

美国密歇根州麦克斯顿平原矮化植被群丛视觉指标研究

Visual Metrics for the Maxton Plains Alvars in Michigan, USA

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摘要

在美国，规划师、设计师、环保主义者、热心市民和政府官员对保护和管理拥有独特生态环境的小型自然区域充满热忱。相关研究表明，土地利用类型与视觉质量评价指标之间联系密切；在同一个连续区间中，相较于人造元素居多的用地类型，受访者更偏好自然元素更多的用地类型。本研究评估并记录了在美国密歇根州德拉蒙德岛麦克斯顿平原矮化植被群丛中植物群落的视觉指标情况。大尺度的有关视觉质量的制图项目通常以城市区域、林地、水体、耕地、牧场和草原为评估对象，矮化植被这类小型却独特且稀有的景观类型较少被关注。本研究采用了两个版本的预测模型来评估视觉指标。基于对60张现场照片的研究，麦克斯顿平原矮化植被群丛的视觉指标评估结果显示，研究区域在视觉感官上拥有中等水平的吸引力和视觉一致性：由方程（1）计算出的结果在52~58分之间，由方程（2）计算出的结果在47~53分之间。相较于许多其他的景观和土地利用类型，研究区域的环境具有中等水平的视觉偏好。若得分的浮动在平均值的±2.5分区间之外，那么与现状相比，可预测到显著的（ $p \leq 0.05$ ）视觉质量变化。视觉指标系统为矮化植被群丛自身及其周边区域的空间管理提供了一个定量评估框架。研究表明，建筑物、入侵林地、农业用地、铺装等景观元素对视觉质量均具有显著的负面影响（超过±2.5分范围）。

关键词

环境设计；景观设计学；植物生态学；景观评价指标；视觉评估

ABSTRACT

Planners, designers, environmentalists, concerned citizens, and government officials are interested in the management and preservation of small rare and unique ecological environments. Scholars have discovered that land-use and visual quality metrics often co-vary together and that various land-uses reside on a continuum scale from high respondent preference (biospheric land-uses) to low respondent preference (noospheric land-uses). This study assessed and documented the visual metrics for the Maxton Plains alvar/alvar grassland plant communities found on Drummond Island, Michigan, USA. These unique, small, and rare landscape types are not usually studied by large-scale visual quality mapping efforts which assess urban areas, woodlands, water, farmland, pastureland, and prairies. The visual metrics were assessed using two versions of predictive visual quality assessment models. Results from 60 field photographs reveal that the visual metrics assessment for the Maxton Plains alvars/alvar grasslands have a moderate visual preference, consistent visual quality scores: ranging from the low to middle 50s with the first equation and high 40s to low 50s with the second equation. Compared to many landscape and land-uses, these environments have scores that indicate a moderate visual preference and appreciation. Scores beyond ±2.5 of the mean would indicate a significant ($p \leq 0.05$) perceivable drift from the existing conditions. The visual metrics provide a numerical framework for managing the spatial contents within and adjacent to the alvars. Landscape features such as buildings, invasive woodlands, agriculture, and pavement would all decrease the visual quality beyond the ±2.5 score range.

KEYWORDS

Environmental Design; Landscape Architecture; Plant Ecology; Landscape Metrics; Visual Assessment

1 引言与文献综述

在密歇根州这样的景观环境中，遍布着各类独特的小型景观环境和生态系统，它们尚未被纳入粗粒度的景观规划工作中，其中许多也只是使用了典型的植物群落。植物群丛通常被认为是以（相对频度、相对密度和相对显著度等重要值均最高的）优势植物为特征的生态系统，甚至其本身就构成了某种土地利用类型^[1]。矮化植被（alvar）通常形成于薄土层（厚度不足25cm）区域，匍匐在平坦的钙质基岩上，如石灰岩（碳酸钙）或白云岩（碳酸钙镁）^{[2]-[7]}。这类植被也通常依水而生（密歇根流域拥有自寒武—奥陶纪到侏罗纪形成的古老海床，为苏必利尔湖、密歇根湖、休伦湖和伊利湖等淡水湖泊所环绕）；同时面临寒冬、酷夏、洪水、干旱、狂风和偶发性野火等严酷的季节性条件。一般而言，能够适应强碱性稀薄土壤、强烈外界干扰与环境压力的大多为地面芽植物、旱生植物、盐生植物和耐火植物，木本植物（高位芽植物）基本难以在此条件下生存。而矮化植被几乎成为了石灰石采石场的地面^[8]。在这些条件的共同作用下产生了一种独特的植物群落，它们主要分布于全球两大地区——北欧的瑞典、爱沙尼亚、英国和爱尔兰；北美中部的魁北克省、安大略省、马尼托巴省、密歇根州、俄亥俄州和纽约州（包括五大湖地区）^{[9][10]}。在矮化植被群丛附近通常可以发现矮化植被草原，这里土壤深度稍大，主要被禾草状植物所覆盖，与裸露的地面或基质斑块形成了鲜明的对比；同时，也已有地图标注出了矮化植被草原在密歇根州的分布位置^{[11][12]}。在本研究中，“矮化植被群丛”概念涵盖了矮化植被草原。

密歇根州矮化植被包括禾草和藁草类植物，例如小须芒草（*Schizachyrium scoparium*）、草原鼠尾粟（*Sporobolus heterolepis*）和藁草（*Carex scirpoidea*）。在湿度更加适中的地区，可以发现植株更大更扁平的沼泽荸荠（*Eleocharis compressa*）、大须芒草（*Andropogon gerardii*）、垫状乱子草（*Muhlenbergia richardsonis*）和大米草（*Spartina pectinata*）。矮化植被中常见的杂草包括小叶蝶须（*Antennaria neglecta*）、加拿大耬斗菜（*Aquilegia canadensis*）、硬毛南芥（*Arabis pycnocarpa*）、圆叶风铃草（*Campanula rotundifolia*）、火焰草（*Castilleja coccinea*）、卷耳（*Cerastium arvense*）、矮新风轮（*Clinopodium arkansanum*）、杂交柳穿鱼（*Comandra umbellata*）、草原石陵菜（*Drymocallis arguta*）、北美独行菜（*Lepidium virginicum*）、石米努草（*Minuartia michauxii*）、拟美国薄荷（*Monarda fistulosa*）、千里光（*Packera paupercula*）、早花毛茛（*Ranunculus fascicularis*）和老田一枝黄花（*Solidago nemoralis*）。密歇根州矮化植被中常见的灌木包括金露梅（*Dasiphora fruticosa*）、欧洲刺柏（*Juniperus communis*）、紫叶稠李（*Prunus virginiana*）、香盐肤木（*Rhus aromatica*）和白雪果（*Symphoricarpos albus*）。生长于矮化植

