Learning to Live in Dynamic Dunes

Citizen Science and Participatory Modeling in the Service of Michigan Coastal Dune Decision-Making

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Michigan Environmental Council

Michigan Environmental Council—a nonprofit charitable organization—is a coalition of more than 65 organizations formed in 1980 to lead Michigan's environmental movement in achieving positive change through the political process. We bring a solutions-oriented approach to our work, combining deep environmental policy expertise with decades of experience in working with diverse stakeholders to achieve results. We work closely with our member organizations and partners in environmental, conservation, public health, and faith communities to protect our Great Lakes, promote healthy cities, safeguard our drinking water, and establish clean energy policies for a vibrant, sustainable future.

Since 2013, we have been engaging with ecologists, geologists and environmental economists to improve our understanding of Michigan's coastal dunes—how they came to be, how they change and evolve naturally and what they mean to Michigan's people and environment. Our goal is to provide resources and information to help the State of Michigan and coastal communities engage in science-based management of dunes.

Michigan Coastal Management Program

Established in 1978, the Michigan Coastal Management Program (MCMP) is committed to providing substantial technical assistance and strategic grant funding to assist in coastal communities' ability to understand risks and options to mitigate coastal hazards; create healthy habitats that provide for human use and enjoyment; support coastal eco-tourism opportunities while ensuring for safe public access; and support resilient and sustainable coastal economies. As connectors and collaborators, the MCMP advances the research on a changing climate, resilient planning methods, and seeks balanced approaches to sustainable coastline.

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Table of Contents

Appendices

Executive Summary

In late 2018 the Michigan Coastal Zone Management Program, through NOAA and the Michigan Office of the Great Lakes, funded the Michigan Environmental Council (MEC) project, *Learning to Live in Dynamic Dunes: Citizen Science and Participatory Modeling in the Service of Michigan Coastal Dune Decision-Making*. The results described here represent an exciting new chapter in our understanding of Michigan's coastal dune landscapes and how citizens understand and perceive these complex systems. The knowledge gained in this project will prove critical to the long-term management and preservation of a true global treasure—the largest collection of freshwater coastal sand dunes found anywhere in the world.

The project is part of an ongoing effort to advance the collective awareness and understanding of Michigan's coastal dunes. The first effort, also funded by the Coastal Management Program, began in 2014 with the project, "*Bringing the Latest Science to the Management of Michigan's Coastal Dunes,*" followed by a project launched in late 2016, *Valuing Michigan's Coastal Dunes: GIS Information and Economic Data to Support Management Partnerships*." Collectively these projects expanded our historical understanding of dune management, enhanced dune mapping resources, and estimated a value of coastal dunes based on the citizen's recreational use. Results of these projects can be found on the Michigan Environmental Council website at www.environmentalcouncil.org/coastaldunes.

The current effort, which kicked off in late 2018, was conceived based on the results and discussions from the earlier projects. The core project team included Alan Arbogast and Robert Richardson (Michigan State University), both of whom were members of previous project teams, and Tom Zimnicki (Michigan Environmental Council). Additionally, a citizen science steering committee was formed which included Shaun Howard (The Nature Conservancy), Jonathan Jarosz (Heart of the Lakes), and Lisa Brush (The Stewardship Network) to assist with engagement and outreach. Collectively the team focused on delivering three core project goals to improve decision making within Michigan's coastal sand dunes:

1. Assessing human impacts to dune processes

This is the first attempt to deploy repeat photography along Lake Michigan's shoreline for the purpose of cataloging changes in dune morphology and human induced landscape changes.

As described in more detail in Part 1, researchers generally understand the chronological changes within dunes morphology over hundreds and/thousands of years, but often lack the knowledge of changes on a shorter, decadal timescale. To illustrate this, Professor Alan Arbogast and his research assistant, Kevin McKeehan, collected a cache of over 200 historical photos from various state and private archives along with contributions from citizen scientists in the general public. A subset of these historical photos was then paired with exact modern replicates and mapped. This work is foundational in understanding the main contributors to coastal dune changes over the last 150 years and when coupled with other products from this project, is vital to long-term management planning.

