are increasingly facing politico-economic pressures of global society.

PRACTISING ARCHAEOLOGY IN THE LOWER OMO VALLEY

The lower valley banks of the Omo River retain a valuable legacy of fossilised hominin remains that, with associated material residues, has since the 1960s been an object of detailed palaeoanthropological investigation into the origins and development of the human species (Gowlett 1990, pp. 32–3; Asfaw 1991). Similarly, the diverse cultural groups that inhabit the valley are today an important area of detailed anthropological study. In spite of this attention to pre-human and contemporary occupation, and evident archaeological potential for later prehistoric occupation (e.g. Brown 1975), there has been a virtual absence of investigation into the valley's prehistory and protohistory. This conceptual void has simultaneously resulted from and perpetuated a notion that the Lower Omo Valley is a wilderness devoid of human impact until the perceived arrival of its current inhabitants in comparatively recent times. In practice, the conceptual void has presented a challenge for archaeological fieldwork since there is little background research to provide comparison for much of what has been found in the current project, therefore making regional contextualisation and chronological profiling especially difficult. On the other hand this prompts alternative and perhaps equally rewarding lines of enquiry (see Clack and Brittain 2011). Nonetheless, as becomes evident in the following sections, the notion of wilderness has encultured a powerful and enduring image within policy and discourse pertaining to conservation, land management and settlement.

In response to this, the initiative that prompted the current project, begun in 2008, was aimed towards assessment of the true archaeological potential of the Lower Omo Valley. Consultation with anthropologists familiar with the landscape and people of the region, and particularly observation of likely areas of interest depicted in archived photographs, presented clear and encouraging potential of what an examination of the landscape could disclose. Of particular note were photographs and transcripts of interviews collected by David Turton in the 1970s relating to unique stone platforms in a region inhabited by the Mursi ethnic group. Oral testimony aligned the construction of these platforms with pre-Mursi communities living under different – wetter – environmental conditions to the dry arid climate of today. The primary objective, therefore, has been assessment of the short- and long-term human responses to environmental fluctuations in Mursiland, as well as identification of the temporal depth

of continuities and interruptions of inhabitation in this landscape. So far the results, briefly outlined below, have exceeded expectation.

Throughout the project we have triangulated archaeological evidence with ethnohistorical, archival and palaeoecological data in an effort to produce the thick description necessary for human–environmental reconstruction (Clack and Brittain 2010). This cross-referencing is a general methodological requirement for the maximisation of data. The varied contribution that interpretation of this data can make to the enhancement of scientific knowledge is becoming increasingly evident. However, from the outset we have been conscious that the project's contribution not only could but should transcend academic concerns. In fact, we believe this to be not only desirable but essential to the overall success of the project and its breadth of contribution to the production of knowledge of multiple forms. Our aim has therefore been to combine recognised methodologies for the collection and interpretation of archaeological data with approaches that embody a broader remit for the outcome of research in an arid or desert environment.

Participatory research

For these purposes we emphasise the value of participatory research, sometimes referred to as participatory action research. This stems from the emerging development in archaeology of community-focused collaboration. Broadly speaking, 'community archaeology' is one of the numerous terms used to refer to the engagement of communities in archaeological projects, developing from recognition of the social dimensions of archaeology and the desire to increase its relevance in the contemporary world (Pyburn 2003; Ross *et al.* 2011, pp. 41–3; Sabloff 2008). These approaches have arisen from a sustained enquiry into the socio-political context of archaeological work and the recognition that issues of heritage apply to a multitude of stakeholders, often in competition, each with potentially legitimate claims to knowledge concerning the past (Brittain and Clack 2007, Hamilakis and Anagnostopoulos 2009). Heritage may therefore be considered a part of social practice and 'a cultural process or performance of meaning-making' (Smith and Waterton 2009, p. 44). Moreover, the intricate connection of myriad forms of heritage to the formation, maintenance and negotiation of collective identities means that stewardship of the past is deeply implicated with issues of power, governance and access (González-Ruibal 2008, Matthews and Palus 2009, Smith 2004). Much of the focus of community archaeology has been a democratisation of the process of meaning-making in the social practice of heritage discourse and working in partnership with communities at every stage of archaeological practice has been viewed as a means towards community empowerment in the construction of local identity (Clarke 2002).

Participatory research has developed from aims not only towards the decolonisation of knowledge, but also of methodology; and certainly there are close parallels with post-colonial, post-structuralist and feminist values. Seven primary methodological areas have been identified for participation in archaeological research:

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1. communication and collaboration
2. employment and training
3. public presentation
4. interviews and oral history
5. educational resources
6. photographic and video archive
7. community-controlled merchandising (Moser *et al.* 2002: 229; see also Smith and Waterton 2009, p. 16).

These may best be considered as guidelines for practice, since participatory research is not a reference to an overbearing general theory and nor is it to be regarded as a specific component of methodology in general. Rather, participatory research may be described as an *attitude* through which are manifested multiple forms of theory and methodology (Chataway 2001, Petras and Porpora 1993). Likewise, participatory research is not about what sort of knowledge is produced but is instead focused on the location(s) at which knowledge resides. This calls for commitment and responsiveness to community needs and concerns and acceptance of the individual vulnerability and social complexity that comes with community participation at every stage of a project.

Most notably a focus towards collaboration with communities has emerged through dialogue with descendent and non-descendent communities in North America and Australia in particular, with detailed programmes of participation spreading through other predominantly Western contexts (e.g. Atalay 2010, Collwell-Chanthaphonh and Ferguson 2008, Moser *et al.* 2002; see also Smith and Waterton 2009). It is broadly acknowledged that the nature of participation of communities in archaeological projects takes its form in relation to a myriad of context-specific factors, such as the local needs of the community or the availability of research funding. However, participatory research has been largely overlooked in international archaeological projects in Africa, about which criticism has recently been raised (Mapunda and Lane 2004, Clack and Brittain 2011; see also Bruchac *et al.* 2010, pp. 241–88). Moreover, the context of archaeology with the Mursi, a non-literate pastoral people with a very different measurement of time and set of values towards heritage from that of the researcher, may render many of the reported examples of participatory archaeology incommensurate with the issues that arise in working under the conditions of Mursiland.

The character of participatory archaeology developed for the current project in Mursiland is very much a product of the desert environment and the associated research conditions. Indeed the bush of Mursiland, and for that matter deserts more generally, forces the adoption of certain methodologies, practices and participations and often morally obligates us to undertake a range of traditionally non-academic pursuits for the benefit of the participant communities. The spirit of this approach, rather than a detailed outline, is documented below against the context of an imagined wilderness

that has in many ways underpinned the conditions under which research is carried out in the Lower Omo Valley.

MURSILAND: PEOPLE AND PLACE

The Mursi are one of eight distinct ethnic groups that inhabit the Lower Omo Valley. These groups speak six different languages derived from Afro-Asiatic and Nilo-Saharan dialects. Today there are between 8,000 and 10,000 Mursi people whose identity, according to oral tradition, finds its origins in various large-scale migrations over the last two centuries, motivated mainly by environmental stresses and expressed in terms of the search for a 'cool place' (Turton 1979, 1988). Although this origin narrative implies some fashion of population replacement in the past, it does not exclude more probable forms of colonisation involving pulses of entry, contact and amalgamation between historic and migratory peoples. The Mursi employ agro-pastoral subsistence, primarily herding zebu cattle but also engaging in a range of other options as conditions oscillate. Mursiland occupies a roughly oblong-shaped territory, bounded to the east by the River Mago, to the north by the River Mara and to the west and south by the River Omo (Figures 1 and 2). Geologically this territory mostly consists of the 'Mursi

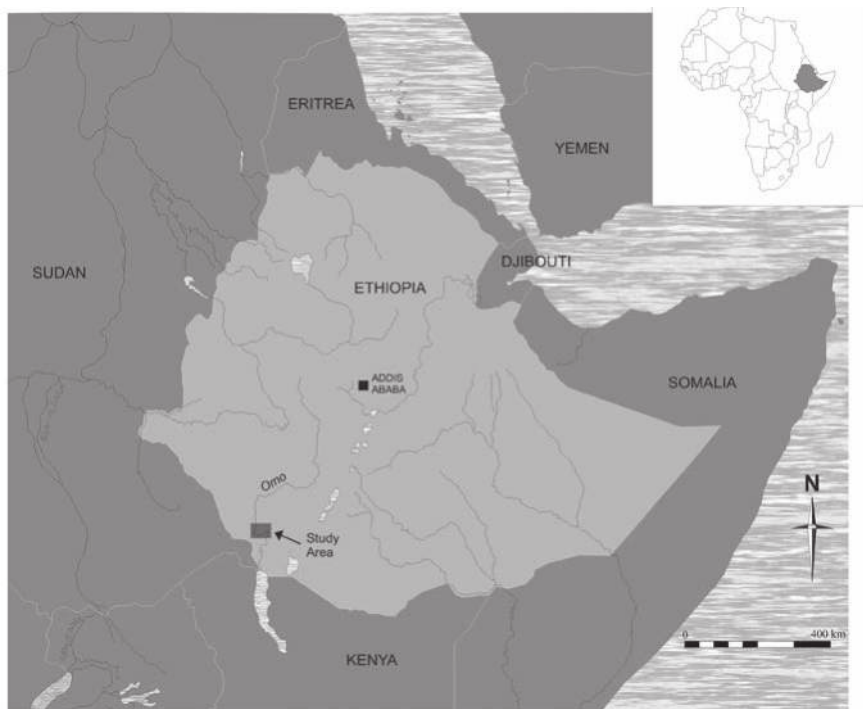


Figure 1. Map of project research location in south-west Ethiopia.

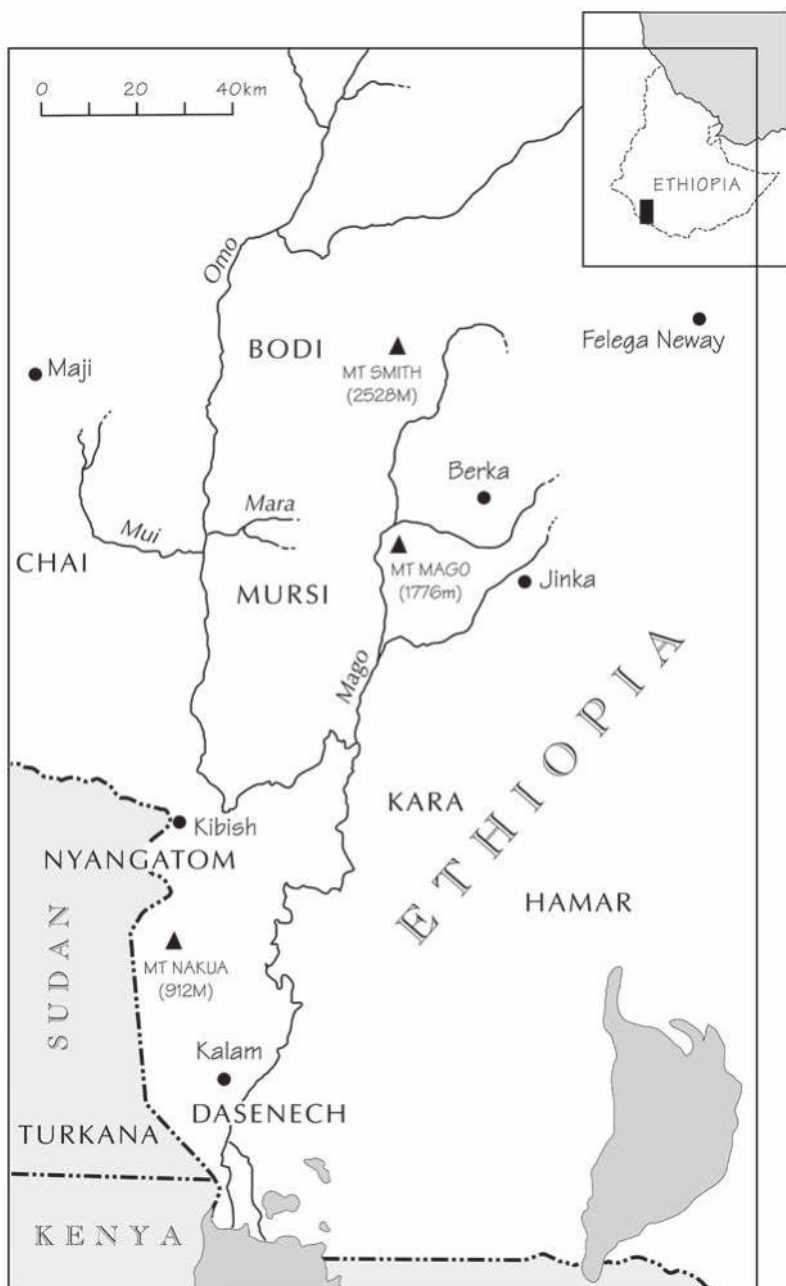


Figure 2. Map showing the approximate areas occupied by the larger ethnic groups in the Lower Omo Valley (Permission: Mursi online – <http://mursi.org>).

Formation', a volcanic plain sloping from east to west and the lowlands are cut from south-west to north-east by the volcanic Dara Range. The climate of Mursiland ranges from semi-arid to arid, with annual rainfall between 300–800 mm. The River Omo is a major waterway, flowing from the Blue Nile and Sobat watersheds in the north to its outlet at Lake Turkana, a distance of over 1,000 km. Its levels are determined by the rainfall regime of the Ethiopian highlands, its primary catchment. Mursiland can best be described as a dynamic environment, regrettably one that offers little climatic certainty for its inhabitants. This unpredictability makes rain-fed cultivation precarious and the watering of cattle difficult. This increases the Mursi dependency on flood-fed cultivation, which is reliant on highland rainfall to the north. This too is erratic, although less so than rainfall in Mursiland, as can be evidenced by the level of Lake Turkana, which has fluctuated by over twenty metres in the last century. This corresponds with a general trend of exposure found throughout the lowlands and the drying of many of the River Omo's tributaries over the last six millennia (Butzer 1971).

Owing to indigenous way-finding and limitations of access, the majority of the project's fieldwork has to date focused on an area between the perennial Elma River and a spur of the Arichigirong hills, near to the settlement of Dirikoro (E 36°6' N 5°42'). Here survey has revealed a long sequence of human inhabitation. The stone platforms identified in David Turton's photographs have proven the most enigmatic of finds, totalling 25 so far. Known locally as *benna kulugto* ('stone circles'), these unique platforms range in size from 2.5 m to 25.2 m in diameter and are composed of a concentric order of large stones interrupted by a linear gully consistently oriented to the west (Figure 3). Excavation has retrieved fragments of highly burnt cattle bone and chipped stone flakes and, although the origin and function of the platforms has yet to be fully ascertained, the platforms share qualities in architectural form, raw material and acts of deposition to sites found elsewhere in the region, such as Northern Kenya, Somalia, Yemen, Southern Sudan and Eritria, as well as further afield across the Sahara (Clack and Brittain 2011: 95–9). Furthermore, successive inhabitations of the Dirikoro setting can also be inferred from other materials encountered by our survey, in particular Middle and Late Stone Age lithic assemblages, Iron Age pottery scatters and monumental stone pillars, burial cairns and stone enclosures of unknown date (Brittain and Clack in press; Clack and Brittain 2010).

Clearly, based on the growing archaeological evidence, the characterisation of this landscape as a wilderness devoid of any longevity of human activity is insecure. Nonetheless, as we show in the following sections, resistance to images of wilderness in the Lower Omo Valley is expected to be strong largely due to the cultural and historical depth and complexity within which it is embedded. The next section continues this discussion and offers an exploration of some the derivations, complexities and resonances associated with wilderness, and describes how, working in concert, they have significantly impacted on representations and attitudes at a variety of scales.



Figure 3. Photograph of two *benna kulugto* cleared of vegetation, outside the village of Ulum Holi.

HISTORICAL AND CURRENT PERSPECTIVES ON WILDERNESS

The idea of African wilderness traditionally has deep roots in conventional Western discourse, 'in the nature of the colonial relationship itself, which allowed Europeans to impose their image of Africa upon the reality of the African landscape' (Anderson and Grove 1984, p. 4), often resulting in a symbolic polarisation between a 'despoiled' Europe and a 'natural' Africa. Henceforth, the characterisation of the Lower Omo Valley as wilderness or wasteland also has historic pedigree.

Exploring the wilderness

From the 1880s, the descriptions of assorted early visitors, especially explorers, military adventurers and travellers, were fragmentary and confusing but, nonetheless, mutually reinforcing; and for a long time these were the only accounts available to regional and global audiences. By comparison to other expeditions to the Lower Omo, the Italian Vittorio Bottego's expedition of 1896 was the most notable in terms of duration and discovery but it coincided with local turmoil as herds had been devastated by rinderpest, and epidemics of smallpox and sleeping sickness had desperately impacted on communities (Turton 1981). Other explorers' descriptions reduced local tribes' cattle raiding and general behaviour to that of savages and the environment to that of a wasteland. The American explorer, Arthur Donaldson Smith made reference to the Mursi's 'war-

like spirit' (1900: 609) and yet also described finding them in a 'flourishing condition' and 'most friendly'. Leading a caravan of conscripted porters and guides from Nepal, India and Somalia in 1899 (Figure 4) he recounted on his return, during a lecture in London to the Royal Geographical Society, that he was frustrated routinely by the environment, locals and members of his expedition. Whilst the ethnocentric attitudes of the time are clearly apparent in this and other accounts, so too are the aggravations and difficulties associated with the harsh realities of the conditions, particularly water shortages, bush fires, poor soils and lack of game.

At the same time, within Ethiopia perception of the Lower Omo became tainted in failed attempts by the Emperor Menelik to extend his territory southwards. Various neutral accounts refer to these ventures as 'Abyssinian raids' (Donaldson Smith 1900: 609) that resulted in a 'country devastated' (Austin 1899, p. 149). Expedition failure owing to the lack of natural resources, epidemic disease, climate and raids, coupled with understandable hostility and distrust on the part of locals, left a somewhat tainted impression in European social memory (e.g. Austin 1902). After a handful more ex-



Figure 4. Photograph of 'locals' and 'aliens' in Mursiland taken during the 1899 expedition of Donaldson Smith.

Pristine Wilderness ...

peditions to demarcate the territorial boundary between the British East Africa and Menelik during 1902–9 the phase of exploration was effectively concluded (see Gwynn 1911, Maud 1904). The lasting impressions of the environment were of emptiness and inhabitability, with primitive and combative tribes. The pervasive nature of these images has ensured their endurance into the present despite, many decades later, the considerable efforts of linguists and anthropologists to ‘humanise’ the place. The resilience of such images is demonstrated in their underlying of present-day conservation agendas.

Conserving the wilderness

Conservation policy and practice has also reinforced the image of *terra nullius*. Amidst the wildernesses of African natural habitats, species and soils are all considered precariously endangered. This ‘crisis in Africa’ manifests a sustained ‘scramble for Eden’ (Anderson and Grove 1987), in which influential Western conservationist agendas largely ignorant of long-established indigenous techniques of survival and environmental management in rural non-industrial locales (Homewood and Rodgers 1987, Watson 2003, Widgren 2004), combine ‘wilderness’ with ‘conservation’ (see Durrant 2007, Hughes 2005). A result of this is that certain environments across the globe have been conceptually transformed into ‘natural heritage’; this derives significance from various celebrated characteristics: being untouched, pristine and timeless. These are contrasted against narratives of resource depletion, contamination and encroachment, more usually associated with human impact. Working in concert with appreciations of universal humanity, shared future and global commons, these characterisations underpin protectionist ethics, otherwise known as ‘fortress conservation’, which often results in negative local realities. In the main, local governments, often with funding from the developed world, strive to demarcate and regulate specific environments in order to curtail infringements and impacts (Brockington 2001, 2004). As virtually all anthropogenic impacts are considered negative, this time and again results in the establishment of national parks and the expulsion or forced resettlement of local communities.

Today Mursi territory exists within and between the Omo and Mago National Parks (Figure 5), although neither has been legally gazetted. The interplay of wilderness, conservation and prohibition is promoted through the park management strategy. For example, in addition to specifying entrance fee and vehicular arrangements, the main ‘welcome sign’ outside of the Mago National Park reads:

Prohibited activities within the park area:

- Collecting wild flora, fauna and their products
- Carrying machine guns
- Those activities that contradict conservation rules and regulations
- Disturbing the park staff and the wilderness

The Mursi live in both parks because they incorporate the best quality grazing and agricultural lands. The Omo National Park (4,068 km²) was designated in 1966 and

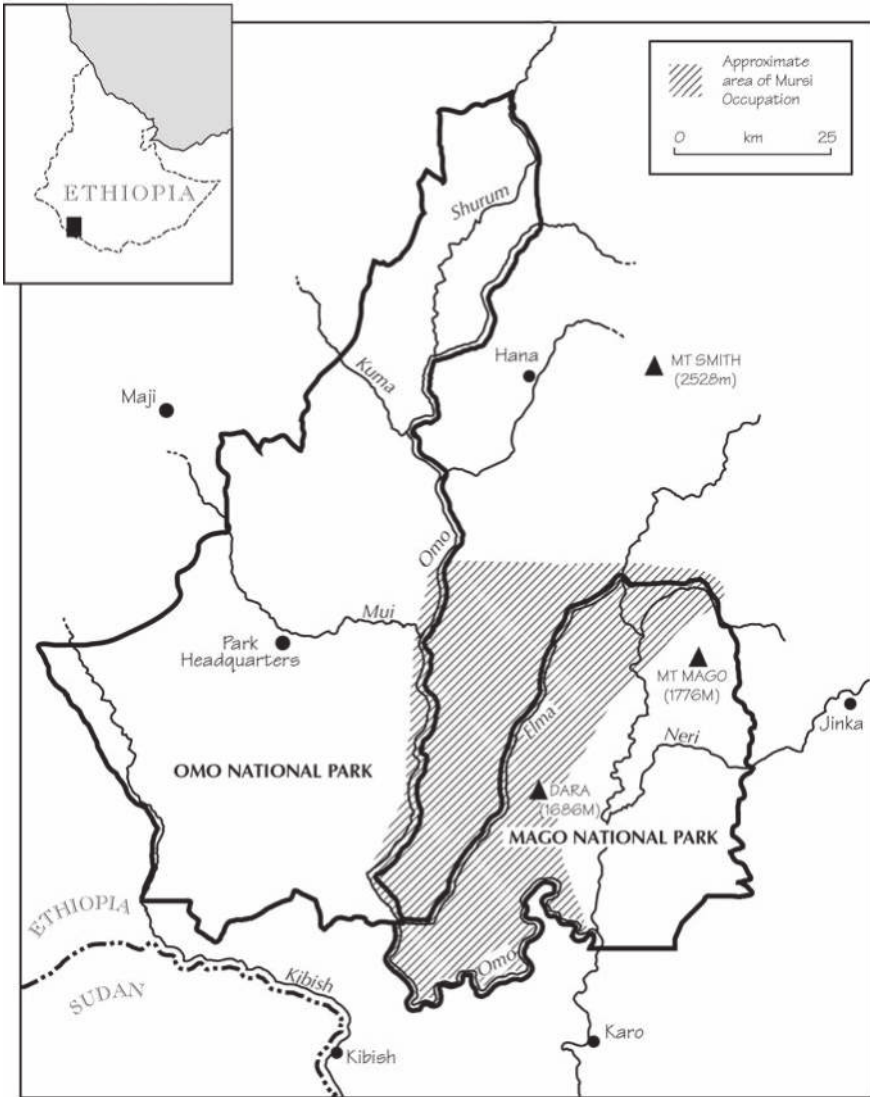


Figure 5. Map of the Mago and Omo National Parks, showing the approximate area of Mursi occupation (Permission: Mursi online – <http://mursi.org>).

the Mago National Park (2,162 km²) in 1978 but problems have abounded since their formation. Indeed, since their origins the parks have been managed by numerous organisations, both domestic and foreign, with recurrent themes concerning the protection of wild game animals and the control of the local inhabitants living within them

(Turton 1987, 2002, 2011). In 1978, a report to the Ethiopian Wildlife Conservation Department recommended the forcible resettlement of the Mursi, whilst in 1995 Ag-riconsulting, the Italian firm conducting the 'Southern National Parks Rehabilitation Project', planned, in the preliminary phase, both to gazette the parks and to resettle any remaining inhabitants. Neither of these objectives was achieved. In 2006, African Parks Foundation (APF), a corporate entity from the Netherlands, signed an agreement with the Ethiopian government to manage the Omo National Park on a 25-year lease. Once again preparations were made for gazettelement. Most notoriously this included a 'demarcation ceremony' whereby non-literate members of local communities were asked to sign, using their thumbprints, documents detailing the park boundaries. This represented the first contact between officials and local inhabitants about the park but, as those present were not given copies of any documents nor advised on the legal implications for their customary land rights and livelihoods, it was clearly a duplicitous engagement. The activities of APF, in particular their lack of consideration for their park's inhabitants, came to the attention of various human rights organisations, which exerted considerable pressure on APF to give formal assurances concerning traditional rights of occupation and use (Mursi Online 2011). These were not forthcoming and in 2008 APF terminated its agreement and handed over management responsibility to the federal government.

National and international incorporation of wilderness

The potted history concerning the administration of the Omo conservation landscape demonstrates the frequency of disharmony between local, regional and global perspectives on wilderness. It also demonstrates the increasing intervention by national and international authorities that will undoubtedly impact upon local identities across Mursiland and its neighbouring regions.

The Mursi were officially 'incorporated' into the Ethiopian state as a buffer zone when Emperor Menelik II established administrative control over the south-western lowlands towards the conclusion of the nineteenth century (Hamilton 1974; Marcus 1994, pp. 104–115). With the revolution of 1974 and the military *Derg* takeover of power, a new period of engagement with the Lower Omo was heralded. As Watson (2009: 173) notes, the *Derg* authorities 'penetrated the structures of government more deeply into the grassroots communities of southern Ethiopia than any regime that had gone before'. Motivated by scientific socialism, the revolutionary government enforced many far-reaching changes, including transformations of local-level state administrative structures, land reform programmes, agricultural reforms and enhancements to the infrastructure. Moreover, focus on collective secular units was manifest in efforts to dismantle the symbolic power of traditional leaders and institutions, although, on occasions, safe, screened forms of diversity were cautiously celebrated (Clapham 1992, James *et al.* 2002). Regime change in 1991, when the *Derg* were violently overthrown and replaced by the Ethiopian Peoples' Revolutionary Democratic Front (EPRDF), again impacted the Lower Omo. A federal constitution was introduced, along the

principles of equitable representation and regional autonomy for sub-national ethno-linguistic groups (see Turton 2006a). In the absence of an obvious dominant group in the south-west of the county, around which a federated regional unit could be formed, 45 smaller groups, including the Mursi, were collected together into the 'Southern Nations, Nationalities and Peoples' Region' (SNNPR). So, whilst the restructuring of Ethiopia has proved successful in many respects, particularly for peace and security, the further division of the SNNPR into zones and *weredas*, with boundaries delineated according to the geographical distribution of languages, has forced locals to make irrevocable choices between identities that had formerly been situationally available to them (Turton 2006b, pp. 20–3). Moreover, efforts to exert greater political control over groups such as the Mursi and to promote the use of Amharic and standardise local languages have been apparent and met with mixed reaction.

Detailing this historical context demonstrates how complex outsider dynamics have operated, ensuring that the Lower Omo Valley has increasingly been perceived as a 'hub' rather than 'periphery'. As a result, various other national and international agencies, motivated by political and economic agendas, have 'found' the Lower Omo Valley and started to exert a succession of influences, the impact of which remains unforeseen, but there is strong reason to doubt that these will enhance regional cultural and ecological diversity. Most of these influences fall within the area of development, from which the benefits are usually experienced to a greater degree outside the region: reserves (concessions and parks), extraction (of bio-fuels and cotton) and power (hydro-electric projects). Further impacts under the banner of development are likely to follow, for clearly they have started to dilute the former 'protection' afforded by the difficulties of asserting administrative control in a 'remote' region. These influences are neither fixed nor static but constantly in flux, manifested against the changing needs and motivations of a range of interested parties but rarely local inhabitants.

In the context of these outsider influences in the Lower Omo Valley, the image of wilderness lies in combination with an interchangeable perception of inhabitant communities either as recent interlopers or as timeless and intimately bound with the landscape. Archaeology's conceptual void concerning the Lower Omo Valley is implicated in the promulgation of the idea of wilderness with these separate perspectives. The dominance of research into human origins has foregrounded concern with hominin–environmental interactions in which the landscape itself became the crucible of humanity where only the fittest, optimal foragers survived to pass on their genes. This may have inadvertently generated a popular viewpoint that the environment of the Lower Omo Valley has largely remained unchanged from the deep time of species evolution and into the present. As such, 'descendent communities' are loosely considered to exist in something akin to the Hobbesian state of nature, as a relic of some distant human past. Henceforth, despite the best efforts of ethnographers, the Mursi and neighbouring ethnic units continue to be perceived as people fixed in time – exotic, primitive and dangerous. In fact, many external actors perpetuate this view, whether

Pristine Wilderness ...

SHAPED BY WAR
PHOTOGRAPHS BY DON McCULLIN

Imperial War Museum North
Free entry
6 February – 13 June 2010

Imperial War Museum North presents the largest ever UK exhibition about the life and work of Don McCullin, one of the world's most acclaimed photographers, marking his 75th year. Many of his seminal photographs for *The Sunday Times* are featured alongside colour photography, new work and personal items on public display for the very first time.

For more than 50 years, McCullin's photographs have shaped our awareness of modern conflict and its consequences on people's lives. His courage and integrity, as well as the exceptional quality of his work, are a continuing inspiration and influence worldwide.

A major new book *Don McCullin: Shaped by War* accompanies the exhibition, published by Jonathan Cape in association with the Imperial War Museum.

Pictured here: A family of the Gosa tribe with their prized possession, an AK-47 assault rifle in Ethiopia, 2002. Above left: Don McCullin by Philippe Verheul, early 1990s. Above right: The camera which shopped a bullet and saved McCullin from injury in Cambodia, 1970.

Event programme
For full details and dates of this special event series and free regular exhibitions from visit www.iwm.org.uk/shapedbywar

In conversation with Don McCullin
Monday 15 March, 6pm
Don McCullin talks about his extraordinary career in photojournalism.

ER/EA case. Booking required on 0943 208 6900 or queytschets.com

Conflict and the camera
Saturday 17 April
Talks and case studies from 12pm
Debate 6pm

Are we in danger of losing photojournalism coverage of key events of our history? Chaired by Paul Hendra, director of Red Eye, panelists include photographers Simon Norfolk and Simon Willmet, Jon Levy, Fahad and Professor David Campbell, Durham University.

ER/EA case. Booking required on 0943 208 6900 or queytschets.com

Integrating photography
Sunday 18 April, 2-5pm, free
Learn how to integrate photography through the work of Don McCullin with Hilary Roberts, exhibition curator.

Free entry
6 February – 13 June 2010
www.iwm.org.uk/shapedbywar

Imperial War Museum North
The Quay, Manchester M17 1T2
0161 834 4000
www.iwm.org.uk/shapedbywar
Open daily: 10am–5pm,
Mar–Oct 10am–6pm

Media partner: **THE SUNDAY TIMES** **THE IRISH TIMES** **THE DAILY MAIL**
Exhibition supported by: **Imperial War Museum North**

Figure 6. Flyer for the 'Shaped by War' exhibition at Imperial War Museum North. Despite assertions to the contrary in the blurb, the Omo tribe is a fiction and the people represented are from the Kara group.

calculatingly or unknowingly, often lumping together the distinctive ethnic groups into a single Omo tribe or culture (Figure 6).

This viewpoint of a timeless people lies in combination with the conservationist presentation of Mursi as a fringe population and recent interloper into an otherwise pristine wilderness. Although these images appear to coexist, they fulfil the requirements of differing agencies that share in equal economic benefit. To use a final example, tourism into the national parks has turned the timelessness of people and landscape wilderness into commodities. Unfortunately the social impact of these unchecked tourism industries in the Lower Omo Valley has not been found to be positive, either from the point of view of development or, in the case of the Mursi, for the preservation of cultural practice and wellbeing (see Abbink 2000, Turton 2004). As Turton (2004: 8) explains, the infiltration of restrictions and exposure from these national and international agencies has over the last thirty years transformed the Mursi view of themselves from the physical and moral centre of the world to a 'small, localised, poor, technologically backward, and relatively powerless group living on the margins of the Ethiopian state'. 'Local' in this context is clearly not in reference to a geographically defined community but to communities whose movement is spatially restricted by contrast with the open non-space of globalised modernity (Augé 1995).

Importantly, archaeology does not stand apart from outsider dynamics and practitioners are advised to consider the impacts and potential unintended consequences of their well-meaning endeavours.

PARTICIPATORY ARCHAEOLOGY IN MURSILAND

Being local in a globalised world may eventually challenge the Mursi sense of place in the world, if it has not already done so, including collective memory of their past as well as the perceived direction of their future. Significantly, participative archaeology working closely with local communities is envisaged as providing 'a broader continuity from prehistoric past to present' (Field *et al.* 2000: 46). However, to echo an earlier statement, participative archaeology in Mursiland is unlikely to mirror the character of community archaeologies that form the bulk of writings on this topic from contexts where modern Western social dynamics are more clearly established. In working with the Mursi, a very different set of social strategies must be adopted before sustainable participation can be implemented. Moreover, accountability of archaeological research is legally bound towards zonal, regional and, ultimately, national representatives who are required to oversee fieldwork and whose incorporation into the participatory process is clearly essential for positive outcomes.

In Mursiland it is beneficial to regard the participatory encounter as intermittent; it simply is not possible, at least in these early stages of the current project, to enrol local community participation at every stage of project design, implementation and dissemination. The cultural and conceptual distance between the three groups is, at present, too vast to let it be announced that complete integration has been achieved. For example, whilst from an academic point of view there is comfort in linking understanding of the past to the maintenance and formation of identities in the present, Mursi valuing of a tangible record of heritage (that is, 'our' notion of heritage), such as 'stones people put there long ago', is less than straightforward to gauge. An important aspect of our research is therefore aimed towards an understanding of the value of the tangible past in the Mursi present. From the viewpoint of archaeology, it is therefore beneficial to approach the participatory encounter between communities as an engagement that takes place within multiple contact zones in which different forms of knowledge or expert systems are called upon for understanding the world. The challenge is to identify common ground upon which local traditional forms of knowledge and Western scientific discourse may cohabit. The principle behind this is a decentring of archaeological knowledge, and the opening of new possibilities for understanding the past and its role in the present.

It is therefore within contact zones that creative possibilities are formed and trust between partners solidified (Figure 7). This is important when community knowledge regarding the impacts of outsider influence is in its infancy. Most Mursi openly acknowledge basic ignorance of the character, intention and mechanics of the world outside the Lower Omo Valley. So whilst we may consider the benefits within



Figure 7. Photograph of local warrior using project surveying equipment.

the contribution of archaeological research to the debate on the impacts of rangeland communities on local environments, for example, and by implication its potential for buttressing contemporary identities, Mursi recognise participation with archaeological researchers from the outside world as an opportunity for their 'voice' and concerns to be raised in appropriate fora. As one elder remarked poignantly during the first season of fieldwork,

You know more things about the outside world than we do so you must help us ... you must tell the history of the Mursi to the people of your country. You can tell all people about this land, the Mursi, the cattle, the sickness and problems and you can tell them of the *benna kulugto*.

In response to this and similar requests a museum exhibit on the project's research aims and findings, along with dialogue from Mursi representatives, is undergoing design for display in Jinka, the nearest town from which tourists embark to the National Parks. In peopling the past whilst outlining some present issues it is hoped

that this will be a first encounter with a Mursi worldview for many tourists, fostering respect for traditional practices and etiquette in intercultural dialogue between Mursi and outsider. Moreover, a charitable Trust is being established to support sustainable aid and locally-defined development schemes. These embody the same participatory principles for maximising benefit to water and land resources in times of difficulty and education appropriate to the needs and lifestyle of Mursi communities (Besette 2006, Drijver 1992, Rahman 1991). Websites for both the archaeological project (www.mursi-archaeology.co.uk) and the Trust (www.elmatrust.org.uk) are obvious communication devices for these schemes but remain inaccessible to most Mursi communities.

CONCLUSION

This chapter has offered an outline of a project working in the spirit of participatory research, adapting the experiences of published models to the context of an arid landscape and mobile pastoral community. Across desert environments, an image of natural wilderness perpetuates the view that human inhabitation is recent and perhaps out of sequence with the natural dynamics of ecological systems. The image of wilderness has deep roots in policy development and popular imagination and pervades issues of conservation. The programme of field investigation in Mursiland has been initiated to challenge many of these assumptions concerning the Lower Omo Valley and is establishing a participatory approach in response to socio-political and economic conditions that have been identified both within and outside local communities.

Significant progress towards greater participation between researcher, local community and heritage authorities have been made in the last three years but participation at all levels requires considerable work, commitment and recognition of changing circumstances. In embracing respect for plurality, there is great potential for working towards a simultaneous release from the wilderness for archaeology and local inhabitants in the Lower Omo Valley.

Postscript

After the writing of this paper the Ethiopian government released plans for the implementation of a major sugar plantation scheme along the banks of the Lower Omo River. At this stage, due to the proposed size of this development initiative and the lack of available information, most impacts are impossible to discern. Nonetheless it is clear this landscape intervention will have significant bearing upon the broader context of the participative programme described herein.

ACKNOWLEDGEMENTS

Sincere gratitude is owed to the local community and those other participants who have helped the authors negotiate the contact zones in Mursiland, including Alberto Arzoz, Emily Bennett, Uligidangi Bidameri, Juan Salazar Bonet, Catherine Brinkworth,

Patrick Clack, Demerew Danye, Karatiramai Dunige, Kate Fayers-Kerr, Will Hurd, Andrew Lloyd-Harris, Olitharali Olibwi, Olirege Rege, Jess Smith-Lamkin and Tadele Solomon. Finally, especial thanks are due to David Turton for sharing so generously with us his archives, knowledge and experience. Seasons in the field were funded by the Christensen Fund, Cambridge and Oxford Universities and the British Institute in Eastern Africa. Figures 2 and 5 are reproduced with the permission of Mursi Online (<http://mursi.org>). Authorisations to conduct fieldwork were received from the ARCC and appropriate local representatives.