1 Introduction and Literature Review

In a landscape setting like Michigan, there are abundant, small, special, and unique landscape environments and ecosystems not indicated by coarse-grained landscape planning efforts, many of which can also be represented by their respective plant communities. Often vegetation associations are identified as an ecosystem characterized by its dominant plants (the most relative frequency, relative density, relative dominance—known as the importance value), and could even be qualified as a land use category^[1]. An alvar forms on a thin (< 25 cm) layer of soil, situated and perched over flat, calcareous bedrock, such as limestone (calcium carbonate) or dolomite (calcium-magnesium carbonate)^{[2]-[7]}. Alvars typically form near water sources (the Michigan Basin, an ancient sea bed formed from the Cambrian-Ordovician times until the Jurassic, now imbedded with freshwater lakes: Superior, Michigan, Huron, and Erie), and experience harsh seasonal conditions, such as cold winters, warm summers, flooding, drought, scouring winds, and occasional fire. Due to the high soil pH, punishing disturbance regime, environmental stresses, and thin soil, very few woody plants (phanerophytes) are able to survive and are more suitable to hemicryptophytes, xerophytes, halophytes, and pyrophytes. Alvars are similar to the floors of limestone quarries^[8]. These conditions create a unique plant community primarily found in only two regions worldwide (northern Europe: Sweden, Estonia, United Kingdom, and Ireland; central North America: Quebec, Ontario, Manitoba, Michigan, Ohio, and New York, including the Great Lakes region)^{[9][10]}. An alvar grassland, usually found next to an alvar is characterized by slightly larger soil depths and predominately graminoid cover as opposed to bare patches of ground or exposed substrate, and has been mapped in Michigan^{[11][12]}. For the purposes of this particular study, the term “alvar” is inclusive of alvar grasslands.

Plants in Michigan alvars include grasses and sedges such as little bluestem [*Schizachyrium scoparium* (Michx.) Nash], prairie dropseed (*Sporobolus heterolepis* A. Gray), and bulrush sedge (*Carex scirpoidea* Michx.). In more mesic-like areas, greater flattened spike-rush (*Eleocharis compressa* Sull.), big bluestem (*Andropogon gerardii* Vitman), mat muhly [*Muhlenbergia richardsonis* (Trin.) Rydb.], and cordgrass [*Spartina pectinata* Bosc ex (Link)] are found. Typical forbs in an alvar include small-leaved pussytoes (*Antennaria neglecta* Greene), wild columbine (*Aquilegia canadensis* L.), hairy rock cress (*Arabis pycnocarpa* M. Hoikins), harebell (*Campanula rotundifolia* L.), Indian paintbrush [*Castilleja coccinea* (L.) Spreng.], field chickweed (*Cerastium arvense* L.), low calamint [*Clinopodium arkansanum* (Nutt.)], bastard toadflax [*Comandra umbellata* (L.L. Nutt.)], prairie cinquefoil [*Drymocallis arguta* (Pursh) Rydb.], common peppergrass (*Lepidium virginicum* L.), rock sandwort [*Minuartia michauxii* (Fenzl)], wild bergamot (*Monarda fistulosa* L.), balsam ragwort [*Packera paupercula* (Michx.) Á. Löve & D. Löve)], early buttercup (*Ranunculus fascicularis* Muhl. ex Bigelow), and old-field goldenrod (*Solidago nemoralis* Aiton 1789). Common shrubs in a Michigan alvar include shrubby cinquefoil [*Dasiphora fruticosa* (L.) Rydb.], common juniper (*Juniperus communis* L.), chokecherry (*Prunus virginiana* L.), fragrant sumac (*Rhus aromatica* L.), and



被边缘的常见树木包括北美香柏 (*Thuja occidentalis*)、白云杉 (*Picea glauca*)、北美乔松 (*Pinus strobus*) 和美洲颤杨 (*Populus tremuloides*)^①。图1展示了位于密歇根州北部的一片矮化植被。

矮化植被群丛等独特自然环境的属性和评价指标是研究人员和学者的重要关注点。自20世纪初以来,景观指标这一通过定量测量环境变量来比较环境构成的评价方法一直备受关注。尤其在矮化植被群丛这类环境中,景观植被指标通常仅限于测量植被物种的情况,包括相对频度、相对密度和相对显著度^{[1][13]}等。乔治·H·博格霍恩等人的研究表明,近年来研究人员已开始使用尤其与可持续性相关的各种指标来评价景观(特别是包括建筑、道路、汽车、公共设施、围墙、围栏和相关干预设施等人造元素的景观)^[14]。利用指标来比较不同设计方案的方法和途径也已成为研究热点^{[15]~[21]}。此外,研究人员借鉴先前植物生态学家所探讨的调查方法,探索了建成环境的分类模式^{[22]~[24]}。美国非营利组织景观设计基金会也一直致力于研究景观指标^[25],其中一个方向即为视觉特性度量。

自20世纪60年代后期埃尔伍德·谢弗发表研究成果以来,其他有关环境视觉空间特性的测量研究也在持续进行^{[26]~[28]}。相关的学术成果不断涌现,其中欧文·H·祖伯等人的论文试图阐释并归纳关于景观感知的各种研究方法^[29]。尽管争论不断,但无可争议的是,受访者更偏爱具有更多自然元素的环境(如植被、天空、水体和地质地貌)。安德鲁·洛锡安归纳总结了许多杰出研究人员在这方面的研究成果^[30],其中的许多研究首先聚焦于受访者对景观类型的偏好,其次是(观察图片的)受访者的健康状况。

来自密歇根州立大学(MSU)的团队曾针对其他形式的视觉传达媒介展开研究。其中大多数早期受访者的反馈均通过观察照片或视频获得。采取这类方式主要是因为若以画作为观察对象,受访者会更倾向于评价画作的质量,而非其所表现的景观内容。随着数字显影和各类表现方式的不断发展,研究人员担心数字图像可能会产生与画作相类似的反馈。但肖恩·帕廷等人的研究发现,数字影像与照片能够实现共变(即彼此相关性较强)^[31]。了解这一点对设计人员而言十分必要,因为这意味着通过数字图像来评价某一设计作品的市民所给予的是有关设计质量的反馈。另一项针对山脚下山地环境和城市景观的研究表明,如果城市范围内所有位置都能看到山景(即使是有限的景象),那么将有效改善

snowberry [*Symphoricarpos albus* (L.) S. F. Blake 1914]. Trees commonly occurring along the edges of the alvar include northern white-cedar (*Thuja occidentalis* L.), white spruce [*Picea glauca* (Moench) Voss], white pine (*Pinus strobus* L.), and quaking aspen (*Populus tremuloides* Michx.). Figure 1 illustrates an alvar from northern Michigan.

