A Visual Quality Prediction Map for Michigan, USA: An Approach to Validate Spatial Content

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Abstract

For a least the last half-century, scholars have been seeking methods to predict and assess the visual and environmental quality of the landscape. In these investigations, some scholars have been interested in applying predictors to create maps, representing visual and environmental quality. In our study, we employed a reliable environmental quality prediction equation that assesses environmental quality to create a validated visual quality map of Michigan containing a variance of 0.67, containing an overall p-value less than 0.0001, and p-values less than or equal to 0.05 for each predictor. Measures ranging in the mid-40s and 50s indicate a moderate level of environmental quality, while scores in the 80s through 110 indicate a very poor environmental quality. Through the Kendall's coefficient of concordance statistical test, we determined that the map is significantly reliable ($p \leq 0.005$) and conclude that constructing such a large area (250,493 km^2) is possible. This type of map can be employed to evaluate progress and decline in measuring the environmental quality/land-use change of extensive landscape areas.

Keywords: environmental psychology, landscape architecture, land-use planning, landscape planning

1. Introduction

For almost 50 years, investigators have been seeking quantitative methods to predict and assess the visual and environmental quality of the landscape. The literature on this subject is vast and continues as illustrated through recent investigations and contributions by psychologists, engineers, landscape architects, planners, and natural resource specialists [1–11]. One of the best summaries of the early efforts was described by Taylor et al. [12]. Despite the

scientific advances, the application of equations and exploration of theories seemed somewhat impractical for many practitioners. In attempts to translate the research, two of the best practical summaries of the ideas revealed by the research were found in *The Experience of Nature: a Psychological Perspective* and in *With People in Mind: Design and Management of Everyday Nature* [13, 14]. Along with developing predictive equations, investigators were interested in constructing maps that predict visual quality. Brush and Shafer produced one of the earliest well known visual quality maps [15]. But this approach was not widely adopted. In the United States, a heuristic approach (without strong statistical evidence for the variables and coefficients but instead based upon normative theory) comprised of an index developed by Jones and Jones, becoming widely employed and over time refined [16, 17]. The success of this index may have hindered the development of more science-based equations, as stakeholders adopted this relatively easily understandable methodology and were unwilling to seek additional methods. The actual science supporting this normative theory approach has been relatively weak and not aggressively challenged by the scientific community. But to landscape architects not trained in the ways of statistical analysis, p-values, and variance explanations, the index seemed to make good logical sense. In some respects, there seemed to be a lull at the turn of the century concerning visual quality assessment, where a methodology to validate maps was not self-evident, and the production of equations to explain increased levels of the variance were at a standstill. The early attempts to predict visual quality were primarily focused upon artistic composition normative values such as foreground, mid-ground, background, geometrical harmony, and natural/urban components. By pursuing this set of esthetic and spatial variables, investigators were able to explain 30% to nearly 70% of the variance [18].

At the time, some scholars were frustrated with being unable to make much new headway. Some more recent investigators entered the subject area and began to explore the importance of other types of variables that were less esthetic in character, and more ecological, cultural, economic, and functional [19]. At a conference in 2005 in Switzerland (Our Shared Landscape 2005, Integrating ecological, socio-economic and esthetic aspects in landscape planning and management´ http://www.osl.group.shef.ac.uk, at Centro Stefano Franscini in Ascona, Switzerland), scholars were coming to the realization that respondents evaluated the landscape with more than just esthetic values. When these other potential predictors are added to the study, more of the variance was explained collectively and statistically. Stronger and more reliable predictive equations evaluating landscapes could be generated from respondents, explaining over 90% of the variance when esthetic, ecological, cultural, functional, and economic predictors are combined [20–22]. Along with the equations a series of theories to explain the results evolved [23]. Investigators noted that contents where humans infringed upon other humans (buildings, roads, people) were less preferred (even high quality architecture)—human disturbance theory; the benign environment (plants, waters, sky) were neutral in preference—natural preference theory; and temporal features (wildlife, momentary views of mountains, and flowers) were in preferred environments—temporal enhancement theory. Thus, theory and models were advancing together concerning evaluating and assessing the quality of the environment.