REFERENCES

- Abbinck, J. (2000). 'Tourism and its discontents: Suri-tourist encounters in southern Ethiopia'. *Social Anthropology* 8 (1): 1–17.
- Anderson, D. and R. Grove (1987). 'Introduction: the scramble for Eden: past, present and future in African conservation', in D. Anderson and R. Grove (eds.) *Conservation in Africa: people, policies and practice*. Cambridge: Cambridge University Press. pp.1–12.
- Asfaw, B., Y. Beyene, S. Semaw, G. Suwa, T. White and G. WoldeGabriel (1991). 'Fejej: a new palaeoanthropological research area in Ethiopia'. *Journal of Human Evolution* 21: 137–43.
- Atalay, S. (2010). "'We don't talk about Çatalhöyük, we live it": sustainable archaeological practice through community-based participatory research'. *World Archaeology* 42 (3): 418–29.
- Augé, M. (1995). *Non-places: Introduction to an Anthropology of Supermodernity*. London: Verso.
- Austin, H.H. (1899). 'Journeys to the north of Uganda'. *Geographical Journal* XIV: 148–52.
- Austin, H.H. (1902). *Among Swamps and Giants in Equatorial Africa: An Account of Surveys and Adventures in Southern Sudan and British East Africa*. London: C. Arthur Pearson.
- Barker, G. and D. Gilbertson (eds.) (2000). *The Archaeology of Drylands*. London: Routledge.
- Bessette, G. (ed.) (2006). *People, Land and Water. Participatory Development Communication for Natural Resource Management*. London: Earthscan and the International Development Research Centre.
- Brittain, M.W.R. and T.A.R. Clack (in press). 'Archaeological investigations in Mursiland, S.W. Ethiopia, second interim report'. *Nyame Akuma* 75.
- Brittain, M.W.R. and T.A.R. Clack (2007). 'Archaeology and the media: An introduction', in T.A.R. Clack and M.W. Brittain (eds.) *Archaeology and the Media*. Walnut Creek, CA: Left Coast Press. pp. 1–65.
- Brockington, D. (2001). *Fortress Conservation: the Preservation of the Mkomazi Game Reserve, Tanzania*. Oxford: James Currey.
- Brockington, D. (2004). 'Community conservation, inequality and injustice: myths and power in protected area management'. *Conservation and Society* 2 (2): 411–32.
- Brown, F. (1975). 'Barbed bone points from the Lower Omo Valley, Ethiopia'. *Azania* 10: 144–8.

- Bruchac, M., S. Hart and H. Wobst (eds.) (2010). *Indigenous Archaeologies: A Reader on Decolonization*. Walnut Creek, CA: Left Coast Press.
- Butzer, K.W. (1971). *Recent History of an Ethiopian Delta: The Omo River and the Level of Lake Rudolf*. Chicago, IL: The University of Chicago Department of Geography Research Paper No. 136.
- Chataway, C. (2001). 'Negotiating the observer–observed relationship: participatory action research', in D. Tolman and M. Brydon-Miller (eds.) *From Subjects to Subjectivities: A Handbook of Interpretative and Participatory Methods*. New York and London: New York University Press. pp. 239–55.
- Clack, T.A.R. and M.W.R. Brittain (2010). 'Excavations and surveys in Mursiland, S. W. Ethiopia: a preliminary fieldwork report'. *Nyame Akuma* 73: 65–76.
- Clack, T.A.R. and M.W.R. Brittain (2011). 'Place-making, participative archaeologies and Mursi megaliths: some implications for aspects of pre- and proto-history in the Horn of Africa'. *Journal of Eastern African Studies* 12 (1): 85–107.
- Clapham, C. (1992). 'The Socialist experience in Ethiopia and its demise', in A. Hughes (ed.) *Marxism's Retreat from Africa*. London: Frank Cass. pp. 105–25.
- Clarke, A. (2002). 'The ideal and the real: cultural and personal transformations of archaeological research on Groote Eylandt, northern Australia'. *World Archaeology* 34 (2): 249–64.
- Colchester, M. (2004). *Salvaging Nature: Indigenous peoples, Protected Areas and Biodiversity Management*. Montevideo: World Rainforest Movement.
- Colwell-Chanthaphonh, C. and T. Ferguson (eds.) (2008). *Collaboration in Archaeological Practice: Engaging Descendent Communities*. Walnut Creek, CA: AltaMira Press.
- Donaldson-Smith, A. (1900). 'An expedition between Lake Rudolf and the Nile'. *Geographical Journal* XVI: 600–625.
- Drijver, C.A. (1992). 'People's participation in environmental projects', in E. Croll and D. Parkin (eds.) *Bush Base: Forest Farm: Culture, Environment and Development*. London: Routledge. pp. 131–145.
- Durrant, J.O. (2007). *Struggle over Utah's San Rafael Swell: Wilderness, National Conservation Areas and National Monuments*. Tucson, AZ: University of Arizona Press.
- Field, J., J. Barker, R. Barker, E. Coffey, L. Coffey, E. Crawford, L. Darcy, T. Fields, G. Lord, B. Steadman and S. Colley (2000). 'Coming back: Aborigines and archaeologists at Cud-die Springs'. *Public Archaeology* 1: 35–48.
- González-Ruibal, A. (2008). 'Time to destroy: an archaeology of supermodernity'. *Current Anthropology* 49 (2): 247–79.
- Gowlett, J. (1990). 'Archaeological studies of human origins and early prehistory in Africa', in P. Robertshaw (ed.) *A History of African Archaeology*. London: James Currey. pp. 13–38.
- Gwynn, C.W. (1911). 'A journey in southern Abyssinia'. *Geographical Journal* 38: 113–39.
- Hamilakis, Y. and A. Anagnostopoulos (2009). 'What is archaeological ethnography?' *Public Archaeology* 8 (2–3): 65–87.
- Hamilton, D.N. (1974). 'Ethiopia's frontiers: the boundary agreements and their demarcations 1896–1956'. Unpublished D.Phil. thesis, University of Oxford.

Pristine Wilderness ...

- Hiscock, P. and L.A. Willis (2005). 'Pleistocene settlement of deserts from an Australian perspective', in P. Veth, M. Smith and P. Hiscock (eds.) *Desert Peoples: Archaeological Perspectives*. Oxford: Blackwell. pp. 34–57.
- Homewood, K. and W.A. Rodgers (1987). 'Pastoralism, conservation and the overgrazing controversy', in D. Anderson and R. Grove (eds.) *Conservation in Africa: People, Policies and Practice*. Cambridge: Cambridge University Press. pp. 111–28.
- Hughes, D.M. (2005). 'Third nature: making space and time in the Great Limpopo Conservation Area'. *Current Anthropology* 20 (2): 157–84.
- James, W., D. Donham, E. Kurimoto and A. Triulzi (eds.) (2002). *Remapping Ethiopia: Socialism and After*. Oxford: James Currey.
- Kassa, T. (2008). 'Aspects of administrative history of Lower Omo 1941–1974: "Nomadic Tax" and border dispute'. Unpublished M.Phil. thesis, Mekelle University.
- Mapunda, B. and P. Lane (2004). 'Archaeology for whose interest – archaeologists or the locals?' in N. Merriman (ed.) *Public Archaeology*. London: Routledge. pp. 211–23.
- Marcus, H.G. (1994). *A History of Ethiopia*. London: University of California Press.
- Matthews, C.N. and M. Palus (2009). 'About face: on archaeology, heritage, and social power in public', in L. Mortensen and J. Hollowell (eds.) *Ethnographies and Archaeologies: Iterations of the Past*. Orlando, FL: University of Florida Press. pp. 131–49.
- Middleton, N. and D. Thomas (1997). *World Atlas of Deserts*. London: Arnold.
- Moser, S., D. Glazier, J. Phillips, L. Nasser el Nemr, M. Mousa, R. Aiesh, S. Richardson, A. Connor and M. Seymore (2002). 'Transforming archaeology through practice: strategies for collaborative archaeology and the Community Archaeology Project at Quesir, Egypt'. *World Archaeology* 34 (2): 220–48.
- Mursi Online (2011). 'The Omo and Mago National Parks: an unresolved problem'. <http://www.mursi.org/national-parks> (Accessed 14 March 2011).
- Petras, E. and D. Porpora (1993). 'Participatory research: three models and an analysis'. *The American Sociologist* 24: 107–26.
- Powys, L. (1925). *Black Laughter*. London: Jonathan Cape.
- Pyburn, A. (2003). 'Archaeology for a new millennium: the rules of engagement', in L. Derry and M. Molloy (eds.) *Archaeologists and Local Communities: Partners in Exploring the Past*. Washington, DC: Society for American Archaeology. pp. 167–84.
- Rahman, M.A. (1991). 'Glimpses of the "other Africa"', in O. Fals-Borda and M. Rahman (eds.) *Action and Knowledge: Breaking the Monopoly with Participatory Action-research*. London: Intermediate Technology Publications. pp. 84–108.
- Ross, A., K. Sherman, J. Snodgrass, H. Delcore and R. Sherman (2011). *Indigenous Peoples and the Collaborative Stewardship of Nature: Knowledge Binds and Institutional Conflicts*. Walnut Creek, CA: Left Coast Press.
- Sabloff, J. (2008). *Archaeology Matters: Action Archaeology in the Modern World*. Walnut Creek, CA: Left Coast Press.
- Smith, L. (2004). *Archaeological Theory and the Politics of Cultural Heritage*. London: Routledge.

- Smith, L. and E. Waterton (2009). *Heritage, Communities and Archaeology*. London: Gerald Duckworth & Co.
- Smith, M., P. Veth, P. Hiscock and L.A. Wallis (2005). 'Global deserts in perspective', in P. Veth, M. Smith and P. Hiscock (eds.) *Desert Peoples: Archaeological Perspectives*. Oxford: Blackwell. pp. 1–13.
- Turton, D. (1979). 'A journey made them: territorial segmentation and ethnic identity among the Mursi', in L. Holy (ed.) *Segmentary Lineage Systems Reconsidered*. Belfast: Queen's University Papers in Social Anthropology. pp. 119–43.
- Turton, D. (1981). 'Explorations in the Lower Omo Valley of southwestern Ethiopia between 1890 and 1910', in M. Caravaglios (ed.) *L'Africa ai tempi di Daniele Comboni*. Rome: Atti de Congresso Internazionale di Studi Africani, Istituto Italo-Africano e Missionari Comboniani. pp. 202–15.
- Turton, D. (1987). 'The Mursi and national park development in the Lower Omo Valley', in D. Anderson and R. Grove (eds.) *Conservation in Africa: People, Policies and Practice*. Cambridge: Cambridge University Press. pp. 169–86.
- Turton, D. (1988). 'Looking for a cool place: the Mursi, 1890s–1980s', in D. Anderson and D. Johnson (eds.) *The Ecology of Survival: Case Studies from Northeast African History*. London: Westview Press. pp. 261–82.
- Turton, D. (2002). 'The Mursi and the elephant question', in D. Chatty and M. Colchester (eds.) *Conservation and Mobile Indigenous Peoples: Displacement, Forced Settlement and Sustainable Development*. Oxford: Berghahn. pp. 97–118.
- Turton, D. (2004). 'Lip-plates and the "people who take photographs": uneasy encounters between Mursi and tourists in southern Ethiopia'. *Anthropology Today* 20 (3): 3–8.
- Turton, D. (ed.) (2006a). *Ethnic Federalism: The Ethiopian Experience in Comparative Perspective*. Oxford: James Currey.
- Turton, D. (2006b). 'Introduction', in D. Turton (ed.) *Ethnic Federalism: The Ethiopian Experience in Comparative Perspective*. Oxford: James Currey. pp. 1–31.
- Turton, D. (2011). 'Wilderness, wasteland or home? Three ways of imagining the Lower Omo Valley'. *Journal of Eastern African Studies* 5 (1): 158–176.
- Veth, P., M. Smith and P. Hiscock (eds.) (2005). *Desert Peoples: Archaeological Perspectives*. Oxford: Blackwell.
- Watson, E.E. (2003). 'Examining the potential of indigenous institutions for development: a perspective from Borana, Ethiopia'. *Development and Change* 35: 287–309.
- Watson, E.E. (2009). *Living Terraces in Ethiopia: Konso Landscape, Culture and Development*. Oxford: James Currey.
- Widgren, M. (2004). 'Towards a historical geography of intensive farming in Eastern Africa', in M. Widgren and J. Sutton (eds.) *Islands of Intensive Agriculture in Eastern Africa: Past and Present*. Oxford: James Currey. pp. 1–18.

PART III. CHANGING PROBLEMS

CONSERVING HISTORY IN CHANGING ARID ENVIRONMENTS: A GEOMORPHOLOGICAL APPROACH

Lisa Mol and Heather Viles

A thing of beauty is a joy forever

John Keats

INTRODUCTION

One brief glance at the UNESCO World Heritage List (August 2010) shows that currently eighteen cultural sites are ‘under severe threat’. Of these, fourteen are situated in arid environments. The harsh nature of these climates in combination with the often inaccessible and unstable nature of their geographical location means that cultural heritage is often difficult to monitor, manage and conserve. Of the number of threats described in the ‘Case studies on Climate Change and World Heritage’ report (UNESCO 2007), many apply specifically to arid regions – such as increased erosion and weathering through desertification and salt weathering, ground water fluctuations, changes in wetting and drying cycles and extreme temperature fluctuations.

Whilst our knowledge of the causes of decay and how to control it is continually progressing, monuments are deteriorating at an alarming rate. Many stone monuments, which are a testimony to and record of our history and cultural development, are now at risk of fading away into the past rather than standing tall for future generations to see. Even when deterioration does not appear to be catastrophic, weathering processes are slowly chipping away at statues, fountains, doorways and foundations. This is a problem for stone-built heritage in any environment; Durham Cathedral (UK), for example, recently had to be completely surveyed and substantial parts of its structure had to be replaced due to honeycombing and flaking of the stone work (Attewell and Taylor 1990). Similarly, pollution has created problems for the future of the Cathedral of Cadiz, Spain (Torfs and Van Grieken 1997) while sandstone weathering is damaging monuments such as Giza, Egypt (Fitzner *et al.* 2003). In addition, numerous reports are available discussing rapid deterioration of well-known heritage such as Petra, Jordan (Heinrichs 2008) and Angkor Wat, Cambodia (Uchida *et al.* 2000). What makes weathering in arid environments different from weathering in temperate climates is the astonishing process rate. Research has shown, for example, that test blocks of stone

left in the Namib Desert virtually dissolved over the span of a few years (Goudie *et al.* 1997, Viles and Goudie 2007). Furthermore, there are many examples of structures such as newly built housing and pipelines decaying badly in a matter of years (Goudie and Viles 1997).

Arid environments are home to a vast range of different heritage sites; these vary from the stunning remains of Babylon (Iraq), where wholly intact temples, murals and houses can still be seen, to the fantastic rock art sites of the Tadrat Acacus (Libya) and the extensive ruins of the trade city Paquimé Casas Grandes (Mexico). The entire area just north of the Tropic of Cancer is home to a vast number of UNESCO Cultural Heritage Sites, showing not only the density but also the importance of the historical and archaeological sites found in this region.

The questions that beg to be answered are 'How bad is stone weathering in arid environments, what can we do about it and what implications does it have for the future enjoyment of stone heritage?' Placing heritage in the larger picture of war, food and water shortages and lack of education opportunities, how important is it to focus our efforts on understanding the decay of heritage? Keats' statement could actually go a long way towards explaining the importance of preserving cultural heritage. Many of these structures are 'things of beauty', positive additions to our cities and landscapes and reminders of cultural achievements. The ones that are not obviously beautiful but bear historical significance such as the barracks at Auschwitz also provide an important reminder of our past. Not only can joy be found in the aesthetically pleasing structures, structures such as Auschwitz also often remind us of the ugly parts of history, events that should never be repeated. They may not be able to solve worldwide problems, but they can act as a reminder to prevent future events that should never take place.

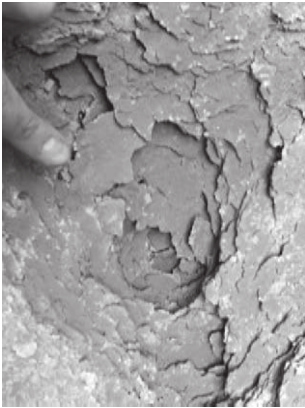

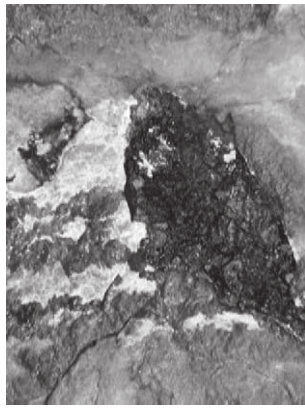
STONE WEATHERING, A REALISTIC THREAT?

As mentioned previously, stone weathering is a widely researched topic in which there has been significant progress over the past decade or so. Several international research projects have been set up for the further understanding of heritage deterioration and conservation. National and international organisations such as English Heritage, the Getty Conservation Institute and UNESCO focus on managing heritage sites while research projects such as the EU-funded NOAH's Ark Project have been set up to further collaboration and interdisciplinarity within stone weathering research.

So what are the primary processes that affect stone heritage in arid environments? Goudie and Viles (1997) have shown that salt weathering is prevalent in a wide geographical variety of arid areas. The destructive nature of soluble salts in combination with high evaporation rates causes high levels of salt to be mobilised within the rock surface and subsurface, creating a hostile environment in which rock weathering is rapid and often catastrophic. However, salt weathering is only one of a larger set of weathering processes. Table 1 shows an overview of the most common weathering processes and key research published on each process.

Conserving History in Changing Arid Environments

Table 1. Overview of rock weathering processes and examples of research.

| Weathering Process | Sub-type | Research examples (further reading) |
|--|---|--|
| Physical/Mechanical  | <i>Thermal expansion</i> Contraction and expansion of rock masses by temperature fluctuations | Siegesmund <i>et al.</i> (2002) Hall and Hall (1991) |
| | <i>Frost weathering</i> Shattering of minerals by continual fluctuations of temperatures around zero °C | McGreevy and Whalley (1985) Matsuoka (2001) |
| | <i>Salt weathering (haloclasty)</i> Disintegration of rocks by saline solution seeping into cracks and joints | Goudie and Viles (1997) Robinson and Williams (2000) |
| | <i>Insolation weathering</i> Solar energy induced stress on rock surface | Singh (1988) McCabe <i>et al.</i> (2006) |
| | <i>Hydration weathering</i> Wetting and drying of rock leading to expansion and contraction | Day (1994) Hall and Hall (1996) |
| Chemical  | <i>Solution (chemical denudation)</i> Decomposition of minerals by solution in water | Welch and Ullman (1996) Sherlock <i>et al.</i> (1995) |
| | <i>Hydrolysis</i> Replacement of metal cations (most commonly K ⁺ , Na ⁺ , Ca ⁺ and Mg ⁺) in a mineral lattice by H ⁺ ions and the combining of these released cations with hydroxyl OH ⁻ ions, causing disintegration of the mineral structure of the rock | Pope <i>et al.</i> (1995) Matsuoka (1995) |
| Biological  | <i>Lichen and mosses</i> These perform a dual role by creating a protective cover but also a damaging micro-environment through altered chemistry, temperature and intrusion in the actual rock face | Winchester (2004) Carter and Viles (2005) |
| | <i>Bacteria, algae and fungi</i> Geochemical agents in the upper lithosphere, mobilising mineral constituents with inorganic or organic acids or ligands they excrete, as well as promote rock weathering by redox attack of mineral constituents such as Fe or Mn | Ehrlich (1998) Hoffland <i>et al.</i> (2004) |

The range of weathering processes presented here shows the large number of deteriorating circumstances built heritage is subjected to on a day-to-day basis. These processes will be present in virtually every geographical location; however the intensity of each individual process will vary according to environmental circumstances. This includes factors such as exposure to sun, rain and degree of temperature fluctuations as well as exposure to pollution. However, a secondary category of threats does need to be briefly discussed. Physical contact with humans, such as chemicals deposited by sweat, bike handles and even shrapnel in armed warfare zones can do significant damage.

A rather shocking example of the impact of human interference and usage of weapons in arid environments is the Buddhas of Bamiyan (Afghanistan) in March 2001. These 1,700-year-old statues were destroyed because of what has been described as fanatic religious iconoclasm (Francioni and Lenzerini 2006) using a large array of weapons, such as anti-tank missiles and dynamite. However, the problems do not cease with the total destruction of these irreplaceable objects. The high impact blasting has left the entire cliff face unstable and has made the preservation of the remnants of the Buddhas and possible restoration of the sites very difficult (Margottini 2004). The resulting rock face scars are vulnerable to weathering processes as well as catastrophic collapse due to the wider slope instabilities.

Thankfully incidents such as this are rare and heritage is acknowledged to be an important part of the recording of human development. The far larger challenge is to understand the processes which are deteriorating our heritage, developing techniques that will monitor *in situ* effectively and reliably and collecting an array of conservation and restoration techniques to preserve our heritage for future generations.

RESEARCH AND METHODS: HOW MUCH DO WE KNOW AND WHAT CAN BE DONE?

Weathering studies used to be primarily the domain of soil scientists, geomorphologists and geochemists. However, in recent decades a large number of disciplines have taken an interest in understanding these processes. These include archaeologists, architects, engineers and conservators (Pope 2000a). A large number of laboratory as well as field studies have been undertaken to further our understanding of stone weathering in arid environments. This work builds on pioneering fieldwork such as Blackwelder's observations of exfoliation (1925) and Goldich's analysis of chemical changes during weathering of rocks (1938). Winkler (1966) identified a number of important agents of weathering in stone, effectively linking chemical decay and the role of biological activity in weathering rates, followed by his 1987 work on weathering rates which identified the complex interaction of different weathering processes (Winkler 1987). In recent years the techniques and equipment available to researchers have consistently become more sophisticated. Research, both in the laboratory and in the field, has greatly improved our understanding of weathering processes. Methods for investigating, for example, rock fracturing (Liu *et al.* 2007), spalling (Sharmeen and Willgoose 2006),

flaking (Dragovich 1967, Benito *et al.* 1993) and salt weathering (Viles and Goudie 2007), have increased tremendously in availability and accuracy in the past two decades.

In particular, sandstone weathering has become an often-researched field (Turkington and Paradise 2005). This soft stone is particularly susceptible to rapid weathering processes such as flaking and crumbling. Fitzner *et al.*'s work (2003) in Luxor, Egypt, showed a wide range of weathering features within a relatively small area. Similarly, Sancho *et al.* (2003) show that sandstone, in this case in the Ebro basin (Spain), exhibits particularly rapid weathering rates. Previous work by Mol and Viles (2010) has shown that not only external factors, such as temperature fluctuations and precipitation, but also internal factors, such as internal moisture behaviour, play an important role in the surface weathering rates of sandstone. Internal moisture is commonly found in both natural rock and building stone and is maintained by capillary rise of groundwater as well as sources within rock outcrops, such as infiltrated precipitation travelling along bedding planes.

Research has shown that especially salt weathering is a destructive force, causing accelerated flaking and exfoliation of the surface (Goudie and Viles 1997, Kuchitsu *et al.* 2000, Mottershead *et al.* 2003, Smith *et al.* 2005; Hosono *et al.* 2006). Figure 1 shows the impact of salt weathering at the granite inselberg of Mirabib, central Namib Desert. These inselbergs within Namibia are home to important archaeological sites such as extensive rock art sites and other evidence of early-human populations.



Figure 1. Salt weathering of a granitic inselberg, Namibia. Photograph: Heather Viles

Many tools are now available to measure weathering of rock surfaces. We will briefly discuss a small selection to give an overview of the wide range of methods.

The *Schmidt Hammer* is a well-known method that has been employed in measuring rock surface hardness for many decades now. It measures rock surface hardness by measuring the rebound of a mass off the rock wall, a low rebound measurement indicating low rock hardness and a high measurement indicating a hard surface. Various studies have successfully employed this method (Goudie 2006), both in the field (Viles and Goudie 2004, Greco and Sorriso-Valvo 2005) and laboratory (Aydin and Basu 2005, Demirdag *et al.* 2009) situations. To follow up this method a new set of devices has been used which work along the same rebound principle but use far smaller impacts and can therefore be used on more fragile surfaces. The *Equotip* and its little brother the *Piccolo* are handheld devices that measure rock surface hardness in the field, giving the researcher a method for quantifying rock surface hardness and by implication the degree and spatial variability of weathering of the surface (Aoki and Matsukura 2007, Aoki and Matsukura 2008, Viles *et al.* 2010).

To survey small-scale changes in surface weathering, a range of methods are available. The most common of these are *laser scanning* and *photography*. Yilmaz *et al.* (2007) for example, surveyed an eighteenth century heritage building in Konya (Turkey) both before and after two devastating fires and used the photographs to model the damage. Similarly, Thornbush and Viles (2004) surveyed the discolouration and associated weathering of soiled limestone surfaces in Oxford, England. Using this technique, the researcher can build up a database of images, which can be overlain to identify particularly active weathering areas (Lim *et al.* 2010). This data can be taken further with *photogrammetry*. This is a technique which builds up 3-D models of objects by determining the 3-D coordinates of an object, in this case a heritage structure, by combining photos taken at different angles (Fujii *et al.* 2009, Sturzenegger and Stead 2009). Laser scanning works on much the same principle but uses reflection of a laser beam to build up a 3-D image of a surveyed site. By overlaying time-lapse images the researcher can calculate which areas have deteriorated (Birginie and Rivas 2005, McCabe *et al.* 2010). In addition *infrared thermometry* is often used in combination with these methods, as differences in temperature often indicate changes in weathering crust or moisture content, as well as surface response to changing environmental conditions (Hall *et al.* 2007).

Additional *in situ* measurements that are often employed include humidity and saturation measurements. Saturation of the near-surface can be measured using handheld moisture meters such as the *Protimeter* (Galdieri and Alva 1981, Akiner *et al.* 1992, Lai and Tsang 2008) or an *FMW* (Forsén and Tarvainen 2000). These use resistivity and capacitance measurements to determine near-surface relative moisture content (FMW) and saturation (Protimeter). Humidity can be monitored using, for example, probes to monitor in-sample humidity levels (Basheer and Nolan 2001, Gómez-Heras *et al.* 2006) or external monitoring devices such as hygrometers (Cheng *et al.* 2010). All of these methods are then compared against data collected by *weather stations* (where these

have been installed) to determine the importance of the measurements in relation to environmental conditions (see for example Viles 2005).

Once fieldwork is completed, there is a large range of laboratory methods that can be employed to analyse samples, inspect sample surface and test material properties. For example, *microscopy* is often used to take initial images of the weathered surface, as a first step towards understanding the weathering processes that have affected that particular piece of material. Further imaging can be carried out, using for example *scanning electron microscopy (SEM-imaging)*. This method uses a higher resolution and depth of field than the conventional optical microscope. It can be used to find characteristic signals that provide information on material type, weathering and colonisation of the surface (Herrera and Videla 2009). Chemical analysis is also readily available, its methods varying from highly complex technology (such as *Dionex instruments* – Ryu *et al.* 2008 – and *X-ray diffraction (XRD)* – Török 2003) to simpler methods such as determining biological content through peroxide reactions.

ELECTRICAL RESISTIVITY TOMOGRAPHY: A CASE STUDY IN SOUTH AFRICA

There is, however, one particular method we want to discuss in greater detail as it is a good example of the technological advances geomorphology, and weathering studies in particular, have made. It also illustrates the complex interplay between internal and external processes.

Electrical Resistivity Tomography (ERT) applies electrical currents to a rock face, and measures the resulting voltage to determine the resistivity. A transect can be set up on the rock face using medical ECG electrodes to provide contact with the rock face. Currents applied between progressively wider spaced electrode pairs allow the operator to build up a 2-D profile resistivity distribution, from which a most-likely distribution of resistivity is derived using the inversion programme RES2DInv (for more information on this method see Mol and Preston 2010). Resistivity of a porous body is highly affected by its moisture content and thus this resistivity distribution is used to assess which areas in the rock face harbour relatively large amounts of water, where the flow paths are and how these change over time. However, additional factors such as temperature and salt content changes, which are known to affect resistivity measurements (Cassiani *et al.* 2006, de Franco *et al.* 2009, Kemna *et al.* 2002), need to be considered when interpreting ERT measurements. Using additional methods, such as an Equotip, these changes can be correlated to surface weathering, creating a clearer picture of the influence of internal moisture on surface weathering.

This method was used to assess the internal moisture distribution of Clarens sandstone in the Golden Gate Highlands National Park, KwaZulu-Natal (South Africa). The Park is situated in the foothills of the Drakensbergen and consists of rolling hills with areas of exposed sandstone. The area is famous for its mushroom formations, created by the differential weathering of the soft Clarens sandstone and the much more

resilient basalt capping. The subsequent shelter formation has been used by the San for shelter and as a canvas for rock art. Unfortunately the rock face in these shelters is prone to crumbling, flaking and crack formation, threatening the canvas of the rock art (see Figure 2). Because their rock faces are generally sheltered from direct exposure to rain and sunshine, they make ideal study sites for internal processes.

Clarens sandstone is grainy, friable and generally prone to high weathering rates. Its porous nature allows for continuous flow of moisture through the rock face. These flows are concentrated in outlets on the rock surface, where the moisture leaves the rock through small honeycomb-type outlets. This creates an environment in which cyanobacteria thrive, colonising the pockets underneath semi-detached flakes and building substantial colonies. These are joined by algal colonies, predominantly situated directly by the moisture outlets. This dynamic environment creates a problem for the rock art situated in the area, as detachment of the rock surface means an immediate and irrevocable loss of the rock art.

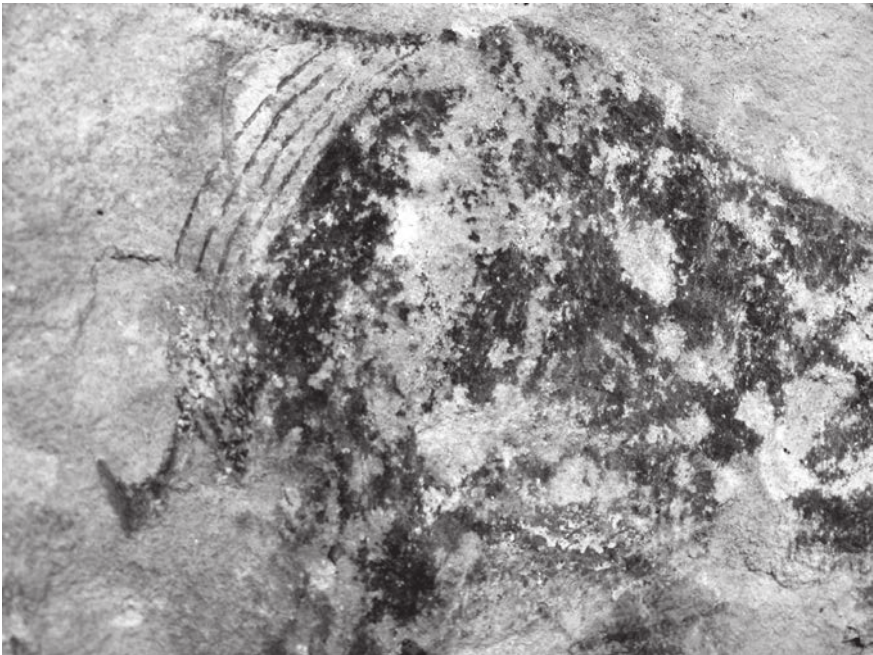


Figure 2. Damaged rock painting in the Golden Gate Highlands National Park, showing the neck and part of the back of an eland. Photograph: Lisa Mol.

Our measurements showed that there is a direct correlation between internal moisture accumulation and surface weathering (Mol and Viles 2010). Where there is an accumulation of moisture the surface shows significantly lowered rock surface hardness values (as measured with the *Equotip* – see Figure 3), indicating flaking, crumbling and general deterioration of the rock surface mineral structure. The moisture accumulation is further shown using near-surface saturation as measured with a *Protimeter* (Figure 3 b). These are then correlated to the ERT measurements (Figure 3 c) and field observations (Figure 3 d). This research was carried out to further our understanding of the extremely complex interaction between moisture and weathering. A number of factors can influence the interaction between moisture and surface, such as temperature and

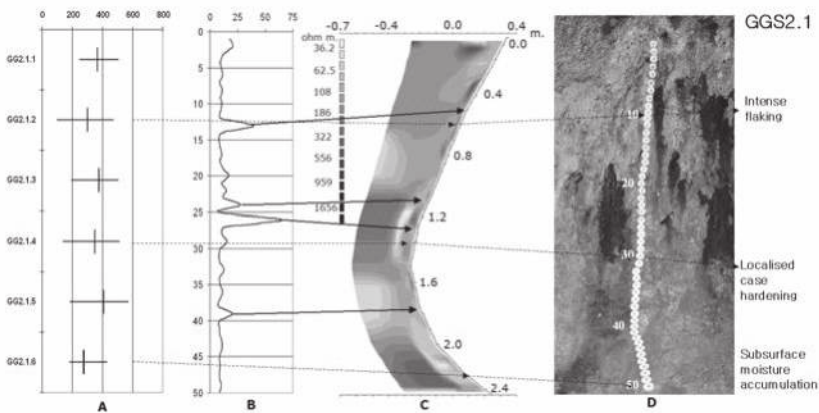


Figure 3. Example of field data correlation of site 2 in the Golden Gate Highlands National Park, showing the relationship between lower surface moisture accumulation and surface weathering. Source: Modified from Mol and Viles (2010).

exposure, although preliminary research suggests that internal moisture is relatively unaffected by outside temperatures and that the nature of the internal moisture regime is a key-element in rock surface deterioration.

This research also shows the many scales on which weathering processes function. On a micro-scale, weathering deteriorates grains and causes crumbling of the surface, accelerating flaking and pitting of the surface. On a meso-scale, it causes rock surface retreat, creating shelters and caves. On a macro-scale, it contributes to large-scale rock falls and rock surface retreat, forming valleys, gorges and large cave systems, changing the dynamics of the landscape. This multitude of scales in combination with the complex interaction of internal and external weathering processes creates a difficult situation for researchers.

SCALE PROBLEMS IN WEATHERING RESEARCH

So where does this interplay of a vast array of both internal and external weathering processes leave us? Despite the advances in weathering studies and techniques, we are still really stuck somewhere between a rock and a hard place. As in most scientific disciplines, the need to see the small detail often conflicts with the necessity to understand the larger picture. It is possible to study and understand every minute weathering process that could take place on a particular rock face in a small part of a remote valley. It is also possible to study the general weathering effects of precipitation on sandstone globally. Both types of studies are helpful but neither achieves the ultimate goal of understanding weathering processes in any stone type in any environment. In addition to this, the difficulty of upscaling or downscaling conclusions drawn from specific studies is sometimes an obstacle that simply cannot be overcome (see, for example, Viles 2001, for a comprehensive discussion on scale issues). The continuous interplay of factors increases the complexity of the situation even further. Figure 4 shows an example of the complexity of scale within research. In this case it is an investigation into rock weathering in southern Africa.

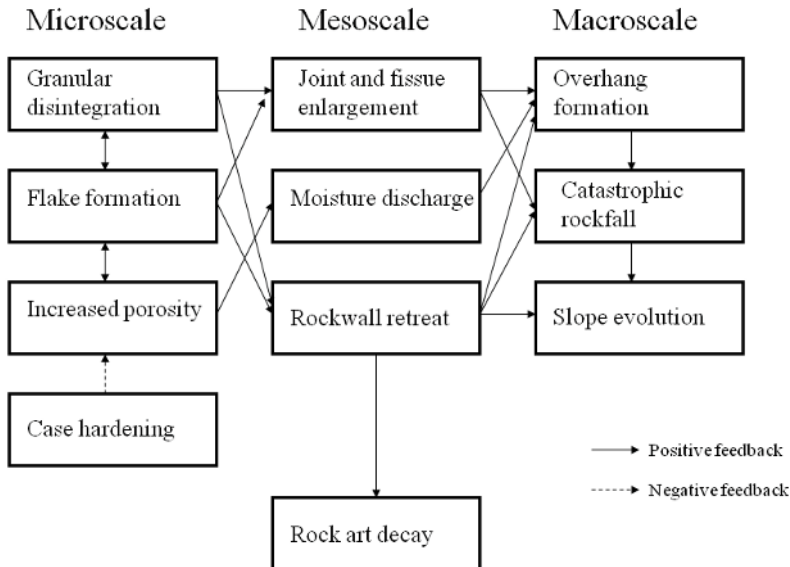


Figure 4. Flow diagram of the complexity of scale within a project on rock art deterioration in South Africa. This figure illustrates the many connections on micro-, meso- and macro scales and the difficulty in ‘disentangling’ these.

Conserving History in Changing Arid Environments

Winkler (1987) accurately points out that, while physical and chemical weathering were studied as separate processes, they are in fact physicochemical processes that should be studied as connected factors. This has left the door open for a case-study approach, where weathering is now studied through individual sites or small-scale laboratory studies, giving us a large database of weathering studies through which we can start piecing together the larger picture. We will look at a few case studies, specifically arid environment heritage, to illustrate the progress made in weathering studies and the challenges still faced.

PETRA, JORDAN

The world famous heritage site of Petra in Jordan continues to attract many thousands of visitors each year. This is not surprising, as the awe-inspiring buildings of the Treasury and the Amphitheatre are more than reason enough to brave the heat and the long trek through the gorge. This continued interest not only provides the local economy with a boost – it also ensures that Petra continues to enjoy a prominent place on the World Heritage List.



Figure 5. Weathering damage on the facade of the temples of Petra; the arrow indicates the capillary rise to above human height, illustrating the possibility of deterioration from soluble salts. Photograph: Heather Viles.

However, this continued attention also brings many problems. Unfortunately, as well as having a World Heritage Listing, it also regularly features amongst the most endangered sites (World Monument Fund 2009) because of increased magnitudes of weathering (Akasheh 2002, Paradise 2005, Waltham 1991). The continued stream of tourists brings with it sweat and laboured breath, increasing humidity and salt content in the air which precipitates onto the rock. Add to this touching of the walls with sweaty, sun block covered fingers and a toxic mix of chemicals is added to the natural deterioration processes already attacking the stone surfaces. Smith (1986) studied the problems of humidity and erosion and found that, in particular, tafoni formation has intensified but that weathering rates on the stone surface of Petra are high in general and pose a substantial risk to the future of these structures (see Figure 5). Paradise (2005) showed that, in a relatively short time span, the walls had retreated significantly due to the chemical deterioration of the surface and the increased humidity, both of which can be directly linked to the increased stream of tourists.