Investigators and scholars are interested in the properties and metrics of these unique special environments, such as within alvars. Landscape metrics, the empirical measurement of environmental variables to compare settings has been of great interest since primarily the beginning of the twentieth century. In particular, landscape vegetation metrics for such settings has been typically restricted to a measure of vegetation species such as relative frequency, relative density, and relative dominance^{[1][13]}. More recently, landscapes, especially those containing human artifacts and features such as building, roads, automobiles, utility structures, walls, fences, and related interventions have been assessed with a wide variety of metrics, especially related to sustainability, as reviewed recently by George H. Berghorn et al.^[14]. Methods and approaches to comparing the results of various design alternatives through the metrics have also been recently discussed^{[15]~[21]}. In addition, investigators have explored ordinations of built environments in the same manner that was earlier investigated by plant ecologists^{[22]~[24]}. The American non-profit organization Landscape Architecture Foundation has been deeply engaged in this quest concerning landscape metrics^[25]. This quest includes measuring visual properties.

The quest to measure visual spatial properties of environments has been in full earnest since the works of Elwood Shafer in the late 1960s^{[26]~[28]}. The literature quickly expanded, with a paper by Ervin H. Zube et al. attempting to explain and identify the various versions of research approaches on the topic of landscape perception^[29]. There was much debate and discussion. Overwhelmingly, it was noted that respondents preferred green environments (vegetation, sky, water, and geological formations). Many stellar researchers have contributed to this body of literature, being recently compiled and reviewed by Andrew Lothian^[30]. Much of the literature focuses upon respondent preference for landscape types and then the health of the respondents to images.

A team from Michigan State University (MSU) have focused upon other types of visual applications. Most of the early respondent efforts were based upon photographs or videos. It was found that drawings could not be used as the respondents evaluated the drawing for the quality of the drawings, not the contents of the landscape. With the advancement of digital visualization and representation methods, there was concern that digital images may generate the same type of response as drawings. However, Shawn Partin et al. discovered that digital visualizations co-vary (they correlated well together) with photographic images^[31]. This was helpful to know because it meant that practitioners who generated digital representations and had citizens viewing their works were obtaining responses

① 由于缺少官方物种名称,本段部分植物的中文译名为非正式版本。

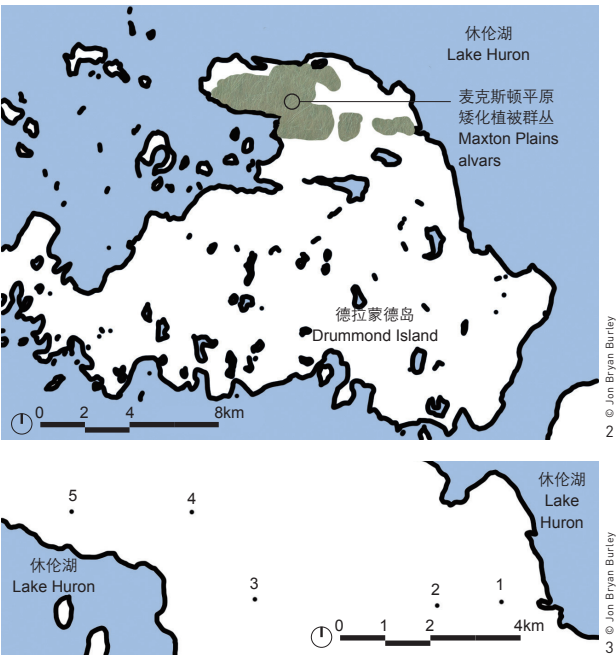
对城市环境的视觉感知^[32]。还有研究调查了人们从火车上观看视觉图像来识别到达站点的情况，结果表明受访者需要具有视觉冲击力且内容丰富的图像来确认沿途的位置^[18]。团队在此研究的基础上生成了一个根据土地利用 / 覆盖情况进行统计验证，进而生成视觉质量土地利用图的方案^{[33]-[35]}。但这种基于粗粒度网格单元的地图不会呈现诸如矮化植被之类的特殊环境，或此类特殊环境可能被广义地归类为草地 / 荒地。在州级地图中，矮化植被可能仅由几个网格单元组成，因此不值得被单独分类。这是一个有待改进的问题，因为面积较小、独具特色的生态环境经常被忽视或遗忘。在密歇根州的地图中，如果一个网格单元占地1km²，同时假设密歇根州矮化植被的总占地面积为15km²，则矮化植被可能仅占密歇根州总土地面积（253 800km²）的0.0059%——由于密歇根州矮化植被的总面积尚未可知，该百分比仅为估计值。

在本文所呈现的研究中，MSU团队希望量化密歇根州德拉蒙德岛矮化植被的视觉指标。研究的目标并非对景观之美或受访者的偏好进行量化，而是测量人们对矮化植被的感知程度，进而利用量化的标准和视觉边界来定义矮化植被。本研究的创新之处在于对特定环境的具体指标进行量化，而非开发通用而宽泛的景观偏好模型。上述视觉指标可以帮助规划师、设计师和环保人士更好地管理景观。

2 研究区域和方法

2.1 研究区域概况

德拉蒙德岛位于密歇根州上半岛以东的休伦湖上，毗邻美国和加拿大边界，与安大略省相邻（图2，3）。麦克斯顿平原位于该岛北部，大自然保护协会对其拥有地役权。麦克斯顿平原由面积达4.8km²、散布着北方那样的林地、灌木地、矮化植被群丛和矮化植被草原，可通过汽车、自行车或步行等方式到访^[36]。



focused upon the quality of the design. Another study addressing a mountainous environment and the urban landscape at the foot of the mountain revealed the visual impact of allowing all viewsheds in the urban area to have a view of the mountains, even a limited view^[32]. One more study examined the arrival cognition with visual images when viewing from a train, suggesting that very blatant and abundant imaging was necessary to confirm location along the route^[18]. The team also derived a solution to develop visual quality land-use maps that are statistically validated based upon land-use/cover^{[33]-[35]}. However, special environments such as alvars would not be presented upon such maps derived from coarsely grained grid cells, or may be broadly classified as undifferentiated grassland/forblands. At the state level, alvars may be comprised of only a few grid cells and not worth classifying. This is a problem because small, unique, and special ecological environments is often overlooked or forgotten. In Michigan, if the grid cells are 1 square kilometer, and suppose the total area of all alvars in Michigan comprise a total of 15 square kilometers, an alvar may only be about 0.0059% of the total land area of Michigan (253,800 square kilometers). This is just an estimate of the percentage, because the total extent of alvars in Michigan at a fine resolution has not been determined.