During this period, some scholars were beginning to explore the potential for globally universal predictive equations. Mo et al. recently reviewed much of this pertinent literature and discusses the perceptions of respondents in North America, France, Portugal, and PR China [24]. One finding suggests that Europeans and North Americans may have broad similar

perceptions about landscape. Asians may have a different sensibility concerning environmental preference. Concurrently, on the digital visualization forefront Partin et al. studied the response of participants to computer generated images and reported that the perception of computer images was similar to the perception of photographs of landscapes [25]. In other words, it was possible for investigators to present computer-generated images to respondents and to obtain a similar response as if the respondents were examining photographs. He also demonstrated how a small study could be folded into a larger and widely studied set of images to obtain stable and reliable results. However, these equations and results are still formative and require duplication by others to refute them or support them. In addition, there are opportunities to explore the responses of various cultural groups and to refine these equations. While the literature on this topic is vast, there seems to be many more instances to add to the body of knowledge.

Also during this recent timeframe, attempts to explore mapping making potential were renewed. Lu et al. examined the Lower Muskegon watershed, located on the west side of the lower peninsula in Michigan [26]. He and his colleagues studied images of urban areas, farmland, wetlands, and forests and attempted to construct an environmental quality map of his study area. The results he obtained through statistical analysis revealed that the relationship between his predictions in the map and the real photographs are in concordance and at a reasonable (95%) confidence level. He concluded that visual/environmental quality could be mapped and reliably predicted in the Lower Muskegon Watershed. There was a strong relationship between the perception of environmental quality and land cover. Following Lu, Jin examined the southern portion of Michigan, an area much larger than the Lower Muskegon Watershed [27]. She reported similar results to Lu. She had demonstrated that it was possible to develop reliable maps for much larger areas, but still not at the scale of a province or state.

Figure 1. The location of Michigan, the study area in North America.

Lothian presents the fundamentals and an overview of various approaches to constructing visual quality maps and is a substantia update to the work of Taylor et al. [12, 28]

These recent studies provide a setting for our investigation. As an extension of Lu's et al. and Jin's research, we were interested in applying this approach to all of Michigan (**Figure 1**) [26, 27]. We wanted to make a validated map for all of Michigan.

2. Methodology

Michigan is located in the Great Lakes Region of the United States of America. It is the only state to consist of two peninsulas with the longest shoreline of any state of the lower 48 states. These two peninsulas are linked by the Mackinaw Bridge. The Straights of Mackinac separate the Upper Peninsula from the Lower Peninsula, whose shape looks like a mitten (**Figure 1**). The study area spans abundant agricultural lands in the south, hardwood forests in the middle portion, and mixed evergreen forests in the north. The study area also contains a large urban landscape comprised of metropolitan Detroit, plus numerous industrial sites, especially in the lower part of the state. The study area contains level glacial lake plains, hilly moraines, and ancient eroded mountain chains. The population of the state is only 10 million people (roughly the same population number as the Kingdom of Sweden but about half the size in overall land area).

The methodology used for this study was similar to that utilized by Lu et al., where land cover and visual/environmental quality covary [26]. A comprehensive explanation of this methodology can be found in Lu et al. [26]. Adhering closely to this method, images of various landscapes across the study area were collected and randomly sorted into two groups: one group to assist in making a prediction and another group to validate or refute the prediction. From the first group, scores for the images were generated by employing Eq. (1) developed by Burley [19]. The information presented by Burley is the formative paper in this line of work and investigators interested in understanding the fundamentals of this line of research are urged to examine this paper. Once the scores were obtained, they were applied to similar land-uses to form a map predicting environmental quality.