Identifying the problem is only half of the work, though. Once weathering processes have commenced it is very difficult to halt or reverse them. This makes conservation of these sites very difficult, as the complex interaction of processes demands a complex approach.

ROCK ART DETERIORATION: A WIDELY SPREAD PROBLEM

Rock art is a particularly vulnerable type of heritage. It is often painted or carved onto friable rock, such as sandstone, and the sheer number of rock art sites makes monitoring and protecting all of them an almost impossible task. There are a few famous examples of rock art from around the world, such as the Game Pass Shelter in KwaZulu-Natal, South Africa (Meiklejohn *et al.* 2009), the caves of Lascaux, France (Malaurent *et al.* 2007, Bastian and Alabouvette 2009), and the aboriginal rock paintings in the Jenolan Caves, Australia (Dragovich and Grose 1990), which are well-documented and preserved but nonetheless still at risk of rapid deterioration. These, however, represent only the tip of the iceberg: in 1997 15,000 rock art sites in southern Africa were recorded but it is estimated there could be well in excess of 50,000 sites (Deacon 2002).

Many of these sites are under threat from various factors. Exposure to precipitation and thermal fluctuations has caused fading of the pigments, leaving sometimes only faint outlines of the original painting. In the Albarracín Cultural Park in Spain, for example, some paintings have deteriorated to such an extent that they are barely identifiable (Benito *et al.* 1993). Similarly, abrasion of rock surfaces has caused widespread deterioration of rock carvings, especially ones carved into friable rock such as sandstone (Pope 2000b). In arid environments the problems are exacerbated by the extreme thermal fluctuations, abrasion by sand picked up by air currents effectively sanding down the rock surface and, where applicable, intense rainstorms during limited annual periods.



Figure 6. Engraving of a bull, Messak Settafet plateau, Libya. Photograph: Heather Viles.

The rock art of southern Libya, for example is under constant threat of weathering damage. The friable sandstone is prone to deterioration through crumbling, flaking and cracking of the surface. Figure 6 shows an engraving of, presumably, a bull, surrounded by a flaking and cracking rock surface.

The Messak Settafet in south-west Libya is a sandstone plateau within the Sahara Desert with plentiful and important engraved rock art. The climate today is hyperarid but much evidence points to wetter conditions in the past, such as around the early to mid Holocene. The rock art probably dates back to about 3,000–6,000 years ago, when conditions started to dry out in the area. Much of the rock art is carved into sandstone surfaces, which exhibit a dark brown patination, thought to be a desert varnish rich in iron and manganese oxides. Salt efflorescences are commonly found on the rocks within which the engravings are found, especially in cracks and shaded overhangs. Whilst the conditions today are generally too dry for much activation of the salts to occur, if future climate change caused any increase in precipitation the rock art could become seriously threatened. Already it is apparent that the rock surfaces flake easily around cracks and within sheltered areas where more moisture can accumulate.

CLIMATE CHANGE AND HERITAGE PRESERVATION

As mentioned previously, a large number of cultural heritage sites in arid environments are currently under threat. However, as bad as the situation may seem at the moment, it is only set to get worse in many cases. Climate change is undeniably happening, even though the reports may be controversial and the predictions probabilistic, and our attitude towards preservation of heritage will have to adapt to changes in the physical environment. However general the IPCC projections may be at the moment, there are overall trends that can be extrapolated to estimate how conditions will change.

As an example, let's look at northern Africa. Climate change projections for Mediterranean Africa show an increase in extreme events, with higher temperatures but lower precipitation. According to the latest IPCC report, Tunisia is one of the countries where climate change will be most acutely felt, with approximately 1.5 times the global average temperature increase (Solomon *et al.* 2007) and a decrease in overall precipitation. These changes in climate regimes could have a disastrous effect on the conservation of heritage in this region, which abounds in Roman monuments that document its rich and turbulent history (Ennabli 2000). Salinisation of arable land, caused by over-irrigation in low-precipitation areas, is known to be a large problem in northern Tunisia (Hachicha *et al.* 2000) but this increased level of salt may also pose a serious threat to the conservation of its built Roman heritage. Increased temperatures lead to increased evaporation of moisture from stone surfaces, leading to an accumulation of soluble salts on the surface. The salts, in combination with the increased thermal stressing of the stone surface, can speed up the already rapid deterioration process.

El Jem is a UNESCO World Heritage site, described as 'impressive ruins of the largest colosseum in North Africa, a huge amphitheatre which could hold up to 35,000 spectators ... This third century monument illustrates the grandeur and extent of Imperial Rome.' (UNESCO World Heritage List). Due to its location in an arid environment with close proximity to the Mediterranean Sea and its high salt levels, as well as high levels tourism interest, this site could be at risk of rapid decay within a relatively short time span. It faces the same problems which Petra is currently dealing with – increased chemical weathering of the surface due to the proximity of large crowds of people – but in addition now faces increased thermal stress due to higher temperatures as well as potential salinisation problems due to over-irrigation in the region. Figure 7 shows the walls of El Jem, which have deteriorated heavily over the centuries. Rates of deterioration have been slowed down or accelerated by a number of restoration projects over the past century.

This is just one example of a cultural heritage site under threat. As uncertainties persist, or even grow, about the impact of climate change worldwide, the future of cultural heritage is also at risk. Increased intensity of temperature fluctuations, rainstorms, wind speeds and droughts are all possibilities raised by the IPCC reports (Soloman *et al.* (eds.), IPCC Climate Change 2007 I, section 11.2.3.1). Similarly, many investigations are available discussing the movement of, for example, moisture through stonework (see for example Hall and Hoff 2002, McKinley and McCabe 2010, Sass and Viles



Figures 7 A and B. Walls of El Jem, Tunisia, which show much evidence of past restoration and deterioration and may be further affected by future climatic changes in the area. Photograph: Heather Viles.

2010). However, only recently has the impact of climate change on moisture regimes become one of the primary focuses of weathering research (Hall *et al.* 2011). Based on the knowledge we have of current processes and weathering rates, we can estimate how climate change will affect a variety of heritage sites using a multitude of models. But the difficulty lies in the exact prediction of climate change in a particular geographical location and it may not be possible to pinpoint the consequences until it is too late.

Pessimistic as this may sound, there is also good news. Our increasing understanding of geomorphological processes, and weathering in particular, can make identification and monitoring of deterioration processes more accurate. Environmental simulation tests have given us an understanding of the behaviour of stonework in a range of environments (Warke and Smith 1998, Goudie *et al.* 2002, Smith *et al.* 2005) and the consequences of environmental change (Gislason *et al.* 2009). As discussed previously, we now have an ever-increasing array of field and laboratory tests at our disposal. This means that, while we may not, currently, be able to predict the exact effect of future climate change on particular heritage sites, we may be able to gain a good understanding of changes in geomorphological processes at a variety of geographical locations far more accurately and swiftly than before.

RESTORATION AND CONSERVATION, CAN A GEOMORPHOLOGICAL APPROACH HELP?

There is one last question that should be briefly touched upon. Once deterioration has set in, to what extent should we be allowed to interfere? In previous decades, some rather disastrous restoration and conservation work has been carried out, often leading to far greater damage to the structure or object than deterioration processes could have done. This is largely due to a lack of understanding of deterioration processes in previous decades and also insufficient knowledge of conservation material behaviour. However, research is carried out which focuses on both the treatment of deteriorated stone surfaces and limiting deterioration processes by, for example, pollution control, traffic control, control of groundwater, visitor management and disaster planning (Baer 1991). Recent research has focused on improving conservation techniques to prevent damage and instead stabilise the material without interfering with its structure too much (see for example Pinto and Rodrigues 2008). This varies from large-scale conservation projects, such as adding supporting braces to structures, to small-scale interventions, such as injecting wood and stonework with solidifiers to prevent further disintegration of materials (Favaro et al. 2006, Son *et al.* 2009). Geomorphological research can play a vital role in the selection of conservation method as it can identify deterioration processes, especially in stonework, map affected areas and pinpoint areas at future risk if the deterioration continues. Especially when an object – whether a building, a statue or a rock carving – is *in situ*, geomorphology has a range of measurement techniques to offer that can determine the influence of exogenic processes on surface deterioration.

CONCLUDING REMARKS

What future research needs to be undertaken to be better prepared for preserving our heritage in changing environments? As argued in this chapter, geomorphological research is making rapid progress. We are gaining a greater understanding of weathering processes and are now able to identify deterioration more accurately and swiftly than in previous decades. The wide range of techniques available to researchers has led not only to a wide knowledge base but also to a considerable variety of research approaches. However, in addition to the existing natural processes, we now also have to factor in the potential consequences of climate change. This is of even greater importance for fragile heritage sites. The disproportionate number of heritage sites ‘under severe threat’ on the World Heritage List that are located in arid areas indicates the harsh environmental circumstances to which these sites are subjected, which is expected to worsen over time, as climate change becomes even more noticeable. A geomorphological approach within conservation science could therefore be valuable, as recent advances in weathering research can greatly increase our understanding of heritage at risk, the challenges faced and the techniques required; and prepare us for future events that could prove to be the a considerable challenge for conservation science.

REFERENCES

- Akashch, T. S. (2002). 'Ancient and modern watershed management in Petra'. *Near Eastern Archaeology* 65 (4): 220–224.
- Akiner, S., R.U. Cooke and R.A. French (1992). 'Salt damage to Islamic monuments in Uzbekistan'. *Geographical Journal* 158: 257–272.
- Aoki, H. and Y. Matsukura (2007). 'A new technique for non-destructive field measurement of rock-surface strength: an application of the Equotip hardness tester to weathering studies'. *Earth Surface Processes and Landforms* 32: 1759–1769.
- Aoki, H. and Y. Matsukura (2008). 'Estimating the unconfined compressive strength of intact rocks from Equotip hardness'. *Bulletin of Engineering Geology and the Environment* 67 (1): 23–29.
- Attewell, P.B. and D. Taylor (1990). 'Time-dependent atmospheric degradation of building stone in a polluting environment'. *Environmental Geology* 16 (1): 43–55.
- Aydin, A. and A. Basu (2005). 'The Schmidt hammer in rock material characterization'. *Engineering Geology* 81 (1): 1–4.
- Baer, N.S. (1991). 'Assessment and management of risks to cultural property', in: N.S. Baer, C. Sabbioni and A.I. Sors (eds.) *Science, Technology and European Cultural Heritage*. Oxford: Butterworth-Heinemann. pp. 27–36.
- Basheer, P.A.M. and É. Nolan (2001). 'Near-surface moisture gradients and in situ permeation tests'. *Construction and Building Materials* 15 (2–3): 105–114.
- Bastian, F. and C. Alabouvette (2009). 'Lights and shadows on the conservation of a rock art cave: the case of Lascaux Cave'. *International Journal of Speleology* 38 (1): 55–60.
- Benito, G., M.J. Machado and C. Sancho (1993). 'Sandstone weathering processes damaging prehistoric rock paintings at the Albarracín Cultural Park, NE Spain'. *Environmental Geology* 22: 71–9.
- Birginie, J.M. and T. Rivas (2005). 'Use of a laser camera scanner to highlight the surface degradation of stone samples subjected to artificial weathering'. *Building and Environment* 40 (6): 755–764.
- Blackwelder, E. (1925). 'Exfoliation as a phase of rock weathering'. *The Journal of Geology* 33 (8): 793–806.
- Carter, N.E.A. and H.A. Viles (2005). 'Bioprotection explored: the story of a little known earth surface process'. *Geomorphology* 67: 273–281.
- Cassiani, G., V. Bruno, A. Villa, N. Fusi and A.M. Binley (2006). 'A saline trace test monitored via time-lapse surface electrical resistivity tomography'. *Journal of Applied Geophysics* 59 (3): 244–259.
- Cheng, C.Y., K.K.S. Cheung and L.M. Chu (2010). 'Thermal performance of a vegetated cladding system on facade walls'. *Building and Environment* 45 (8): 1779–1787.
- Day, M.J. (1994). 'Weathering of expensive sedimentary rock due to cycles of wetting and drying'. *Bulletin of the Association of Engineering Geologists* 31 (3): 387–390.
- Deacon, J. (2002). *Southern African Rock-Art Sites*. Published by ICOMOS (www.icomos.org/studies/sarockart.htm Accessed 25 October 2010).

- Demirdag, S., H. Yavuz and R. Altindag, R. (2009). 'The effect of sample size on Schmidt rebound hardness value of rocks'. *International Journal of Rock Mechanics and Mining Sciences* **46**: 725–730.
- Dragovic, D. (1967). 'Flaking, a weathering process operating on cavernous rock surfaces'. *Geological Society of America Bulletin* **78**: 801–804.
- Dragovich, D. and J. Grose (1990). 'Impact of tourists on carbon dioxide levels at Jenolan Caves, Australia: an examination of microclimatic constraints of tourist cave management'. *Geoforum* **21** (1): 111–120.
- Ehrlich, H.L. (1998). 'Geomicrobiology: its significance for Geology'. *Earth Science Reviews* **45** (1–2): 45–60.
- Ennabli, A. (2000). 'North Africa's Roman art. Its future', in *World Heritage No 16, UNESCO – San Marcos Sept 2000*. pp 18–29. Accessed at <http://whc.unesco.org/en/review>
- Favaro, M., R. Mendichi, F. Ossola, S. Simon, P. Tomasin and P.A. Vigato (2007). 'Evaluation of polymers for conservation treatments of outdoor exposed stone monuments. Part II: Photo-oxidative and salt-induced weathering of acrylic-silicone mixtures' *Polymer Degradation and Stability* **92** (3): 335–351.
- Fitzner, B., K. Heinrichs and D. La Bouchardiere (2003). 'Weathering damage on Pharaonic sandstone monuments in Luxor – Egypt'. *Building and Environment* **38** (9–10): 1089–1103.
- Forsén, H. and V. Tarvainen (2000). *Accuracy and Functionality of Hand Held Wood Moisture Content Meters*. Espoo 2000. VTT Publications **420**. Technical Research Centre of Finland.
- Francioni, F. and F. Lenzerini (2006). 'The obligation to prevent and avoid destruction of cultural heritage: from Bamiyan to Iraq', in B.T. Hoffman (ed.) *Art and cultural heritage: law, policy and practice*. Cambridge: Cambridge University Press. pp: 28–40.
- de Franco, R., G. Biella, L. Tosi, P. Teatini, A. Lozej, B. Chiozzotto, M. Giada, F. Rizetto, C. Claude, A. Mayer, V. Bassan and G. Gasparetto-Stori (2009). 'Monitoring the saltwater intrusion by time lapse electrical resistivity tomography: The Chioggia test site (Venice Lagoon, Italy)'. *Journal of Applied Geophysics* **69** (3–4): 117–130.
- Fujii, Y., E. Fodde, K. Watanabe and K. Murakami (2009). 'Digital photogrammetry for the documentation of structural damage in earthen archaeological sites: The case of Ajina Tepa, Tajikistan'. *Engineering Geology* **105** (1–2): 124–133.
- Galdieri, E. and A. Alva (1981). *Visual inspection of the Al-Ashrafyah Mosque*. UNESCO Technical Report (1981) RP/1979-1980/4/7.6/05 FMR/CC/CH/81/144E.
- Gislason, S.R., E.H. Oelkers, E.S. Eiriksdottir, M.I. Kardjilov, G. Gisladottir, B. Sigfusson, A. Snorrason, S. Elefsen, J. Hardardottir, P. Torssander and N. Oskarsson (2009). 'Direct evidence of the feedback between climate and weathering'. *Earth and Planetary Science Letters* **227** (1–2): 213–222.
- Goldich, S.S. (1938). 'A study in rock-weathering'. *Journal of Geology* **46** (1): 17–58.
- Gómez-Heras, M., B.J. Smith and R. Fort (2006). 'Surface temperature differences between minerals in crystalline rocks: Implications for granular disaggregation of granites through thermal fatigue'. *Geomorphology* **78** (3–4): 236–249.
- Goudie, A.S. (2006). 'The Schmidt Hammer in geomorphological research'. *Progress in Physical Geography* **30**: 703–718.

Conserving History in Changing Arid Environments

- Goudie, A., H.A. Viles and A.G. Parker (1997). 'Monitoring of rapid salt weathering in the central Namib Desert using limestone blocks'. *Journal of Arid Environments* 37 (4): 581–598.
- Goudie, A.S. and H.A. Viles (1997). *Salt Weathering Hazards*. Chichester: Wiley.
- Goudie, A.S., E. Wright and H.A. Viles (2002). 'The roles of salt (sodium nitrate) and fog in weathering: a laboratory simulation of conditions in the northern Atacama Desert, Chile'. *CATENA* 48 (4): 255–266.
- Greco, R. and M. Sorriso-Valvo (2005). 'Relationships between joint apparent separation, Schmidt hammer rebound value, and distance to faults, in rocky outcrops, Calabria, Southern Italy'. *Engineering Geology* 78 (3–4) 309–320.
- Hachicha, M., C. Cheverry and A. Mhiri (2000). 'The impact of long-term irrigation on changes of ground water level and soil salinity in northern Tunisia'. *Arid Land Research and Management* 14 (2): 175–182.
- Hall, C., A. Hamilton, W.D. Hoff, H.A. Viles and J.A. Eklund (2011). 'Moisture dynamics in walls: Response to microenvironment and climate change'. *Proceedings of the Royal Society* 467 (2125): 194–211.
- Hall, C. and W.D. Hoff (2002). *Water Transport in Brick, Stone and Concrete*. London: Spon Press.
- Hall, K. and A. Hall (1991). 'Thermal gradients and rock weathering at low temperatures: some simulation data'. *Permafrost and Periglacial Processes* 2 (2): 103–112.
- Hall, K. and A. Hall (1996). 'Weathering by wetting and drying: some experimental results'. *Earth Surface Processes and Landforms* 21 (4): 365–376.
- Hall, K., I. Meiklejohn and J. Arocena (2007). 'The thermal responses of rock art pigments: Implications for rock art weathering in southern Africa'. *Geomorphology* 91 (1–2): 132–145.
- Heinrichs, K. (2008). 'Diagnosis of weathering damage on rock-cut monuments in Petra, Jordan'. *Environmental Geology* 56: 643–675.
- Herrera, L.K. and H.A. Videla (2009). 'Surface analysis and materials characterization for the study of biodeterioration and weathering effects on cultural property'. *International Biodeterioration and Biodegradation* 63 (7): 813–822.
- Hoffland, E., T.W. Kuyper, H. Wallander, C. Plassard, A.A. Gorbushina, K. Haselwandter, U.S. Holström, A. Rosling, R. Sen, M.M. Smiths, P.A.W. van Hees and N. van Breemen (2004). 'The role of fungi in weathering'. *Frontiers in Ecology and the Environment* 2 (5): 258–264.
- Hosono, T., E. Uchida, C. Suda, A. Ueno and T. Nakagawa (2006). 'Salt weathering of sandstone at the Angkor monuments, Cambodia: identification of the origins of salts using sulphur and strontium isotopes'. *Journal of Archaeological Science* 33 (11): 1541–1551.
- Kemna, A., B. Kulessa and H. Vereecken (2002). 'Imaging and characterisation of subsurface solute transport using electrical resistivity tomography (ERT) and equivalent transport models'. *Journal of Hydrology* 267 (3–4): 125–146.
- Kuchitsu, N., T. Ishizaki and T. Nishiura (2000). 'Salt weathering of the brick monuments in Ayutthaya, Thailand'. *Developments in Geotechnical Engineering* 84: 319–327.

- Lai, W.L. and W.F. Tsang (2008). 'Characterization of pore systems of air-water-cured concrete using ground penetrating radar (GPR) through continuous water injection'. *Construction and Building Materials* 22: 250–256.
- Lim, M., N.J. Rosser, R.J. Allison and D.N. Petley (2010). 'Erosional processes in the hard rock coastal cliffs at Staithes, North Yorkshire'. *Geomorphology* 114 (1–2): 12–21.
- Liu, H.Y., S.Q. Kou, P.-A. Lindqvist and C.A. Tang (2007). 'Numerical modelling of the heterogeneous rock fracture process using various test techniques'. *Rock Mechanics and Rock Engineering* 40 (2): 107–144.
- Malaurent, P., J. Brunet, D. Lacanette and J.-P. Caltagirone (2007). 'Contribution of numerical modelling of environmental parameters to the conservation of prehistoric cave paintings: the example of Lascaux Cave' *Conservation and Management of Archaeological Sites* 8: 59–76.
- Margottini, C. (2004). 'Instability and geotechnical problems of the Buddha niches and surrounding cliff in Bamiyan Valley, central Afghanistan'. *Landslides* 1: 41–51.
- Matsuoka, N. (1995). 'Rock weathering processes and landform development in the Sor-Rondane Mountains, Antarctica'. *Geomorphology* 12 (4): 323–339.
- Matsuoka, N. (2001). 'Microgelivation versus macrogelivation: towards bridging a gap between laboratory and field frost weathering'. *Permafrost and Periglacial Processes* 12 (3): 299–313.
- McCabe, S., B.J. Smith and P.A. Warke, (2006). 'Preliminary observations on the impact of complex stress histories on sandstone response to salt weathering: laboratory simulations of process combinations'. *Environmental Geology* 52 (2): 251–258.
- McCabe, S., J.M. McKinley, M. Gomez-Heras and B.J. Smith (2011) 'Dynamical instability in surface permeability characteristics of building sandstones in response to salt accumulation over time'. *Geomorphology* 130: 65–75.
- McGreevy, J.P. and W.B. Whally (1985). 'Rock moisture content and frost weathering under natural and experimental conditions: a comparative discussion'. *Arctic and Alpine Research* 17 (3): 337–346.
- McKinley, J.M. and S. McCabe (2010). 'A geostatistical investigation into changing permeability of sandstones during weathering simulations'. *Geographical Analysis* 42: 180–203.
- Meiklejohn, K.I., K. Hall, K and J.K. Davis (2009). 'Weathering of rock art at two sites in the KwaZulu-Natal Drakensberg, South Africa'. *Journal of Archaeological Science* 36 (4): 973–979.
- Mol, L. and P. Preston (2010). 'The writing's in the wall: A review of new preliminary applications of Electrical Resistivity Tomography within Archaeology'. *Archaeometry* 52 (6): 1079–1095.
- Mol, L., and H.A. Viles (2010). 'Geoelectric investigations into sandstone moisture regimes: implications for rock weathering and the deterioration of San Rock Art in the Golden Gate Reserve, South Africa'. *Geomorphology* 118: 280–287.
- Mottershead, D., A. Gorbushina, G. Lucas and J. Wright (2003). 'The influence of marine salts, aspect and microbes in the weathering of sandstone in two historic structures'. *Building and Environment* 38 (9–10): 1193–1204.

Conserving History in Changing Arid Environments

- Paradise, T. (2005). 'Petra revisited: an examination of sandstone weathering research in Petra, Jordan', in A. Turkington (ed.) *Stone Decay in the Architectural Environment*. Geological Society of America, Special paper 390. Boulder, Colorado. pp.39–50.
- Pinto, A.P.F. and J.D. Rodrigues (2008). 'Stone consolidation: the role of treatment procedures'. *Journal of Cultural Heritage* 9 (1): 38–53.
- Pope, G.A., R.I. Dorn and J.C. Dixon (1995). 'A new conceptual model for understanding geographical variations in weathering'. *Annals of the Association of American Geographers* 85 (1): 38–64.
- Pope, G.A. (2000a). 'Review: *Weathering: An introduction to the Scientific Principles* by Will Bland; David Rolls'. *Annals of the Association of American Geographers* 90 (2): 409–411.
- Pope, G.A. (2000b). 'Weathering of petroglyphs: direct assessment and implications for dating methods'. *Antiquity* 74: 833–843.
- Robinson, D.A. and R.B.G. Williams (2000). 'Experimental weathering of sandstone by combination of salts'. *Earth Surface Processes and Landforms* 25: 1309–1315.
- Ryu, J.-S., K.-S. Lee, H.-W. Chang and H.S. Shin (2008). 'Chemical weathering of carbonates and silicates in the Han River basin, South Korea'. *Chemical Geology* 247 (1–2): 66–80.
- Sancho, C., R. Fort and A. Belmonte (2003). 'Weathering rates of historic sandstone structures in semiarid environments (Ebro basin, NE Spain)'. *CATENA* 53 (1): 53–64.
- Sass, O. and H.A. Viles (2010). 'Wetting and drying of masonry walls: 2D-resistivity monitoring of driving rain experiments on historic stonework in Oxford, UK'. *Journal of Applied Geophysics* 70 (1): 72–83.
- Sharmeen, S. and G.R. Willgoose (2006). 'The interaction between armouring and particle weathering for eroding landscapes'. *Earth Surface Processes and Landforms* 31: 1195–1210.
- Sherlock, E.J., R.W. Lawrence and R. Poulin (1995). 'On the neutralization of acid rock drainage by carbonate and silicate minerals'. *Environmental Geology* 25 (1): 43–54.
- Siegesmund, S., H.A. Viles and T. Weiss (2004). 'Stone decay hazards'. *Environmental Geology* 46 (3–4): 303–304.
- Singh, S.P. (1988). 'Burst energy release index'. *Rock mechanics and Rock Engineering* 21 (2): 149–155.
- Smith, B.J., P.A. Warke, J.P. McGreevy and H.L. Kane (2005). 'Salt-weathering simulations under hot desert conditions: agents of enlightenment of preconceptions?' *Geomorphology* 67 (1–2): 211–227.
- Smith, S. E (1986). 'An assessment of structural deterioration of ancient Egyptian monuments and tombs in Thebes'. *Journal of Field Archaeology* 13 (4): 503–510.
- Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) (2007). *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*. Cambridge: Cambridge University Press.
- Son, S., J. Won, J.-J. Kim, Y.D. Jang, Y.S. Kang and S.D. Kim (2009). 'Organic-inorganic hybrid compounds containing Polyhedral Oligomeric Silsesquioxane for conservation of stone heritage' *ACS Applied Materials & Interfaces* 1 (2): 393–401.
- Sturzenegger, M. and D. Stead (2009) 'Close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts'. *Engineering Geology* 106 (3–4): 163–182.

- Thornbush, M. and H. Viles (2004). 'Integrated digital photography and image processing for the quantification of colouration on soiled limestone surfaces in Oxford, England'. *Journal of Cultural Heritage* 5 (3): 285–290.
- Torfs, K. and R. Van Grieken (1997). 'Chemical relations between atmospheric aerosols, deposition and stone decay layers on historic buildings at the Mediterranean coast'. *Atmospheric Environment* 31 (15): 2179–2192.
- Török, Á. (2003). 'Surface strength and mineralogy of weathering crusts on limestone buildings in Budapest'. *Building and Environment* 38 (9–10): 1185–1192.
- Uchida, E., Y. Ogawa, N. Maeda and T. Nakagawa (2000). 'Deterioration of stone materials in the Angkor Monuments, Cambodia'. *Developments in Geotechnical Engineering* 84: 329–340.
- UNESCO (2007). *Case Studies on Climate Change and World Heritage*. <http://whc.unesco.org/uploads/activities/documents/activity-473-1.pdf>
- Viles, H.A. (2001). 'Scale issues in weathering studies'. *Geomorphology* 41 (1): 63–72.
- Viles, H.A. (2005). 'Microclimate and weathering in the central Namib Desert, Namibia'. *Geomorphology* 67 (1–2): 189–209.
- Viles, H.A. and A.S. Goudie (2004). 'Biofilms and case hardening on sandstones from Al-Qwayra, Jordan'. *Earth Surface Processes and Landforms* 29: 1473–1485.
- Viles, H.A. and A.S. Goudie (2007). 'Rapid salt weathering in the coastal Namib Desert: Implications for landscape development'. *Geomorphology* 85 (1–2): 49–62.
- Viles, H., A. Goudie, S. Grab and J. Lalley (2010). 'The use of the Schmidt Hammer and Equotip for rock hardness assessment in geomorphology and heritage science: a comparative analysis'. *Earth Surface Processes and Landforms* 36 (3): 320–333.
- Waltham, T. (1994). 'The sandstone fantasy of Petra' *Geology Today* (May–June): 105–111.
- Warke, P.A. and B.J. Smith (1998). 'Effects of direct and indirect heating on the validity of rock weathering simulation studies and durability tests'. *Geomorphology* 22 (3–4): 347–357.
- Welch, S.A. and W.J. Ullman (1996). 'Feldspar dissolution in acidic and organic solutions: compositional and pH dependence of dissolution rate'. *Geochimica et Cosmochimica Acta* 60 (16): 2939–2948.
- Winchester, V. (2004). 'Lichens', in S. Harrison, S.J. Pile and N.J. Thrift (eds.) *Patterned Ground: Ecologies of Nature and Culture*. London: Reaktion.
- Winkler, E.M. (1966). 'Important agents of weathering for building and monumental stone'. *Engineering Geology* 1 (5): 381–400.
- Winkler, E.M. (1987). 'Weathering and weathering rates of natural stone'. *Environmental Geology* 9 (2): 85–92.
- World Monuments Fund (WMF) (2009). *World Monuments Watch: 2008 Watch*. <http://wmf.org/watch.html> Accessed 6 October 2009.
- Yilmaz, H.M., M. Yakar, S.A. Gulec and O.N. Dulgerler (2007). 'Importance of digital close-range photogrammetry in documentation of cultural heritage'. *Journal of Cultural Heritage* 8 (4): 428–433.

WATER IN THE DESERT: APPLYING DISASTER RISK REDUCTION (DRR) LESSONS FOR CLIMATE CHANGE IN ARID LANDS

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OVER THE BRINK: THE REAL AND PRESENT DANGER OF CLIMATE CHANGE

This chapter discusses climate change, its impacts on arid environments and possible actions to deal with it. Inspiration is then drawn from disaster risk reduction (DRR), since dealing with climate change is one aspect of DRR activities (Shaw *et al.* 2010). Particular focus is placed on adaptation strategies that have been developed by those living in arid environments. Desert communities have developed specific strategies in order to cope with their day-to-day hazards. Some of this knowledge could be transferred to rapidly changing environments across, for example, North America and Europe – or, where the knowledge is not directly transferable, it could inspire other locations to seek their own knowledge and techniques for dealing with climate change.

Climate change is no longer something that may happen in the future; it is happening now. The effects of climate change, including changes in seasonal weather patterns, modifications of extreme weather and relatively rapid sea level rise, are becoming more obvious and demand action. The ten hottest years on record have occurred since 1991 and temperatures have risen by 0.6°C in the last hundred years (King 2004). We are now no longer on the brink but are entirely immersed within this human-caused global change (Parmesan and Yohe 2003, Letcher 2009). The Intergovernmental Panel on Climate Change (IPCC) was established in the late 1980s by the United Nations Environment Programme and the World Meteorological Organization to provide scientific consensus and policy advice on the current state of knowledge about climate change and its impacts. The IPCC reviews and assesses recent scientific research on climate change and has found overwhelming evidence to suggest that human actions are modifying the atmosphere through significantly contributing to an increase in atmospheric greenhouse gas concentrations which, in turn, is modifying the world's climate (IPCC 2007).

THE NOT-SO-SLOW ONSET OF CLIMATE CHANGE

Prior to the twentieth century, the notion that human activity could change the world's climate was often dismissed as impossible, although a few scientists discussed possible human modification of climate (e.g. Weart 2010). Following a few others before him, in the 1930s, an engineer called Callendar suggested that global temperatures were rising. He examined records of atmospheric CO₂ measurements and concluded that during the previous hundred years they had increased by ten per cent and that this was the cause of the observed warming (Callendar 1949, Weart 2010). Even small changes in climate can have a devastating impact in environmentally sensitive arid environments. It is therefore vital that climate change research works towards reducing the uncertainties related to climate change impacts in dry lands (Lioubimtseva 2004).

Climate change research has developed at an increasing pace over the past fifty years. In 1960 a young geochemist called Charles Keeling examined atmospheric CO₂ concentrations and announced he had detected a rise (Keeling 1960, Keeling *et al.* 1995). Keeling's CO₂ curve became a turning point in understanding contemporary climate change and its potentially dangerous impact on civilisation. Throughout the 1970s connections were made between other gases and climate change. By the early 1980s another realisation was taking hold: that climate change could happen faster than previous calculations based on CO₂ measurements alone had forecast (Weart 2010).

Following several previous initiatives examining the wide scope of climate change, the IPCC was established in 1988. That was followed by the international environmental treaty, the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, which led to the Kyoto Protocol. The Kyoto Protocol is a legally binding international treaty that seeks to limit net emissions of greenhouse gases (UN 1998). It was signed in December 1997 but did not come into force until 2005 when enough countries had ratified it. Despite its legally binding nature, most countries that signed up to greenhouse gas emissions reductions are not likely to meet the targets to which they agreed. In fact, some believe that the Kyoto Protocol has failed (Kellow 2010) and the negotiations for a replacement or follow-on treaty are also unlikely to yield much that is legally binding and substantive (e.g. Rogelj *et al.* 2010). Nonetheless, the Kyoto Protocol coming into force is seen as an official, international acknowledgment that climate change is occurring and that some form of global action is a necessity.

The most recent IPCC report (IPCC 2007) indicates that, prior to industrialisation, global CO₂ concentrations increased by twenty parts per million (ppm) over 8,000 years. In contrast, since 1750, concentrations have increased by 100 ppm (IPCC 2007). Approximately half the anthropogenically derived CO₂ emissions are taken up by oceans and vegetation but other greenhouse gases can have less uptake, so their atmospheric concentrations have been increasing rapidly over several decades, usually by several ppm per year. The impact of these gases on the planet appears to be extensive and dangerous.

Global surface temperatures between 1906 and 2000 have increased by 0.74°C and the rate of warming has approximately doubled during the last fifty years. Despite

evidence for a warmer planet overall, local variations result (IPCC 2007). In some places, averages could stay near the same as before, yet extreme hot spells and extreme cold spells could both increase. In higher latitudes, many places are expected to flip above and below zero more frequently in the winter, with the possibility of severe freeze/thaw damage to infrastructure and farming soils along with increased frequency of ice storms. In other places, averages might change significantly and in some circumstances, especially in polar regions, become substantially warmer. The situation is complex, with global projections not always reflecting the challenges that will manifest at the local level.

Precipitation patterns will change but the nature of change is less certain. As IPCC (2007) notes, drier climates have already been observed in locations such as the Sahel (an arid land area just south of the Sahara Desert), the Mediterranean, parts of South Asia and parts of southern Africa. Locals across South Asia are reporting severe disruptions to the usual monsoon, making farming- and water-related decision-making difficult (Mirza 2011). In the Caribbean, the normal dry seasons are seeing never-before recorded amounts of precipitation. Changes to hurricanes, cyclones and typhoons are expected to disrupt water supplies and lead to increasing intensity of storms, even if frequency decreases (Knuston *et al.* 2010).

Although future projections are bleak, many of the physical processes and feedbacks are poorly understood. This uncertainty sometimes makes it difficult to motivate communities into taking preventative measures, although examples of observed climate changes have proved to be catalysts for action (Radić and Hock 2011).

Local, relatively small, changes in weather can have extreme results in sensitive environments such as deserts. Despite this, Gouldie (2006) argues that, although drylands cover one third of the Earth's land surface, little detailed attention has been paid to the impact of climate change on these regions. Small changes in climate within these sensitive places create environmental degradation and, without adequate measures being taken, can expose local people to famine. This was observed in the early 1970s when the drought combined with long-term poor land management and social disruption led to widespread famine in the Sahel (Sporton and Thomas 2002; see further discussion later).

The inactive dune systems in the Sahel and southern Africa are static due to low wind energy and good vegetation cover. With projected changes in climate, this region is likely to be exposed to longer dry periods, which will reduce soil moisture. A reduction in soil moisture would lead to a loss of vegetation and increase erodability. Combined with possible increases in windiness, a potential exists for these regions to become nearly uninhabitable through dune movement. Studies on the impact of climate change on the dune systems of the Sahel and southern Africa have found that, regardless of the emissions scenario used, dune activity was significantly enhanced across the southern dune systems by 2039 and all dune systems by 2099, a region stretching from South Africa to northern Angola (Thomas *et al.* 2005).

An increasingly inhospitable interior in Africa could lead to an increase in migration to the coastal regions but a warming planet also means an increase in sea

levels (Church *et al.* 1991). Nicholls *et al.* (2009) estimate that by 2080 over 35 million people in West Africa alone will be exposed to annual coastal flooding.

Many such locations already suffer from the possibility of a major disaster from a normal sea-based storm, called a storm surge. Nicholls *et al.* (1999) suggest that arid lands that are susceptible to sea-based flooding include the Southern Mediterranean (Turkey to Algeria), West Africa (from Morocco to Namibia) and East Africa (from South Africa to Sudan).

A major concern is the potential irreversibility of some of climate change's effects. Models that simulate future climate scenarios have found that, even with a complete reduction of CO₂ emissions immediately, global temperatures do not necessarily decrease, indicating that the effects of warming are, to an extent, irreversible in the short-to-medium term (Solomon *et al.* 2009).

FURTHER IMPACTS

In 2010 the United Nations estimated that over 900 million people worldwide are currently malnourished and 98 per cent of these people live in developing countries (FAO 2010). The world's poorest communities tend to be the most vulnerable to natural hazards including climate change. It has been estimated that ninety per cent of dryland peoples live in developing countries and are therefore some of the most vulnerable people in the world (UNDP 2010). The difference between survival and death in hostile arid environments often relies on small but significant atmospheric changes as well as small but significant changes in human behaviour. For those already living in poverty and in arid environments, an already difficult life will not become easy under climate change.

The arid lands of southern Africa have been identified by the IPCC (2007) and Lobell *et al.* (2008) as a region without sufficient adaptation measures to cope with negative impacts of climate change on current agriculture. Rice, maize and wheat contribute half the calories consumed in developing countries. Lobell *et al.* (2008) give a 95 per cent chance that changes in temperature will have a harmful effect on maize and wheat crop production in southern Africa. In the absence of other measures taken, the impact would be direct and local, yielding famine and disease. Wider implications are less certain.

It is an open question whether or not, in the longer term, famine could trigger civil unrest and wider political impacts. Studies published in 2009–2010 (Buhaug 2010, Burke *et al.* 2009) contradicted each other regarding whether or not climate change's impact would increase or not affect civil conflict in sub-Saharan Africa. The overall assessment suggests that no clear-cut evidence exists for an increase.

It is clear that those living in arid environments are particularly vulnerable to climate change and accompanying hazards. The question remains as to what can be done to reduce people's vulnerability and increase their capacity to survive in drylands.