In this study, the MSU team desired to quantify the visual metrics of alvars on Drummond Island, Michigan. The goal was not to quantify the beauty or preference, but rather to measure the perception score for the alvar, giving a numerical standard and numerical visual boundaries that define an alvar. What is new is that the specific metrics of particular environments are being quantified, as opposed to developing general, broad models of landscape preference. The visual metrics can assist planners, designers, and conservationists in the management of the landscape.

2 Study Area and Methodology

2.1 Study Area

Drummond Island is situated east of the state's Upper Peninsula, near the Canadian-American international border, next to the province of Ontario, on Lake Huron (Fig. 2, 3). The northern part of the island is the location of the Maxton Plains, a part of a land holding by The Nature Conservancy. Maxton Plains is composed of up to 4.8 square kilometers of loosely distributed boreal-like woodlands, shrublands, alvar and alvar grassland, which is accessible by car, bicycle, or on foot^[36].

1. 2015年研究区域内的密歇根州矮化植被群丛，背景中的树木生长于更深的土壤中。
2. 德拉蒙德岛麦克斯顿平原（矮化植被群丛）主要分布的位置（2021年绘制）
3. 德拉蒙德岛麦克斯顿平原（矮化植被群丛）中5个图像采集区的位置（2021年绘制）

1. A photograph of a Michigan alvar within the study area in 2015. The trees in the background were on deeper soils.
2. The general location of the Maxton Plains alvars on Drummond Island (2021)
3. The location map of the five study areas for gathering images within the Maxton Plains alvars on Drummond Island (2021)

2.2 研究方法

2015年夏季，研究人员从31个取样点（摄影师站立的地方）采集了60张照片用于研究。这些照片可在详细介绍本研究的文档附录B中获取^[37]。这些取样点主要分布在5个区域（图3），每个区域由一片独立且连续的矮化植被群丛或矮化植被草原组成。

研究通过如下两种不同的方程——方程（1）和方程（2）对图像进行评估^{[38][39]}：

$$Y1 = 68.30 - (1.878 \times HEALTH) - (0.131 \times X1) - (0.064 \times X6) + (0.020 \times X9) + (0.036 \times X10) + (0.129 \times X15) - (0.129 \times X19) - (0.006 \times X32) + (0.00003 \times X34) + (0.032 \times X52) + (0.008 \times X1 \times X1) + (0.00006 \times X6 \times X6) - (0.0003 \times X15 \times X15) + (0.0002 \times X19 \times X19) - (0.0009 \times X2 \times X14) - (0.00003 \times X52 \times X52) - (0.0000001 \times X52 \times X34) \tag{1}$$

$$Y2 = 58.98827 + (0.07725 \times V2) + (0.03775 \times V10) - (1.18505 \times CVQ) - (0.01074 \times V32) + (0.01161 \times V52) - (0.00181 \times V1 \times V2) - (0.00026 \times V1 \times V5) + (0.00134 \times V1 \times V10) - (0.00071 \times V2 \times V14) + (0.00018 \times V5 \times V9) - (0.00092 \times V7 \times V18) + (0.00025 \times V8 \times V14) + (0.00425 \times V8 \times V15) + (0.00023 \times V15 \times V18) - (0.00012 \times V2 \times V32) + (0.000000613388 \times V6 \times V34) - (0.000000783802 \times V8 \times V34) + (0.00117 \times V11 \times V52) \tag{2}$$

尽管有其他较多方程可供选择，但研究团队认为以上两个方程之间可能存在相似性。表1和表2罗列了两个方程中的变量^[37]。由于以往基于景观美学变量建立的方程存在缺陷（仅可获得最多约65%的方差解释率），MSU社会科学学院的一名景观研究员进一步研究建立了上述方程。自此，包括MSU团队在内的不同研究团队开始探索具有生态、经济、功能（服务于某种目的的建成环境）价值的变量，以及图像自身的文化和美学价值^{[40][41]}。MSU研究团队提议让受访者评估一些与产生于后现代主义 / 语境的敏感性设计具有相似价值观的图像^[42]。基于这些变量建立的一些方程可以获得90%以上的受访者（来自美国、加拿大、葡萄牙和法国）方差解释率。这些方程还被用于评估设计方案间的差异和景观管理^[43]。一篇题为《绿色植被和开花植物确实有所作为：量化视觉质量》的论文总结了上述研究背后的理论和基本发现^[44]。尽管新建立的这些方程主要根据受访者对景观图像的偏好来评估视觉 / 环境质量，但

2.2 Methodology

A collection of 60 photographs, gathered from 31 sample points (places where the photographer stood), were collected for study in the summer of 2015. Images can be found in Appendix B of a document detailing the study^[37]. These points are spread over five general locations (Fig. 3), each location consisting of a single, contiguous alvar or alvar grassland.

The images were evaluated by two different equations—Equation (1) and Equation (2)^{[38][39]}:

$$Y1 = 68.30 - (1.878 \times HEALTH) - (0.131 \times X1) - (0.064 \times X6) + (0.020 \times X9) + (0.036 \times X10) + (0.129 \times X15) - (0.129 \times X19) - (0.006 \times X32) + (0.00003 \times X34) + (0.032 \times X52) + (0.008 \times X1 \times X1) + (0.00006 \times X6 \times X6) - (0.0003 \times X15 \times X15) + (0.0002 \times X19 \times X19) - (0.0009 \times X2 \times X14) - (0.00003 \times X52 \times X52) - (0.0000001 \times X52 \times X34) \tag{1}$$

$$Y2 = 58.98827 + (0.07725 \times V2) + (0.03775 \times V10) - (1.18505 \times CVQ) - (0.01074 \times V32) + (0.01161 \times V52) - (0.00181 \times V1 \times V2) - (0.00026 \times V1 \times V5) + (0.00134 \times V1 \times V10) - (0.00071 \times V2 \times V14) + (0.00018 \times V5 \times V9) - (0.00092 \times V7 \times V18) + (0.00025 \times V8 \times V14) + (0.00425 \times V8 \times V15) + (0.00023 \times V15 \times V18) - (0.00012 \times V2 \times V32) + (0.000000613388 \times V6 \times V34) - (0.000000783802 \times V8 \times V34) + (0.00117 \times V11 \times V52) \tag{2}$$