$$
\begin{aligned}
Y = {} & 68.30 - (1.878 * HEALTH) - (0.131 * X1) - (0.064 * X6) + (0.020 * X9) \\
& + (0.036 * X10) + (0.129 * X15) - (0.129 * X19) - (0.006 * X32) \\
& + (0.00003 * X34) + (0.032 * X52) + (0.0008 * X1 * X1) + (0.00006 * X6 * X6) \\
& - (0.0003 * X15 * X15) + (0.0002 * X19 * X19) - (0.0009 * X2 * X14) \\
& - (0.00003 * X52 * X52) - (0.0000001 * X52 * X34)
\end{aligned}
\tag{1}
$$

where

HEALTH = environmental quality index (**Table 1**)

X1 = perimeter of immediate vegetation

X2 = perimeter of intermediate non-vegetation

X3 = perimeter of distant vegetation

X4 = area of intermediate vegetation

X6 = area of distant non-vegetation

X7 = area of pavement

X8 = area of building

X9 = area of vehicle

X10 = area of humans

X11 = area of smoke

X14 = area of wildflowers in foreground

X15 = area of utilities

X16 = area of boats

X17 = area of dead foreground vegetation

X19 = area of wildlife

X30 = open landscapes = X2 + X4 + (2 × (X3 + X6))

X31 = closed landscapes = X2 + X4 + (2 × (X1 + X17))

X32 = openness = X30 − X31

X34 = mystery = X30 × X1 × X7/1140

X52 = noosphericness = X7 + X8 + X9 + X15 + X16

Next, the second group of images was compared to predictions made by the map through the use of Kendall's Concordance, a statistical technique that examines and tests for significant agreement/similarity [29, 30]. If the scores statistically agree, it is possible to create a reliable visual quality prediction map. This step in the methodology used here is explained in great detail by Jin [31]. Investigators interested in applying this methodology are advised to obtain copies of Lu et al. and Jin for a complete explanation [26, 31].

The test statistics were determined by applying Eqs. (2) and (3) to the data. The results are based upon rankings of treatment scores across rows. In this case, the rows are pairs of images between two treatments: (1) the predicted score for a randomly chosen site in the study area and (2) the actual score from a photograph taken at that location. There are 30 rows (pairs of scores) for this study (n = 30). The treatments are the columns (m = 2). The rankings are summed and squared, to compute Kendall's W value (Eq. 2). $(Rj)^2$ is the sum of the squares of the rankings for a column in computing the Kendall's W value [29, 30].

$$W \;=\; 12\sum_{j=1}^{n} (Rj)^2 - [3\,m^2\,n\,(n+1)^2]/[m^2\,n(n^2-1)] \tag{2}$$

Kendall's W value is a number ranging between 0 and 1. When W is near 0, there is no strong overall trend of agreement among the respondents. If W is near 1, then the responses could be

Health index	
Variable	**Score**
A. Purifies Air	+1 0–1
B. Purifies Water	+1 0–1
C. Builds Soil Resources	+1 0–1
D. Promotes Human Cultural Diversity	+1 0–1
E. Preserves Natural Resources	+1 0–1
F. Limits Use of Fossil Fuels	+1 0–1
G. Minimizes Radioactive Contamination	+1 0–1
H. Promotes Biological Diversity	+1 0–1
I. Provides Food	+1 0–1
J. Ameliorates Wind	+1 0–1
K. Prevents Soil Erosion	+1 0–1
L. Provides Shade	+1 0–1
M. Presents Pleasant Smells	+1 0–1
N. Presents Pleasant Sounds	+1 0–1
O. Does not Contribute to Global Warming	+1 0–1
P. Contributes to the World Economy	+1 0–1
Q. Accommodates Recycling	+1 0–1
R. Accommodates Multiple Use	+1 0–1
S. Accommodates Low Maintenance	+1 0–1
T. Visually Pleasing	+1 0–1
Total score	

Table 1. Variables for the environmental quality/health index in Eq. (1).