DRR AND ARID ENVIRONMENTS

The United Nations International Strategy for Disaster Reduction (UNISDR) defines DRR to be:

The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events. (<http://www.unisdr.org/we/inform/terminology>).

Dr Salvano Briceño, then the director of UNISDR, noted in 2008 that ‘DRR is based on a philosophy of prevention not reaction’ (UNISDR 2008a, p. 2). By simply reacting to disaster, people’s vulnerability will not be reduced effectively. Instead, we need to be proactive and work towards adaptation strategies that can help our communities to be more resilient (Lewis 1999, Wisner *et al.* 2004).

DRR is a framework and process for evaluating hazards, such as floods and drought, as well as vulnerabilities – of people, communities, infrastructure and ecosystems. Implementing DRR is important because, as Dr Briceño notes, the hazards we face are changing. For example, regions of temperate climate may experience warmer temperatures and drier regimes, increasing the possibility of worse droughts. In addition, areas of increasingly warm temperatures may increase the incidence and range of diseases such as malaria (IPCC 2007).

In Sahelian Africa, warmer and drier conditions with less predictable rainfall patterns have reduced the growing season, contributing to food shortages without adequate human adjustment to the new climate. Unfortunately, this is not an isolated event and, in combination with projected increases in extreme drought and flood events, and without adequate human action, food shortages in arid areas could become more common (e.g. Glantz 1994, Devereux 1994, Maxwell 2002). It is not possible to stop immediately the large-scale climate changes that are already occurring, so communities must recognise the reality that they face in order to adapt.

From a DRR perspective, these communities are at increased risk from the impacts of climate change due to their already high vulnerability. The concept of vulnerability is defined in this chapter as the societal processes – values, actions, behaviour, and decisions – that undermine a person’s, community’s or society’s ability to deal with hazards (or just normal environmental changes), thereby leading to a disaster (Lewis 1999, Wisner *et al.* 2004).

Two important and well-respected DRR texts detail the main factors of vulnerability to include individual characteristics such as income, location, gender, age, access to health care and access to livelihood choices as well as societal characteristics such as power, political structures, justice, equality and culture – all of which are influenced by environmental changes. These two texts are ‘At Risk’ (Wisner *et al.* 2004) and ‘Development in disaster-prone places’ (Lewis 1999). Hewitt (1983, 1997) also evidences the importance of underlying causes of vulnerability, deeply embedded in society’s

day-to-day structures and norms, leading to disasters and thereby also exacerbating the challenges of dealing with climate change.

Over the last several decades, definitions of vulnerability, hazard and risk have lacked consistency, with confusion often added by disputes amongst different schools of thought. Complicating this further are additional terms and concepts that have emerged, such as adaptation, capacity and resilience, often without reference to previous literature or without fully embracing what other disciplines have written with respect to the meanings. All of these terms are nonetheless widely used in development and disaster research and practice, including work dealing with climate change, sometimes with and sometimes without clear definitions and descriptions. As a consequence their meanings are interchanged, misunderstood, misused and overused. In order to discuss adaptation and resilience to climate change, it is important to suggest definitions. Box 1 discusses the definitions of adaptation and resilience used here.

BEING AWARE AND TAKING ACTION: RISK PERCEPTION AND LOCAL ADAPTATION

Adaptation to an increasingly arid environment is extremely challenging – yet there are examples from arid lands around the globe where both small and large resilience-building strategies appear to be successful (e.g. Gaillard 2007, Glantz 1976, Glantz 1997, Holloway 2000). Resourceful communities in arid environments have learnt to live with extreme conditions and their experiences could inspire future adaptation. But adaptation will only occur if a community understands and is aware of the hazards faced.

A major element of DRR and climate change adaptation is risk perception. As Gaillard (2008: 315) notes, ‘risk perception is different from the simple knowledge that a hazard exists in the environment and instead refers to the possibility people give that a hazard will affect them’. In other words, action might only be taken by those who believe that the risk will negatively affect their lives. In relation to climate change, this is a crucial element for action in regions that have not yet been negatively influenced, as far as the people have experienced, or have so far had the ability – financial and otherwise – to cope with changes.

Risk perception has a major role to play in adapting to climate change, especially in more affluent countries, which tend to see themselves as more advanced and resilient than other locations. This human trait has been referred to as ‘unrealistic optimism bias’ and may lead to a decrease in preparation because these people perceive themselves to be more resilient than they actually are (Gregg *et al.* 2008, Paton *et al.* 2008). As an example, water is increasingly a concern in the drylands of Colorado, east of the Rocky Mountains, partly due to overuse and partly due to climate variability and change. The public do not always realise the extent of the state’s water vulnerability because many believe that Coloradans can use any precipitation falling on the state, which is not the case under complicated water law agreements (Western Water Assessment, 2011).

Box 1. Resilience and adaptation: the new buzzwords

In much work over the decades, the idea of exploring the vulnerability of a community living in a potentially dangerous region appeared to be an excellent method of identifying their weaknesses and finding solutions to improve their ability to cope with the hazards they faced. Over this time period, many definitions of vulnerability, hazard and risk have been used. Smith (2001, p. 25) concludes that the concept of vulnerability has been refined over time but still has no fully acceptable and discipline-free definition. Nonetheless, it has proven to be highly useful in widely varying contexts (Hewitt 1983, 1997; Lewis 1999; Wisner *et al.* 2004).

Because vulnerability is often used to describe elements of a society that are negative, or assumed to be negative, some critics suggest that this does not produce a useful foundation for positive action, especially for policy makers and decision takers. They preferred a concept that they could own and build upon.

Over the last few years the term resilience – emerging from fields such as engineering, ecology, and psychology – has played an important role in DRR and climate change policy (e.g. Gaillard 2010, UNISDR 2005). Resilience is often seen as a positive concept. But much depends on the definition, because some interpretations of resilience demonstrate it as being the inability to change for the better. Resilience is often described as the ability of an individual, structure or community to ‘bounce’ back from adversity or to avoid fundamental change due to an imposition. More recently, resilience has been used as an umbrella term to describe a community’s ability to deal with a challenge, possibly through recovery or possibly through positive change (Twigg 2007).

Resilience therefore has root ideas in sustainable livelihoods and poverty alleviation, encompassing development topics. That links it to ‘build back better’, a notion suggesting that disaster-struck communities must be able not only to recover to their previous state but also to do better in the long-term. After all, there is no point in being resilient enough to recover to a pre-disaster state, when that older state represents the conditions that caused the disaster in the first place.

For example, the approximately 13,000 years of human occupation of the Atacama Desert in northern Chile are punctuated by a period of several millennia of apparent human absence due to drought conditions (Núñez *et al.* 2002). After humans left the area, if they had returned and recovered to the pre-disaster state, then they would have been vulnerable to the same drought conditions. Instead, humans have done better through continuous and continuing human occupation despite major climate variations. Adaptation was possible by continuing to build resiliently in the Chilean desert.

With these concepts, adaptation could be defined as the measures taken to become more resilient. While this definition does not cover all the formal language and concepts in official climate change documents, it is a more practical and grounded interpretation of adaptation, helping to focus on the tools and processes that a community uses to address the challenges it faces on the people’s own terms.

In arid areas of less affluent locations, communities are often aware of the hazards they face but have few resources or other opportunities to implement the adaptation that they know is necessary. Referring to ongoing research in 2011, Prof. Tony Oliver-Smith from the University of Florida personally described observations from the drylands of the Peruvian Andes:

People there report that the temperatures are oscillating wildly, with searing daytime temperatures that 'burn' the pastures and crops and dry up water sources and unusually cold night-time temperatures that endanger both human and animal health. The high altitude pastoralists say that the cold temperatures are hurting their herds, causing the females to abort and killing the young animals before they are hardy enough to withstand the freezes. They are fearful that these dual extremes will diminish their herds and endanger their livelihoods. People in the Andes have always had to deal with a fairly wide range of weather variation, but these extremes seem to be exceeding even what they are accustomed to.

To deal with the root causes of challenges such as climate change, everyday threats such as poverty, marginalisation, inequality and political neglect need to be tackled. There are many scientists, academics and politicians who appropriately and reasonably believe that reducing risk should focus on improving livelihoods and livelihood choices for everyone in a community, not just the majority, not just those with political or financial power or not just those with the loudest voices. This contention takes us to the key texts such as Alexander (1993), Hewitt (1983, 1997), Lewis (1999) and Wisner *et al.* (2004), connecting this chapter to the field of development studies and development action in order to recognise that DRR (including dealing with climate change) is not an isolated process but a development challenge:

Disasters do not just happen – they result from failures of development which increase vulnerability to hazard events. (DFID 2004, p. 3).

The above quotation epitomises the ethos of the sustainable livelihoods approach to DRR. Natural hazards unequally affect those who are poor and vulnerable, meaning that less affluent countries are often worst hit. Even in more affluent countries, a disparity between rich and poor sometimes emerges in disasters, such as in the 1995 Chicago heat wave (Klinenberg 2002) and the 2003 European heat wave (Poumadère *et al.* 2005), which saw comparatively few affluent people dying. When considering climate change, as with other hazards, it is absolutely necessary to address the larger social, cultural, economic and political issues in order to be certain of establishing successful adaptation measures that support sustainable livelihoods.

Chambers (1995: 175) claims, 'Sustainable livelihood refers to a living which is adequate for the satisfaction of basic needs, and secure against anticipated shocks and stresses'. The shocks and stresses relate in part to the natural hazards that affect communities. Chambers (1995) describes sustainable livelihoods as long-term support of the means by which poor people live. Table 1 demonstrates that this, by definition, must go beyond employment and earning cash, especially since, in many poor loca-

tions, employment 'is more widespread as an aspiration than as a reality' (Chambers 1995: 195).

Table 1. Elements of sustainable livelihoods. Source: Chambers (1995).

| Element of sustainable livelihoods | Description |
|-------------------------------------|--|
| Natural Resources | Sustainable management of natural resources, especially common property resources and equitable access to them for the poor. |
| Redistribution | Of private and public livelihood resources to the poor. |
| Prices | Marketing, prices and prompt payment for what poor people sell and terms of trade between what poor people sell and what they buy. |
| Health | Accessible health service for the prevention of disease and for prompt and effective treatment of disabling accidents and disease. |
| Restriction and hassle | Removal of restriction on livelihood activities otherwise used to hassle and exploit the poor. |
| Counter-seasonality and safety nets | For poor people at bad times, mitigating seasonal stress and enabling them to conserve their livelihood assets. |

Encouraging participation within development and DRR (including climate change adaptation) has been strongly encouraged by various academics, non-governmental organisations (NGOs) and international organisations (e.g. Benson *et al.* 2001, Shaw *et al.* 2008, UNISDR 2008a) with UNISDR (2008a) particularly highlighting the role of women. As Dr. Briceño noted in a speech at the *3rd Global Congress of Women in Politics and Governance* in the Philippines in 2008, 'women are key natural resource managers and guardians of environmental knowledge in traditional societies' (UNISDR 2008a, p. 3). The role of women in climate change adaptation should not be overlooked, as they often hold the knowledge and skills for water collection and food production (Denton 2002), as well as many DRR lessons to build on (Enarson and Morrow 1998). Encouraging communities to use their own knowledge on their own terms for adaptation through participatory initiatives improves local livelihood opportunities.

Yet often mistakes are made in assuming that such action must rely heavily on the implementation and distribution of funds by governments and authorities. Smith *et al.* (2001) demonstrate this in investigating livelihood improvements in Uganda. They show that, although the government planned to carry out a variety of livelihood-improving actions through micro-finance initiatives, in reality little impact occurred, due to the perceived levels of corruption and a refusal by locals to pay taxes for services that they had not necessarily asked for. Yet improving the roads did assist with livelihood diversification. Overall, a balance of top-down and bottom-up initiatives worked

and further successes might have been seen if the communities had been involved in the top-down plans from the beginning.

Similarly, in the Sahel, the inhabitants have traditionally used both farming and nomadism for livelihoods in a region that experiences severe droughts. In the late 1960s and early 1970s, a catastrophic drought killed tens of thousands and left many more dependent on external food aid. Debates have raged regarding the various factors that led to the catastrophe (e.g. Cook 2008, Glantz 1976, Lau *et al.* 2006), with explanations including overpopulation, overgrazing, loss of nomadic options due to new international borders, forced settlement to end nomadic lifestyles and unusual climate fluctuations. As is normal, the full story includes a combination of complex factors interacting. Climate change is one more variable in the mix of social and environmental changes across all space and time scales for which local adaptation strategies will need to be implemented.

As Fleuret (1986: 224) notes in the context of sub-Saharan Africa, 'Drought is a subjective phenomenon' (see also Glantz and Katz 1977) and seeing Sahel droughts as unusual or abnormal is a viewpoint mainly of external, not local, eyes (see also Hewitt 1983). People in arid lands around sub-Saharan Africa have, according to Fleuret (1986), long used a variety of actions to deal with fluctuating rainfall and food production. These include food sharing and exchange, food preservation and storage, livestock and dietary diversity and owning several small plots of land in different ecological zones rather than a single large farm. In modern times, many of these traditional systems have broken down, being replaced by social and environmental structures that might be more efficient in the short-term but that create longer-term vulnerability. Examples are loss of knowledge about preserving food and gathering wild foods during famines, laws or land protection decrees prohibiting migration and hunting/gathering in many areas, land reforms fracturing traditional plot owning and encouraging the use of external varieties of food over local, traditional crops.

PARTICIPATORY ADAPTATION MEASURES

Humans are capable of living in the most extreme locations – the Inuit, the Mongolians and the nomadic Bedouin are just a few examples of thousands of communities surviving in hostile environments around the globe, especially in arid areas from Chile to China. These resourceful people have adapted to live with the hazards they face, often turning them into advantages. Ironically, these communities usually have the lowest emissions of greenhouse gases and yet they are amongst those suffering most obviously from climate change impacts (Mortimore 2010). The past millennia of human experience show that society is inherently adaptive and that lessons can be learnt from the most successful approaches (Blanco 2006). Examining how these communities survive in extremes could provide inspiration for others in regions that are on the brink of dramatic environmental change – coupled with ongoing dramatic social changes.

In the Sahel, rainfall has decreased by 25 to thirty per cent overall since 1960 and an increased frequency in rainfall-related drought conditions has amplified the strain – often with social and political causes at heart – on its diverse inhabitants. These farmers are sometimes considered to have low adaptive capacity because most strategies are too expensive for the poor; local knowledge is claimed to be insufficient; and community responses are criticised as being too focussed and local. Yet following on from Fleuret (1986) amongst others, Mortimore (2010) challenges these assumptions by providing examples of drought adaptation in the Sahel between 1968–2008. Examples of agricultural, income and food diversification during the 1982–84 droughts demonstrated that local knowledge is an essential resource for an adaptive and resilient community. In the Sahel, traditional knowledge of plant biodiversity including the identification and preparation of ‘famine foods’ has been handed down over generations of women (Fleuret 1986, Mortimore 2010). Having a diverse range of foods available enables these people to survive a drought and, although this has limitations, livelihood diversification is being championed in many hostile environments.

It is important too to ask how much rainfall variability really contributes to drought (Glantz 1994). Droughts have many causes. Some are due to reduced rainfall, while others are due to increased water use, often wastage or diversion away from people who have relied on the water for centuries. Some ‘droughts’ appear because land has been over-cultivated, often at the behest of national governments or multinational corporations who force local farmers to change. The farmers might be forced to sell their land in order to be part of a larger farming collective or the farmers might be cajoled into switching from subsistence farming to cash cropping. The latter tends to have advantages in terms of income and affluence but leaves little contingency if outside market forces reduce buyers for the cash crop. Both small-scale subsistence farming and larger-scale cash cropping have advantages and disadvantages. An observed sudden reduction in farming output might or might not be due to simultaneously changing weather or climate conditions (see also Devereux 1994).

Overall, food and crop diversification in arid lands tends to have strong advantages in terms of dealing with vagaries in climate or markets. At times, adapting to change might nonetheless be difficult. In Uganda increasing floods and droughts are creating enormous problems for farming. In times of drought the women and children of a family must walk many kilometres to collect water and this has significant knock-on effects. Children spend less time in school, the women have less time to tend to crops and to attempt to diversify their food groups, calories are spent in walking and enough water might not be available for proper washing or safe cooking.

Unlike the government-implemented micro-finance schemes mentioned previously, the International Institute for the Environment and Development (IIED) has supported local adaptation projects that have helped families to construct water tanks. These tanks can hold up to 20,000 litres of water, enough to sustain a farming family for four months of a rainfall drought. During the rainy season these tanks collect excess run-off and in the Masaka district, Uganda, families are able to diversify their

crops so that their children do not sacrifice school time. Water storage is a simple but effective adaptation measure to climate change in arid environments (Reid *et al.* 2010).

But knock-on effects from adaptation need to be considered too, because no solution is perfect. Is the local community monitoring for increased mosquitoes? If water tanks are closed improperly or sealed improperly, they might provide breeding ground for disease-carrying mosquitoes, depending on the mosquito species and on anti-mosquito measures that have been taken. What about knowing how to repair leaks quickly, to avoid wasting water and to avoid stagnant pools that might also favour insects? What measures are taken to avoid contamination of the water, which could make people sick? Storing water on-site is a big change for a community with major advantages – but care is essential to ensure that further problems do not result.

Another IIED case study shows how communities in Malawi have planted elephant grass in order to reduce soil erosion during frequent flood events. Other adaptation measures to cope with drought have been supported by the work of Cordaid and involve the promotion of drought resistant crops, seed banks, small-scale irrigation and water saving initiatives (Cordaid 2011). Creativity, using local resources and using local knowledge, can go a long way to dealing with any climatic regime that manifests in the future – even if outside support is needed to facilitate the people developing their own solutions on their own terms. Examples are semi-formal mechanisms for combining internal and external knowledge to deal with climate change (Kelman *et al.* 2009) and working with people to map their own communities, dangers and solutions (Maceda *et al.* 2009).

In addition more and more people in dryland areas like those in Malawi have adapted to the drying conditions by becoming nomadic and following the rain where feasible – or they have simply gone elsewhere, often cities, for a combination of economic reasons and lack of resources and choices to deal with climatic variations. Migration has always been a reality for people in arid locations, as noted above for the Sahel. That will continue to be one strategy amongst many to deal with climate change. Yet the movement of people and cultures means that a potential exists for losing local knowledge and community-based adaptation strategies. In many cases, climate change will make local knowledge outdated anyway. That is why a combination of internal and external approaches to knowledge is essential for supporting people to deal with climate change on their own terms.

Recording and retaining local knowledge, and understanding where and when it does and does not apply, is an essential task. DRR practitioners working alongside communities using participatory methods can encourage local knowledge and the transfer of experience in order to understand what climate change will do to the community and how to deal with it. These methods are becoming increasingly popular within academia and NGOs (e.g. Gaillard 2007, Plan International 2011, Shaw *et al.* 2008, 2010).

As one example – which continues to be updated, modified and developed – the method Participatory Rural Appraisal (PRA) is often used. The preferred term applied

in different contexts is not important, and many variations and modifications exist, but the ethos of action in the field should be focused on. PRA and variants were born from a series of research methods that incorporated conversations, informal interviews, focus groups and detailed recording. Chambers (1994) developed PRA as an approach consisting of a series of methods for learning about rural life. His activities could be used within a workshop environment by specialist facilitators.

One aspect of PRA and related techniques is using visual representations and analyses. Maps, models and diagrams, on the ground or on paper, are produced during activities that permit contributions from all members of the community – the young, old, illiterate and those who speak different languages. Ethnic and religious groups that are not normally part of a community's decision-making process are also included. This means that the data collected from these activity sessions – in the form of recordings, photographs, paper maps and diagrams – form a more representative and complete vision of the whole community.

With dryland ecosystems supporting over one billion people, it is essential that good land management be encouraged (UNCCD 2011). Participatory methods for encouraging sustainable livelihoods and climate change adaptation have been applied in many arid environments. In the Kalahari region of Botswana, PRA was used to support local people in identifying good land and water management practices (Fraser *et al.* 2006). In semi-arid Tanzania, PRA was used to better understand local needs in relation to water management in a changing climate (Quinn *et al.* 2003). And participatory methods have been used to encourage dialogue amongst stakeholders and therefore to identify sustainable land management practices in the semi-arid mountain region of Aarsal, Lebanon (Zurayk *et al.* 2001).

There are criticisms and concerns about the philosophical and theoretical predilections of PRA and related techniques. Kapoor (2002: 102) suggests that a reliance on knowledge derived from experience produces 'insufficient attention to such critical issues as legitimacy and justice in participatory development'. Kapoor (2002) also argues that Chambers' 'view of power is inadequate and does not cover the broader issues such as gender'. These criticisms are easily overcome by ensuring that the action in the field, and the theoretical method on paper, explicitly address power relations, explicitly seek input from all members of the community and explicitly encompass topics of legitimacy, justice and equality (e.g. Pretty 1995, <http://www.powercube.net>). Many drylands examples exist.

In Kitut in Kenya, a local NGO has been assisting the community to cope with climate change using participatory methods. Local people have been building their own water retention schemes called Sand Dams. These dams enable communities to cope with climate fluctuations and to enhance their livelihood opportunities (Lasage *et al.* 2008). Meanwhile, Li *et al.* (2000) detail recent developments in combining rainwater harvesting, water management and crop management in the semi-arid Gansu province, China. This leads to improved crop yields, reduced soil erosion and adequate water for domestic needs.



Figure 1. Picture of a *Qanat*. Photograph courtesy of Dr Richard Walker, University of Oxford.

Water management is an essential skill for survival in a changing arid environment. Examples of resourceful and innovative water storage, irrigation and transport can be found in many arid environments. In Iran, where ninety per cent of the country is arid land, 27,000 km of underground tunnels called *Qanats* have been created to transport water from the mountain watersheds to desert cities. Figure 1 shows the *Qanat* that provides protection from evaporation, also being a vital element of the traditional Iranian air conditioning system.

Figure 2 is a photograph of a large cooling tower capturing the desert winds and funnelling the air flow across the vertical *Qanat* shaft opening in order to create a lower pressure and draw cool air up from the *Qanat* tunnel. These systems have been supplying and cooling Iranian cities for thousands of years (Boustani 2009). As well as the *Qanats*, the Iranian desert is scarred with irrigation dams designed to store and release water in a controlled system (Figure 3).

Yet despite Iran's innovative traditional water management, population pressures and an increase in damming and aquifer pumping have meant that *Qanats* are drying

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Figure 2. Picture of a cooling tower. Photograph courtesy of Dr Richard Walker, University of Oxford.



Figure 3: Desert dams. Photograph courtesy of Dr Richard Walker, University of Oxford.

up. Morid *et al.* (2004) have modelled that, without further adaptation, the effect of climate change could in extreme cases lower certain water tables by 2.6 m a year. Iran needs to consider larger-scale changes to water management. Just as their ancestors adapted to the desert conditions, modern Iranians must now adapt to an increasingly urban population under climate change.

That must be done within the context of other challenges. Earthquakes in Iran have killed tens of thousands of people, with the capital city, Tehran, having immense vulnerability to a major earthquake catastrophe (Coburn and Spence 2002). Yet the seismic activity is strongly linked to water availability for those cities (Jackson 2001). Living in arid regions is possible with creativity, even under climate change, but can have a high price unless steps are taken to reduce all vulnerability, not just due to climate change.

URBAN AND LARGE-SCALE ADAPTATION

As with Tehran, many large cities in arid lands around the world are under threat from lack of appropriate action regarding climate change. Mobility is not necessarily a quick and easy approach, due to the sheer size of many urban areas and the populations that must be supported. Even if they could be convinced to move, where would the populations of Tucson, Arizona and Tripoli, Libya move to? How would those dwelling along the Nile River in Khartoum, Sudan be convinced to move elsewhere, away from their homes and livelihoods? Why should they move, when conditions might not be better elsewhere? What if they moved from locations with increasing droughts to locations with increasing floods?

Large swathes of land incorporating major cities are predicted to become drier in the future, leading to a strain on water resources. For example, climate change models are currently projecting that south-western North America will be increasingly drier during the next century (Seager and Vecchi 2010). That covers the high plains of Colorado through to the Pacific Ocean and from the latitude of the California–Oregon border down to southern Mexico. Large cities affected include Denver, Los Angeles and Mexico City.

Los Angeles, for instance, relies on outsourced water supplies, making the population extremely vulnerable to water shortages. The redirection of water from natural reservoirs, such as Owens Lake, to Los Angeles has led to environmental destruction and detrimental impacts on the local native communities (Karhl 1983). Increasing water supply fluctuations could lead to water outages in urban areas in the same way that many locations across California are increasingly experiencing brownouts – planned times without electricity that roll across a grid – during heat waves when electricity usage increases.

Yet population in this region has also increased explosively over past decades. Water use has skyrocketed, especially amongst the most affluent, who often want nice trees from eastern North America in their front garden, despite those trees sucking up

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water in the western desert. How much water do the casinos and hotels of Las Vegas use? How often must people put on sprinklers to maintain their manicured lawns in the leafy suburbs of San Francisco? How much of the drought threat is from climate change and how much is from poor water management?

Many such vulnerabilities were exposed during the 1997–98 El Niño event, when many arid locations suffered from a severe drought. Glantz (2001) provides national perspectives from countries with arid lands such as Peru, Ethiopia and China. A complex series of factors led to the problems experienced due to El Niño, not just the climate variability or the aridity of the locations.

An extravagant ‘experiment’ to tackle both the crisis of water and the production of greenhouse gases is underway in the desert, 17 km from Abu Dhabi, in the United Arab Emirates. Masdar city is an entirely new urban area that is claimed to be the world’s first entirely self-sufficient green city. It is attempting to rely almost entirely on renewable energy while the landscape design aims to encourage temperature control from natural features. With no cars permitted, the carbon footprint of this city is claimed to be close to zero – except that the calculations do not factor in all carbon sources. The attempt and ethos is admirable, but critical examination is necessary to ensure that the initiative is truly successful and honest in its reporting. Nonetheless, it indicates possibilities for creating and sustaining a resilient urban community from the beginning. What about existing cities? Could they be retrofitted to adapt to climate change?

Consider Libya’s controversial Great Manmade River project. This large-scale long-term project aims to draw water from aquifers beneath the Sahara to quench this desert country’s thirst. Pumping the hoped for six million cubic metres of water daily and then transporting the ancient water through the 4,000-kilometre-long, four-metre-diameter concrete pipes was intended to be the showpiece of Colonel Gaddafi’s revolution. This project is a decades-long construction endeavour. Even if it does fully succeed, is this a sustainable water source? Are enormous concrete engineering works really the way to go for adaptation?

CONCLUSION: CHANGING OUR BEHAVIOUR

As this chapter has demonstrated, communities living in a variety of arid environments have found various ways to survive. From the traditional water management techniques in Iran to the attempts at modern sustainable cities in the United Arab Emirates, humans have demonstrated that they can be resilient despite variations in climate and the environment’s dryness. The clear message from the past is that we need to lead more sustainable, often simpler, lives that work with the environment rather than against it – and that the past can support us in doing so as long as we also look to the future.

Nonetheless, this ideal may not be realistic for two main reasons: population increase and the human desire for wealth. The UN projects that the global population will grow by 2.53 billion by 2050 from 2008 levels. This growth alone is equivalent to the global population in 1950. Almost all of the net growth is expected to take

place within developing countries. According to the United Nations Convention to Combat Desertification (UNCCD), drylands have seen faster population growth than any other sector and with ninety per cent of arid communities living in developing countries, some of the most vulnerable communities in the world will likely suffer the most from a changing climate.

But population numbers are not the only factor. The desire for wealth, especially linked to consumption, has created a global catastrophe. Energy supply decisions are caught between taking over large swathes of land for giant wind farms and nuclear power plants that will leave a waste legacy of millennia. Why is tackling energy demand not always taken as seriously? Meanwhile, the desire for cheap single-use products has led to plastics straining fossil fuel reserves for supply and straining landfills as waste.

Community resilience in arid lands has long demonstrated how viable livelihoods are possible, despite significantly limited water resources. The skills in creating and maintaining those communities demonstrate that not everything could, or should, be done through top-down, government- or international-led, large-scale interventions. Bottom-up, community-led approaches are essential, provided that they do not create problems for others. The best approach is combining top-down and bottom-up endeavours. Ultimately, we must look to ourselves, at changing our own behaviour.

Is that feasible? Do we have the time and energy? Do we have the resources, especially the money? Do we have the knowledge and wisdom? Since it is apparent that climate change is a problem emerging from the actions of mainly affluent people and groups, including affluence in countries such as Brazil, China, India, Russia and South Africa, the answer is that, yes, the resources are available that, in turn will give us the time, energy, knowledge and wisdom that we need. If we choose.

REFERENCES

- Alexander, D. (1993). *Natural Disasters*. London: UCL Press.
- Benson, C., J. Twigg and M. Myers (2001). 'NGO Initiatives in risk reduction: An overview'. *Disasters* 25 (3): 199–215.
- Blanco, R.A.V. (2006). 'Local initiatives and adaptation to climate change'. *Disasters* 30: 140–147.
- Boustani, F. (2009). 'Sustainable water utilization in arid region of Iran by Qanats'. *International Journal of Human and Social Sciences* 4 (7): 505–8.
- Buhaug, H. (2010). 'Climate not to blame for African civil wars'. *Proceedings of the National Academy of Sciences* 107 (38): 16477–82.
- Burke, M.B., E. Miguel, S. Satyanath, J.A. Dykema and D.B. Lobell (2009). 'Warming increases the risk of civil war in Africa'. *Proceedings of the National Academy of Sciences* 106 (49): 20670–4.
- Callendar, G.S. (1949). 'Can carbon dioxide influence climate?' *Weather* 4: 310–14.
- Chambers, R. (1994). 'The origins and practice of participatory rural appraisal' *World Development* 22 (7): 953–969.

Water in the Desert

- Chambers, R. (1995). 'Poverty and livelihoods: Whose reality really counts?' *Environment and Urbanization* 7 (1): 173–204.
- Church, J. A., J.S. Godfrey, D.R. Jackett and T.J. McDougall (1991). 'A model of sea level rise caused by ocean thermal expansion'. *Journal of Climate* 4(4): 438–456.
- Coburn, A.W. and R.J.S. Spence (2002). *Earthquake Protection*. London: John Wiley & Sons.
- Cook, K.H. (2008). 'Climate science: The mysteries of Sahel droughts'. *Nature Geoscience* 1: 647–648.
- Cordaid (2011). *Case Study Malawi: Community Managed Risk Reduction and Climate Change Adaptation in Malawi*. The Hague: Cordaid.
- Denton, F. (2002). 'Climate change vulnerability, impacts, and adaptation: Why does gender matter?' *Gender & Development* 10 (2): 10–20.
- Devereux, S. (1994). *Theories of Famine*. Hertfordshire: Harvester Wheatsheaf.
- DFID (2004). *Disaster Risk Reduction: A Development Concern*. London: DFID.
- Enarson, E. and B.H. Morrow (1998). *The Gendered Terrain of Disaster: Through Women's Eyes*. Westport: Praeger.
- FAO (2010). *The State of Food Insecurity in the World: Addressing Food Insecurity in Protracted Crises*. Rome: FAO.
- Fleuret, A. (1986). 'Indigenous responses to drought in sub-Saharan Africa'. *Disasters* 10 (3): 224–229.
- Fraser, E.D.G., A.J. Dougill, W.E. Mabee, M. Reed and P. Mcalpine (2006). 'Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management'. *Journal of Environmental Management* 78: 114–127.
- Gaillard, J.C. (2007). 'Resilience of traditional societies in facing natural hazards'. *Disaster Prevention and Management* 16 (4): 522–544.
- Gaillard, J.C. (2008). 'Alternative paradigms of volcanic risk perception: The case of Mt. Pinatubo in the Philippines'. *Journal of Volcanology and Geothermal Research* 172 (3–4): 315–328.
- Gaillard, J.C. (2010). 'Vulnerability, capacity and resilience: Perspectives for climate and development policy'. *Journal of International Development* 22 (2): 218–232.
- Glantz, M.H. (1976). *The Politics of Natural Disaster: The Case of the Sahel Drought*. New York: Praeger.
- Glantz, M. (ed.) (1994). *Drought Follows the Plow*. Cambridge: Cambridge University Press.
- Glantz, M.H. (ed.) (1997). 'Using science against famine: food security, famine early warning, and El Niño'. *Internet Journal of African Studies* 1 (2). Online. Available at <http://ccb.colorado.edu/ijas/ijasno2/ijasno2.html> Accessed 23 November 2010.
- Glantz, M. (ed.) (2001). *Once Burned, Twice Shy? Lessons Learned from the 1997–98 El Niño*. Tokyo: UNU Press.
- Glantz, M.H. and R.W. Katz (1977). 'When is a drought a drought?' *Nature* 267: 192–93.
- Goudie, A. (2006). *The Human Impact on the Natural Environment: Past, Present and Future*. Oxford: Wiley-Blackwell Publishers.

- Gregg, C. E., B.F. Houghton, D.M. Johnston, D. Paton and D.A. Swanson (2004). 'The perception of volcanic risk in Kona communities from Mauna Loa and Hualalai volcanoes, Hawai'i'. *Journal of Volcanology and Geothermal Research* 130 (3–4): 179–196.
- Hewitt, K. (ed.) (1983). *Interpretations of Calamity from the Viewpoint of Human Ecology*. London: Allen and Unwin.
- Hewitt, K. (1997). *Regions of Risk: A Geographical Introduction to Disasters*. Essex: Addison Wesley Longman.
- Holloway, A. (2000). 'Drought emergency, yes ... drought disaster, no: Southern Africa 1991–93'. *Cambridge Review of International Affairs* XIV (1): 254–276.
- IPCC (Intergovernmental Panel on Climate Change) (2007). *IPCC Fourth Assessment Report*. Geneva: IPCC.
- Jackson, J. (2001). 'Living with earthquakes: know your faults'. *Journal of Earthquake Engineering* 5(special issue 1): 5–123.
- Kapoor, I. (2002). 'The devil's in the theory: a critical assessment of Robert Chambers' work on participatory development'. *Third World Quarterly* 23: 101–17.
- Karhl, W.L. (1983). *Water and Power: The Conflict over Los Angeles Water Supply in the Owens Valley*. London: University of California Press.
- Keeling, C.D. (1960). 'The concentration and Isotopic abundances of Carbon in the atmosphere'. *Tellus* 12 :200–203.
- Keeling C.D., T. Whorf, M. Whalen and J. van der Plicht (1995). 'Interannual extremes in the rate of rise of atmospheric Carbon Dioxide since 1980'. *Nature* 378: 666–670.
- Kellow, A. (2010). 'Is the Asia-Pacific partnership a viable alternative to Kyoto?' *Interdisciplinary Reviews Climate Change* 1 (1): 10–15.
- Kelman, I., J. Mercer and J. West. (2009). 'Combining different knowledges: community-based climate change adaptation in small island developing states'. *Participatory Learning and Action Notes* 60: 41–53.
- King, D.A. (2004). 'Climate change science: Adapt, mitigate or ignore?' *Science* 303: 176–177.
- Klinenberg, E. (2002). *Heatwave: A Social Autopsy of Disaster in Chicago*. Chicago: University of Chicago Press.
- Knutson, T.R., J.L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J.P. Kossin, A.K. Srivastava and M. Sugi (2010). 'Tropical cyclones and climate change'. *Nature Geoscience* 3: 157–163.
- Lasage, R., J. Aerts, G.-C.M. Mutiso and A. de Vries (2008). 'Potential for community based adaptation to droughts: Sand dams in Kitui, Kenya'. *Physics and Chemistry of the Earth, Parts A/B/C* 33(1–2): 67–73.
- Lau, K.M., S.S.P. Shen, K.-M. Kim and H. Wang (2006). 'A multimodel study of the twentieth-century simulations of Sahel drought from the 1970s to 1990s'. *Journal of Geophysical Research* 111: paper D07111.
- Lioubimtseva, E. (2004). 'Climate change in arid environments: revisiting the past to understand the future'. *Progress in Physical Geography* 28: 502–530.
- Letcher, T.M. (2009). *Climate Change: Observed Impacts on Planet Earth*. Oxford: Elsevier.

Water in the Desert

- Lewis, J. (1999). *Development in Disaster-prone Places: Studies of Vulnerability*. London: Intermediate Technology Publications.
- Li, F., S. Cook, G.T. Geballe and W.R. Burch Jr. (2000). 'Rainwater harvesting agriculture: An integrated system for water management on rainfed land in China's Semiarid Areas'. *AMBIO: A Journal of the Human Environment* 29 (8): 477–483.
- Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon and R.L. Naylor (2008). 'Prioritizing climate change adaptation needs for food security in 2030'. *Science* 319 (5863): 607–610.
- Maceda, E., J.C. Gaillard, E. Stasiak, V. Le Masson and I. Le Berre (2009). 'Experimental use of participatory 3-dimensional models in island community-based disaster risk management'. *Shima: The International Journal of Research into Island Cultures* 3 (1): 46–58.
- Maxwell, D. (2002). 'Why do famines persist? A brief review of Ethiopia 1999–2000'. *IDS Bulletin* 33 (4): 48–54.
- Mirza, M. (2011). 'Climate change, flooding in South Asia and implications'. *Regional Environmental Change* 11 (1): 95–107.
- Morid, S., A.R. Massah, M. Agha Alikhani and K. Mohammadi (2004). 'Maintaining sustainable agriculture under Climate Change: Zayanderud Basin (Iran)', in J.C.J.H. Aerts and P. Droogers (eds.) *Climate Change in Contrasting River Basins: Adaptation Strategies for Water, Food and Environment*. Wallingford: CABI Publishing. pp. 115–132.
- Mortimore, M. (2010). 'Adapting to drought in the Sahel: Lessons for climate change'. *Wiley Interdisciplinary Reviews: Climate Change* 1 (1): 134–143.
- Nicholls, R.J., F.M.J. Hoozemans and M. Marchand (1999). 'Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses'. *Global Environmental Change* 9 (Supplement 1): S69–S87.
- Núñez, L., M. Grosjean and I. Cartajena (2001). 'Human occupations and climate change in the Puna de Atacama, Chile'. *Science* 298 (5594): 821–824.
- Parmesan, C. and G. Yohe (2003). 'A globally coherent fingerprint of climate change impacts across natural systems'. *Nature* 421 (6918): 37–42.
- Paton, D., L. Smith, M. Daly and D. Johnston (2008). 'Risk perception and volcanic hazard mitigation: Individual and social perspectives'. *Journal of Volcanology and Geothermal Research* 172 (3–4): 179–188.
- Plan International (2011). *Child-Centred Disaster Risk Reduction: Building Resilience Through Participation, Lessons from Plan International*. London: Plan International.
- Poumadère, M., C. Mays, S. Le Mer and R. Blong (2005). 'The 2003 heat wave in France: Dangerous climate change here and now'. *Risk Analysis* 25: 1483–1494.
- Pretty, J.N. (1995). 'Participatory learning for sustainable agriculture'. *World Development* 23 (8): 1247–1263.
- Quinn, C. H., M. Huby, H. Kiwasila and J.C. Lovett (2003). 'Local perceptions of risk to livelihood in semi-arid Tanzania'. *Journal of Environmental Management* 68: 111–119.
- Radić, V. and R. Hock (2011). 'Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise'. *Nature Geoscience* 4 (2): 91–94.