There are potentially many equations one could choose, but the study team was interested in how similar these two equations might be to each other. Table 1 and Table 2 describe the variables from these equations^[37]. The equations were developed by a landscape researcher in the College of Social Science, MSU at a time when past equations reached an impasse that they were primarily developed based upon landscape aesthetics variables, being able to explain up to only about 65% of the variance. In this case, researchers such as the team at MSU began to explore variables that were ecological, economic, functional (built environments that serve a purpose), and cultural aspects of images, as well as aesthetic^{[40][41]}. The MSU team suggested that respondents assess images similar to the values imbedded within post-modernism/context sensitive design^[42]. Some of these equations could explain over 90% of respondent (Americans, Canadians, Portuguese, and French) variances. The equations were also employed to assess differences in design proposals and for landscape management^[43]. A paper titled “Green vegetation and flowering plants do make a difference: Quantifying visual quality” describe the theory and essential findings behind these studies^[44]. The equations measure visual/environmental quality upon the preference for the landscape image as perceived by the respondents. In the development of the equations, the respondents were not told that the study is to measure visual/environmental quality, but instead to rate the images based upon their opinion from the most preferred image to the least preferred image. Three theories evolved in the study: 1) respondents preferred special unique temporal elements in the landscape such as wildlife, views of mountains, and foreground flowers; 2) respondents were neutral in their preference for the common features of natural

在实际操作过程中，受访者并未被告知该研究的实际目的，他们仅需要根据自己的喜爱程度对图片进行排序。研究得出了三个结论：1）受访者更喜欢景观中独特的、临时性元素，如野生动物、山景和前景花卉；2）受访者对天空、水体、植被等常见的自然元素无明显偏好；3）受访者不喜欢人造元素的干扰，包括建筑物（即使是弗兰克·劳埃德·赖特所设计的标志性建筑“流水别墅”——实际上，图片中的建筑物越少，图像越受欢迎）、道路、汽车、人、公共设施和工厂。这些结论与许多关于视觉质量的研究结果一致，其中包括雷切尔·卡普兰和已故的斯蒂芬·卡普兰对此领域影响深远的研究，以及他们的学生威廉·C·苏利文的相关研究（苏利文此后转向研究景观和人类健康的关系）^{[45]-[47]}。

方程（1）和方程（2）由可获得最大方差解释率的变量组合而成。在这两个方程中，所有变量都是显著（ $p \leq 0.05$ ）且明确的（ $p \leq 0.001$ ）。近年来，相关研究人员通过将斯迈瑟指数中的每个变量作为主效应项、平方项和一阶交互项建立了其他的方程，能够获得超过

landscape elements such as sky, water, and vegetation; and 3) respondents did not prefer intrusions of human artifacts such as buildings (even great architecture such as Falling Water, an iconic building of architectural design by Frank Lloyd Wright—the less of the building in the picture, the more the image was preferred), roads, automobiles, people, utility structures, and industry. These findings are consistent with many studies on visual quality, especially the formative work of Rachel Kaplan and the late Stephen Kaplan, as well as the work of their former graduate student William C. Sullivan who has since gone on to study landscape and human health^{[45]-[47]}.

The equations represent the combination of variables that explain the most variance. When developed all of the variables in the equations were significant ($p \leq 0.05$) and were definitive ($p \leq 0.001$). Recently other equations were developed exploring each variable in the Smyser Index as main effect terms, squared terms, and first order interaction terms, resulting in over 90% of the

表1：方程（1）和方程（2）中的变量
Table 1: The listed variables in Equation (1) and Equation (2)

方程（1） Equation (1)	方程（2） Equation (2)	变量 Variable	方程（1） Equation (1)	方程（2） Equation (2)	变量 Variable
Y1	Y2	预估的视觉得分 Predicted visual score	X15	V15	公共设施面积 Area of utilities
HEALTH	CVQ	景观健康指数（见表2） Landscape health index [in Table 2]	X16	V16	船只面积 Area of boats
X1	V1	直接植被周长 Perimeter of immediate vegetation	X17	V17	枯萎前景植被面积 Area of dead foreground vegetation
X2	V2	中间非植被元素周长 Perimeter of intermediate non-vegetation		V18	前景中裸露基质面积 Area of exposed foreground substrate
X3	V3	远处植被周长 Perimeter of distant vegetation	X19		野生动物面积 Area of wildlife
X4	V4	中间植被面积 Area of intermediate vegetation	X30	V30	方程（1）中的开放式景观：X2 + X4 + [2 × {X3 + X6}]; 方程（2）中的开放式景观：V2 + V4 + [2 × {V3 + V6}] Open landscapes in Equation (1): X2 + X4 + [2 × {X3 + X6}] Open landscapes in Equation (2): V2 + V4 + [2 × {V3 + V6}]
	V5	水体面积 Area of any kind of water			
X6	V6	远处非植被元素面积 Area of distant non-vegetation	X31	V31	方程（1）中的封闭式景观：X2 + X4 + [2 × {X1 + X17}]; 方程（2）中的封闭式景观：V2 + V4 + [2 × {V1 + V17}] Closed landscapes in Equation (1): X2 + X4 + [2 × {X1 + X17}] Closed landscapes in Equation (2): V2 + V4 + [2 × {V1 + V17}]
X7	V7	铺装面积 Area of pavement			
X8	V8	建筑面积 Area of buildings	X32	V32	方程（1）中的开放度：X30 – X31; 方程（2）中的开放度：V30 – V31 Openness in Equation (1): X30 – X31; Openness in Equation (2): V30 – V31
X9	V9	机动车面积 Area of vehicles			
X10	V10	人群面积 Area of humans	X34	V34	方程（1）中的新奇度：X30 × X1 × X7 / 1140; 方程（2）中的新奇度：V30 × V1 × V7 / 1140 Mystery in Equation (1): X30 × X1 × X7 / 1140; Mystery in Equation (2): V30 × V1 × V7 / 1140
	V11	烟雾面积 Area of smoke			
X14	V14	前景中的野花面积 Area of wildflowers in the foreground	X52	V52	方程（1）中的人造元素：X7 + X8 + X9 + X15 + X16 方程（1）中的人造元素：V7 + V8 + V9 + V15 + V16 Noosphericness in Equation (1): X7 + X8 + X9 + X15 + X16; Noosphericness in Equation (2): V7 + V8 + V9 + V15 + V16