regarded as close to unanimous in their agreement. The W test statistic approximates a Chi-square distribution with n−1 degrees of freedom (Eq. (3)). If computed values for Chi-square (results of (Eq. (3)) are greater than significant values in a Chi-square table for n−1 degrees of freedom (in this case 29 = 30–1), then there is a high level of agreement/concordance—the predicted scores and the actual scores are in agreement.

$$X^2 = m(n-1)W \tag{3}$$

3. Results

The sample of images gathered in the investigation includes forested lands (**Figure 2**), agricultural lands (**Figure 3**), residential environments (**Figure 4**) (known as urban savanna), downtown-like environments (**Figure 5**) (known as cliff detritus), industrial sites (**Figure 6**), and open water (**Figure 7**) [32].

Figure 2. Image of sample number 67 of a forested landscape in the upper peninsula of Michigan (visual score of 38.548).

Figure 3. Image of sample number 80 of a farmland landscape in north-east of the lower peninsula of Michigan (visual score of 44.09).

Figure 4. An image of a residential landscape (urban savanna with visual quality score of 46.587), sample number 12 in the northwest of the lower peninsula.

Figure 5. An image of sample number 73 of a downtown environment (cliff detritus with a visual score of 82.766).

Figure 6. An image of sample number 77 of an industrial environmental (with a visual score of 78.778).

Figure 7. An image of sample number 46 of a primarily open water environment of Lake superior (with a visual score of 41.498).

Table 2 presents the rankings of the images from the study. The predicted ranks are scores generated from the expected a land-use scores and applying the expected score to a land-use map of the study area. The actual scores are values taken and measured from random sites in the study area. Kendall's Concordance analysis revealed a Chi-square score of 54.267. The

Property	Predicted ranking	Mean expected score	Actual score	Set 2 ranking
Residential l	18	63.06312	73.69797	21
	18	63.06312	55.94164	15
	18	63.06312	46.58693	8
	18	63.06312	70.73992	20
	18	63.06312	68.34915	18
Downtown	23	81.56982	69.28333	19
	23	81.56982	84.30117	24
	23	81.56982	86.72108	27
	23	81.56982	82.76631	23
	23	81.56982	84.77721	25
Farmland	13	55.92384	59.12320	17
	13	55.92384	57.74200	16
	13	55.92384	45.25820	7
	13	55.92384	44.09459	6
	13	55.92384	53.27078	13
Industrial	28	90.91938	86.56068	26
	28	90.91938	94.63968	28
	28	90.91938	96.94017	29
	28	90.91938	78.77838	22
	28	90.91938	97.67801	30
Forested	3	42.67716	54.40120	14
	3	42.67716	46.98920	9
	3	42.67716	36.70580	2
	3	42.67716	36.70580	2
	3	42.67716	38.58380	4
Water	8	44.99797	52.89468	12
	8	44.99797	47.78978	11
	8	44.99797	35.62803	1
	8	44.99797	47.27917	10
	8	44.99797	41.39820	5