- Reid, H., S. Huq and L. Murray (2010). *Community Champions: Adapting to Climate Challenges*. London: International Institute of Environment and Development.
- Rogelj, J., J. Nabel, C. Chen, W. Hare, K. Markmann, M. Meinshausen, M. Schaeffer, K. Macey and N. Höhne (2010). 'Copenhagen Accord pledges are paltry'. *Nature* **464**: 1126–1128.
- Seager, R and G.A. Vecchi (2010). 'Greenhouse warming and the 21st century hydroclimate of southwestern North America'. *Proceedings of the National Academy of Sciences* **207** (50) 21277–21282
- Shaw, R., J.M. Pulhin and J.J. Pereira (eds.) (2010). *Climate Change Adaptation and Disaster Risk Reduction: Issues and Challenges. Community, Environment and Disaster Risk Management*. Bingley: Emerald Group Publishing Limited.
- Shaw, R., N. Uy and J. Baumwoll, J. (eds.) (2008). *Indigenous Knowledge for Disaster Risk Reduction: Good Practices and Lessons Learned from Experiences in the Asia-Pacific Region*. Bangkok: United Nations International Strategy for Disaster Risk Reduction (UNISDR).
- Smith, K. (2001). *Environmental Hazards Assessing Risk and Reducing Disaster*. London: Routledge.
- Smith, D. R., A. Gordon, K. Meadows and K. Zwick (2001). 'Livelihood diversification in Uganda: patterns and determinants of change across two rural districts'. *Food Policy* **26** (4): 421–435.
- Solomon, S, G.-K. Plattner, R. Knutti and P. Friedlingstein (2009). 'Irreversible climate change due to carbon dioxide emissions'. *Proceedings of the National Academy of Sciences* **106** (6): 1704–1709.
- Sporton, D. and D.S.G. Thomas (2002). *Sustainable Livelihoods in Kalahari Environments: A Contribution to Global Debates*. Oxford: Oxford University Press.
- Thomas, D.S.G., M. Knight and G.F.S. Wiggles (2005). 'Remobilization of southern African desert dune systems by twenty-first century global warming'. *Nature* **435**: 1218–21.
- Twigg, J.(2007). *Characteristics of a Disaster-resilient Community: A Guidance Note*. London: DFID.
- United Nations (UN) (1998). *Kyoto Protocol to the United Nations Framework Convention on Climate Change*. Online, available at <http://unfccc.int/resource/docs/convkp/kpeng.pdf> Accessed 11 July 2011.
- UNCCD (2011). *Progress Report, Global Drylands: A United Nations System-wide Response*. Available at <http://www.unccd.int/cop/officialdocs/cric9/pdf/crp1eng.pdf>
- UNDP (2010) *The Forgotten Billion: MDG Achievement in the Drylands*. Online, available at www.undp.org/energyandenvironment.html Accessed 26 July 2011.
- UNISDR (United Nations International Strategy for Disaster Reduction) (2005). *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters*. Geneva: UNISDR.
- UNISDR (2008a). *Third Global Congress of Women in Politics and Governance Focus on Gender in Climate Change and Disaster Risk Reduction Manila, Philippines 19–22 October 2008*. Keynote address by Sálvano Briceño. Online, available at <http://www.capwip.org/genderandrrr.html> Accessed 11 July 2011.

Water in the Desert

- UNISDR (2008). *Gender Perspectives: Integrating Disaster Risk Reduction into Climate Change Adaptation Good Practices and Lessons Learned*. Geneva: UNISDR.
- Weart, S.R. (2010). 'The idea of anthropogenic climate change in the 20th century'. *Interdisciplinary reviews climate change* 1 (1): 67–81.
- Western Water Assessment (2011). *Colorado Climate Preparedness Project: Final Report*. Boulder, Colorado: Western Water Assessment. Available online at http://wwa.colorado.edu/climate_change/docs/CCPP_final_report.pdf
- Wisner, B., P. Blackie, T. Cannon and I. Davis (2004). *At Risk: Natural Hazards, People's Vulnerability and Disasters*. London: Routledge.
- Zurayk, R., F. El-Awar, S. Hamadeh, S. Talhouk, C. Sayegh, A.-G. Chehab and K.A. Shab, (2001). 'Using indigenous knowledge in land use investigations: a participatory study in a semi-arid mountainous region of Lebanon'. *Agriculture, Ecosystems and Environment* 86: 247–262.

HAZARD IMPACT ON DESERT ENVIRONMENTS

Troy Sternberg

Globally, very dry areas have more than doubled since the 1970s. (UN 2009, p. 216)

Mankind is becoming ever more susceptible to natural disasters, largely as a consequence of population growth and globalization ... a calamity with a million deaths is just a matter of time. This situation is mainly a consequence of increased vulnerability. (Huppert and Sparks 2006: 1875)

INTRODUCTION

A common perception of natural hazards is of sudden intense events that cause great damage to nature and society. However, not all disasters are so dramatic. In the Gobi desert extreme climate factors, including temperatures $< -50^{\circ}$, snow and ice and wind storms create an unusual hazard known locally as *dzud*. In 2010 harsh winter conditions in Mongolia created the nation's worst natural disaster as the hazard devastated the pastoral environment and disrupted socio-economic systems in the country (EM-DAT 2011). Physical conditions, economic forces and livelihood choices contributed to the disaster's severity. The hazard event, recurrent in the Gobi desert region of northern China and southern Mongolia, is a timely example of how geography, exposure and human dynamics shape natural hazard impact in dryland environments.

Mongolia's steppe grasslands receive little precipitation (224 mm annually) and have the limited vegetation, vast expanse and extreme climate that are common factors throughout drylands. More locally, pastoral livelihoods are dependent on ecology and weather; weak governance and poor infrastructure levels limit alternative development and adaptive capacity. A *dzud* encompasses physical and the social parameters; its immediate impact is great animal mortality followed by a humanitarian crisis. Initiated by climate and exacerbated by human activity, a *dzud* disaster is one of several hazards in the desert realm. Arid and semi-arid landscapes feature limited resources (particularly water and vegetation), physical environments and extreme climates that contribute to severe events like drought or flood. Susceptibility to hazards and potential adaptability to serious events is shaped by dryland conditions; over this are layers of development, social perception and institutional capability across global drylands.

Hazard Impact on Desert Environments

Mongolia's disaster displays several socio-environmental qualities typical across arid regions. One is the concentration of environment-dependent livelihoods that put large populations at risk to natural forces, represented by the high percentage of pastoralists in the country (Johnson *et al.* 2006). Another is accessibility of essential resources that determine human viability. In drylands this first means water for domestic use, livestock, farming and development. Related are ecological productivity, soil quality and moisture levels amidst natural processes such as wind, heat, evapotranspiration and erosion. For herders this has meant strategising to maximise grassland forage; on the steppe this includes migration, multiple water sources and utilising different pasture, often determined by seasons or pasture elevation. The continued effectiveness of these traditional patterns is uncertain in evolving environmental, social and political conditions.

The spatial extent of drylands constrains physical access, provision of services, infrastructure and communication. The 'tyranny of distance' originally referred to the Australian Outback's geographical remoteness yet is applicable across drylands. In Mongolia this is manifested in a country half the size of Western Europe having a total of 1,500 kilometres of paved roads (World Bank 2011). The dearth of infrastructure restricts the ability to prepare for or respond to *dzud*. A corollary is the relative isolation of deserts from geo-political and economic centres. In Mongolia the lack of financial clout or political power further limits response capability and global engagement with the result that disaster response in 2010 did not arrive in time to alleviate the *dzud* impact. Often conceived of as inhabiting marginal or unproductive land (see 'drylands as wastelands', IUCN 2010, p. 22), the majority of dryland populations are in less developed countries that lack the ability or influence to reduce disaster risk (UN 2010). Mongolia exemplifies this, as *dzuds* are common events but practice and policy leave the country unable to adequately mitigate them. Desert areas also encompass highly developed nations – Qatar, the US, Australia – that show how, with technical skill and financial resources, hazards may cause physical destruction but minimal human casualties (Bryant 2005).

The dominant societal concern in hazards is vulnerability and resilience. Vulnerability measures the exposure of a community to hazard impact; resilience assesses its ability to adapt to changing physical conditions. Awareness of environmental parameters acknowledges that hazard engagement in each region is governed by external factors. Whereas in Mongolia the key hazard is severe cold, for a pastoralist in East Africa drought predominates and in central Pakistan floods are a main issue. In each place the ability to address a hazard event depends on community exposure to and its ability to mitigate disaster impact. Vulnerability is influenced by location, development, organisation and preparation, conditions that favour developed nations. In Mongolia, once the *dzud* was identified there was not the preparation or capacity to halt the disaster or improve relief efforts. In the past, resilience was part of a pastoral system where losses were minimised through migration, herd selection and forage preparation. As customary livelihoods, such as agro-pastoralism, adjust to market realities, the challenge

in drylands is to maintain livelihood features that encourage resilience and adaptability when hazards occur. Mongolia exemplifies how mitigation requires skills and financial resources that are often out of reach of less developed countries; this is critical as an estimated one billion dryland residents live in developing nations (UN 2010).

Whilst the 2010 *dzud* in Mongolia serves as a focal event, the aim of this chapter is an exploratory consideration of natural hazards in dryland environments. The existing hazard research paradigm primarily focuses on risk, causal events, impact and implication. This approach suggests global hazard susceptibility rather than differentiated landscapes and environments subject to a variety of extreme events. Geography can often contribute to and determine exposure and resilience whilst social dynamics are local in scale and landscape dependent (Stewart and Donovan 2008). Understanding of, and interaction with, hazards can be strengthened by study across similar environments rather than focusing solely on the trigger event. For instance, drought or floods in drylands will have shared characteristics and implications with other dryland zones more than with tropical or temperate regions. This chapter looks at hazards in a drylands context, examines Mongolia's *dzud* in depth and then reviews topics that are often considered as part of the desert hazard paradigm.

PART I. THE BIGGER PICTURE

Naturally occurring hazards are an integral part of our dynamic planet. Events have marked impacts in desert landscapes where resource limitations, a lack of water and low vegetation cover affect livelihoods and the environment. Loosely defined, deserts and drylands are areas with low precipitation, variable climates, high temperatures and evaporation rates and limited ecological productivity. Drylands are significant biomes because arid, semi-arid and dry sub-humid (steppe grasslands) regions encompass more than a third of the earth's land surface and are home to between one and two billion people (Washington-Allen 2008, UNDP 2010). System complexity, extreme and unpredictable weather, physical characteristics and differing social systems present a challenge for hazard mitigation across arid regions (Warner 2004). Mapping victims of natural disasters per capita highlights the concentration of serious disasters in dryland regions in Asia, Africa and Australia (Figure 1).

We live in a time of increasing hazard-awareness, due to improved documentation, population exposure and environmental change (Table 1). Hazards become disasters when they directly impact on lives and nature, incur economic costs and have long-term indirect consequences for societies; disaster effect depends on social vulnerability and system resilience (Noy 2009, McGuire *et al.* 2002). The realisation that environmental and human factors can severely impact on our world, as with the Australian droughts (2002–2007) and the Japanese earthquake/tsunami (2011), has strengthened hazard comprehension. A growing body of work addresses hazards, yet their occurrence in and interaction with desert environments is seldom studied (see

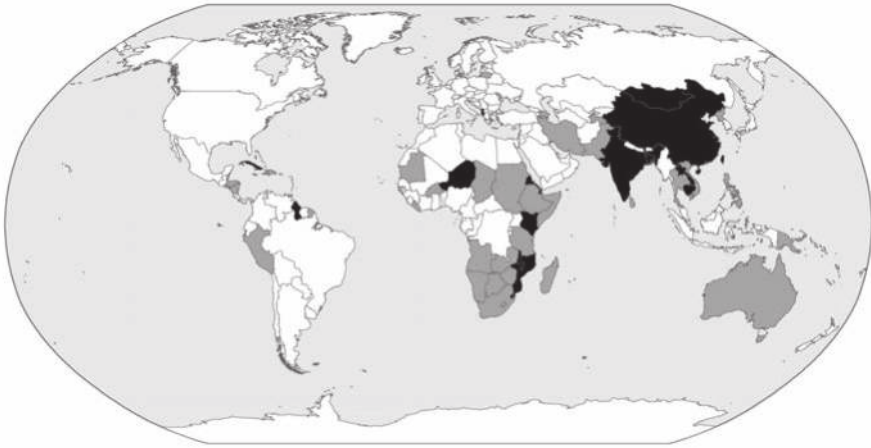
Hazard Impact on Desert Environments

Figure 1. Number of victims (killed, injured, homeless and affected) of natural disasters per 100,000 inhabitants 1985–2005. Black = > 5,000, gray = 1–5,000, other = <1,000. Note the high concentration in dryland areas of Asia, Africa and Australia. Source: Centre for Research on the Epidemiology of Disasters, 2009.

Table 1. Number of natural disasters in selected dryland countries, 1974–2003

| Country | 1974– 1978 | 1979– 1983 | 1984– 1988 | 1989– 1993 | 1994– 1998 | 1999– 2003 |
|-----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Algeria | 1 | 8 | 6 | 5 | 6 | 18 |
| China | 5 | 35 | 65 | 77 | 75 | 131 |
| Iran | 9 | 14 | 19 | 21 | 22 | 37 |
| Mexico | 9 | 17 | 12 | 19 | 35 | 42 |
| Somalia | 3 | 3 | 3 | 2 | 5 | 11 |
| South Africa | 3 | 6 | 8 | 6 | 11 | 22 |
| World | 497 | 812 | 929 | 1,116 | 1,116 | 1,897 |

Source: EM-DAT 2004. Note: data is not broken down within country.

Bryant 2005, Smith and Petley 2009). It is the significant human and socio-economic disruption, physical destruction and population exposure that make disasters a serious issue today (Kellenberg and Mobarak 2008).

Box 1. Hazard terms

DISASTER – an unforeseen and often sudden event (hazard) that causes serious disruption to a community or a society that overwhelms local capacity.

GEOPHYSICAL HAZARD – natural earth processes including earthquakes, tsunamis, volcanic activity, mass movements (landslides) and mud flows.

HYDROMETEOROLOGICAL HAZARD – natural processes or phenomena of atmospheric, hydrological or oceanographic nature, including flood, drought, storms, fire, temperature/weather extremes, hurricane, cyclone, dust storms and avalanches.

NATURAL HAZARD – a potentially damaging physical event or phenomenon within a given time period and area.

RISK – the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity or environmental damage) resulting from interactions between hazards and vulnerable conditions. Risk can be inherent (natural) or created (human action) within social systems.

ISDR 2004; EM-DAT 2009

Natural hazards can be categorised as geophysical and hydro-meteorological, with the latter (floods; drought; climate; extreme hot/cold weather; storms – of dust, snow, wind; wildfire) dominant in drylands (Box 1). Hazards can be further quantified as rapid-onset (earthquake) or slow onset (drought) events, a key distinction in how hazards are dealt with. High magnitude, low frequency events receive much attention because of death and damages inflicted – yet, perhaps surprisingly, it is slow-onset disasters that affect the most people and result in greater mortality. Such events develop over time, have potentially large spatial coverage and temporal range and high frequency rates that make extreme weather events, particularly drought, the most recurrent hazard (Keyantash and Dracup 2002, Leroy 2006, Goudie 2010).

DESERTS AND DRYLANDS

Deserts are characterised by landforms and geomorphological processes that are physically and climatologically distinct from other major environments (Laity 2008). In addition, drylands encompass nations at low and high latitudes and all development levels; their global extent and exposure encourages interaction and exchange of knowledge and effective practices that may be applicable across countries and tailored to local

conditions. Arid environments shape societies and frame interaction with the physical world. Attempts to alter the landscape through water transfer schemes (Beijing, Mexico City, Libya), expanding irrigation (Israel, Iraq, Australia) and resettlement (northern and western China, Arabian Peninsula, Botswana) involve great effort and expense. Ecosystem fragility in drylands constrains human action and response as well as the resilience of social and natural systems (UN 2008).

Whilst the causal factors are natural, the role of human action is pervasive in creating disasters. Interaction with, and transformation of, the environment, population growth, climate change and multiple socio-economic factors, such as population and poverty, are examples of anthropogenic forces that can influence the magnitude of disasters and the response and recovery rate. Development patterns, urbanisation and livelihood patterns can also contribute to social vulnerability and a loss of ecosystem resilience when encountering extreme events. Urban centres near tectonic fault lines (Los Angeles, Teheran, Las Vegas), mega-cities on floodplains (Cairo, Delhi, Karachi) and attempts at agricultural livelihoods in drought-prone areas (Ethiopia, Mali, Australia, northern China) are examples of human agency that can increase vulnerability to disaster. Exposure to hazards is a major concern; mitigation depends on prediction, preparation and timely response. These processes favour the developed world because of funding, research capacity, organisational levels and technical capabilities that poor nations seldom match. The outcome is that, despite significant knowledge about geophysical and climatological processes, hazards continue to devastate the global community, as seen during the 2010 Pakistan floods and 2011 Horn of Africa drought. Growing international attention and initiatives, such as the United Nations' 'International strategy for disaster reduction' (2010) and the 'Hyogo framework' (Stanganelli 2008) represent efforts to address hazards on a global scale.

Drylands present a great variety of environments and geomorphological processes and incorporate diverse societies, human activities and income levels. Deserts encompass coastal regions of Chile and Namibia; much of Australia, south-western North America and southern South America; the Sahara and large portions of southern Africa, the Middle East and the arid steppe of Central and East Asia (see map in the foreword to this volume). Common factors across drylands are significant because aridity, climate extremes and marginal environments influence hazards. Whilst floods, dust storms and debris flows occur across deserts, hazard events vary by region (Table 2). Although parts of arid and semi-arid regions are highly developed, the vast majority of inhabitants in drylands are what the UNDP (2010, p. 2) has labelled the 'Forgotten Billion', indicating poverty, vulnerability and limited capacity to mitigate extreme events (UN 2008). The variety and complexity of drylands, their unpredictable climates and characteristics and differing social systems present a challenge for hazard mitigation across desert regions and differentiate arid landscapes from other environments. (Warner 2004).

Table 2. Hazards in major world deserts.

| Continent | Country | Desert | Hazard |
|----------------------|---------------------|------------------|--|
| <i>Asia</i> | China/ Mongolia | Gobi | Drought, extreme weather, flood, landslide, earthquake |
| | China | Taklamakan | Extreme weather |
| | Central Asia | Kara-Kyzyl Kum | Extreme weather, drought, landslide, earthquake |
| | Iran | Lut | Earthquake, drought. Flood |
| | India/Pakistan | Thar | Flood, earthquake, drought |
| <i>Middle East</i> | Arabian Peninsula | Arabia | Extreme weather, flood |
| | Syria, Jordan, Iraq | Syrian | Drought, flood |
| <i>Africa</i> | Africa | Sahara | Drought, flood, extreme weather |
| | Libya, Egypt, Sudan | Libyan | Drought, flood, extreme weather |
| | Southern Africa | Kalahari | Flood, drought |
| | " | Karoo/Namib | Drought, flood |
| <i>Australia</i> | Australia | Simpson | Drought, flood, extreme weather, wildfire |
| | " | Victoria, Gibson | Drought, extreme weather |
| <i>North America</i> | Mexico/US | Chihuahua | Earthquake, drought, volcano |
| | " | Mojave | Earthquake, drought, flood, wildfire |
| | " | Sonoran | Drought, flood, earthquake |
| | US | Great Basin | Earthquake, flood, drought, extreme weather |
| <i>South America</i> | Peru | Peruvian | earthquake, drought, landslide |
| | Chile | Atacama | Earthquake |
| | Argentina/ Chile | Patagonia/Monte | Flood, landslide, earthquake |
| | Brazil | Noreste | Storm, drought |

Source: Goudie 2004; EM-DAT 20011.

HAZARDS

Though significant variability exists across deserts, common factors trigger hazards and lead to social exposure. A dryland perspective is essential for (1) pan-desert understanding of potential hazards, means of prediction, preparation and mitigation; (2) identification of physical factors that frame events and affect immediate response; and (3) the critical process of disaster mitigation and addressing social vulnerability and landscape and human resilience. The potential benefit of coordinated engagement is greater knowledge, more effective engagement and reduced hazard-related damage.

Predominant hazards in drylands are drought, floods and extreme weather, with earthquakes and dust storms also prevalent. Concern focuses on the intersection of physical conditions, climate and people. Stark environmental conditions means that plants, animals and humans operate within a limited adaptive range that is constrained by water for growth and survival. The relative ecological inflexibility and dearth of alternatives in drylands increases system vulnerability. The lack of available resources binds desert life to virtual oases, often created by man (think of Riyadh or Phoenix). Once a hazard strikes there are few options, a situation that creates famine refugees in the Horn of Africa and causes great hardship for Mongolian pastoralists in extreme weather. Life in drylands is tenuous, often artificial and thus hazards expose the fragility of humans in such environments.

Given the physical limitations, the first challenge is understanding hazard dynamics. Bagnold (1941) showed with his work on sand transport that desert processes can be identified in one location and applicable across drylands. Similarly, how a drought develops has common traits across low-moisture regions, as do flood dynamics in barren landscapes. Human modifications intensify natural processes; comprehension begins in the physical realm. As cities and societies develop, and at times disappear, in deserts people are exposed to parallel forces. Within this realm, institutions, economics and lifestyles vary globally to provide points of comparison as well as models of success and failure in adaptation and development. Digging great canals to transport water for cotton in Arizona may seem like a success today but may be unsustainable over time. Required costs, inputs and effectiveness provide insight that can be assessed and evaluated before being implemented elsewhere.

We are repeatedly dealing with the same hazards in different cultural and technical ways and so can examine disasters from several angles. In this way a desert-oriented perception can draw on global research, customs and action that highlight applicable methods for hazard prediction, preparation and response. We have great capability to generate hazard related data, track events and assess damage through satellite imagery, indices, seismography, modelling, historical records and socio-economic data – what is key is effectiveness and applicability. Highly developed countries provide a trail to follow that focuses on engineering, technical skill and cost-intensive processes. This may involve, say, redirecting rivers to reduce flooding risk, a practice that may work in the US but perhaps not be feasible in Pakistan. Drought indices, remotely sensed vegetation and moisture levels, migration patterns and water availability are examples of current

knowledge and capabilities that, irrespective of origin, can be widely distributed and applied – the potential exists to be equally aware of drought conditions in Australia, Somalia and Mexico. The reasonable, perhaps idealistic, view would aver that across drylands there is mutual intent, even obligation, to identify and share knowledge and methods to reduce disaster risk.

Physical

Climate, geomorphological and aeolian processes, evapotranspiration, sediment yield and vegetation are all influenced by aridity (Goudie 2004). Desert topography is varied, with landforms dominated by mountains, piedmonts, gravel plains, dunes and badlands. Continual evolution, climate fluctuation, dessication, global warming and human agency – subsidence, salinisation, dune activation, irreparable modifications – shape today's drylands. Against this background we create cities, undertake agro-pastoralism, exploit mineral resources and pursue lives framed by limitations identified throughout this chapter. An unforgiving nature characterises drylands as environments that provide sun, warmth and vast horizons yet lack in any abundance water and several of life's essentials.

When hazards strike, drylands face the same challenges – response capacity, access to water, emergency relief. Severe weather, remoteness or lack of infrastructure, supplies, relief distribution networks constrain mitigation efforts. Exposed populations, limited environmental adaptive capacity and lack of alternatives lead to human crises – think of emergency camps in deserts of Iran after an earthquake or displaced flood victims in Pakistan. Within the hazard relief, framework methods tailored for drylands that consider distance, the narrow range of realistic options and the exposure of people to physical elements and climate are essential. This needs a different model from that used in temperate or tropical zones with more abundant natural resources. Mongolia offers an example of how dryland restrictions can turn a hazard into a disaster.

Social

Population growth in desert megacities (Table 3); dependency on piped or delivered water, often transported over great distances; environmentally dependent livelihoods (crops, livestock); and living in fragile or risk-prone areas (such as Los Angeles on the San Andreas Fault, flood zones of the Kalahari) all tax adaptativity. Conflict; a lack of alternative livelihoods, particularly amongst poor; sub-standard homes; and inadequate infrastructure increase disaster risk in arid lands. Housing and school collapse after earthquakes in Iran, Turkey and China; degradation caused by goats raised for cashmere in Mongolia; and the displacement of thousands in floods in Pakistan, South Africa and Australia are all examples of human exposure.

*Hazard Impact on Desert Environments***Table 3. Dryland megacities.**

| | | | | | |
|-------------|------------|--------------|------------|------------|-----------|
| Delhi | 23,300,000 | Cairo | 15,400,000 | Dallas | 6,650,000 |
| Mexico City | 22,900,000 | Tehran | 13,300,000 | Baghdad | 6,550,000 |
| Los Angeles | 18,100,000 | Lima | 9,250,000 | Riyadh | 5,650,000 |
| Karachi | 17,000,000 | Lahore | 8,900,000 | Khartoum | 5,000,000 |
| Beijing | 16,000,000 | Johannesburg | 7,800,000 | Alexandria | 4,700,000 |

Source: Brinkhoff 2011.

We are well aware of how human pressure can increase vulnerability and concomitantly decrease resilience against hazard events (see next section). Disaster related actions in arid lands are exacerbated by harsh landscapes, as human lives in deserts are based on (over)exploitation of finite resources. Inexorable processes (development, urbanisation, finite resources) are unlikely to change, yet awareness of exposure, increasing climate impact (IPCC 2007), population pressure and the cost both of mitigation efforts and failure to reduce risk are shared across deserts. The key difference is the regional ability to engage with these issues. This is where a desert-oriented approach to mitigation is most important, as researchers, international organisations and governments can cooperate to enhance capability in developing drylands that are disproportionately affected by disaster. It is more logical and reasonable to have intra-desert communication and guidance rather than following North–South or temperate-to-dryland zone paradigms to lessen hazard vulnerability.

An early example of cross-desert knowledge sharing was the British Government project that sent Wilfred Thesiger from Ethiopia to the Arabian Peninsula in 1945 to track potential sources of the desert locusts. At the time it was feared locust invasions could spread from Africa, through the Middle East to India. By investigating potential locust outbreaks in Arabia, research was able to identify local conditions, assess regional implications and inform policy in South Asia. Though now known as an explorer, Thesiger's efforts provide a model of working across deserts to address important threats.

A current illustration is Israel's transfer of desert water techniques that reduce drought impact in arid regions (Tal 2006). Agricultural and domestic practices, including subsurface drip irrigation, water harvesting, reuse and related technologies, have been adapted in diverse drylands from Kenya, Kazakhstan and China to Australia to reduce water use. Dust storm research connects sources in the Sahara and Gobi with research in Japan, US and the UK to better understand and reduce aeolian transport and impact. Today's great resources from technology, travel and the internet to satellite imagery and global monitoring networks enable rapid, effective interaction between researchers, governments and people in drylands. This interconnectivity can be harnessed to assess and address hazard mitigation in drylands.

Vulnerability and risk

One key to addressing hazards is to understand how people and societies interact with the landscape. Hazard reduction requires knowledge, prediction, preparedness and response. The vulnerability of a society and its response to an event depends on the resilience of physical and social systems and their ability to adapt to hazards while operating within a sustainable range. These well-used concepts are integral to the debate, as there is a great difference in hazard impact depending on location. Consider the 2010 Haitian and New Zealand earthquakes of similar magnitudes, the former resulting in 235,000 deaths, the latter in zero. This was due to differing levels of societal exposure, preparation, population density at the epicentre, quality of the built environment and infrastructure, response, funding and governmental organisation. Similarly, drought occurred in Australia and Ethiopia in the 1980s; while Ethiopia experienced famine and high mortality, in Australia there were high economic consequences but no loss of life (Bryant 2005). The implication is clear: in highly developed nations better organisation, knowledge and coping abilities that reflect stable governments and economies contribute significantly to hazard mitigation. Today ninety per cent of dryland inhabitants live in developing countries whilst, worldwide, 65 per cent of hazard fatalities and ninety per cent of disaster victims are in low-income countries (income < \$760 per capita – Kahn 2005, UN 2008). Access to funding, technological advances, early warning systems, informed populations and multiple sources of information independent of the government contribute to improved disaster related mechanisms and processes.

Desert zones have a low resource base where fluctuations in bio-physical conditions or human activity can significantly impact on landscape and livelihood productivity. Intertwined human–physical roles shape the exposure of inhabitants and determine if natural hazards become disasters. Two key theoretical concepts are relevant – the vulnerability of people to, and the nature of, events outside the system (i.e. hazards); and the resilience of social and physical systems when encountering disruption. Vulnerability is a measure of exposure and susceptibility to external conditions, sensitivity to disturbance and the ability to cope with difficulty; the focus is on risk and how a society and its members may be exposed to and negatively impacted on by a hazard (Cutter *et al.* 2003, Adger 2006). Vulnerability considers how internal or external stresses and events outside normal variability, such as an earthquake or a drought, may have a limiting or detrimental effect on livelihoods and wellbeing. The applicability of vulnerability to hazards focuses on impacts on the human landscape and requires a social context such as access to resources (water, food) or economic forces (effect on livelihoods). When a natural hazard occurs, focus is on the social context – how the external event may have a detrimental effect on livelihoods and wellbeing – rather than physical parameters (Smit and Wandel 2006).

Resilience examines the ability of a physical or human system to cope with disturbance but maintain a basic structure and functioning. It assesses adaptability and the capacity of a system to return to a stable state when encountering changing conditions, such as drought, without lasting adverse consequences (Holling 1973,

Walker and Salt 2006). Flexible processes are implied that can encompass shifts in physical dimensions, such as quakes or floods; or social factors, like intensified land use or increased populations. Resilience encompasses variability and is of particular importance when deserts with limited resources encounter extreme external events. Resilient physical and social systems are able to react to a hazard without crossing a threshold to a different (negative) state (Pelling 2003).

PART II – NATURAL HAZARDS IN DESERTS – AN EXAMPLE FROM MONGOLIA

Up to this point the chapter has evaluated hazards in deserts in general. Herein we examine one specific hazard – the 2010 *dzud* in Mongolia. This presents a seldom-reported event that has a significant regional impact, namely the unusual extreme cold weather hazard known as *dzud*. Recurrent in the Gobi desert of northern China and southern Mongolia, it is considered the area's worst natural disaster (Batima *et al.* 2005). The 2010 winter *dzud* became Mongolia's most serious disaster in the last hundred years (EM-DAT 2011); examining the *dzud* provides a current example of how natural hazards interact with societies to create disaster in dryland zones (Figure 2).

Disentangling the multiple factors that produce disaster and damage society is important for understanding climatic hazards. *Dzud* is an unusual extreme weather hazard in northern Asian drylands that occurs when snow, ice, cold or freezing wind restrict animal access to forage, a process that often results in high livestock mortality rates and humanitarian disaster (Suttie 2005, Sternberg *et al.* 2009). As an iterative event in Inner Asian high-latitude drylands, *dzud* can have devastating effects, particularly

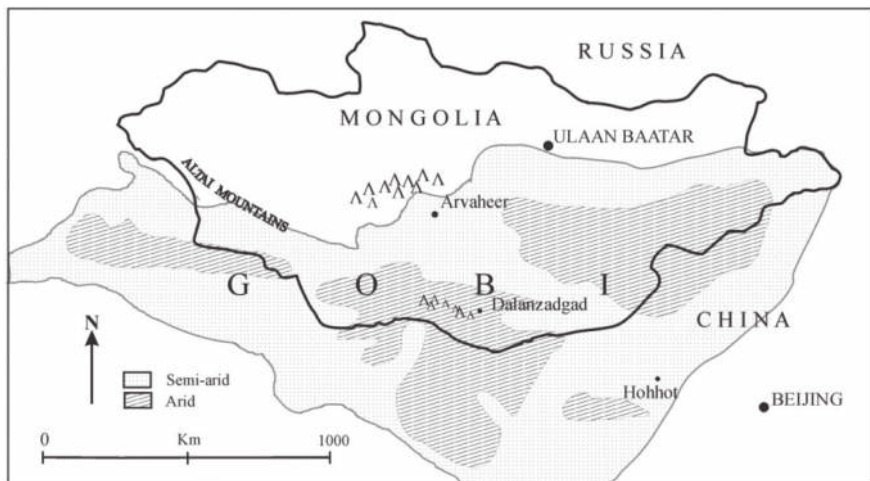


Figure 2. Map of the Gobi Desert.

when exacerbated by drought (Table 4). Such an event occurred in winter 2010, when temperatures in much of Mongolia fell below -40°C and precipitation was higher than average. The combination of abnormally cold weather and greater snowfall resulted in frozen groundcover and loss of forage access for livestock and ultimately starvation for 25 per cent of the national herd in this pastoral country (UN 2010). The outcome was Mongolia's greatest hazard in terms of people affected (Table 5) over the last century (thirty per cent of the population), the loss of livelihood for three per cent of the population and high out-migration from rural communities (UN 2010). The event has affected long-term pastoral viability and social dynamics in provincial towns and the capital (Em-Dat 2011, UN 2010, Sternberg 2011)

Table 4. Major *dzud* events in Mongolia.

| Year | Type of Disaster |
|-----------|-----------------------|
| 1944–5 | <i>dzud</i> + drought |
| 1954–5 | <i>dzud</i> |
| 1956–7 | <i>dzud</i> |
| 1967–8 | <i>dzud</i> + drought |
| 1976–7 | <i>dzud</i> |
| 1986–7 | <i>dzud</i> |
| 1993–4 | <i>dzud</i> |
| 1996–7 | <i>dzud</i> |
| 1999–2000 | <i>dzud</i> + drought |
| 2000–01 | <i>dzud</i> + drought |
| 2009–10 | <i>dzud</i> |

Source: Reading *et al.* (from UN Mongolia archives) 2006

Table 5. Natural hazard impact on Mongolian society, 1900–2010.

| Disaster | Date | People Affected |
|---------------------|---------|-----------------|
| Extreme temperature | 12/2009 | 769,113 |
| Storm | 12/2002 | 665,000 |
| Storm | 12/2000 | 571,000 |
| Storm | 1/2000 | 500,000 |
| Drought | 2/2000 | 450,000 |
| Flood | 7/1996 | 270,000 |
| Storm | 4/2004 | 175,000 |
| Storm | 3/1993 | 100,000 |
| Flood | 7/2009 | 15,000 |
| Wildfire | 4/1996 | 5,061 |

Source: EM-DAT 2011

Hazard Impact on Desert Environments

The Mongolian word *dzud* signifies severe winter conditions that affect livestock mortality (Figure 3). White *dzud* denotes heavy snowfall, black *dzud* indicates extensive ice cover, *huiten dzud* reflects extreme cold and storm *dzud* connotes a blizzard, storm or heavy snowdrift. These are iterative events on the steppe, with *dzuds* occurring approximately once or twice per decade (Begzuren *et al.* 2004). Whilst harsh weather is a climate constant, the human engagement and societal interaction with *dzud* has transformed over time; *dzud* impact on livestock-raising is important, as recently Johnson *et al.* (2006) reported that fifty per cent of the population was dependent on pastoralism for their livelihood. In the last hundred years Mongolia has transitioned from a feudal state run by religious and noble elites to a strict communist regime in the 1920s, switching in 1990 to democracy and a market economy. The shift to participatory government and capitalism has had a dramatic effect on the way pastoralism has been practiced in the countryside; the different political systems provide contrasting approaches to the endemic hazard. Under the centrally-planned Soviet regime pastoralism was controlled by the state, with livestock numbers, herd movements and pasture use determined by local officials. *Dzud* response was well organised and included emergency fodder and



Figure 3. *Dzud* conditions in the Gobi region, winter 2010.

food, whilst herders received a fixed salary that reduced livelihood hardship during *dzud*. Regulation ensured limited animal numbers (150 maximum per family in the Gobi region), herd migration, pasture reserves and fixed prices for products. Post-transition pastoral management has been markedly different. Openness and market forces have changed herding dynamics from a subsistence approach suited to ecological conditions to an income-driven activity. Private livestock ownership, market forces and livelihood needs have led to decisions based on socio-economic factors that can increase exposure to hazards. New behaviour includes greatly increased livestock numbers to generate greater income; reduced migration due to costs; a shift to goats for cashmere production, now the main source of revenue; settlement near towns for health and education benefits; and debt obligations that drive livestock numbers ever higher. At the same time, regulation is minimal, government support for animal breeding or transport has ceased and infrastructure, particularly water wells, has declined precipitously. The result has been livestock intensification, greater animal and human concentration near water sources and decreased mobility. These factors have led to degraded land cover and increased herder vulnerability to hazards as pastoral resilience has been affected.

Dzud dynamics focus on two aspects: the variable climatological factors that affect ecological productivity and the human points of interaction with the environment. The former, the causal factor, is severe winter weather conditions that typify the region; the latter effects are driven by economic parameters that amplify the disaster. Dominant is the perceived need for income that leads herders to maximise their revenue sources, which are limited to livestock and related products – animals, meat, milk, cashmere and wool, while minimising expenses. To maximise income, herd numbers are expanded; this leads to more intensive use of the grasslands. As the main income source, cashmere production has increased dramatically in recent years. This has meant a doubling in the number of goats in six years (nine million in 2002, twenty million in 2008) with detrimental effect on pasture vegetation (Tumurjav 2003). Increased livestock (Table 6), combined with decreasing resources (little government support or access to transportation, poor infrastructure), reduced pasture productivity and led to greater hazard exposure. Highest-ever livestock levels created the situation where severe climate factors became a tipping point, as current herding practices exacerbated sparse environmental conditions. As cold weather settled over the steppe, the majority of herders were unable to cope with harsh circumstances, reflecting limited resilience to environmental conditions, a factor that in the past had been a Mongolian strength.