表2：景观健康指数
Table 2: The HEALTH Index

变量 Variable	定义 Definition	得分 Score	变量 Variable	定义 Definition	得分 Score
A	净化空气 Purifies air	+1, 0, -1	K	防止水土流失 Prevents soil erosion	+1, 0, -1
B	净化水体 Purifies water	+1, 0, -1	L	提供荫蔽 Provides shade	+1, 0, -1
C	积累土壤资源 Builds soil resources	+1, 0, -1	M	提供宜人气味 Presents pleasant smells	+1, 0, -1
D	促进人类文化多样性 Promotes human cultural diversity	+1, 0, -1	N	提供宜人声音 Presents pleasant sounds	+1, 0, -1
E	保护自然资源 Preserves natural resources	+1, 0, -1	O	不加剧全球变暖 Does not contribute to global warming	+1, 0, -1
F	减少使用化石燃料 Limits use of fossil fuels	+1, 0, -1	P	促进世界经济发展 Contributes to the world economy	+1, 0, -1
G	使放射性污染降到最低 Minimizes radioactive contamination	+1, 0, -1	Q	有助于回收利用 Accommodates recycling	+1, 0, -1
H	促进生物多样性 Promotes biological diversity	+1, 0, -1	R	有助于多用途使用 Accommodates multiple use	+1, 0, -1
I	提供食物 Provides food	+1, 0, -1	S	有助于低维护 Accommodates low maintenance	+1, 0, -1
J	改善风况 Ameliorates wind	+1, 0, -1	T	视觉效果良好 Visually pleasing	+1, 0, -1

注
该指数取自斯迈瑟指数，并由乔恩·布莱恩·伯利和帕特里夏·马赫默进行详细注解（参见参考文献[42][48]）。得分总和将应用于方程（1）和方程（2）中。

NOTE
The index was adopted from the Smyser Index and explained in detail by Jon Bryan Burley and Patricia Machemer [Source: Refs. [42][48]]. The sum of the scores represents the value to be used in Equation (1) and Equation (2).

90%的受访者方差解释率^{[41][49]}。使用既有方程的好处在于研究人员可直接通过该方程求得受访者的偏好，而无需在每项研究中建立新的方程，由此可以专注于研究和解释图像。与谢弗提出的方程一样，上述两个方程的结果中，20 ~ 30分（低分）表示强烈偏好；50 ~ 70分表示中度偏好，80 ~ 110分表示低度偏好。本研究也采用了与谢弗采用的网格法相似的方法对图像进行评分^[26]。

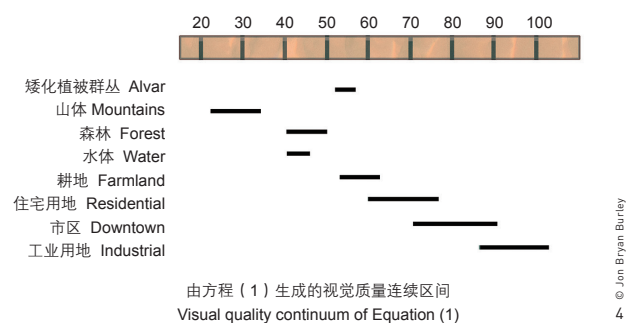
当完成了对所有图像的评分，就可以计算不同组图像的平均得分及方差。若某组图像的得分集中于一个较窄范围（±5分）内，则可能表明该生态系统所涵盖的视觉质量指标较为单一且相当一致；若组内得分差异稍大（±20分），则可能表明该生态系统包含更丰富的指标；更大的得分差异（±40分）可能意味着生态系统所包含的指标定义不明确且内容灵活。此类评估的结果通常简洁易懂。

本研究中应用的两个方程相关性较强^{[38][39]}。得分20 ~ 30分的图像大多包含山脉、野花和野生动物；得分30 ~ 40分的图像通常是热带草原般的荒野；得分40 ~ 50分的图像为水景和林地；而农田和草原的得分一般为50 ~ 60分；住宅环境得分为60 ~ 70分；高度城市化的环境得分为80 ~ 90分；最后，工业环境的得分在90分以上。由此可以明确，这两个方程可以根据视觉偏好在连续区间内对环境进行划分。研究团队期望探究矮化植被群丛在这一连续区间中的位置。

variance explained^{[41][49]}. The benefit of employing an equation is that the respondent preference for a study has already been achieved (meaning one does not have to first develop an equation to do the study) and instead one can focus upon studying and interpreting images. Like Shafer’s equation, low scores (20 ~ 30) indicate strong preference; while scores ranging from 50 to 70 indicate moderate preference and scores ranging from 80 to 110 indicate low preference. The images in the study were scored with a grid similar to Shafer^[26].

Once the images were scored, the average score for a set of images could be computed along with the variance. Scores within a tight range (± 5) might suggest that the visual quality metric for the ecosystem is narrow and fairly uniform. Scores that have larger ranges (± 20) might suggest that the ecosystem contains a wider metric. Highly variable scores (± 40) might suggest that the metric for the ecosystem may be only weakly defined and flexible in content. The results for such evaluations are simple and short.

Both equations co-vary together^{[38][39]}. Scores in the 20s are comprised of mountains, wildflowers, and wildlife. Scores in the 30s are often savanna-like wilderness. Scores in the 40s are water scenes and forested lands; while, agricultural lands and often grasslands score in the 50s. Residential environments score in the 60s. Usually, highly urbanized environments score in the 80s. Finally, industrial settings score in the 90s or higher. It is clear that the equations can discriminate



4. 根据方程（1），矮化植被群丛的得分在视觉质量连续区间中的位置。
4. Location of the alvar in relation to the visual quality continuum based upon Equation [1]

3 结果

由方程（1）得出的一组得分为52.70~57.17分（以下称为“组1”）；由方程（2）得出的一组得分为47.12~52.67分（以下称为“组2”）。两组结果表明所研究的矮化植被群丛具有相当稳定的视觉质量指标。完整的得分列表和图像集可在艾米丽·艾夫斯（普瑞斯康）的论文中查阅^[37]。图4展示了矮化植被群丛的得分在视觉质量偏好连续区间中的位置。

4 讨论与总结

4.1 讨论

总体而言，上述结果符合研究的预期。麦克斯顿草原矮化植被产生了两组较低且较一致的得分，与预期的视觉质量和一致性相吻合。尽管组1和组2的结果在数值上比较接近，但两个方程之间确实存在差异，进一步的有效对比可能有助于深入了解每个方程。