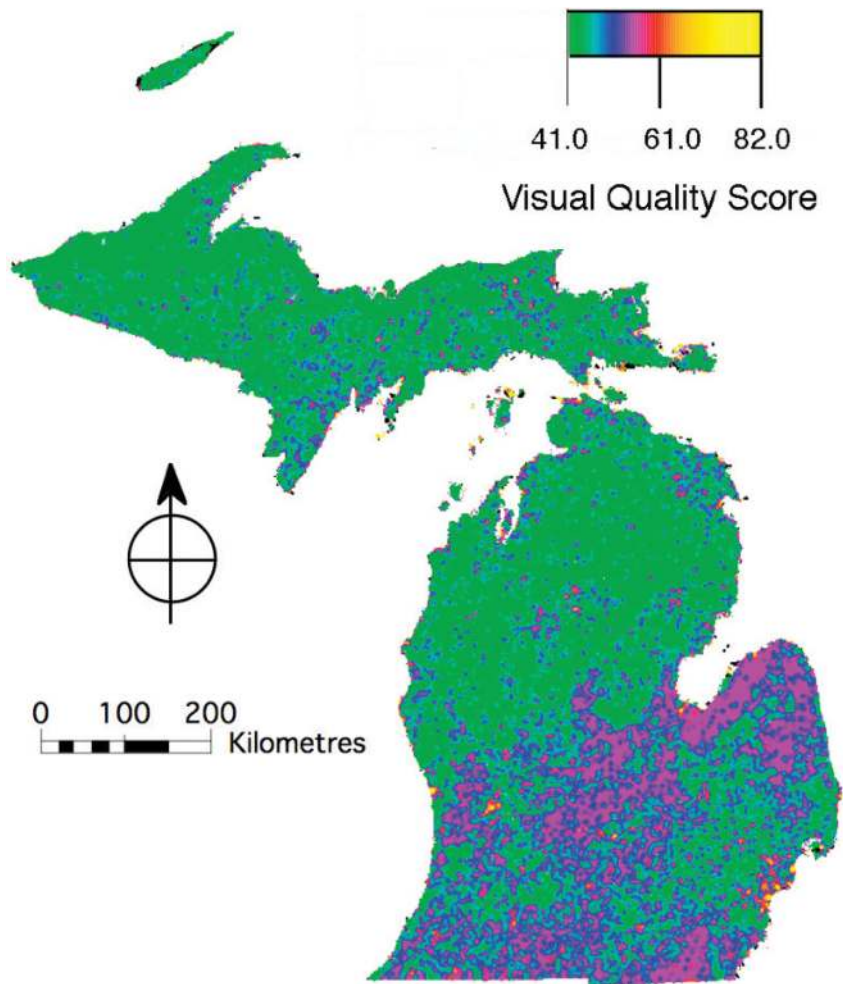**Table 2.** Comparison of ranks between the average expected score and actual site photographs.

Figure 8. A map of the predicted environmental/visual quality of the Michigan landscape. Green areas are environments with good visual quality. Blue, magenta, red, and orange indicate successively less preferred environments. Yellow areas are the least preferred.

number found in a standard table for such a Chi-square is 52.336 (a 99.5% confidence level ($p \leq 0.005$) for 29 degrees of freedom. Since 54.267 is larger than 52.336, the predicted scores and the actual scores are in agreement at a 99.5% confidence level ($p \leq 0.005$). These results suggest that it is possible to construct an environmental/visual quality map of Michigan that is relatively statistically reliable (**Figure 8**). In other words it is possible to predict the visual quality of any site in Michigan by knowing the land-use and to accurately predict the expected visual quality correctly 199 times in 200 attempts for any one attempt.

4. Discussion

4.1. Understanding the map

To interpret the scores, Burley notes that scores in the 30s indicate highly preferred environments [23]. From randomly selected sites across the study area, no landscape scored in

this category. The study revealed numerous landscapes with scores in the 40s and 50s. Such landscapes are often modestly preferred environments. Scores in the 70s are less preferred and scores near or above 100 are not preferred [23]. Across the state, least preferred environments were rarely encountered, primarily in the southeastern portion of the state. The 95% confidence interval for any scores is ±5 points [33]. Thus, it takes a separation of 10 points for any pairs of images to be notably different as perceived by respondents.

4.2. Applications of the map

The average expected score (the sum of the products between the number of grid cells by their expected score, divided by the total number of grid cells) for the whole state is approximately 47.4. This score suggests that collectively the whole state of Michigan may not be the most beautiful of all environments; on the other hand, the environmental score is quite respectable and viewed by respondents as at least somewhat scenic.