Table 6. National livestock herd 2002–2008, in millions.

| 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|------|------|------|------|------|------|------|
| 23.9 | 25.4 | 28.2 | 30.4 | 34.8 | 40.2 | 43.3 |

Source: Mongolian Statistical Yearbook 2005, 2009.

Hazard Impact on Desert Environments

Animal fatalities first appeared as isolated events; only as mortality intensified did the magnitude of the event become clear. In January the National Emergency Management Agency notified the government of the developing crisis; the government then asked the international community (donor nations, NGOs, UNDP) for emergency assistance. In February the United Nations began an initial relief programme to bury carcasses in order to limit the spread of disease, an ancillary issue unable to directly mitigate the hazard-induced death rate. By April, donations from the international community began to arrive but these were insufficient and too late to slow spiralling mortality. The response highlighted three processes common in dryland disasters. First, the unfolding disaster reflected the government's limited ability to mitigate hazards, which in turn exacerbated hazard impact and damage. Second, even with willing donors the country's remoteness presented great difficulty in getting appropriate aid to disaster-stricken areas. The diffuse nature of the hazard in a country half the size of western Europe and the lack of infrastructure (transport, services, technical capability) meant that timely, relevant aid – fodder in this case – was not feasible. Third, as a slow-onset hazard, identification and response to the crisis were gradual processes. Prediction and preparation were lacking and the key to response – emergency fodder – was unavailable.

The pastoral impact has been devastating for herding households. Loss of animals means loss of livelihood and food supply. A lost herd cannot be quickly overcome – there is no ability to replant the following year as a farmer would do after a disaster. Livestock replacement has a long timeframe (years) and animals suffering from malnutrition that do survive to the spring birthing season can be too weak to give birth. Below a certain level (under a hundred small livestock) pastoralism loses viability in Mongolia, putting herders themselves at risk of hunger. These dynamics drive out-migration from herding, as those who no longer have animals have little choice but to resettle, whilst a further twenty per cent or more who lost more than half of their herd may not be able to continue herding (UNCTCR 2010). Herder displacement drives resettlement to towns and cities, specifically the capital Ulaan Baatar, compelling a poor country (121st in the Human Development Index) with a 36 per cent poverty rate to integrate waves of herders that have relocated to urban centres. The migrants possess minimal relevant job skills and stress the limited education, health and social services available. The results mirror the processes after a similar serious *dzud* event a decade ago, which prompted discussion of 'environmental migration' on the steppe.

The vulnerability stemmed from attempts to maximise income in a marginal environment. Socio-economic forces (particularly income maximisation) led to intensification, larger herd numbers than ecological productivity could support, overgrazing and land degradation (Borgford-Parnell 2011). In tandem with variable climate factors, periodical drought (claimed but as yet undocumented), as in previous *dzud* episodes (see Table 4), led to the disaster. The driver, increased income to obtain the perceived necessities of modern life, shows how even herding on the Inner Asian steppe is affected by globalisation. As cashmere prices plunged in 2008, goat numbers expanded to maintain income levels, leading to the accumulation of the country's highest livestock

numbers ever (Mongolian Yearbook 2009). In the past, *dzud* was an environmental way of correcting unsustainable herd numbers; today it is a societal disaster.

Mongolia has a stable government with good political and development ties with neighbours China and Russia as well as Japan and Korea, the European Union and the United States. The government encourages international engagement and is one of the world's largest per-capita recipients of foreign aid. Such a country could be a model state for hazard preparation and response in the developing world for several reasons. There is high awareness of drought and *dzud* and a genuine desire to reduce their detrimental impact. Pastoralism is revered and essential to the country's self-conception, provides a livelihood for forty to fifty per cent of the population and accounts for over twenty per cent of GDP (Borgford-Parnell 2011). For these reasons, measures to continue herding viability have wide support.

With minimal agriculture, due to unsuitable soils, there is not competition between herders and farmers. The newest dynamic is a mining tax windfall, as Oyu Tolgoi, claimed to be the world's biggest new copper and gold mine, and other mines around the country are opened. This is projected to generate hundreds of millions of dollars in tax revenue annually, funds that in part can potentially address hazard mitigation. Improved hazard prediction is needed – Mongolia has a competent Institute of Hydro-Meteorology that could increase climate monitoring and prediction. Greater rural organisation, infrastructure and support could strengthen livelihoods, as the majority of inhabitants live in the countryside. Effective former Soviet practices could be reinstituted, including emergency fodder depots in the provinces, reserve pastures, greater livestock migration, more wells to better distribute grazing and improved economic organisation and development. The new mineral wealth could pay for relatively inexpensive measures to reduce disaster vulnerability in the country. At the same time, the country faces standard developing-world dilemmas – concerned but ineffective governance, particularly in the countryside; competition for resources (education, health); and physical and technical obstacles. Increasing corruption and limited long-term vision are further challenges to reducing *dzud* risk. Until pastoralists have a stronger voice in the national debate, hazard mitigation will remain ineffective.

DISCUSSION

The challenge for residents of desert regions, who live principally in developing countries, is to reduce vulnerability and improve hazard preparedness and response. Globally it has been difficult to get funds for hazard prevention before an event – 95 per cent of disaster funding goes to relief efforts rather than planning and prevention (Hochrainer and Melcher 2011). Interest focuses on the immediacy of high death tolls, not the intangibles of gradual threats to livelihoods. In 2009, Mongolia began efforts to improve disaster preparedness through the United Nation's programme '*Strengthening the Disaster Mitigation and Management System in Mongolia*'. The topic was timely but efforts were swept aside by the magnitude of the *dzud* catastrophe. Much is known

about hazards that strike deserts and several practical methods exist that could reduce hazard risk. Mitigation requires interest and intent and the ability to establish hazard reduction procedures before events occur. Even where there is government interest, structural barriers are hard to surmount, reflecting low development levels where dryland populations are concentrated. These conditions contribute to hazard vulnerability and challenge the resilience of both physical and social systems.

The varied hazard issues framed by dryland conditions – system exposure, limited water, remoteness, poverty – call for relevant mitigation efforts. The experience and technical knowledge of advanced desert nations (Australia, the US) can inform practice in the developing world though the organisational structures and technical levels are difficult to repeat. The international community recognises the inherent difficulties of risk reduction and has instituted several programmes to address increasing hazard events and enhance risk reduction. These include the United Nations ‘International Strategy for Disaster Reduction’ and the ‘Hyogo Framework for Action: Building the Resilience of Nations and Communities to Disasters’, programmes that have been adopted by the international community (Stanganelli 2008). These initiatives draw upon current knowledge and represent substantial efforts to reduce societal risk. Programmes provide guidance that needs to be adapted to regional conditions; initiating complex strategies can be impractical on a global scale as local parameters greatly affect programme implementation. As a Mongolian researcher stated, ‘if we could do all these things, we would be developed!’ This is pertinent in drylands where challenges and capabilities are shaped by development, landscape constraints and social dynamics that may differ from those in temperate zones.

Related issues: climate change, desertification and environmental migration

There are several related issues when addressing hazards in drylands. These issues encompass concepts of climate change (Warner *et al.* 2009), desertification (Yang *et al.* 2005), environmental hazards (Adamo and Crews-Meyer 2006) and environmental migration (Reuveny 2007) that are linked with natural hazards, both as regards physical causation and social impact. The broad point is that these processes often have a negative effect in drylands. These processes are independent of, though often exacerbated by, hazards; they should be evaluated as part of the complex interaction between physical processes and human action in drylands, not as hazards themselves.

The dominant desert issue for our time is climate change and how it may affect natural and social systems. The key issue in this context is how climate change may affect hydro-meteorological processes and the vulnerability of populations to external forces. Foremost in drylands is concern over rising temperatures and reduced water availability for agricultural and human needs. Much research addresses future climate change, with work on desert zones being part of national or regional analysis, global monitoring of water resources and vegetation coverage and risks to human wellbeing. A brief historical perspective shows numerous occasions of civilisations collapsing as a result of climate factors. These include the Babylonians in Mesopotamia in the fourth

millennium BC, Mohenjo-daro in the Indus Valley (Pakistan) in 1,500 BC, ancient Chinese dynasties, the Mayans in the ninth century in southern Mexico and the Anasazi in the American Southwest in the fifteenth century (Leroy 2006, Diamond 2005, Zhang *et al.* 2010). Drought, loss of water resources and agricultural decline have often been considered the cause of social disintegration.

Today changing climate parameters and their implications for the environment are particular concerns for drylands, since these regions are regarded as fragile ecosystems subject to great environmental variability and have fluctuating productivity for human needs. Positively, the great increase in climate research over the last decade provides a clearer idea of its potential effects in arid regions. The IPCC (2007) identifies warming temperatures, reduced water resources, greater climate volatility and considerable increase in drought risk as having the greatest impacts on deserts. Physical factors contributing to climate change include El Niño Southern Oscillation (ENSO) patterns, shifts in jet stream (polar and subtropical) paths caused by earth's rotation and heating/solar radiation in the atmosphere and alteration of the inter-tropical convergence zones (Bryant 2005). Human impact on climate is now considered the primary reason for change, as increased greenhouse gases resulting from fossil fuel use unnaturally affect the climate (UK 2010). Additional factors are environmental changes (deforestation, degradation, desertification) that often result from population pressure. As climate affects physical hazards directly through precipitation, storms or extreme weather and indirectly via human action and social vulnerability, it becomes a principal force in hydro-meteorological disaster episodes.

The United Nations (2007) identifies desertification exacerbated by climate change as the 'greatest environmental challenge of our time' while the UNCCD states that desertification affects seventy per cent of global drylands and threatens a billion people (Yang 2010). It is sometimes presented as a natural hazard, yet its definition as 'the process of land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations (drought) and human activities' makes desertification an indirect result of hazards rather than a natural phenomenon itself (UNCCD 2007). It often results from human action, particularly livelihood decisions in marginal environments, land cover change, development and exploitation of resources. In the developing world agricultural practices, overgrazing, firewood collection and population density are major causes throughout drylands (Chen and Tang 2004, Adamo and Crews-Meyer 2006). Unlike a quake or severe storm, desertification is not a natural hazard – rather it is a progression of degradation that reflects the change from ecological viability to a permanent loss of productivity. In a hazards framework it would be an indirect effect that hazard events, particularly drought, may contribute to. Competition for resources in drylands, particularly for water; shifting vegetation zones as a result of variable precipitation or land use; wind or water-driven soil erosion; and human stressors such as population and conflict are contributory forces that lead to degradation processes and behaviour. Climate change is another factor that indirectly

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affects desertification, as landscapes evolve due to climate parameters. Further, concise identification of desertification is difficult because of endemic dryland variability.

Concepts of environmental hazards and environmental migration stretch the idea of hazards to external causes that impact on people. The former draws in physical conditions and processes that threaten livelihoods and lives (Adamo and Crews-Meyer 2006) whilst the latter reflects how sudden or slow-onset environmental changes or degradation processes lead to migration by people dependent on the environment for their livelihood, as when drought makes farming untenable (Dun and Gemenne 2008). Neither circumstance is a hazard, though they may be influenced by natural hazards. This distinction is useful to assess the capability of societies to adequately deal with indirect impacts, a process that differs from hazard response. Environmental hazards and migration become part of the debate because declines in food supply, economic levels, health and water access are paramount concerns in the less developed countries that comprise ninety per cent of dryland population. These nations have a high dependence on the environment for livelihoods and lower adaptive and mitigation capacity due to poverty, low technical skills and limited government support (Reuveny 2007). Low capacity leaves people vulnerable first to hazards and secondly to resultant environmental stresses.

CONCLUDING REMARKS

Desert complexity, variety and spatial extent makes addressing hazards dependent on climate, geomorphology and natural forces as well as human development and social vulnerability in a region. The intensity of rapid- and slow-onset events, the remoteness and physical barrier that deserts can present and the natural obstacles to mitigating hazards are matched by the limitations of people and institutions found in the predominantly less-developed arid and semi-arid zones. Identifying geographical constraints and livelihood obstacles is essential for improved understanding of dryland hazards and awareness of potential risks. The ability to mitigate risk depends on perception, capability and action at local levels, a situation exemplified by the 2010 extreme winter event in Mongolia. Planning and *dzud*-preparedness was limited and response was too late to effectively reduce hazard impact. Acknowledging vulnerability levels in arid zones and identifying paths to resilience and decreasing exposure are vital to mitigate hazard risk as events increase. The recognition that hazard impact and mortality is greatest in less-developed regions stresses the importance of international efforts to mitigate hazards. As an integral part of our dynamic planet, hazards present an enduring challenge across desert regions (Warner 2004, UN 2008).

REFERENCES

- Adamo, S. and K. Crews-Meyer (2006). 'Aridity and desertification: exploring environmental hazards in Jachal, Argentina'. *Applied Geography* **26**: 61–85.
- Alcantara-Ayala, I. and A. Goudie (2010). *Geomorphological Hazards and Disaster Prevention*. Cambridge: Cambridge University Press.
- Bagnold, R. (1941). *The Physics of Blown Sand and Desert Dunes*. London: Methuen.
- Batima, P., L. Natsagdorj, P. Gombluudev and B. Erdenetsetseg (2005). 'Observed climate change in Mongolia'. *AIACC Working Paper No. 12*. www.aigccproject.org
- Begzsuren, S., J. Ellis, D. Ojima, M. Coughenour and T. Chuluun (2004). 'Livestock responses to droughts and severe winter weather in the Gobi Three Beauties National Park, Mongolia'. *Journal of Arid Environments* **59**: 785–796.
- Borgford-Parnell, N. (2011). 'Synergies of scale: A vision of Mongolia and China's common energy future'. *Energy Policy*. **39** (5): 2764–2771.
- Brinkhoff, T. (2011). 'The principal agglomerations of the world'. www.citypopulation.de
- Brooks, M., J. Matchett, C. Wallace and T. Esque (2004). 'Fuels mapping and fire hazard assessment in a desert ecosystem'. *Arid Lands Newsletter* **55**. www.ag.arizona.edu/OALS/ALN/aln55/brooks.html
- Bryant, E. (2005). *Natural Hazards*. 2nd ed. Cambridge: Cambridge University Press.
- Centre for Research on the Epidemiology of Disasters (2009). www.cred.be
- Chen, Y. and H. Tang (2005). 'Desertification in north China: background, anthropogenic impacts and failures in combating it'. *Land Degradation and Development* **16**: 367–376.
- Diamond, J. (2005). *Collapse: How Societies Choose to Fail or Survive*. London: Allen Lane.
- Dun, O. and F. Gemenne (2008). 'Defining environmental migration'. *Forced Migration Review* **31**: 10–11.
- Emergency Event Database (EM-DAT) (2009). www.emdat.be/world-map
- EM-DAT (2011). www.emdat.be/disaster-profiles
- Fernandez-Gimenez, M. and B. Allen-Diaz (1999). 'Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia'. *Journal of Applied Ecology* **36**: 871–885.
- Goudie, A. (2004). *Great Warm Deserts of the World*. Oxford: Oxford University Press.
- Goudie, A. (2010). 'Introduction', in I. Alcantara-Ayala and A. Goudie (eds.) *Geomorphological Hazards and Disaster Prevention*. Cambridge: Cambridge University Press. pp. 1–2.
- Goudie, A. and N. Middleton (2001). 'Saharan dust storms: Nature and consequences'. *Earth Science Review* **56**: 179–204.
- Green, P. (2005). 'Disaster by design'. *British Journal of Criminology* **45**: 528–546.
- Hochrainer, S. and R. Melcher (2011). 'Natural disaster risk in Asian mega-cities: a case for risk pooling?' *Cities* **28**: 53–61.
- Holling, C. (1973). 'Resilience and stability of ecological systems'. *Annual Review of Ecology and Systematics* **4**: 1–23.

Hazard Impact on Desert Environments

- Huppert, H. and R. Sparks (2006). 'Extreme natural hazards: population growth, globalization and environmental change'. *Philosophical Transactions of the Royal Society* **364**: 1875–1888.
- IPCC (Intergovernmental Panel on Climate Change) (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. by M. Parry, O. Canziani, J. Palutikof, P. van der Linden and C. Hanson. Cambridge: Cambridge University Press. pp. 469–506.
- ISDR (International Strategy for Disaster Reduction) (2010). 'Connect and convince: to save lives and reduce disaster impact'. www.unisdr.org/preventionweb/files/14044_ISDRbrochure2010.pdf
- ISDR (2004). *International Strategy for Disaster Reduction Terminology: Basic Terms of Disaster Risk Reduction*. Available at www.unisdr.org
- IUCN (International Union for Conservation of Nature) (2010). *Drylands Situation Analysis*. Available at cmsdata.iucn.org/downloads/iucn_esaro_drylands_situation_analysis.pdf
- Kahn, M. (2005). 'The death toll from natural disasters: the role of income, geography and institutions'. *Review of Economics and Statistics* **87**: 271–85.
- Kellenberg, D. and A. Mobarak (2008). 'Does rising income increase or decrease damage risk from natural disasters?' *Journal of Urban Economics* **63**: 788–802.
- Keyantash, J. and J. Dracup (2002). 'The quantification of drought: an evaluation of drought indices'. *Bulletin of the American Meteorological Society* **83**: 1167–1180.
- Laity, J. (2008). *Deserts and Desert Environments*. Chichester: Wiley-Blackwell.
- Leroy, S. (2006). 'From natural hazard to environmental catastrophe: past and present'. *Quaternary International* **158**: 4–12.
- Mongolian Statistical Yearbook (2005). Ulaan Baatar: National Statistical Office.
- Mongolian Statistical Yearbook (2009). Ulaan Baatar: National Statistical Office.
- Olsson, E. and E. Paglia (2008). 'Global problem: National accountability: Framing accountability in the Australian context of climate change'. *Contingencies and Crisis Management* **16**: 70–79.
- Pelling, M. (2003). *The Vulnerability of Cities: Natural Disasters and Social Resilience*. London: Earthscan.
- Smit, B. and J. Wandel (2006). 'Adaptation, adaptive capacity, and vulnerability'. *Global Environmental Change* **16**: 282–292.
- Smith, K. and D. Petley (2009). *Environmental Hazards: Assessing Risk and Reducing disaster*. 5th ed. London: Routledge.
- Stanganelli, M. (2008). 'A new pattern of risk management: The Hyogo Framework for Action and Italian practise'. *Socio-Economic Planning Sciences* **42**: 92–111.
- Sternberg, T. (2011). 'Regional drought has a global impact'. *Nature* **472**: 169.
- Sternberg, T. (2010). 'Unravelling Mongolia's extreme winter disaster of 2010'. *Nomadic Peoples* **14**: 72–86.
- Stewart, I. and K. Donovan (2008). 'Natural hazards', in S. Buckingham and M. Turner (eds.) *Understanding Environments*. London: Sage Publications. pp. 207–234.

- Stott, P., D. Stone and M. Allen (2004). 'Human contribution to the European heatwave of 2003'. *Nature* 432: 610–614.
- Tal, A. (2006). 'Seeking sustainability: Israel's evolving water management strategy'. *Science* 313 (5790): 1081–1084.
- Tumurjav, M. (2003). 'Traditional animal husbandry techniques practiced by Mongolian nomadic people', in D. Badarch, R. Zilinskas and P. Balint (eds.) *Mongolia Today*. London: Routledge Curzon.
- UK (2010). 'Causes of Climate Change'. http://www.direct.gov.uk/en/Environmentandgreen-living/TheWiderEnvironment/Climatechange/DG_072920
- United Nations (UN) (2008). 'Desertification'. www.un.org/esa/sustdev/publications/trends2008/desertification.pdf
- UNCCD (2007). 'United Nations convention to combat desertification'. www.unccd.int/convention/text/convention.php?annexNo=-1
- United Nations Country Team Consolidated Report (UNCTCR) (2010). 'Dzud appeal'. Available at www.undp.org/cpr/documents/recovery/mongoliaappeal.pdf
- Walker, B. and D. Salt (2006). *Resilience Thinking*. London: Island Press.
- Washington-Allen, R., R. Ramsey, N. West and B. Norton (2008). 'Quantification of the ecological resilience of drylands using digital remote sensing'. *Ecology and Society* 13: 1–18.
- Wisner, B., P. Blaikie, T. Cannon and I. Davis (2004). *At Risk: Natural Hazards, People's Vulnerability and Disasters*. London: Routledge.
- Yang, X., K. Zhang, B. Jia and L. Ci (2005). 'Desertification assessment in China: An Overview'. *Journal of Arid Environments* 63: 517–531.
- Yang, X. (2010). 'Desertification and land degradation in arid and semi-arid regions', in I. Alcantara-Ayala and A. Goudie (eds.) *Geomorphological Hazards and Disaster Prevention*. Cambridge: Cambridge University Press. pp. 189–198.
- Zhang, Z., H. Tian, B. Cazelles, K. Kausrud, A. Brauning, F. Guo and N. Stenseth (2010). 'Periodic climate cooling enhanced natural disasters and wars in China during AD 10–1900'. *Proceedings of the Royal Society B*. 277: 3745–53.

KNOWLEDGE SYSTEMS HAVE NOT SERVED THE DRYLANDS WELL: REFLECTIONS ON STAKEHOLDER INTERACTIONS

Michael Mortimore

The purpose of this reflection is to draw attention to an anomaly that troubles me after spending some years researching dryland development. The anomaly is that while scientific knowledge – based on a proliferation of excellent research – multiplies all the time, the application of it to better the condition of dryland peoples is patchy at best. Indeed, the application of new knowledge is apparently more difficult than its creation. Why is this so, and is it acceptable?

The drylands are defined as land areas having an aridity index of <0.65 (Thomas and Middleton 1992). They comprise 41.3 per cent of the global area and accommodate 35.5 per cent of the global population. The hyper-arid deserts are a subset (6.6 per cent of global area); then we have arid, semi-arid and dry sub-humid ecosystems. The defining and mapping of drylands are the products of knowledge systems originating outside the drylands and therefore dominated by the concept of aridity as a deficiency from a human developmental perspective. From such a perspective, it makes good sense to consider together all regions where seasonal or permanent aridity is a major driver of ecosystem management, livelihoods and human well-being. Dryland populations are overwhelmingly concentrated in poor countries. Development is therefore seen as a global priority, and as a condition for achieving the Millennium Development Goals. To facilitate this is a primary mission of applied science.

Indigenous or local knowledge systems do not necessarily share this perspective. They are rich in management experience, which includes how to sustain production systems under conditions of high rainfall variability. For example, in Niger the WoDaaBe describe the arid savannah bushland as ‘*beldum*’ which means ‘sweet’, or ‘nice’ (Krätli 2008). The preconceptions which are used to justify development interventions (low productivity or poverty measured by external indicators) may not satisfactorily reflect such local evaluations.

Within the applied science model of development, the achievements in reducing poverty have been too few, as suggested by the failures of many technology-based interventions over the past five decades (the era of independence in many African dryland countries) and the persistence (some would say the worsening) of poverty,

both rural and urban. While it is true that science – as shown in agricultural research, for example – has been significantly under-funded when compared with the research and development extravaganzas observed in rich countries, it is not an exaggeration to say that the optimism surrounding new technologies forty years ago has largely given way to scepticism and pragmatism. The green revolution, it now turns out, failed to transform livelihoods in South Asian rain-fed drylands as it had done in irrigated and humid lowlands; and much discussion surrounds the question of its failure to penetrate and transform Africa (Djurfeldt *et al.* 2005). This failure may reflect the many barriers to implementation as much as any intrinsic failings of technologies.

I propose to unpack this question a little and show that drylands are adversely affected by fragmented knowledge systems that have emerged from historical patterns of engagement, as well as by alternative framings within scientific debate. Such an analysis can equip us to ask the question, ‘Have knowledge systems served the drylands well?’ I shall do this by, first, reviewing the problem of diversity, second, exploring the geography of stakeholder groups in the knowledge system and third, examining briefly the role of Time. This is intended to be a practical rather than a theoretical approach.

THE PROBLEM OF DIVERSITY

The category ‘drylands’ incorporates great diversity, not only in the biophysical variables of dryland ecosystems but also in the management and knowledge systems that determine their condition or state. Herein lurks a major impediment to integrated drylands science, and to adaptive development policy: every stakeholder in dryland knowledge systems, from the smallest and poorest resource user to corporate institutions, approaches the challenge of dryland management from a restricted perspective formed by personal experience (or institutional memory) in a particular ecosystem, management regime or knowledge system. The ecosystemic diversity of the world’s drylands makes it practically difficult for specialists to have an adequate understanding of more than a few dryland habitats. Diversity counters a popular demand for simple and universally applicable models and solutions for ‘the policy makers’.

Diversity became apparent in early global mapping initiatives, notably the *World Atlas of Desertification*. Greatly enhanced by the arrival of GIS technologies, mapping and measuring the biophysical properties of drylands has reached new heights of technical expertise (e.g., earth satellite data on land cover; and atlas inventories of China’s drylands). GIS mapping not only shows biophysical diversity in graphic and colourful images but also generates reliable global statistical data sets.

But several dilemmas have emerged as to how to respond appropriately. First is the tension between the global and local scales. Aggregated findings at a high level of generality – though generating impressive mega-data sets – disguise the detail of local variation, offering little help to policy at local level. Resource inventories were a popular form of donor assistance in the early post-colonial period in Africa, when technocratic

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planning was expected to emerge under governments that closely resembled their colonial forbears in being top-down and undemocratic.¹ But the extraction of policy messages from the new data sets is not a foregone conclusion. With the intensifying politicisation of natural resources, under conditions of growing market demand, and the weakening of central governments, under democratisation and decentralisation (not to mention penury in some countries), the optimisation of mapping and data generation in political dialogues is a complex challenge. While interest at global level seems to be mainly in generating global messages for global policy (e.g., for the FAO and UNCCD),² at national or sub-national levels, the new knowledge underlines a need for local solutions and negotiations with local stakeholders.

Second, the new data sets distract attention from *process* to *incidence*. The level of sophistication shown in distribution maps or data is not matched by progress in understanding how the distributions came to be, through complex processes such as cycling, degradation and accumulation and climate change. Yet understanding of such processes is a precondition for policy intervention. Unfortunately, this need is commonly side-stepped in a search for *indicators* – a search which is continuously documented from the first world conference on desertification (UNCOD, in 1977³) to the science conference at the 9th COP⁴ of the UNCCD (in 2009). The mapping or measuring of single components, considered of key importance, can provide descriptors of ecosystem status but exposes a scarcity of holistic explanatory models that can synthesise the interactions in complex systems and point to the key drivers of change.

SCIENCE FOR THE DRYLANDS

Science and dryland management are commonly perceived as two sides of a coin. In a simplistic model of development, it might be assumed that there are only two parties to the deal: generators of new knowledge (scientists) on the one hand and users (policy-makers, farmers, livestock herders, etc.) on the other. Such a model assumes that indigenous or local knowledge needs to be replaced or ‘improved’ and has little to contribute to development.⁵ While such a form is no longer accepted, the goal of ‘sustainable land management’ (SLM) underwrites efforts to transform land use systems, both by the FAO and more generally, and not only in the drylands.

Agricultural research has been vigorously pursued from the founding of colonial experimental farms to the international institutions such as ICRISAT, ILRI and

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1. See the many Land Resources reports of the UK Government's Land Resources Division (Overseas Development Administration, Tolworth, Surrey).
 2. See the Food and Agriculture Organisation of the United Nations and the United Nations Convention to Combat Desertification.
 3. United Nations Conference on Desertification, Nairobi, 1977.
 4. Conference of the Parties to the Convention, Buenos Aires, 2009.
 5. Such views were challenged in the different rain forest biome of West Africa by Richards (1985).

ICARDA.⁶ The term 'dryland science' is used here in a more restricted sense to refer to disciplinary and multi-disciplinary efforts that share a commitment to formal scientific method in advancing knowledge of dryland systems. It is a global enterprise; a major part of its funding comes from rich countries (not necessarily having drylands of their own). Debates under the banner of 'drylands' are probably most frequent outside the drylands. There is a tension between scientific agendas and local or indigenous knowledge and as long as dryland science is predominantly 'owned' outside the drylands, this creates a duality in the knowledge landscape. There is, however, reason to believe that this situation may be temporary, as the rapid growth of autonomous scientific research institutions in India and China suggests.

More than one paradigm is employed by scientists in the search for understanding of dryland management challenges, opportunities and constraints. A polarisation is identified between, on the one hand, a 'Desertification paradigm' of irreversible environmental degradation, perpetuated by inappropriate land use practices of small scale resource users under pressure from demographic growth, poverty and variable rainfall; and, on the other hand, a 'counter-paradigm' of local adaptive capacity, achieved through adjustments in resource use, livelihood diversification and temporary migration (Millennium Ecosystem Assessment 2005). As awareness of systemic complexity has grown, another paradigm has been offered in the form of the 'syndrome' approach to characterising major environmental regions. For example, the Sahel of Western Africa is portrayed as a unique combination of key interactive variables, developed over a long period (Schellenhuber *et al.* 1997). The Drylands Development Paradigm seeks resolution of these different interpretations through a theory of co-evolving human and ecological systems, interactions between 'fast' and 'slow' variables, and sustainable or degrading land management resulting from the nature, practices and institutional framework linking the coupled systems over time (Reynolds *et al.* 2007). Complex systems analysis is integral to the recent approaches, calling for interdisciplinary and integrated practice and holistic models, in contrast to reductionist and narrow disciplinary specialisation, or a preoccupation with indicators.

FRAMING DRYLAND KNOWLEDGE SYSTEMS

The starting point of this discussion is that dryland science has under-achieved in its implicit aim of transforming land use systems and in merging seamlessly with indigenous or local knowledge in dryland management. Because of the political economy of poor countries and the patterns of their historical engagement with external powers, markets, NGOs and global institutions, as well as the diversity of local resource users, it is worth while briefly to differentiate the wider framework within which knowledge systems work. I propose a six-fold typology of stakeholders: scientists, global institu-

6. International Commission for Research in the Semi-Arid Tropics; International Livestock Research Institute; International Centre for Agricultural Research in Dry Areas.

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tions, non-governmental organisations (NGOs), commercial interests, national and sub-national government and local communities (including CBOs, or community based organisations). Of course these groups are internally differentiated, but commonalities emerge from their functions within the knowledge system as a whole. It is proposed that stakeholder knowledge systems are non-coincident, and that their fragmentation impedes socially and environmentally sustainable development.

Scientists

The dissemination of new knowledge is not straightforward, given the multiple paradigms used by scientists, the dynamic nature of their knowledge system and the duality that may be said to exist between science and indigenous or local knowledge. Science is inherently dynamic, and there are conceptual, language, translation and 'earthing' issues. Worse – it can be argued – is the restriction of new science knowledge, through exclusive access to 'peer reviewed' journals and expensive books, as well as educational barriers, to a scientific elite which, though international in its membership and debates, is driven by career trajectories and remote from the dryland people who ought to be its beneficiaries.

Until recently, the individual participation of nationals in dryland science depended on undertaking, outside their country, a long process of education, qualification and initiation. Most of the opportunities are in strictly disciplinary fields, rather than in the science of complex systems. When the scientist returns to engage with dryland resource users – not necessarily knowing the local language – the duality is perpetuated and amplified by the access barriers to new scientific knowledge just mentioned.

Global institutions (e.g. conventions) and donors.

'Desertification' was institutionalised by the UNCOD in 1977 with UNEP's Desertification Branch and Plan of Action to Combat Desertification (Sift 1996). This goal – a global one – was later enshrined in the UNCCD following the Rio 'Earth Summit' of 1992. The complexities, contradictions and diversity of dryland management around the world were deliberately subordinated to a simplified battle plan ('combar') based on the desertification paradigm. A bureaucracy was created and the overriding objectives became raising donor resources for projects to transform land use systems and embedding 'action plans' in national policy agendas. These agendas are driven by taxpayer-funded constituencies, traditionally in northern countries but increasingly influenced by representatives of poor countries through global conventions and forums, who want discernible progress on issues highlighted by media publicity.

Much science became instrumental in the pursuit of these aims, expected to consolidate an institutional and political agenda, supporting a 'consensus' rather than reflecting an evolving knowledge.⁷ However, the UNCCD recently changed course and

7. See earlier issues of the *Desertification Control Bulletin*, published by UNEP.

sought greater openness and independent science collaboration, with a Science Conference at the 9th Conference of Parties in 2009 (Winslow *et al.* 2011). In dryland issues there is little sign of the scientists driving the political agenda and the UNCCD has no equivalent body to the IPCC⁸ in relation to the UN Convention on Climate Change.

Interactions between knowledge and policy are likely to be variable within the global sector. Major donors have sometimes been accused of pursuing their own agendas and being influenced by whimsical shifts in opinion at home. The impact of new knowledge is likely to be reduced by pressure on scientists to eliminate uncertainty and simplify their findings to three pages or less, despite the admitted complexity of the issues; and by a need to be selective in recommendations in order to attract support from country representatives at multi-national meetings.

NGOs – the ‘voluntary’ sector.

Strongly driven by highly fragmented but motivated home constituencies, on which they depend for support (though recently more and more NGOs spend donor funds), international NGOs (and emerging national ones) can be significant players in dryland development.

Relative freedom from political control, and experience in advocacy, should create a potential for NGOs (especially national ones) to promote ‘voice’ among local people and expose local (beneficiary) viewpoints and understandings, in the pursuit of minority interests, justice issues and pro-poor programmes. Sustained interventions should create well-defined areas of competence, openness to local perspectives and innovative approaches to livelihood support, improved wellbeing, and rehabilitation. Some perceptive analyses of problematic dryland situations have been published by NGOs, probably at a fraction of the cost of more formal research. They are in a good position to foster local knowledge banks and social capital formation. The NGO is often in the best position to facilitate stakeholder negotiation, consensus, regulation and community level adaptation.

However, actual practice does not always fulfil such promise. NGOs may, like governments, employ non-local staff who are not sympathetic to indigenous knowledge, values and experience and replicate stereotypes of local practice learnt from education systems that are themselves inadequately exposed to new knowledge. Such limitations have been observed particularly in interventions intended to benefit pastoralists, who may already be victims of widely held social and political bias.⁹

The relationship between NGOs and science may be problematic. Especially at the international level, NGOs tend to look to science for ‘certainties’ that can be promoted in the media and among supporters’ constituencies. Inflexibility in response to shifts in scientific understanding may reflect a necessity to ‘keep it simple’ for fund

8. Inter-Governmental Panel on Climate Change

9. Saverio Krätli, personal communication.

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raising. Strongly negative images of humanitarian disasters are most effective and channelling resources into longer-term development has less popular appeal. The dilemma is reinforced by media in northern countries, which tend to recycle assumptions first formulated in the Sahel droughts of the 1970s and 1980s.

The fragmentation of the NGO sector, and variable quality of service provision through weak coordination or entry barriers (especially during disasters), are limitations that may reduce the impact of the NGO sector in drylands.

National governments, agencies and institutions.

In each dryland country, the architecture of policy, regulation, institutions and the political economy of interest groups is unique. There is a wide range from strongly centrist frameworks (such as China's socialist regime) through more democratic assemblages of lobbying, contestation and vote-seeking (such as Senegal's) to anarchy in 'failed states' (such as Somalia). There are differing degrees of corruption and efficiency. It might be expected that strongly centrist systems lend themselves better to science uptake because planning is not fully accountable through democratic channels. Many scientists, indeed, write with 'policy-makers' in view. But this approach ducks the issue of implementation.

Decentralisation, democratisation and stronger accountability, with accompanying improvements in local autonomy, have proceeded in some drylands, where new knowledge has been applied to innovative programmes of community-based forest, wildlife or other natural resource management. Such progress is uneven, however. Improving social capital and government manpower strengthens some countries' capability to use and eventually to generate new knowledge. However, as resource competition intensifies with market and rural population growth, stakeholder negotiations of access rights and benefits are increasingly necessary. Government may not necessarily be the best facilitator; NGOs may be more detached from political interest. Failure may lead to conflict, seemingly endemic in certain African drylands.

Since the concept 'dryland' is ecologically defined, administrative boundaries rarely coincide with ecosystems. Governments may not recognise a 'dryland interest' cutting across normal political or administrative units, unless the country in question consists entirely of drylands (e.g. Niger, Mongolia). A major ambiguity may exist, therefore, in applying new knowledge to the drylands. This barrier is worsened where dryland minority interests are seen as a threat to national governments.

It is at the governance level that risk (from droughts, floods and food security crises) should be managed. However, the greater part of the knowledge used in development is based on equilibrium models and is ill-equipped to deal with unstable (though sometimes highly resilient) ecosystems. This is particularly relevant with respect to pastoral systems (Benhke *et al.* 1993). For the poor, welfare programmes are often non-existent or under-resourced and insurance schemes (presently being tried in some dryland countries) may fail when risks – e.g. of food production failures – are highly

co-variant spatially or socially. However, dryland risk in more developed countries is covered by insurance and this appears to be the only policy option, whether implemented in the private or the public sector.

At the national level, a critical transition must eventually be made from reactive to proactive policy formation. Policy is a major driver of change in dryland countries, for better or for worse, and a wise policy environment has helped to transform some dryland systems from apparently irreversible degradation scenarios into an opportunity for conservation, through the investments of ordinary resource users (Tiffen *et al.* 1994). Both public and private investments in drylands have still to attain their potential (Mortimore *et al.* 2009). Negative stereotypes have contributed to this neglect, and a drive towards increased investment needs to be serviced by the best knowledge available (Figure 1).