本研究的结果来自于对以往一些视觉质量研究中关键理念的应用。这些重要理念有助于对视觉质量数据进行调查、阐释和评估。其中最显著的一个理念是，视觉质量的得分与相应数值所代表的景观偏好水平负相关^[44]。此外，由乔恩·布莱恩·伯利构建的规范理论也对本文有较高的参考价值，它们解释了为什么特定景观会产生特定区间的得分^[38]。首先是“生物圈偏好理论”，它表明受访者倾向于偏好自然的、非人造的景观，其中包括植被、水体和天空等常见空间元素，这类景观通常位于中低得分区间（中度偏好）；其次，人造的、非生物圈的，或受到人类干扰的元素，如铺装、汽车、围墙、烟雾、船只、围栏或其他人等，往往会降低视觉质量偏好并产生更高的分数；最后，人们希望看到的临时自然元素（视觉增强元素）——如前景中的野花和种植的花卉，或野生动物（甚至家畜）——均可提高视觉质量并产生较低的分^[38]。根据定义，矮化植被群丛几乎不包含易降低期视觉质量偏好的人造元素（全部属于生物圈），并且可能存在野花或野生动物等（视觉增强）元素。因此，矮化植被群丛预计会获得中低分和高视觉质量偏好水平，这与两组结果是一致的。

amongst environments along a continuum concerning visual preference. The study team was interested in where alvars resided in this continuum.

3 Results

Equation (1) produced a set of scores (hereafter referred to as Set 1) ranging from 52.70 to 57.17. Equation (2) produced a set of scores (hereafter referred to as Set 2) ranging from 47.12 to 52.67. The results from both sets suggest that the alvar studied contained a visual quality metric that is fairly stable. The complete list of scores and the set of images are available for examination in Emily Ives (Prieskorn)’s thesis^[37]. Figure 4 illustrates where the alvar scores are situated along the visual quality preference continuum.

4 Discussion and Conclusion

4.1 Discussion

Overall, the results conform to the expectations of the study. The Maxton Plains alvars produced two sets of low, consistent scores that reflect the anticipated levels of visual quality and uniformity. While the score sets are somewhat numerically close, there are indeed differences between the two equations that allow for potentially a meaningful comparison and may offer insight into each equation.

The results of this study are derived from the application of key concepts and ideas imbedded in some previous visual quality investigations. These concepts are particularly important and helpful for the examination, interpretation, and assessment of visual quality data. The first and most salient concept is that visual quality scores are numerically inversely related to the level of landscape preference they represent^[44]. It is also useful to consider the normative theories constructed by Jon Bryan Burley, offering insights into why certain landscapes produce certain types of scores^[38]. The first theory is the “biospheric preference theory,” which suggests that respondents tend to prefer nature, nonhuman landscapes that include common spatial elements such as vegetation, water, and sky. These types of landscapes produce mid-to-low scores (moderate preference). Conversely, human or built (noospheric) elements (human intrusions upon one another), such as pavement, automobiles, walls, smoke, boats, fences, or other people, tend to lower visual quality preference and produce higher numerical scores. Finally, desired temporary natural elements (visual enhancements), such as foreground wildflowers and planted flowers, or wildlife (even domestic animals), raise visual quality and produce numerical lower scores^[38]. By definition, alvars contain almost no noospheric elements (all biospheric) to lower their visual quality preference, and may even contain quality boosters in the form of wildflowers or wildlife (enhancements). Therefore, an alvar would be expected to produce neutral to low scores and high visual quality preference, which is in congruence with both sets of results.

组1和组2中的得分较为相近，这表明视觉上统一的植物群落结构和组成具有高度的视觉一致性。陆迪（音译）等人的研究也曾得出类似的结论：景观类型 / 土地利用类型可以用来预测视觉质量偏好，因此是一种较为合理的绘制视觉质量地图的方法^[35]。

对比组1和组2可知，由开发较早的方程（1）求得的组1分数更低、更一致，但方程获得的方差解释率较低。组2中的分数更高，且结果来源于预测效果更好的新版本方程。

上述结果表明，相较于方程（1），方程（2）对视觉刺激的变化更加敏感，这是由其更好的预测效果所决定的。通过对比两个方程可以更深入地了解这一差异产生的原因。尽管二者均从相同的测定变量列表中选择潜在被测变量，但并非所有变量在两个方程中都发挥同样的功能。例如，变量V2（中间非植被元素周长）在方程（2）中所占比重较大——一次作为单独变量，三次作为更大变量项的组成部分。但这一变量在方程（1）中仅出现一次，并与变量X14（前景中的野花面积）相乘作为一个变量项，而X14通常取值为0。从本研究所选取的60张图像来看，只有一张图像的两个变量均为非零整数。因此，变量V2数值的改变只可能对这张图像基于方程（2）的得分产生显著影响，而在方程（1）中几乎无影响。

本研究探究了以往研究中较少涉猎的矮化植被群丛这一景观类型的视觉质量属性，极大拓展了研究的范围，研究结果或有助于建立相关知识库、理解视觉质量偏好和制图研究。虽然粗粒度的土地利用分类制图研究远达不到本研究所关注的植物群落这样精细的尺度，但研究成果尚具有参考价值。鲁亚·耶尔马兹等人研究发现，土地利用高度人工化景观的预期平均分（工业用地90.9分、市区81.6分、住宅用地63.1分、耕地55.9分）要远高于更自然的景观（森林42.7分、水体45.0分）^[34]。事实上，与耶尔马兹等人先前在本区域制图研究中所获得的数据相比，麦克斯顿平原矮化植被群丛获得的分数略高于森林和水体，但低于耕地环境^[34]。不同研究的精细程度与尺度各有差异；相应地，自然景观与人造景观的视觉质量偏好得分也会有所区别，但本研究表明，针对小型独具特色的景观类型进行持续评估是有意义的。

以上方程均基于西方（如美国、加拿大、葡萄牙和法国）受访者的偏好建立。而莫非等人在针对亚洲（中国）受访者偏好的研究中发现，亚洲受访者的视觉偏好情况与西方受访者并不完全一致^[50]。因此，本研究中获得的分数和相关的定量评价结果可能难以代表亚洲受访者的偏好。

40余年前，杰伊·阿普尔顿提出了与“瞭望”和“庇护”相关的理论，该理论认为这是人类更加青睐的生活场景^{[51][52]}。在这类环境中，人们既可以得到庇护，又可以观察外部环境（瞭望）。阿尔普顿的理论也同样可在矮化植被群丛这类与稀树草原相似的环境中（图5）得到了证明——人们更喜欢可远眺并提供了一定庇护的景观。这在某种程度上与稀树草原假说的观点相呼应，也就是说人类更喜欢类似稀树草原的环境^[53]。

为了直观地管理这些颇具价值的环境，可将方程与数字模拟技术相结合来评估矮化植被群丛周边的视觉变化情况，这一方法由伯利在一项评估露天矿山现状的研究中提出^[43]。在讨论矮化植被群丛时，此方法可用于管理这类珍贵的自然景观。此外，监测矮化植被的视觉质量变化 /

Both score sets also have somewhat similar scores, which indicate the high levels of visual consistency that are expected in a visually unified/uniformed plant community structure and composition. This agrees the findings of Lu Di et al. concluding that landscape type/land-use is predictor of visual quality preference, and therefore a somewhat appropriate approach to develop visual quality maps^[35].