To understand the context of the average expected score in Michigan, it is useful to explore the land-uses, published perceptions, recreational activities, and agriculture within the state. In an article published on the 29th of June, 2015, the Detroit Free Press reported that Thrillist who ranked all of the states in America, placed Michigan as the top state [34]. While the results of the list do not definitively demonstrate that Michigan is at the top, it does indicate that the environment of Michigan merits consideration as a noteworthy place in regard to visual quality and may be similar in score to numerous rural mixed agrarian and woodland environments around the world, such as in Poland, Romaina, or Hubei Province, PR China. It may be reasonable to consider the extensive shorelines, vast expanse of national forest lands (3 national forests), state forest lands, national parks, 99 state parks, a national lakeshore, wildlife refuges, woodlots, and agrarian landscapes assist in maintaining a relatively preferred environment [35]. According to the map (**Figure 8**), the impact of the urban and industrial development is not widespread in the state and has not yet affected the state with large megalopolis expanses. Without attempting to be promotional, the state remains a big fishing (salmon, trout, walleye, northern, pan-fish), hunting (black bear, elk, white-tailed deer, and wild turkey), recreation state (camping, boating, hiking, cross country trails, snowshoeing trails, biking trails, snowmobiling trails, and horseback-riding—actually thousands of miles of trails) and in the Upper Peninsula there are 150 waterfalls. Michigan has also been rated as one of the top places in the world for watching sunrises on earth [36]. Such features are promoted in Michigan's 'Pure Michigan' tourist campaign [37]. The state has the most diverse agricultural economy after California [36]. Michigan produces cherries, apples, blueberries, many vegetable crops, nursery plants, sugarbeets, a strong wine producing industry, potatoes, dairy, cattle, hogs, chickens, turkeys, timber, hardwoods for flooring and furniture, and paper pulp, as well as the staple corn, soybeans, and winter wheat. While the state is associated with the famed mid-west rust-belt and the failures of Detroit, the overall impact upon the state's extensive forested lands and agrarian landscape is relatively minimal [38]. In addition, visitors to the Detroit metropolitan area often are surprised with the activity and prosperous nature of the Detroit metropolitan area. The Detroit metropolitan area is a distributed urban environment with no dominant central district, the opposite of many other large cities which are more concentrated in the core such as a city like Shanghai, P.R. of China. The state is a major constituent of the third coast, the longest coastline associated with the United States and Canada (excluding the Arctic) [39]. The results of this study reflect the impression that

the state is still predominantly a rural environment and is modestly beautiful in a 'low-key' manner. In other words, the average expected score and the existing landscape condition are mutually similar in expectations.

The map resulting for this study is an image representing the spatial perceptions of the respondents concerning the quality of the landscape across the state. As the land is managed and developed, the scores can be recomputed to estimate the perceived changes (both improvements and degradation) for the state. With additional research, the map could be considered a metric of the state's general perceived environmental quality. Across the globe, people are concerned about the impacts of human's transforming the environment; yet, comparatively, the compiled total environmental quality has not appreciatively changed since the arrival of Europeans, Africans, and Asians (a score predicted to be around 43 between the years 1816 and 1858 to a score of 47.4 in the year 2001, which is not significantly different in perceived quality) [40]. **Figures 9–11** are images from the landscape with scores near the current expected mean for much of the state. Notice none of the images are spectacular; however, none of the images age dismal either.

Figure 9. An image of a modest rural residential setting collected in the study area with a score of 46.6.

Figure 10. An image of a typical agricultural landscape found in much of Michigan. This image produced a score of 44.1.

Figure 11. An image of a great lakes coastline, generating a score of 47.8.

The results of this study and related studies indicate that land cover type is a strong predictor of visual/environmental quality. In planning and design circles, the nuances of the built environment are heavily debated with small details carefully examined by experts. Yet respondents evaluate these cover types relatively uniformly. In other words the refined changes and differences observed by experts and taught in planning and design schools are not necessarily observed/detected by the public. For experts the differences between communities can be quite distinct. As Charles Jencks indicated, there are at least two levels of cognition: the expert's and the public's [41]. For example, architects debate the merits of buildings; however, the research suggests that a poor building in a warehouse district or a noted piece of architecture such as Frank Lloyd Wright's Falling water house are perceived as simply structures and the less of them comprising the view, the more the environment is preferred [23].