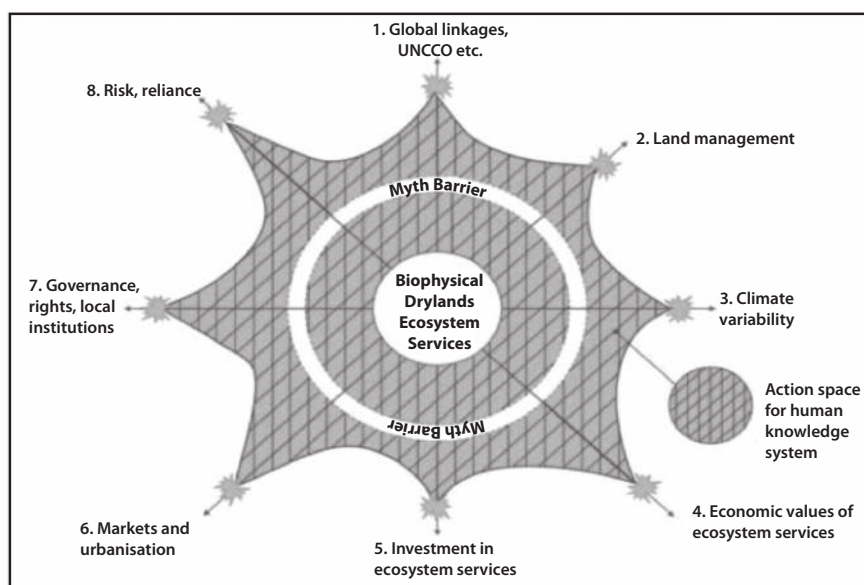


Figure 1. A model of the expansion of the 'action space' of dryland knowledge in development (Mortimore *et al.* 2009, p.7).

Local or community stakeholders?

Ultimately these are or should be the beneficiaries of scientific research that advances knowledge, enables technological solutions, or guides better policies. At the technical level, the language and concepts used by science pose a translation challenge but local knowledge is not intrinsically conservative, static or irrational.

Demand-led research is still rather scarce in comparison with the use of external scientific agendas. The recent prominence of climate change research and policy is a

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case in point. Because the new knowledge necessary to comprehend it is generated from highly specialised research centres (regardless of how they choose to safeguard their data!) it lies beyond most local communities' perceptions and paradoxically seems to encourage a retreat to anecdotal 'evidence'. Because adaptation to climate change is now a first priority (even where its range and severity are still unknown!), much development research tends to be re-branded as adaptation research. But only a small fraction of this work supports local capacities to adapt; mostly it concerns state-level strategies, driven by global priorities. This threatens to undo the progress recently made in democratising development.

Local stakeholder interests reflect the micro-political economy of the community and, to the extent that primary production supports local livelihoods, the key dimension of this political economy is access to the use of, and benefits from, natural resources. The context in which local knowledge is used is that of primary productivity and right-holding.

It is widely believed that declining biological productivity characterises rain-fed production systems in drylands (pastoralism, extensive agriculture or forest clearance). Whether this belief, which has informed many development interventions, accurately reflects local circumstances depends on many factors. For example, mobile pastoralism has been shown to be more productive and sustainable than commercial ranching; the management of soil nutrients in semi-arid farming systems needs to be evaluated in terms of a transition to more intensive forms of land use (Mortimore and Harris 2005); apparently destructive forest clearance may also represent a stage in a transition to wooded farmland (Mortimore and Turner 2005, Cline-Cole 1998).

On the other hand, the pressure of demand for access to productive resources reflects both demographic increase in rural communities and the steady growth in market penetration of local production systems – from the 'surplus' production of colonial export crops to the sale of staple food commodities to rapidly expanding urban populations (Ariyo *et al.* 2001). It is no longer realistic, for example in the West African Sahel, to think of dryland systems as purely subsistence-orientated; the relations between local communities and their ecosystems are increasingly enmeshed in complex livelihoods, which include obtaining education, diversifying trading, migration for employment and the re-capitalisation of farmlands (Tiffen *et al.* 1994).

The latest addition to this complexity is the accelerating growth of external interests in acquiring farmland in Africa, perceived to be 'empty' or under-developed (World Bank 2010). A large literature on 'land-grabbing' has suddenly appeared, bringing tenure issues to the forefront (Cotula *et al.* 2009). The new stakeholders include both large-scale commercial farming interests and corporations looking for bio-fuel production sites or out-sourced food commodity production potentials on behalf of food-importing Gulf oil states. The role of governments in allocating land hitherto subject to common access by local communities is both critical and contentious. Most critical is the assessment of 'under-developed' which, on examination, turns out to

be a dangerous trade-off between informal, locally recognised customary access (for grazing, shifting cultivation or forest harvesting) and statutory allocations by the state to outsiders, based on ultimate sovereignty over 'unoccupied' land that is rooted in colonial land legislation.

In such a fluid context, it makes little sense to isolate 'indigenous knowledge' from 'scientific' – a distinction that has been shown to be unsustainable (Agrawal 1995). Local knowledge is, and must be, adaptive, dynamic and linked with local ownership of productive resources. The conflicts of interest in drylands – newly reconfigured by urbanisation, social change and the entry of 'neo-colonial' global players – are contested at the local scale and take expression in power relations. Local knowledge is evolving in this context, whether it consists in inherited methods of conserving and propagating seed banks or exploiting variable plant communities on rangelands; or in mutual learning between large and small-scale farmers and agricultural researchers. Negotiations between stakeholders, aiming to create 'local conventions' governing use rights, have had some success in West African drylands (Ribot and Larsen 2005). But local or horizontal negotiations, for example governing rights to formerly degraded forest reserves, now need to be stretched in a vertical dimension to ensure that central government participates democratically in allocating resources.

DYNAMICS, MYTHS, AND 'ACTION SPACE'

This review of stakeholder interests in knowledge for development leads to the conclusion that Agrawal's lucidly argued case for preserving the diversity of indigenous knowledges *in situ* – or in context – which 'cannot succeed without indigenous populations gaining control over the use of the lands in which they dwell and the resources on which they rely' is becoming stronger by the day in drylands (Agrawal 1995). Technology *per se* is not the defining issue at the local scale. Rather, it is resource ownership, capitalisation and control.

The Drylands Development Paradigm (Reynolds *et al.* 2007), in placing emphasis on co-evolving dryland systems, recognises the fundamental role of Time – a concept that links the geological scale of many geological, paleontological and archaeological studies nicely with the much shorter term changes evident in contemporary climatic, demographic, developmental, land cover, settlement, educational and many other sub-systems. Co-evolving human and ecological systems are undergoing temporal change across a range of variables and on different scales, from short-term variability ('fast' variables) to long-term trends ('slow' variables). The outcomes are specific to dryland ecologies, whose key properties are variability, poverty and spatial dispersal.

Knowledge systems themselves are not static but responsive. Science itself is engaged in a relentless process of data improvement, methodological development, hypothesis testing and paradigm shifting. As paradigms shift, obsolescence occurs in knowledge that is discarded, superseded or revised. But there is a variable lag effect

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before the newest understanding is disseminated, comprehended and adapted. Donors are affected by policy swings and resource constraints. At the local level, changes occur in perceived opportunities and constraints. Old ideas may harden into populist 'myths'. A recent IUCN Challenge Paper identifies some of these myths as follows (Mortimore *et al.* 2009):

1. Drylands are poor, remote and degraded, and – apart from tourist potentials – do not really matter globally.
2. Drylands are on the edges of deserts and the deserts are expanding owing to human misuse of the environment (overgrazing, deforestation and over-cultivation).
3. Dryland peoples are helpless (their knowledge and adaptive capacity are weak) in the face of climate variability and change.
4. Because of their low biological productivity, drylands have little economic value except to provide subsistence for those who live there,
5. Drylands cannot yield a satisfactory return on investment, owing to high risks resulting from low and variable rainfall
6. Drylands are weakly integrated into markets because of their remoteness, poverty and low productivity.
7. Dryland communities are conservative and resistant to modernisation and institutional change.

The myths are attributable, in part, to the fragmentation of knowledges amongst the stakeholder groups. The demolition or revision of 'myths' forms a part of the larger process of knowledge development. Figure 1 envisages the 'myths' acting as a barrier to the development of dryland knowledge along eight trajectories. Each of these trajectories represents a key dimension of dryland development (improved wellbeing with sustainable ecosystems):

1. Global linkages and conventions
2. Land management
3. Climate variability
4. Economic values of ecosystem services
5. Investment
6. Markets and urbanisation
7. Governance, rights and local institutions
8. Risk and resilience

Progress is not uniform on all the trajectories, where the point reached is shown with a flash. The eight dimensions of knowledge have lives of their own, reflecting the force

of myth, the political economy of change and the value of new knowledge. As progress continues, the 'action space' of drylands knowledge (its scope, applicability, room for adaptive manoeuvre) expands differentially through time.

CONCLUSION

Have knowledge systems served the drylands well?

It is not axiomatic that knowledge necessarily improves wellbeing. In this brief reflective review I have expressed disquiet about the relations between growing knowledge and stagnating human wellbeing in drylands in poor countries and in particular the fragmentation linked to the diversity of stakeholder interests. Weak integration of knowledge systems perpetuates myths, which act as barriers to the advancement of knowledge and its use in development. Traditionally, the scientist has scorned the practitioner. I suggest that the science may be the easy part. Achieving development in drylands requires knowledge at different levels, the engagement of different stakeholders, the penetration of policy process, co-learning and negotiation. This calls in turn for bridges across the divide between the communities of science and practice. Many scientists who work in poor countries make valiant efforts to do this. But attention needs to be paid to the structural questions. The concept of co-evolving human and ecological systems calls for interdisciplinary and time-bound analysis. At the interface between knowledge and practice – which is found at the local scale – the issue of knowledge becomes one of rights, equity and control of resources. Effective engagement between key stakeholder groups with their knowledge systems is a precondition for sustainable co-evolution of ecological with human systems.

ACKNOWLEDGEMENT

I am grateful for by Saverio Krätli's challenging comments on a draft of this chapter.

REFERENCES

- Ariyo, J., J. Voh and B. Ahmed (2001). 'Long term change in food provisioning and marketing in the Kano region'. Drylands Research Working Paper 34. www.drylandsresearch.org.uk
- Agrawal, A. (1995). 'Dismantling the divide between indigenous and scientific knowledge' *Development and Change* 246: 413–439.
- Benhke, R., I. Scoones and C. Kerven (1993). *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaptation in African Savannas*. London: Overseas Development Institute.

Knowledge Systems Have not Served the Drylands Well

- Cline-Cole, R. (1998). 'Knowledge claims and landscape: alternative views of the fuelwood-degradation nexus in northern Nigeria'. *Environment and Planning D – Society and Space* 16: 311–346.
- Cotula, L., S. Vermeulen, R. Leonard and J. Keeley (2009). *Land Grab or Development Opportunity? Agricultural Investment and International Land Deals in Africa*. London: International Institute for Environment and Development
- Djurfeldt, G., H. Holmén, M. Jirstöm and R. Larsson, R (eds.) (2005). *The African Food Crisis. Lessons from the Asian Green Revolution*. Wallingford: CABI Publishing.
- Krätli, S. (2008). 'Cattle breeding, complexity and mobility in a structurally unpredictable environment: the WoDaaBe herders of Niger'. *Nomadic Peoples* 12:11–41.
- Millennium Ecosystem Assessment (2005). 'Dryland systems'. Chapter 22. Washington, DC: World Resources Institute.
- Mortimore, M. and F. Harris (2005). 'Do small farmers' achievements contradict the nutrient depletion scenarios for Africa?' *Land Use Policy* 72: 43–56.
- Mortimore, M. and B. Turner (2005). 'Does the smallholder's management of woodland, farm trees and rangeland support the hypothesis of human-induced desertification?' *Journal of Arid Environments* 63: 567–595.
- Mortimore, M., S. Anderson, L. Cotula, J. Davies, K. Facer, C. Hesse, J. Morton, W. Nyan-gena, J. Skinner and C. Wolfangel (2009). *Dryland Opportunities. A New Paradigm for People, Ecosystems and Development*. Gland, Switzerland: World Conservation Union.
- Reynolds, J. and M. Stafford Smith *et al.* (2007). 'Global desertification: building a science for dryland development'. *Science* 316: 847–851.
- Ribot, J. and A. Larsen (eds.) (2005). *Democratic Decentralisation through a Natural Resource Lens*. London: Routledge.
- Richards, P. (1985). *Indigenous Agricultural Revolution. Ecology and Food Production in West Africa*. London: Hutchinson.
- Schellenhuber, H.-J., A. Block, M. Cassel-Gintz, J. Kropp, G. Lammel, W. Lass, R. Lienenkamp, C. Loose, M.K.B. Lúdeke, O. Moldenhauer, G. Petschelheld, M. Plöchl and F. Reusswig (1997). 'Syndromes of global change'. *Gaia* 6 (1): 10–34.
- Swift, J. (1996). 'Desertification narratives, winners and losers', in M. Leach and R. Mearns (eds.) *The Lie of the Land. Challenging Received Wisdom in African Environmental Change and Policy*. Oxford: James Currey. pp 73–90.
- Tiffen, M., M. Mortimore and F. Gichuki (1994). *More People, Less Erosion: Environmental Recovery in Kenya*. Chichester: John Wiley.
- Tiffen, M. and M. Mortimore (2002). 'Questioning desertification in dryland sub-Saharan Africa'. *Natural Resources Forum* 26 (3): 218–233.
- Mortimore, M. and M. Tiffen. 'Introducing research into policy lessons from country studies of dryland development in sub-Saharan Africa' *Development Policy Review* 22 (3): 259–286.
- Thomas, D. and N. Middleton (1992). *World Atlas of Desertification*. London and Nairobi: Edward Arnold, for United Nations Environment Programme.

- Winslow, M., J. Vogt, R. Thomas, S. Sommer, C. Martius and M. Akhtar-Schuster (2011). 'Science for improving the monitoring and assessment of dryland degradation'. *Land Degradation and Development* 22: 145–149.
- World Bank (2010). *Rising Global Interest in Farmland: Can it Yield Sustainable or Equitable Benefits?* Washington, DC: The World Bank.

HUMAN-ENVIRONMENT INTERACTIONS: THE INVASION OF *PROSOPIS JULIFLORA* IN THE DRYLANDS OF NORTHEAST ETHIOPIA

Simone Rettberg and Detlef Müller-Mahn

INTRODUCTION

Plant transfers have always acted as main drivers of ecological evolution, shaping regional biogeographies and involving various actors on different scales (Kull and Rangan 2008). But the rapid increase in the rate and scale of human-induced plant invasions within the last fifty years has led to unprecedented socio-ecological problems (Warren 2007). The recent spread of invasive plant species within the arid and semiarid lowlands of north-east Ethiopia is an increasing threat for pastoral livelihoods and ecosystems. One of the most invasive species is *Prosopis juliflora* (Figure 1), an evergreen, fast-growing mimosa tree or shrub, native to South and Central America, which is considered in the National Biodiversity Strategy and Action Plan (MoARD 2005) as one of the top invasive species next to parthenium weed (*Parthenium hysterophorus*), water hyacinth (*Eichhornia crassipes*) and lantana weed (*Lantana camara*). In 2006 approximately 700,000 ha of land had been taken over by *Prosopis juliflora*, out of which more than seventy per cent is located in the Afar region, mainly within the Middle and Lower Awash Valley. Based on an empirical case study within one of the most heavily invaded areas in Afar this chapter discusses the introduction and subsequent invasion of *Prosopis juliflora* within the Middle Awash Basin of the Afar region from the perspective of political ecology. It is argued that historical, spatial and political contextualisation of the biological invasion process is of utmost important for understanding the current process of environmental degradation. Focussing on the question of how environmental discourses on invasive species reflect political interests and translate into power-laden environmental practices, it will be highlighted that the management of natural resources within the drylands of Ethiopia is a highly political endeavour, shedding light on asymmetric power relations and contested development visions between pastoralists and the state.



Figure 1. Dense thickets of *Prosopis juliflora* overgrowing a local road. Photograph: Simone Rettberg.

INVASIVE SPECIES WITHIN DRYLAND RESEARCH

The introduction of *Prosopis juliflora* into African and Asian drylands has resulted in critical processes of socio-ecological transformation but social aspects have been generally ignored within studies on invasive species (McNeeley 2001, Robbins 2004). Since the beginning of the systematic study of biological invasions in the late 1950s (Elton 1958) most studies originated in natural science disciplines like invasion/disturbance ecology, which focused on natural parameters of the invasion process, inherent characteristics of invasive plants and the impact on biodiversity. The dominant framing of invasive species in the context of biodiversity conservation largely prevented the emergence of a more social-science oriented research perspective (Shackelton *et al.* 2007, Stoett 2010) and an analysis of the way how plant movements shape and are shaped by distinct convergences of ecology, politics, livelihoods and ideology (Kull and Rangan 2008). This bias has been challenged by various sides calling for increased attention to human–environment relations.

Political ecology offers a valuable conceptual approach for the critical analysis of coupled human–environment systems in a specific political-economic context (Turner and Robbins 2008) and of the ways in which environmental changes become issues of political struggle. Proponents of political ecology analyse the invasive growth of plant species in considering the shifting context of social, cultural, political and institutional factors that informs socially differentiated power-laden discourses of environmental

change and respective management practices on multiple scales. The study of contested environmental discourses and the plurality of environmental knowledge and perceptions has been an important topic in political ecology since the mid 1990s, following the cultural turn and the rise of poststructuralist approaches. Research on human–environmental-relations in dryland areas has focussed especially on a critical engagement with the validity of ecological claims concerning land degradation and desertification (Leach and Mearns 1996). The commonly assumed neutrality of these ecological studies, which favoured neo-Malthusian chains of explanation and which dominated public debate and environmental policy, was questioned in stressing that knowledge is always partial and political. Power struggles over natural resources are motivated by material interests and discursively mediated through practices of knowledge production and circulation. An understanding of the knowledge politics of ecology (Turner 2009) and a politicising of environmental explanations (Forsyth 2011) is therefore of utmost importance. Against this background this chapter aims at analysing the spread of invasive species like *Prosopis juliflora* as a material reality and as a social construct, constantly contested in terms of its nature, its impact, its control and who is to blame for its creation.

Environmental governance of drylands is informed by these knowledge politics. Since the 1970s, non-equilibrium thinking in rangeland ecology has challenged prevailing static notions of carrying capacity, climax vegetation and the conception of the balance of nature that had informed Malthusian resource management interventions (Turner 2003). In this context increased consideration was given to aspects of history, temporal and spatial variability, uncertainty, surprise and complexity (Scoones 1999). The Dryland Development Paradigm (Reynolds *et al.* 2007) follows this line of argumentation, calling for new integrated approaches to dryland management, which recognise the mutual interdependency of ecological and social issues, non-linear system dynamics in drylands, cross-scale linkages, the importance of temporal and spatial variability and the role of local environmental knowledge.

THE CHALLENGING SETTING OF THE CASE STUDY AREA

The Afar region of Ethiopia, located in the north-eastern lowlands of the country, bordering Eritrea to the North and Djibouti to the north-west, is one of nine administrative regions of Ethiopia. Geologically this region is part of the Afar triangle where the East African Rift Valley extends towards the Red Sea. This area is known for its tectonic activity, with recurrent earthquakes and volcanic activity. Its extremely harsh climate averages temperatures between 25 and 48°C; low annual rainfall ranges from 600 mm (adjacent to the western Ethiopian highlands) to less than 100 mm in the most north-eastern parts. Its topography is marked by lava streams, volcanoes, deep faults, salt lakes and stone deserts. The amount of rainfall varies extremely between the two dry and two rainy seasons. This natural seasonal variation is characterised by a high spatial and temporal variability so that recurrent droughts and phases of acute

food insecurity are a normal part of life for Afar pastoralists. The region is inhabited by approximately 1.4 million people (CSA 2008), dominantly ethnic Afar pastoralists, who sustain their livelihood by moving with mixed stocks of animals (camel, cattle, sheep and goats), thereby making opportunistic use of different kinds grazing resources whose availability varies with time and space – a mobile way of life highly adapted to the insecure environmental conditions (Kassa 2001).

Under conditions of low and highly variable rainfall the Awash River (1,200 km), which traverses the southern part of the Afar region, serves as an important perennial water source for pastoral livelihoods. The river originates at an altitude of 3,000 m above sea level in the humid regions of the Ethiopian highlands and evaporates in an inland delta along the border with Djibouti at an altitude of 250 m. The seasonal inundation

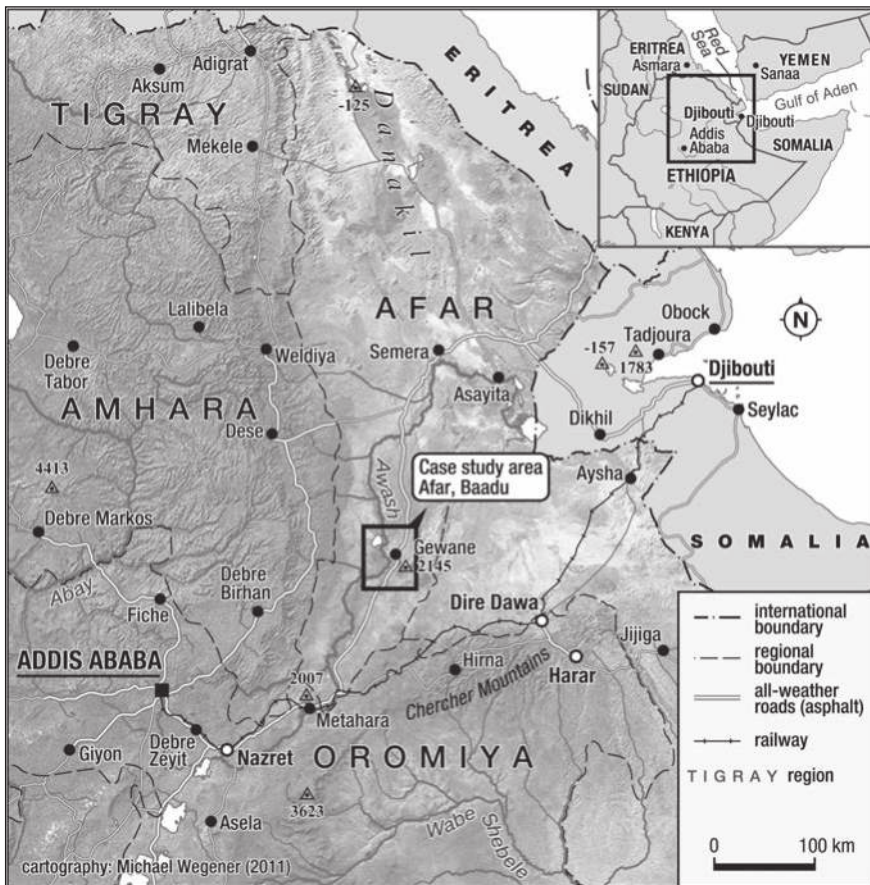


Figure 2. Location of the case study area.

of the river provides abundant grazing, which is essential for pastoralists during dry season and drought; the water provides opportunities for consumption and irrigation.

The case study area of Baadu (Figure 2) is located within the Middle Awash Valley at an altitude of approx. 500 m with an average annual rainfall of 450 mm. It is a flat seasonally inundated alluvial plain (Afar: *Kallo*) surrounded by higher-lying hills and mountains (Afar: *Alta*). Up to 21 pastoral clans, estimated to number approximately 80,000 people (Rettberg 2009), claim to have their distinct settlement area and commonly used dry season grazing areas in Baadu. Up to the 1980s these areas were largely covered by native grass species like *Chrysopogon plumulosus*, *Cenchrus ciliaris* and *Setaria acromelaena*, providing rich grazing opportunities during dry seasons and droughts. Riverine trees like *Acacia nilotica* offered valuable shade for humans and animals and swamps additionally provided wild fruits like *Furra* (root of a water lily species), *Orge* (root of reed grass) and *Burre* (root of a swamp plant) that played an important role as famine foods. *Alta* areas distant from the river generally consisted of open savannah dominated by various acacia species like *Makaarto* (*Acacia mellifera*), *Eebto* (*Acacia tortillis*), and *Adado* (*Acacia senegal*). Due to these favourable environmental conditions, the clans of Baadu were among the wealthiest in Afar, known for their large cattle herds and abundant milk supplies. When the river flooded during the rainy season they moved their animals from *Kallo* to various *Alta* areas towards the east (Figure 3). When the water receded they used to come back to their home territory, making use of the abundant grasslands along the river.



Figure 3. Pastoralists in Alta areas. Photograph: Simone Rettberg.

The agricultural potential of the Awash river and (geo-)political interests fostered increasing interventions by various actors. In an attempt to exploit the fertile land along the river and to extend its political power to its peripheral lowlands the Ethiopian state started to establish large-scale irrigation schemes in Baadu in the 1970s, evicting pastoralists from their traditional grazing areas (Bondestam 1974, Gebre-Mariam 1994, Said 1997). Additionally, the Afar from Baadu have been involved in a chronic violent conflict with neighbouring Issa-Somali pastoralists for generations. The Issa intensified their violent expansion from the middle of the twentieth century to expand their territory westward towards the Awash, claiming Baadu as their own (Markakis 2003). To what extent the increasing influence of external actors has altered the environmental setting, a process marked by a significant spread of *Prosopis juliflora* and a degradation of grazing areas, will be explored in the following pages. Within the last two decades indigenous grasses, the main fodder resource for cattle, have almost completely disappeared from Baadu, leading to an increased vulnerability and impoverishment of pastoralists (Rettberg 2009, 2010).

CONTEXTUALISING THE SPREAD OF *PROSOPIS JULIFLORA*

For many decades the problem of land degradation has dominated the public debate in Ethiopia, informing a multitude of governmental and international environmental policy initiatives that aimed at the conservation of natural resources through various activities of soil and water management (Keeley and Scoones 2003). One of the activities of the governing Derg military regime during the 1980s was the intentional introduction of *Prosopis juliflora* to the Ethiopian lowlands in the marks of its environmental rehabilitation campaign. It was conceived as an afforestation measure, guided by the Forestry and Wildlife Conservation and Development Department under the auspices of the Ministry of Agriculture. *Prosopis* had already been introduced to large parts of the dry tropics of Africa and Asia from the early nineteenth century (Mwangi and Swallow 2008) but its peak time of introduction coincided with the time when the rhetoric on the desertification in African drylands was most intense. *Prosopis* offered potential benefits for soil conservation due to its tolerance towards high temperatures, low rainfall, saline soils; its capacity to rehabilitate and enrich the soil through nitrogen fixation; and for its potential as an additional high-protein animal feed for animals (Pasicznik *et al.* 2001, Shiferaw *et al.* 2004). Its potential for invasion was either unknown, ignored or seen as a benefit at this time. As Richardson *et al.* (2004) note, agroforesters working in dry environments might even favour invasion processes of plants with beneficial characteristics in areas assumed to be highly degraded. But several years after the initial introduction to Ethiopia it became evident that *Prosopis* was invading the drylands with various detrimental impacts on pastoral livelihoods, local biodiversity and hydrology (Berhanu and Tesfaye 2006).

The invasive potential of *Prosopis juliflora* builds on the massive number of seeds produced – about sixty million per hectare per year – and their efficient dispersal strat-

egy. The robust seeds are eaten by local livestock and wild animals, especially warthogs, but they are not digested, so these freely grazing animals are important dissemination agents on the local level. The hard-coated seeds are softened while passing through the digestive tract, which enhances their germination, while the animals' droppings provide a ready supply of nutrients for the developing seedling.

The introduction of *Prosopis* seedlings to Baadu was initiated in 1980 by the governor of Western Hararghe, who called for a meeting to inform political cadres about the challenges of drought and desertification, the need for immediate action to rehabilitate 'degraded' dryland areas and the benefits of planting *Prosopis juliflora* due

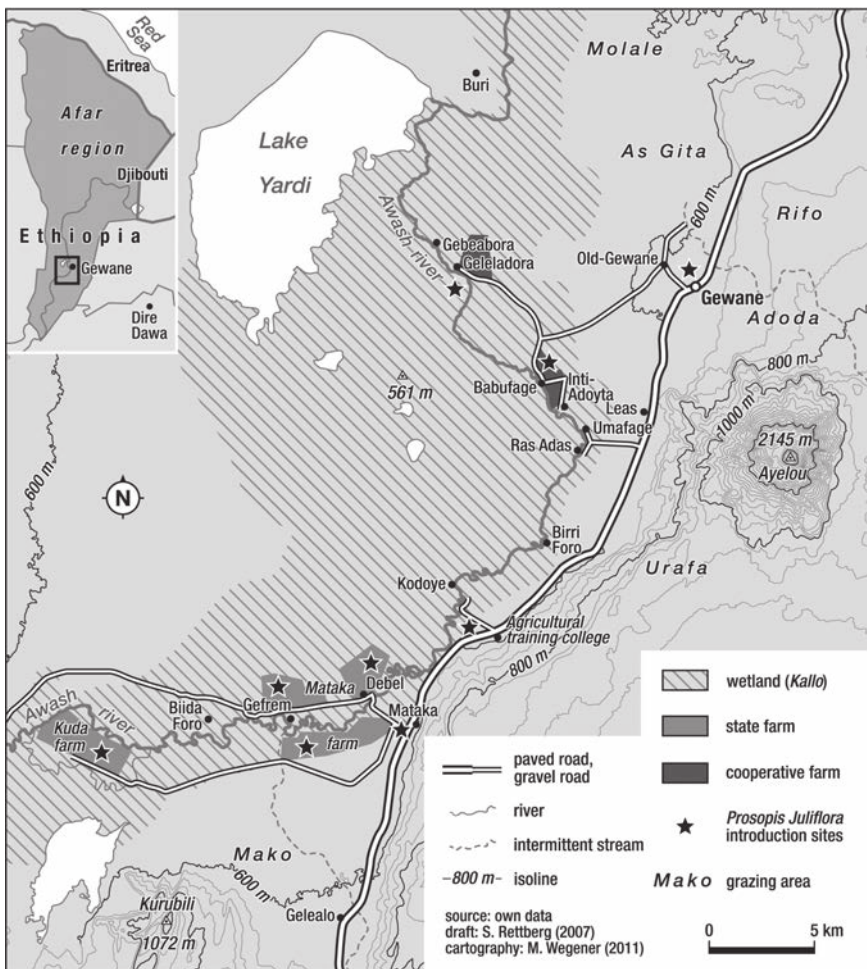


Figure 4. Introduction sites of *Prosopis* in Baadu.

to its drought tolerance. Following this meeting *Prosopis* seedlings were transferred to the dry *woredas* (administrative sub-units) of the administrative districts (*Awraja*) of Chercher, Adal and Gara Guracha. Here local administrators were ordered to enforce the planting of *Prosopis* seedlings within permanent settlements and around irrigation farms. One of the selected *woredas* was Gewane, to which the case study area Baadu belonged administratively at that time. In July 1980 agricultural extension agents transported 2,000 seedlings from the seedling site in Hirna, located in the sub-humid highlands of the Chercher Mountains, to Gewane. There, farm-level committees distributed the seedlings to 1) the large-scale irrigated state farms of Kuda and Mateka (2,071 ha of cotton cultivation); 2) the Amasaburi agricultural training centre, 3) Mateka and Gewane, the only permanent settlements within Baadu at that time; and 4) Intiadoyta and Galeladora, where the governmental Relief and Rehabilitation Commission (RRC) had established collectivised producer cooperatives (400 ha of maize and cotton cultivation) in the late 1970s, in order to improve local income and food security (Figure 4). Here some Afar pastoralists had settled in order to work in the cooperatives where they received governmental salaries. The allocation of seeds by the farm level committee was based on the registration of households within the villages and near the farms. The recipients of the seedlings were ordered to dig holes, water the seedlings on time and fence the plants properly in order to protect them from animals. Two days a week the committee monitored the growth status of each plant and the necessary engagement of the household. If people didn't care for the seedlings properly, three to five days' salary was deducted.

In 1986, a few years after introduction, *Prosopis* could not be tracked on satellite images (Figure 6). But in the 1990s the spread of *Prosopis* started to gain speed, which was the outcome of an increased human-induced invadability of the ecosystem coupled with specific biological features. *Prosopis* started to out-compete indigenous plant species in the early 1990s, at the time when the DERG regime collapsed. State farms in Baadu were abandoned, hydraulic irrigation infrastructure like dikes and irrigation channels went without maintenance. Fallow, previously irrigated agricultural areas with highly salinised soils were rapidly colonised by *Prosopis*. Frequent changes of the riverbed contributed to the increased invasion of the grazing areas and the irrigation farms since the floodwaters of the Awash are important agents for the spread of *Prosopis* seeds. Without maintenance of hydraulic infrastructure, the dikes of the Awash river have been breaking repeatedly in the area of Gefrem/Biida Foro since the mid 1990s (Figure 5), diverting the river in several directions away from the main course. Since then, most water has been discharged into the very flat area between Biida and Lake Yardi, while the main river course sometimes runs the risk of falling dry.

Another driving factor for the increasing invasion of grasslands within Baadu was the violent conflict with the neighbouring Issa-Somali pastoralists, a highly politicised conflict fuelled by geopolitical interests, ideologies and military support of Somali-governed states at the Horn of Africa who were pushing for a 'greater Somalia' including the Ogaden region of Ethiopia. From the 1940s the Issa constantly expanded



Figure 5. Flooded Afar houses surrounded by *Prosopis juliflora*, near Gefrem (2005). Photograph: Simone Rettberg

their grazing territory to the west, displacing the Afar of Baadu from most of their previous rainy season pastures and restricting their grazing areas to a small area along the Awash river and the main road (Rettberg 2010). Instead of moving their animals at the beginning of the rainy season to far away pastures up to 150 km eastward, the Afar now move all year round within a radius of approximately 25 km. This has fostered soil degradation due to overgrazing and higher dissemination rates of seeds within the remaining grazing areas.

The comparison of satellite images (Figure 6) shows the continuous explosive spread within the last ten years. In 2000 36 km² were already covered by dense *Prosopis* thickets (Romanciewicz 2007). In the following seven years the invaded area almost quadrupled. In 2007 it was 128 km² and in 2010 the infested areas in Baadu had increased to 250 km². This environmental change in Baadu in conjunction with limited migration alternatives, due to the occupation of most rainy season grazing areas by Issa-Somali-pastoralists, has resulted in a decrease in cattle numbers since the 1990s. Lack of feed resources and the increasing incidences of water-borne animal diseases have killed and weakened animals, so that during the last severe drought in 2002/03 the Baadu Afar lost most of their cattle within a relatively short time. Due to lack of high-quality grazing areas they have not been able to recover since, so that a large proportion of the pastoralists have shifted from acute to chronic food insecurity.

The reason people used to recover in Baadu before was because there was no *Deta Harar*. Since *Deta Harar* came people can no longer recover. In previous times drought occurred

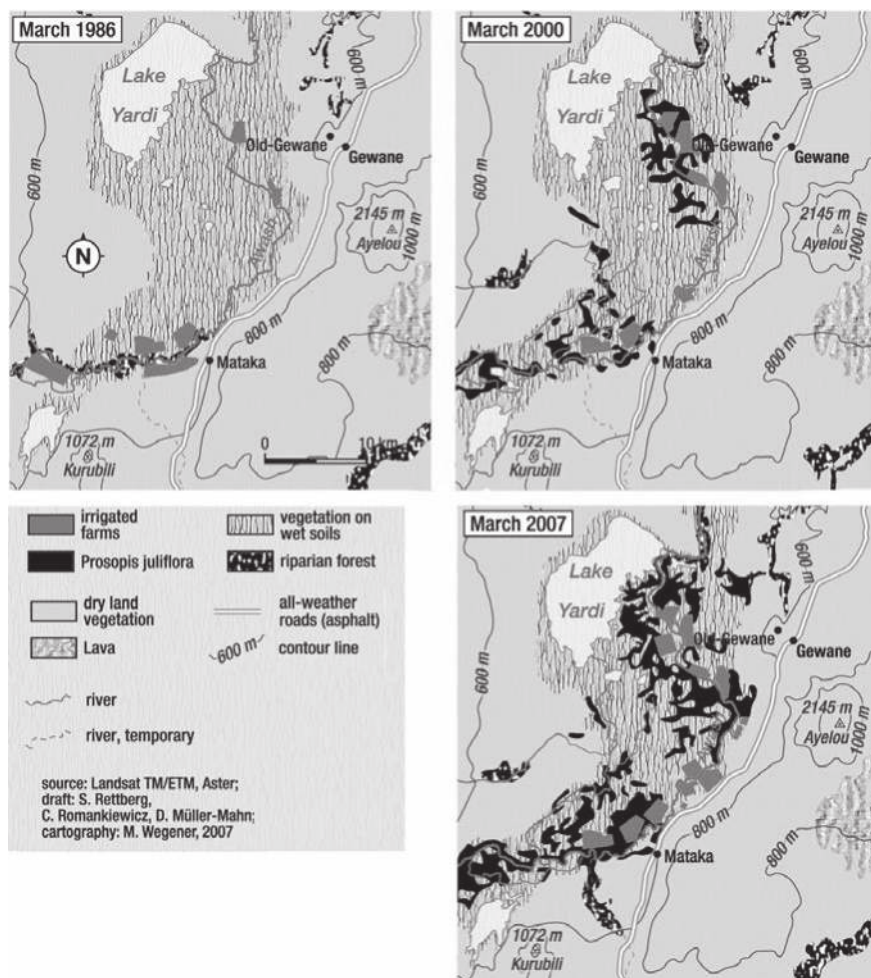


Figure 6. Expansion of *Prosopis* within Baadu from 1986–2007.

and afterwards, when it was over, animals recovered and multiplied quickly. This *Deta Harar* has burned the ground. Wherever it grows grass stops growing. The reason people can't get milk and butter is because of this tree ... Cattle can't resist anything. If they don't get *Sitabu* [native grass species] in Baadu they can't survive. (Fatuma Ibrahim, Leas)

In sum, the massive disturbance of grasslands in Baadu have been the result of the interplay between biological dynamics following the introduction of *Prosopis* and an increased invadability due to a) the chronic violent conflict with the neighbouring Issa-Somali pastoralists in which the Issa have displaced the Afar from large parts of their

rainy season grazing areas; and b) large-scale commercial irrigation agriculture along the Awash River. These two factors have resulted in a reduction of pastoral mobility and overstocking within the remaining grazing areas of Baadu, which are grazed all year round, leaving no time for vegetation recovery and contributing to land degradation. The establishment of irrigation farms and hydraulic infrastructure has additionally altered flood regimes and led to a salinification of the soils, conditions which have fostered the spread of *Prosopis*.