A comparison of the score sets to one another reveals that Set 1's scores are lower and more consistent than Set 2's, and were produced by an older equation that explains less of the variance. Set 2's scores are higher and were derived from a newer, more predictive version of Equation (1).

These results suggest that Equation (2) is more sensitive to variation in visual stimuli than Equation (1), a necessary result of its higher predictive ability. Comparing the equations yields insight into where that variation may originate. Both equations draw potential regressors from the same list of measured variables, but not all of the variables reside in both equations. For instance, Equation (2) relies heavily on the variable V2 (perimeter of intermediate non-vegetation), which appeared once by itself and three times as part of a larger term. However, this variable only was represented once in Equation (1), and is multiplied by X14 (area of wildflowers in foreground), a variable that is frequently 0. To understand the difference, from the 60 images in the study, only one image has non-zero integers for both variables. Thus altering this value would only have a significant effect on Equation (2) for only one image and, have no effect on Equation (1).

The findings of this study may contribute to the knowledge base and understanding of visual quality preferences and mapping investigations by assessing the visual quality properties of a previously undocumented landscape type that resides outside the purview of previous research. While coarse land-use classifications mapping studies are far less detailed than the plant communities this study focused upon, the investigation provide some context. Rüya Yilmaz et al. discovered that the expected average scores of highly noospheric land-uses were numerically much higher (90.9 Industrial, 81.6 Downtown, 63.1 Residential, and 55.9 Farmland) than the expected average scores for more biospheric landscape types (42.7 Forested, 45.0 Water)^[34]. The Maxton Plains alvars had lower scores than any of these land use categories, meaning that these alvars had higher visual quality than any biospheric environments. In fact, the Maxton Plains alvars generated slightly higher scores than forested and water environments, but lower than farmland environment found in the map of the area validated by Yilmaz et al.^[34]. The difference in scores for landscape types from biospheric to noospheric across the continuum are not surprising when the effects of grain and scale for each investigation are considered, but it does imply that there is value in the continued assessment of smaller, special, unique landscape types.

The equations are based upon Western preferences (Americans, Canadians, Portuguese, and French). However, in a study by Mo Fei et al. of Asian preferences (Chinese), it was discovered that their preferences did not completely co-vary with Western preferences^[50]. Therefore, the scores and numerical results produced in the study may not represent Asian values.

Over 40 years ago, Jay Appleton proposed his theory concerning prospect and



5. 在2015年矮化植被群丛研究中使用的图像。中景中的木本植物有助于明确矮化植被群丛类似于稀树草原的特征。

5. An image from the study of the alvar in 2015. The woody plants in the mid-ground help define a savanna-like character of the alvar.

迁移也可能影响景观管理相关决策。例如，2008年，李恩贞（音译）与伯利的一项研究探索了如何利用指标体系来对比环境随时间而发生的视觉变化^[54]。

4.2 总结

本研究所得出的量化视觉质量结果或可为密歇根州矮化植被群丛及其他特殊生态系统和环境的涵养和保护工作提供参考。麦克斯顿平原矮化植被群丛具有较高的视觉质量，部分原因在于当身处穿过研究场地的中心道路进行观察时，较少受到人造元素（建筑物、道路、公共设施、围墙等）和自然元素（林地）的干扰。有效保护这些景色对于维护矮化植被群丛的高水平视觉质量至关重要。同时，了解这类空间的构成也将有助于制定矮化植被群丛的保护方案。上述观点和方法对于其他珍贵且独特植物群落的工作也可能具有重要价值。本文所采用的评价指标体系能够反映生态系统的属性，其原理类似于利用植被频度、密度和显著度对环境进行评估。但这并不意味着需要通过定量的方法来管理景观，这些指标只是帮助了解特定类型环境空间属性的一个途径。

本研究总结了可供探究的视觉质量指标的不同类型。以往的研究大多侧重于对偏好进行探索，而较少通过量化对特定生态系统的感知，为特定的景观环境建立一个量化的视觉质量范围。测量和量化视觉指标为研究人员研究全球范围内常见景观及特殊景观的空间特性提供了新的机遇。LAF

refuge, where he maintained, it was a preferred environmental setting for humans^{[51][52]}. This is an environment where one could be sheltered (refuge), but observe beyond (prospect). Savanna-like settings such as those experienced at the alvar (Fig. 5) would support Appleton's theory that people prefer landscapes with some prospect and offer some refuge. This is somewhat affiliated with the savanna hypothesis, where humans prefer savanna-like environments^[53].

To manage these valued environments visually, the equations can be utilized to assess visual changes adjacent to the alvars with digital simulations, a methodology proposed by Burley when he evaluated a surface mine condition^[43]. But in the case for an alvar it would be for the management of a valued natural landscape. In addition, the visual quality of the alvar can be monitored for visual change/drift which may also influence landscape management decisions. For example, back in 2008, Eun Jeng Lee and Burley illustrated how environments over time can be compared metrically to assess visual change^[54].

4.2 Conclusion

These numerical visual quality discoveries may also be of special interest to the conservation and protection efforts that preserve Michigan's alvars and for potentially many other types of special ecosystems and environments. The high visual quality of the Maxton Plains alvars is due in part to its lack of noospheric elements (buildings, roads, utility structures, fences...) and lack of woodland biospheric elements when viewed from the central road traversing the site. The preservation and protection of those views is essential to the maintenance of the alvar's high numerical visual quality. Understanding this spatial composition may help conservation and protection efforts planned to retain alvars. This insight and methodology may have great value for conservation efforts taking place in other valued and unique plant communities as well. The metrics act as a guideline giving feedback concerning the properties of the ecosystem, just as vegetation frequency, density, and dominance give an assessment of the environment. This does not mean that landscapes should be management by numbers, but rather, the metrics give insight into the spatial properties of a specific type of setting.

The study presents a variation in the types of visual quality metrics that can be investigated. Most studies focus upon preference, as opposed to quantifying perception of specific ecosystems as a means of establishing the numerical visual quality limits for a specific landscape setting. Measuring and quantifying the visual metrics provides new opportunities for investigators to study the spatial properties of both prevalent and special landscapes across the globe. LAF

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