Similarly, landscape architects debate the merits of various plant material and landscape settings; yet, the public sees a noble red pine tree (*Pinus resinosa* Sol. Ex Aiton.) or a weedy box-elder tree (*Acer negundo* L.) as basically the same thing—a tree. It is only when the plant has ornamental flowers, is there an increased appreciation during the period of flowering. Within any cover type, there is variation (scores can range up or down), but the expected mean within the cover type is quite consistent when measured repeatedly across time, across locations, and among respondent groups in America and Europe. In other words, the most important characteristic that the planner or designer makes concerning visual/environmental quality may be in determining the cover type for a parcel of land, not the refined details of a design. In the future, designers may develop improved techniques to mask human intrusions and abundantly incorporate preferred features such as wildlife, flowers, and views of distant landscapes, creating strong variation in the range of scores possible for a given cover type. Then the covariation of land cover type with visual/environmental quality may no longer hold true.

The relationships between the perception of environmental quality and cultural settings are explored in the book From Eye to Heart: Exterior Spaces Explored and Explained [42]. This book begins with discussing expectation values concerning the environment. Then the book examines some of the many interpretations for planning and designing across the globe and

through time. The book concludes with the relationship between environmental science and the built/managed landscape. This book provides some greater and broader context to the visual mapping study presented in this investigation.

4.3. Limitations

Additional research should be conducted to refute, validate, or refine the findings presented here. However, it may be surprising that with only 60 images from across the state, the selected images facilitate a significant statistical result and make a reliable map for a whole state. In some studies, weakly developed experiments with large data sets and numerous observations may produce unremarkable results. The results presented in this paper follow a philosophy that relies upon methodologies that have yielded significant results (such as employing Q-sort techniques as opposed to Likert scales), an exploration of reliable predictors, and non-parametric statistical procedures. We would like to believe that well-grounded, focused, simple experiments often yield results that some expensive and elaborate studies fail to yield. The senior investigator in this study had spent over 30 years, carefully plotting each step, conducting the next logical step/experiment before proceeding. So each study is simple (for example the statistics were done on a spreadsheet), yet yielding meaningful results. This philosophical approach has served the team well and we encourage others to have this level of insight and commitment when formulating environmental quality studies. Investigators sometimes believe that technology, huge sample sizes, and big money make impressive research.

The results produced in the map are dependent upon the quality of the land cover type map. Many cover maps concentrate upon the great variation of vegetation and naturalistic cover types. Urban and suburban cover types are rarely produced with the same level of sensitivity. Brady et al. at the University of Waterloo developed an excellent example concerning the classification of human disturbed areas, based upon morphological and ecological features [32]. Yet this level of description has not yet permeated many land cover maps. We believe that classification systems that adopt ideas embedded in work by investigators such as Brady et al. will produce higher quality maps in urban areas than the maps that are currently produced [32].

In the landscape there are several types of cover types that exist in the landscape such as large sand dunes, mud flats, and bare rock that may be beyond the predicative capabilities of this study. These more rare landscape types were neither studied in the prediction models nor in creating the map presented in this study. Cover types such as these would need to be studied in detail to make a more comprehensive and complete map. This is computed to be a substantial area of land, approximately 1700 km^2. Yet this area is only about 0.68% of the land of Michigan.

The resolution of the map is relatively coarse (2.207 km^2 of land). Large maps with finer resolution will yield more refined results. A grid cell of that size will certainly have variation in it. The score represents the mean expected value within the cell.

5. Conclusions

Predictive, respondent based models have been constructed to measure environmental and visual quality. This work is based upon over 50 years of research by investigators in the social, recreational, and planning and design disciplines/profession. The attributes of the landscape can be measured to form reliable maps of environmental/visual quality, providing a metric to assess landscapes, including urban landscapes. We were able to produce such a metric map for Michigan. We believe our approach allows investigators to evaluate these visions and assess, measure, and quantify environmental perceptions. Furthermore, we believe the methods are reproducible, allowing investigators around the world to produce similar maps of additional areas.

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