CONTESTED ENVIRONMENTAL NARRATIVES BETWEEN PASTORALISTS AND THE STATE

The reasons for, consequences of and responsibilities for these environmental changes are perceived and assessed by different groups of people in different ways. For pastoralists making sense of the experienced invasion of their rangeland through *Prosopis juliflora*, a plant previously unknown about which no adequate environmental knowledge was available, consisted in the framing of the invasion of *Prosopis* in a wider risk discourse of political marginalisation and territorial displacement (Rettberg 2010). One pastoral woman reported:

Baadu is in problems. There is no more Baadu, the *Woyane* tree [*Prosopis juliflora*] is destroying Baadu. And now there is flooding of the Awash ... When we go to Ayelou [name of mountain] the Issa kill the men and take all the livestock. Now we are hungry, our kids are dying of hunger. We are being killed in all directions ... On the one hand the *Woyane* tree destroys Baadu, on the other hand there is Issa ... There is no place to hide. There is no place to go. We cannot go to the sky. We cannot go into the ground, unless when we die ... There were strong men, there were horses back then. Those horses are no longer here, neither are the strong men ... Now, there is nowhere to turn to. Baadu is destroyed. (Ado Biida, Leas)

In this account, which is commonly shared among pastoralists in Baadu, the environmental destruction of Baadu is linked to the loss of mobility and land that the Afar clans from Baadu have experienced in the past decades. This land loss is explained through the combined territorial invasion of Issa-Somali and ‘Woyane’ (*Prosopis*). While ‘Woyane’ is portrayed as the invader of the dry season rangelands of Baadu, the Issa are portrayed as violent invaders who have displaced the Afar from their rainy season pastures. The disappearance of horses, which figure as indicators of the quality of previous grasslands, is used to stress the severity of the current critical situation.

Pastoralists commonly refer to ‘*Woyane harar*’, ‘*Derg harar*’ or ‘*Deta harar*’ when talking about *Prosopis juliflora*. *Deta harar* (Afar: Black tree) refers to the dark evergreen appearance of *Prosopis* thickets in the invaded landscape but the more commonly used denominations of *Derg harar* and *Woyane harar* connect the invasive plant with a political regime. The military Derg regime was in power during the time of the plant’s introduction; Woyane is the Amharic denomination for members of the Tigrinean liberation movement during the civil war and members of the Tigrinean

Peoples Liberation Front (TPLF) who are nowadays absorbed in the governing EPRDF (Ethiopian Peoples Revolutionary Democratic Front). The equation of *Prosopis* and *Woyane* might be explained by the coincidence of the spread of *Prosopis* in the early 1990s and the military victory of 'Woyane' fighters and/or it might disclose the local perception of interventions of the 'Woyane' government as destructive, threatening their pastoral livelihood system (Rettberg 2010).

In this narrative of the destruction of Baadu, the Ethiopian state is given responsibility for the territorial losses and the subsequent socio-ecological crisis. Concerning the reasons for the spread of *Prosopis*, pastoralists blame the government for the forceful introduction of the plant. The pastoralists feel betrayed and blame the government for making false promises when they introduced *Prosopis*. They were even forced to grow the tree and were punished if they didn't care for the planted seedlings.

In a situation of high insecurity due to lack of environmental knowledge, patterns of explanation for the spread of *Prosopis* focus on political actors and mechanisms of power.

When an old government leaves the office it is replaced by a new government, right? There used to be Kokarabto, Subla, Kasalto, Kilayto [native trees]. The same way one government replaces the other, Woyane tree replaced all those trees. The forest that once used to exist, is no longer there. A new type of forest is in place ... Once this tree came, it displaced all the other trees and conquered their place. The same way Meles replaced Mengistu, Woyane also replaced all other trees. (Elder during group discussion, Inti-Adoyta)

Only a few pastoralists connect the invasion with environmental observations, arguing that the displacement of the native vegetation is caused by the increasing water scarcity within the main course of the Awash river.

The land used to grow Sitabu when it overflowed, women used to get Furra from inside the water and cattle used to get different grasses like Rareta. When the river had water all these plants and grasses used to get water. Now everything is dry and everywhere is covered by Deta Harar. And the reason those grasses and plants disappeared is because of lack of water. Animals have nothing to eat. Where grasses used to grow, now Woyane tree grows. (Elder during group discussion, Inti-Adoyta)

Pastoralists perceive the spread of *Prosopis* as an extremely threatening, purely detrimental process of environmental change. They only mention the negative impacts of *Prosopis* on their livelihoods: loss of grasses for cattle; restricted movements of livestock and herders to grazing areas and water points due to the dense, impenetrable *Prosopis* thickets. The densely invaded areas also offer improved hiding opportunities for lions and hyenas, increasing the risk of attacks on humans and animals. Furthermore the noxious thorns of *Prosopis* are feared by pastoralists as causing severe injuries and inflammations. The only feed resource, especially for goats, that has remained in the previously abundant grazing areas is the ripe *Prosopis* pods but they cause indigestion and dental problems for the animals and are not perceived as a benefit.

Comparing environmental discourses of pastoralists and state representatives different patterns of contextualisation of the invasion of *Prosopis* can be noted. The pastoral ‘invasion’ discourse focuses on the governmental *Prosopis* introduction and loss of grazing areas to Issa as root causes for environmental degradation. This narrative highlights the responsibility of the government for the initial introduction, for the concealment of its invasive potential and the subsequent non-interventions to contain its growth. Blaming the state for its mismanagement contributes to the general discursive strategy of ‘othering’, of boundary-making in order to strengthen the unity of the clan society.

One has to wonder how the government assessed the potential benefits and risks of *Prosopis* during the peak phase of its planned introduction in Africa during the 1970s and 1980s. Richardson *et al.* (2004) note that, during this phase, the invasive potential of *Prosopis* was widely known but that it was rather perceived as a chance for rapid reforestation within degraded areas than as a risk. The intentional introduction reflected the dominant environmental policy discourses of environmental rehabilitation and the widespread concerns about desertification, land degradation and soil conservation (Keeley and Scoones 2000). Although state representatives are currently admitting the deficiencies and repeated failures of past pastoral policies, the environmental discourse with its neo-Malthusian storyline and its focus on drought, degradation and pastoral backwardness is still dominating the debate. Leading assumptions include exceeded carrying capacities of pastoral grazing areas and degraded rangelands due to pastoral mismanagement (overgrazing) and high population growth so that the ‘uncivilised pastoral way of life’ and nature’s vagaries appear to be the main causes for the current environmental problems, a line of argumentation that serves to consolidate state power and legitimises ongoing development interventions in the lowlands.

The conception of *Prosopis* as a beneficial, intentionally introduced forestry tree in the scope of planned natural resource management shifted during the 1990s when it became obvious that the socio-ecological costs of the plant invasion were far greater than the assumed environmental services. Current government environmental policy papers show a certain ambiguity concerning *Prosopis*, which reflects the lack of a clear strategy as to how to control the invasion. In some documents, like the Nation Biodiversity Strategy and Action Plan (NBSAP), *Prosopis* is considered as a prime threat to biodiversity in dryland areas (MoARD 2005), while reports from the Ethiopian Institute for Agricultural Research (EIAR) stress the possibilities for a controlled management of *Prosopis* due to its multiple benefits and the benefits of afforestation with *Prosopis* as an activity for fuel wood production and soil and water management within the Afar regional state (Rezenne 2006). The government follows a strategy of passive promotion, identifying *Prosopis* as an invasive, alien invader but at the same time stressing its role as highly valuable resource.

The government perception of potential benefits and chances of an economisation of *Prosopis* is shared by international organisations and development agencies whose studies tend to focus on the enormous potential of *Prosopis* to increase feed

production and to generate investment opportunities for feed processing companies (PARIMA 2008). They stress the potential environmental services involved (fodder, fuelwood, charcoal, timber for furniture, grounded protein-rich pods as feed source) that could create benefits for local producers and agro-industries. Prosopis is mainly considered as a valuable asset in the arid drylands of Ethiopia and, instead of eradication, they favour a controlled management of the plant. This discourse of *environmental services* commodification resonates with the *neoliberal* rhetoric that pervades current international environmental policy making and that perceives natural elements as tradable commodities.

DEALING WITH PROSOPIS

The disparate discourses of environmental change and involved risks are reflected in natural resource management regimes. When Prosopis was introduced in the 1980s, neither the local extension agents nor the pastoralists had any knowledge about the invasive potential of Prosopis or about measures to control its spread. Instead they were even enforcing its planting and fighting for its protection.

Some time after that this Woyane tree was introduced by somebody called Abbas. When people asked 'what is the use of this tree' they said it gives a good shade. It also brings air. Because we didn't know anything about it, everybody was given three seedlings to plant in their front yard. So everybody was protecting this tree in front of his house from being damaged. If somebody attempted to break a little piece to make a toothbrush, people were fighting over such things. So, it is this tree that they told us was good for us that has done such damage to us today, the tree that they said was good for us." (Pastoralist, Inti-Adoyta)

During the 1990s, Prosopis started to invade the dry season grazing areas along the Awash River of Baadu. Pastoralists reported that their settlement sites in Baadu were sometimes overgrown by Prosopis when they returned from their distant grazing places after the rainy season. At the beginning, when enough land was still available, pastoralists adapted to this situation in abandoning the invaded areas and simply erecting their temporary shelters in other areas. But with increasingly limited access to water points and grazing sites the negative effects of Prosopis became evident. At that time, pastoralists started to use the branches of Prosopis as a source of firewood, thorny fences and as additional feed for animals. No governmental measures were taken then to control the spread of Prosopis. The transitional government was busy consolidating its power after the collapse of the Derg. Furthermore, knowledge on biological invasion dynamics and effective management strategies were largely absent. It was only at a workshop on agricultural weeds in 1999 that officials came to the conclusion that Prosopis should be eradicated since its negative effects outweighed its benefits (Anonymous, quoted in Richardson *et al.* 2004).

In the last ten years the government has started to commission studies and pilot projects but a clear strategy on how to deal with Prosopis is still missing. Although the

Ethiopian Institute for Agricultural Research (EIAR) implements the GEF funded project ‘Removing Barriers to invasive plant management in Africa’ in Ethiopia, the invasion is so far acknowledged but not actively confronted. Faced with blurred policies and fragmented institutional mandates between sectors the Ethiopian government has not implemented any serious, coordinated control intervention so far. Calls for a coordinated management are everywhere but it hasn’t been decided yet what to favour: eradication or controlled plantation programmes. Efforts to eradicate *Prosopis* have proved to be extremely costly and mostly ineffective. After decades of uncontrolled spread, in which the growth of *Prosopis* in Afar exploded, the drought of 2003 marked a turning point for the existing environmental management strategies of pastoralists. There was widespread impoverishment and destitution, especially among the dominantly cattle owning Afar pastoralists, who were forced to develop socio-spatially diversified and complementary livelihood pathways to adapt and sustain their livelihood (Müller-Mahn *et al.* 2010). For the new agro-pastoralists, destitute Afar who settled along the river and who managed to grow some maize after the last drought in 2003, the uncontrolled growth of *Prosopis* is a massive threat. With simple tools and the help of relatives they constantly remove *Prosopis* from their plots, a hard, laborious task that exceeds the capacity of households with only few members. Additionally, under conditions of enormous land scarcity and vulnerability, most households now engage in several income-generating activities. Most important in this regard is the commodification of natural resources. Pastoralists eradicate *Prosopis* in order to produce and sell charcoal and firewood (Figure 7). Many pastoralists, including women and children, also get



Figure 7. Sale of charcoal along the main road in Mataka (2007). Photograph: Simone Rettberg.

small *per diem* wages of less than \$1 for the clearing of *Prosopis juliflora* from land that has been leased by the clans to private investors for the purpose of irrigation agriculture.

Among these activities, the production of charcoal out of *Prosopis* and further native trees has gained most in importance during recent years, due to its profitability. But it excludes those without sufficient access to human or financial capital, since they cannot afford to hire migrants from the Highlands as employees and nor do they have the knowledge or physical capacity to engage in the production process. The initiative of the British NGO FARM Africa shows the potential for community-based development in invaded areas of Gewane and Amibara *woreda*. They have developed a management approach which includes the production of charcoal out of *Prosopis*, the reclamation of the cleared land for crop and pasture production and the use of the crushed pods for animal feed (Dubale 2006). Pastoralists were supported in uprooting the seedlings in newly invaded areas, officially licensed charcoal cooperatives for cutting matured trees for charcoal production were established and demonstrations of pod collection and crushing were given.

The change of land tenure regimes after the collapse of the Derg in 1991, reflected in the lease of commonly used clan land to private investors, has to be seen in the same context of impoverishment and land scarcity. During the 1990s, most areas in Baadu were invaded by *Prosopis* and could no longer be used for grazing. In contrast to external investors with sufficient capital and agricultural knowledge Afar pastoralists lacked the technical and financial capacities to eradicate *Prosopis*. Additionally many of these areas were affected by salinification and soil degradation, so that the grazing potential after eradication was questionable anyway. The commodification of land offered a strategy to make best use of the previously overgrown areas; additionally it became the main income source for clan leaders and elders who are exclusive beneficiaries of the lease money. At the same time, the commodification of invaded areas in Baadu also served as a territorial strategy to halt a further expansion of Issa-Somalis. Permanent farms and their related infrastructures along the Awash manifest the territorial claims of the Afar clans.

The clan leaders transferred the costs of *Prosopis* to the new investors, who were attracted by the availability of vast areas of irrigation land offering economic potential for commercialised irrigation agriculture. Many investors underestimated the initial costs of clearing and the constantly incurred costs for the elimination of *Prosopis* from the plots, irrigation canals and drainage ditches, since they were neither acquainted with the dynamic regrowth of *Prosopis* nor with the cultural specificities of the pastoral Afar society. Some investors had to quit before the first harvest due to lack of money. Often they were requested by the clan elders, who receive monthly salaries for keeping good relations with the pastoral community, to employ many more clan members for clearing operations and guarding than was actually necessary.

CONCLUSION

The historical and spatial contextualisation of the plant invasion within the Middle Awash Basin stressed the close interlinkage between natural and socio-political factors as drivers of invasion. A deepened understanding of the mutual co-production of the degradation of a dryland ecosystem and the impoverishment of a pastoral clan society requires a relational understanding of human–environment relationships and approaches that goes beyond an analysis of society or ecology.

The way biological invasions are reflected and framed in narratives of socio-ecological change is highly contested between state representatives and local population. Different framings of the invasion of *Prosopis juliflora* may be interpreted with respect to underlying socio-political conflicts and asymmetric distribution of power. Pastoralists embed their discursive interpretation of *Prosopis*' invasiveness into a political narrative of political-economic marginalisation and social injustice, in which *Prosopis* is seen as one among several external invaders that have to be fought. Government officials, on the other hand, explain the invadability of the landscape by pointing at pastoral mismanagement and specific biological features of the plants. Discursive patterns of explanation and blaming inform decisions and legitimise environmental practices and policy. These discursive constructions of environmental degradation are constitutive in the process of boundary-making between pastoralists and the state; and controversial attempts to consolidate state power on the one hand and Afar identity and clan integrity on the other.

Engaging in small-scale subsistence irrigation agriculture and charcoal production are the dominant adaptation strategies of destitute Afar pastoralists in order to deal with the destruction of their communal rangelands due to *Prosopis*. The increasing commodification of commonly used natural resources of Baadu reflects significant changes in environmental governance regimes with severe repercussions for clan society and the wetland ecosystem.

In sum, the invasion of *Prosopis* has created few winners and many losers. The fact that it is only some Afar individuals of specific clans who manage to make profit out of the current situation of land degradation, scarcity and contested land rights increases internal tensions and conflicts within and among clans. The loss of social capital and pastoral values is the socio-political flip side of the current commodification of natural resources. Contrary to this development, the establishment of clan-based charcoal and irrigation cooperatives seems to be better adapted to the Afar 'culture of sharing' and values of reciprocity and collectivity. Dealing with the invasive spread of *Prosopis* in such a way generates income without excluding most of the clan and without creating new social risks.

From an ecological perspective the commodification process has a disastrous impact on the wetland ecosystem, which increasingly loses its beneficial natural functions. Under conditions of high land insecurity and an absent land policy, sustainability has no relevance to the management of natural resources. It can be assumed that the current, largely uncontrolled, extraction of trees, including *Prosopis*, for charcoal

production results in deforestation and changes in the water cycle but ecological studies verifying these socio-ecological interactions in Baadu are still absent. The short planning horizons of agricultural investors and the ambition to get maximum profit in a short time have led to a hit-and-run attitude, increasing salinification of soils and groundwater due to excessive spate irrigation and water pollution from the uncontrolled use of pesticides. Again, although pastoral communities of Baadu claim that water pollution is their biggest environmental problem, the relationships between human use, changing flooding regimes, shifts in species composition and shifts in water quality are so far not adequately researched and need more scientific attention in the future. Without serious studies linking political-economic structures with ecological processes, neo-Malthusian environmental chains of explanation for land degradation due to environmental scarcity, excessive population growth and maladapted pastoral land use will remain dominant.

REFERENCES

- Berhanu, A. and G. Tesfaye (2006). 'The prosopis dilemma, impacts on dryland biodiversity and controlling methods'. *Journal of the Drylands* 1 (2): 158–164.
- Bondestam, L. (1974). 'People and capitalism in the north-eastern lowlands of Ethiopia'. *Journal of Modern African Studies* 12 (3): 423–39.
- Central Statistical Authority (2008). *Report of the 2007 Population and Housing Census*, Addis Ababa.
- Dubale, A. (2006). 'Impacts of *Prosopis juliflora* invasion and control using charcoal production in Afar National Regional State, Ethiopia'. MSc thesis, School of Environment and Natural Resources, University of Wales.
- Elton, C.S. (1958). *The Ecology of Invasions by Animals and Plants*. London: Chapman and Hall.
- Forsyth, T. (2011). 'Politicizing environmental explanations – What can political ecology learn from sociology and philosophy of science?' in M.J. Goldman, P. Nadasdy and M.D. Turner (eds.) *Knowing nature – Conversations at the Intersection of Political Ecology and Science Studies*. Chicago: University of Chicago Press.
- Gebre-Mariam, A. (1994). 'The alienation of land rights among the Afar in Ethiopia'. *Nomadic Peoples* 34/35: 137–146.
- Kassa, G. (2001). *Among the Pastoral Afar in Ethiopia: Tradition, Continuity and Socio-economic Change*. Utrecht: International Books.
- Keeley, J. and I. Scoones (2003). *Understanding Environmental Policy Processes – Cases from Africa*. London: Earthscan.
- Kull, C.A. and H. Rangan (2008). 'Acacia exchanges: Wattles, thorn trees, and the study of plant movements'. *Geoforum* 39: 1258–1272.
- Leach, M. and R. Mearns (1996). *The Lie of the Land: Challenging Received Wisdom on the African Environment*. Oxford: James Currey.

- Markakis, J. (2003). 'Anatomy of a Conflict: Afar & Ise Ethiopia'. *Review of African Political Economy* 96: 445–453.
- Ministry of Agriculture and Rural Development (2005). *National Biodiversity Strategy and Action Plan*. Addis Ababa, Ethiopia: Institute of Biodiversity Conservation.
- Müller-Mahn, D., S. Rettberg and G. Getachew (2010). 'Pathways and dead ends of pastoral development among the Afar and Karrayu in Ethiopia'. *European Journal for Development Research* 22 (5): 660–677.
- Mwangi, E. and B. Swallow (2008). 'Prosopis juliflora invasion and rural livelihoods in the lake Baringo area of Kenya'. *Conservation and Society* 6 (2): 130–140.
- McNeely, J.A. (ed.) (2001). *The Great Reshuffling – Human Dimensions of Invasive Alien Species*. Gland, Switzerland: IUCN.
- PARIMA (2008). 'Demand and potential of Prosopis Juliflora pods as feed resources in Afar region, Ethiopia'. GL CRSP PARIMA Unpublished report.
- Pasiecznik, N.M., P. Felker, P.J.C. Harris, L.N. Harsh, G. Crz, J.C. Tewari, K. Cadoret and L.J. Maldonado (2001). *The Prosopis juliflora - Prosopis pallida Complex: A Monograph*. Coventry, UK: HDRA.
- Rettberg, S. (2009). *Das Risiko der Afar - Existenzsicherung äthiopischer Nomaden im Kontext von Hungerkrisen, Konflikten und Entwicklungsinterventionen*. Saarbrücken: Verlag für Entwicklungspolitik.
- Rettberg, S. (2010). 'Contested narratives of pastoral vulnerability and risk in Ethiopia's Afar region'. *Pastoralism – Research, Policy and Practice* 1 (2): 248–273.
- Reynolds, J.F., D.M. Stafford Smith, E.F. Lambin, B.L. Turner II, M. Mortimore *et al.* (2007) 'Global desertification: Building a science for dryland development'. *Science* 316 (11): 847–851.
- Rezene, F. (2006). 'Challenges and Potentials of Prosopis juliflora in Ethiopia', in R. Fessehaye, A. Teklemariam, K. Ali Mohamed Dawd and S. Ahmed (eds.) *Alien Invasive Weeds and Insect Pests: Management and Control Options*. Second National Workshop on Alien Invasive Weeds and Insect Pests. Addis Ababa, Ethiopia. pp. 53–63.
- Richardson, D.M., P. Binggeli and G. Schroth, G. (2004). 'Invasive agroforestry trees: problems and solutions', in G. Schroth, G.A.B. de Fonseca, C.A. Harvey, C. Gascon, H. Vasconcelos and A.-M.N. Izac (eds.) *Agroforestry and Biodiversity Conservation in Tropical Landscapes*. Washington, DC: Island Press. pp. 371–396.
- Robbins, P. (2004). 'Comparing invasive networks: cultural and political biographies of invasive species'. *Geographical Review* 94 (2): 139–156.
- Romanciewicz, C. (2007). 'Ökologische Veränderungen und Wandel der Lebenshaltungssysteme bei den Afar-Nomaden in Äthiopien'. MSc thesis, Lehrstuhl für Bevölkerungs- und Sozialgeographie, Universität Bayreuth.
- Said, A. (1997). 'Resource Use Conflict in the Middle Awash Valley of Ethiopia: The Crisis of Afar Pastoralism', in R. Hogg (ed.) *Pastoralists, Ethnicity and the State in Ethiopia*. London: HAAN Publishing. pp. 123–141.
- Scoones, I. (1999). 'New Ecology and Social Sciences: What prospect for a fruitful engagement?' *Annual Review of Anthropology* 28: 479–507.

- Shackelton, C.M., D. McGarry, S. Fourie, J. Gambiza, S.E. Shackelton and C. Fabricius (2007). 'Assessing the effects of invasive alien species on rural livelihoods: case examples and a framework from South Africa'. *Human Ecology* 35: 113–127.
- Shiferaw, H., D. Teketay, S. Nemomissa and F. Assefa (2004). 'Some biological characteristics that foster the invasion of *Prosopis juliflora* (Sw.) DC. at Middle Awash Rift Valley Area, north-eastern Ethiopia'. *Journal of Arid Environments* 58: 135–154.
- Stoett, P. (2010). 'Framing Bioinvasion: Biodiversity, Climate Change, Security, Trade, and Global Governance'. *Global Governance: A Review of Multilateralism and International Organizations* 16 (1): 103–120.
- Turner, M.D. (2003). 'Environmental Science and Social Causation in the Analysis of Sahelian Pastoralism', in: K. Zimmerer and T.J. Basset (eds.) *Political Ecology – An Integrative Approach to Geography and Environment-Development Studies*. New York: Guilford Press. pp. 159–180.
- Turner II, B.L. and P. Robbins (2008). 'Land-Change Science and Political Ecology: Similarities, Differences, and Implications for Sustainability Science'. *Annual Review of Environment and Resources* 33: 295–316.
- Turner, M.D. (2009). 'Ecology: Natural and Political', in N. Castree, D. Demeritt, D. Liverman and B. Rhoads (eds.) *A Companion to Environmental Geography*. Oxford: Blackwell Publishing. pp. 181–197.
- Warren C.R. (2007). 'Perspectives on the 'alien' versus 'native' species debate: a critique of concepts, language and practice'. *Progress in Human Geography* 31 (4): 427–446.

CONCLUSIONS

DESERT DIVERSITY AND CHALLENGES

David S.G. Thomas

THE BIGGEST CHALLENGE OF ALL

The diversity of deserts (Chapter 1) is matched by the diversity of topics into which natural scientists and social scientists alike conduct research; and this is well-evidenced by the contents of this volume and the papers presented at the First Oxford Deserts Conference from which they emanated. There is no reason to expect otherwise: deserts and drylands are an extensive part of the earth's land surface, spanning all the continents.¹ They support, at varying levels of occupancy and population densities, societies and communities that practice an increasingly diverse array of activities from traditional nomadic pastoralism to intensive groundwater-fed agriculture and from mineral extraction to sophisticated industrial and hi-tech production. Drylands are also well-known for their importance in the development of human societies over millennia and, due to major advances in our capacity to unravel past dynamics, they are known to have experienced substantial changes in environmental conditions, in response to natural drivers of climatic change operating at the global scale.

Deserts and drylands also face a changing, and uncertain, future. The natural changes that climate has brought over tens – and hundreds – of thousands of years are now enhanced by the direct impact of human activities on atmospheric chemistry, giving rise to climate changes, already beginning to be experienced and expected to be of high magnitude and great rapidity in future centuries. Couple this with the ever-increasing ingenuity of twenty-first century societies and their capacity directly to alter the environments they live in, as well as the negative impacts of human activities (for example, land degradation became an issue of global concern through the spectre of desertification – Thomas and Middleton, 1994), and we have a context of great uncertainty in future decades. Deserts and drylands could experience changes – both negative and positive – in the coming century that impact on ecosystems, landscapes and human beings at a level not previously encountered by so many people over such a short period of time.

1. Even Antarctica, the driest continent on earth but excluded from traditional dryland classifications since Meigs (1953) because of the extreme cold and inability to support crop growth, even if free-moisture were abundant.

The need to better know and understand the nature and histories of our changing deserts has therefore never been greater. The good news is that the level, diversity and quality of desert research has never been higher. These traits have all been demonstrated in the chapters of this book, from which a number of general observations can now be made, in the context of wider research debates in drylands.

UNPACKING THE PAST: THE SCIENCE OF ANCIENT ENVIRONMENTAL CHANGE AND ITS HUMAN CONSEQUENCES

There are major debates in the literature regarding the role of climate and environmental changes in prompting human evolution, dispersal from Africa and around the globe and innovation. Drylands and desert-like conditions play a major role in these debates, on two primary counts. First, as Petraglia *et al.* (Chapter 4) note, the archaeological evidence points towards early humans and human-ancestors showing preference for environments favourable to accessing food. Second is that prolonged and spatially extended drought periods have been seen as barriers to movement, impacting on dispersal routes and on access to resources.

Thus climate changes in the Quaternary period, leading to expanded and contracted deserts or to mega-droughts (a term currently in favour in the literature: e.g. Stager *et al.* 2011), are viewed as a critical part of explanations of our ancestral history. Robust, soundly interpreted and chronometrically controlled data on past desert environments is therefore paramount to successful analysis, though it has been sorely lacking from some theorising (see Thomas *et al.* 2010). Stone (Chapter 2) shows how critical it is to establish the relationships between Quaternary climate changes and specific environmental consequences and how such relationships can be achieved with currently available research tools. Many challenges remain in the context of linking desert-specific changes to global climate change drivers but what is clear is that the analysis of proxy records of the past, specific to the location under investigation, is essential to move forward debates regarding both early human dynamics in and around drylands and the environmental changes these regions have experienced over tens of thousands of years (Maslin and Christensen 2007, Thomas and Burroughs 2011). Generalisations derived from the big global picture of Quaternary climate dynamics are simply insufficient in resolution to capture the spatial and temporal mosaics of landscape variability that existed in the past. In the context of drylands, recent studies in Arabia, for example, show how spatio-temporal complexity in environmental systems may have profoundly affected early human behaviour (Armitage *et al.* 2011, Rosenberg *et al.* 2011).

VALUING TRADITIONAL KNOWLEDGE AND BEHAVIOUR IN A RAPIDLY CHANGING WORLD

Drylands are environments where uncertainty prevails. It is increasingly recognised that knowledge of this environmental variability, and its incorporation into liveli-

hood strategies and resource use patterns, has been a trait of the behaviour of dryland societies for millennia. Indeed it is that very incorporation and embeddedness that has facilitated survival and adaptation in these often harsh environments. Long-gone are the views that indigenous dryland land use practises have been the root cause of land degradation in these regions, as was once widely purported in the literature (see, for example, Rowntree *et al.* 2004 and others for discussions of aspects of this issue). There remain aspects of traditional adaptations and ingenuity that are not well documented in the social science literature. Di Lernia *et al.* in this volume demonstrate this with new research from southern Libya on traditional Tuareg water harvesting and utilisation practices that may have had their origins over 5,000 years ago. These strategies have generated resilience to water shortages that might have a bearing on potential adaptations to future water deficits and uncertainties over coming decades.

In an ever-globalising world, the identification of the primary characteristics of traditional land use systems is of utmost importance: it is one thing to recognise the capacity to cope that they bring but another thing to identify and appropriately attribute the sources of these benefits. One of the great eye-openers of late twentieth century dryland science was the recognition on the non-equilibrium behaviour of many dryland ecosystems (e.g. Behnke *et al.* 1993, Illus and O'Connor 1999). Suddenly traditional pastoralist strategies seemed 'logical' and consequently many range management strategies for drylands, which had been based on theories extracted from temperate systems, were adapted to recognise this 'new-found' (but actually ancient to indigenous groups) system behaviour. Nonetheless, Krätli and Schareika in this volume illustrate how the logic of traditional dryland pastoral systems has yet to be fully incorporated into the way in which livestock production is assessed in development planning.

Traditional land-use knowledge (and the resultant socio-environmental benefits) can only 'work' in a sustainable manner if its fundamental principles are able to operate. Development in many economies, in the context of globalisation drivers, can generate pressures whereby changes at the national level compromise local level practices that have functioned successfully for a long time. Natural resource exploitation demands from multinational companies, especially but not exclusively in the extractive sector, often exacerbate this situation: witness concerns over indigenous rights in Botswana over several decades (Hitchcock 2002, Ndala Marobela 2011, Hitchcock *et al.* 2011), and recently in Mongolia (Reading *et al.* 2010, Reeves 2011). Chatty in this volume (Chapter 9) explores a comparable but lesser-known case from Oman, where, as in Botswana, the indigenous rights of mobile groups are questioned in the context of claims to the resources the environment provides.

When constraints are placed upon the operation of traditional practices, resilience (*sensu* Adger 2000) can be reduced and exposure to hazard increased. Thus natural events, such as droughts and floods, that represent risks to human societies are less able to be coped with. This is because either the resource base has been degraded, reducing the capacity for resilience, or because the capacity to employ traditional practices, such as mobility/migration to areas where risks are lower, has been com-

promised. This is not to say that, without additional disturbances, all risks would be avoided by traditional societies and practices: rather, it is that there are many instances where incorporation within the global patterns of development at the national level has contributed to increased vulnerability at the local/community level. In this volume (Chapter 13) Sternberg discusses the impact of *dzud* (extreme winter conditions) in 2010 on traditional rural society in Mongolia. It is noted how the collision of extreme environmental variability and socio-political changes created a disaster (perhaps not a natural disaster, because of the role of economic change in reducing resilience) that was the worst ever recorded in the country.

Over and above the challenges that socio-political changes are bringing to drylands, twenty-first century global warming and its consequences for ecological and social systems represents perhaps the biggest and fastest-occurring set of challenges that modern human societies have had to cope with. The projected impacts of global warming on dryland systems worldwide are dramatic but not fully certain, though in many cases they represent a diminution in the future of the available resource base (see, for example, Thomas *et al.* 2005, De Wit and Stankiewicz 2006). Nonetheless, in Chapter 12 Crowley and Kelman argue that the inherent capacity of dryland societies to cope with variability and change, compared to those in other environments, may offer models for future adaptation in wider contexts.

DRYLAND FUNCTIONING AND GLOBAL CARBON DYNAMICS

Enhanced atmospheric carbon levels in the twentieth century may be one factor that has contributed to the global dryland phenomenon of bush encroachment (Archer *et al.* 1995, Wigley *et al.* 2010), though land use change is still regarded as the principal driver of shrubby species' encroachment into dryland grasslands. In some instances, encroachment has been by alien invasive species, as Rettberg discusses in her chapter, where impacts are not just ecological but cultural too.

One aspect of an increase in woody biomass in drylands is the impact on atmospheric carbon drawdown, or sequestration. Whilst bush encroachment may accidentally achieve this effect, a growth of planned afforestation schemes, as considered by Rueff and Schwartz (Chapter 5), does so in a planned manner. Such sequestration projects may have multiple aims but their viability is linked to the global carbon market, while environmental negatives (excessive use of local water resources) have to be balanced against the wider targeted benefits. Dryland carbon drawdown is however not solely associated with biomass but with soil carbon in organic and inorganic forms. Knowledge of carbon dynamics in dryland soil systems is surprisingly limited, as Thomas *et al.* (Chapter 3) show, but is vitally important in recognising total system functioning. This represents yet another of the scientific challenges that drylands hold.

CONSERVING HERITAGE UNDER MULTIPLE THREATS

Alien species invasion (Chapter 15), extreme environment hazards (Chapter 13), rapid economic development (Chapters 7 and 9) and global warming impacts (Chapter 5) represent threats to the complex environmental and social mosaics of drylands that have evolved under longer patterns of environmental variability and change (Chapters 2, 4 and 6). Nonetheless, as Brittain and Clark eloquently demonstrate in Chapter 10, even the most apparently 'natural' parts of drylands have developed with human agency playing a critical and long-term role. Embracing that knowledge within strategies to understand the past offers benefits to the very societies that exist today under multitude of threats that drylands face. The global significance of these threats cannot be over-emphasised. As Mol and Viles note in Chapter 11, fourteen of UNESCO's eighteen most-threatened World Heritage sites are in dryland regions. For some of these, the changing rate of operation of environmental processes under global warming impacts, such as rock weathering of archaeological sites, further exacerbates the already considerable risks.

REFERENCES

- Adger, W.N. (2000). 'Social and ecological resilience: Are they related?' *Progress in Human Geography* 24: 347–364.
- Archer, S., D.S. Schimel and E.A. Holland (1995). 'Mechanisms of shrubland expansion: Land use, climate or CO₂?' *Climatic Change* 29 – 91–99.
- Armitage, S.J., S.A. Jasim, A.E Marks, A.G. Parker, V.I. Usik and H.-P. Uerpmann (2011). 'The southern route "out of Africa": Evidence for an early expansion of modern humans into Arabia'. *Science* 331: 453–456.
- Behnke, R.H., I. Scoones and C. Kerven (eds.) (1993). *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaptation in African Savannas*. London: ODI.
- Maslin, M.A. and B. Christensen (2007). 'Tectonics, orbital forcing, global climate change, and human evolution in Africa: introduction to the African paleoclimate special volume'. *Journal of Human Evolution* 53: 443–464.
- De Wit, M. and J. Stankiewicz (2006). 'Changes in surface water supply across Africa with predicted climate change'. *Science* 311: 1917–1921.
- Hitchcock, R.K. (2002). "'We are the first people": Land, natural resources and identity in the Central Kalahari, Botswana'. *Journal of Southern African Studies* 28: 797–824.
- Hitchcock, R.K., M. Sapignoli, W.A. Babchuk (2011). 'What about our rights? Settlements, subsistence and livelihood security among central Kalahari San and Bakgalagadi'. *International Journal of Human Rights* 15: 62–88.
- Illius, A.W. and T. G. O'Connor (1999). 'On the relevance of nonequilibrium concepts to arid and semiarid grazing systems'. *Ecological Applications* 9: 798–813.
- Meigs, P. (1953). 'World distribution of arid and semi-arid homoclimates'. *Arid Zone Hydrology, UNESCO Arid Zone Research Series* 1: 203–209.

- Ndala Marobela, M. (2010). 'The state, mining and the community: The case of Basarwa of the Central Kalahari Game Reserve in Botswana'. *Labour, Capital and Society* 43: 137–154.
- Reading, R.P., D. Bedunah and S. Amgalanbaatar (2010). 'Conserving Mongolia's grasslands, with challenges, opportunities, and lessons for North America's Great Plains'. *Great Plains Research* 20: 85–107.
- Reeves, J. (2011). 'Resources, sovereignty, and governance: Can Mongolia avoid the "resource curse"?' *Asian Journal of Political Science* 19: 170–185.
- Rosenberg, T.M., F. Preusser, D. Fleitmann, A. Schwalb, K. Penkman, T.W. Schmid, M.A. Al-Shanti, K. Kadi and A. Matter (2011). 'Humid periods in southern Arabia: windows of opportunity for modern human dispersal'. *Geology* 39: 1115–1118.
- Rowntree, K., M. Duma, V. Kakembo and J. Thornes (2004). 'Debunking the myth of over-grazing and soil erosion'. *Land Degradation and Rehabilitation* 15: 203–214.
- Stager, J.C., D.B. Ryves, B.M. Chase and F.S.R. Pausata (2011). 'Catastrophic drought in the Afro-Asian monsoon region during Heinrich event 1'. *Science* 331: 1299–1302.
- Thomas, D.S.G. and S.L. Burrough (2010). 'Interpreting geo-proxies of late Quaternary climate change in African drylands: implications for understanding environmental and early human behaviour'. *Quaternary International*. doi:10.1016/j.quaint.2010.11.001.
- Thomas, D.S.G. and N.J. Middleton (1994). *Desertification: Exploding the Myth*. Chichester: Wiley.
- Thomas, D.S.G., M. Knight M. and G.F.S. Wiggs (2005). 'Remobilisation of southern African desert dune systems by 21st century global warming'. *Nature* 435: 1218–1221.
- Wigley, B.J., W.J. Bond and M.T. Hoffman (2010). 'Thicket expansion in a South African savanna under divergent land use: Local vs. global drivers?' *Global Change Biology* 16: 964–976.

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Deserts – vast, empty places where time appears to stand still. The very word conjures images of endless seas of sand, blistering heat and a virtual absence of life. However, deserts encompass a large variety of landscapes and life beyond our stereotypes. As well as magnificent Saharan dunes under blazing sun, the desert concept encompasses the intensely cold winters of the Gobi, the snow-covered expanse of Antarctica and the rock-strewn drylands of Pakistan. Deserts are environments in perpetual flux and home to peoples as diverse as their surroundings, peoples who grapple with a broad spectrum of cultural, political and environmental issues as they wrest livelihoods from marginal lands.

The cultures, environments and histories of deserts, while fundamentally entangled, are rarely studied as part of a network. To bring different disciplines together, the 1st Oxford Interdisciplinary Deserts Conference in March 2010 brought together a wide range of researchers from backgrounds as varied as physics, history, archaeology anthropology, geology and geography. This volume draws on the diversity of papers presented to give an overview of current research in deserts and drylands. Readers are invited to explore the wide range of desert environments and peoples and the ever-evolving challenges they face.

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