Results indicate that vegetation has expanded significantly at all sites assessed since the initial photograph was taken. In addition, development in the form of condos and subdivisions has occurred at select sites.

2. Collaborative mental modeling and dunes literacy

Building off results from the 2017 #HowYouDune Survey, this effort aimed to explore the differences in how diverse citizens perceive and understand dune landscapes. To this end, Professor Robby Richardson deployed a unique tool, mental mapping, which has been used to assess perceptions on various conservation topics across the world. As it relates to dunes, this technique allowed the project team to catalog and visualize how citizens understand the various components of a dunes landscape and the factors affecting these landscapes.

Capturing the insights of over 70 residents from across Michigan, Richardson categorized what the majority of residents perceive as the main factors that influence dune landscapes. This research presents an exciting opportunity for the State of Michigan and local units of government to better tailor future outreach, engagement, and management programs to incorporate citizen perceptions and understanding.

3. Citizen science engagement

In the 2017 #HowYouDune survey, over 700 participants voluntarily shared personal photos of their trips to Michigan's dunes. This suggested to the project team a path to broader and more meaningful stakeholder engagement and at the same time, would support one of the most important information needs for this project. The project team believed that this project would benefit from utilizing citizen science.

Citizen science—in which knowledgeable but generally amateur volunteers serve as data collectors or monitors, providing meaningful data to support scientific research—is a promising approach to translate interest in a conservation issue into useful action and engage community members in collecting data in support of advancing science. The project provided an excellent opportunity to build on the excitement and interest generated through our #HowYouDune survey and outreach work by engaging some of these same people and techniques to support our project's research needs. This project was strengthened by the participation and engagement of citizens scientists who allowed us to bolster our photo collection efforts and mental mapping exercises. Engagement of citizen scientists is discussed in both Part 1 and Part 3.

Introduction

Over the last six years the Michigan Environmental Council (MEC) along with academic researchers at Michigan State University and several partner organizations have worked to expand the knowledgebase of coastal dune areas in Michigan. The landscapes are, as Professor Alan Arbogast says, “some of the best examples of coastal dunes in the world.” In the past ~ 20 years, a new paradigm has emerged about the evolution of these systems. In the time prior, it was generally believed that they formed largely during the Nipissing high stand (~ 5,000 years ago) of the ancestral Great Lakes. We now know that they began to form at that time, but have undergone several cycles of growth and stability in the past 5,000 years. Uncertainties remain, however, about the detailed prehistoric chronology, especially as it relates to potential drivers (e.g., storms, lake-level fluctuations, and drought) at any given time.

In 2014-2015 MEC sought to advance the baseline knowledge and awareness of dunes ecology through the expansion of mapping capabilities which accounted for a range of human development scenarios in a project entitled, *Bringing the Latest Science to the Management of Michigan’s Coastal Dunes*. Building off this initial effort, MEC, along with several organizations and academic entities, attempted to quantify and understand the cultural and economic value that dune landscapes provide to both coastal communities and those who recreate in these incredible landscapes. This work occurred in a 2016-2017 project titled, *Valuing Michigan’s Coastal Dunes: GIS Information and Economic Data to Support Management Partnerships*. Both of these projects were funded through the Michigan Coastal Management Program (MCMP).

Both the 2014 and 2016 projects revealed a striking realization that most Michiganders and visitors have a generally poor understanding of coastal dunes and how these landscapes change over time. For example, in the 2016 *#HowYouDune* survey a portion of respondents commented, “I’m glad the State is planting dune grass” while another segment of respondents commented, “The State should remove dune grasses.” The contrast in these responses indicated to MEC and partner organizations that additional effort should be directed at both understanding dune processes and how residents perceive these processes.

Broadly the current project proposed three objectives. First, through the use of historical photo analysis the project team aimed to better understand the geomorphology of dunes on a shorter, decadal, time scale. This is an important goal as our understanding/visualization of Michigan dune morphology is confined to larger, millennia, scales. Our photo analysis (detailed in Part 1), involved collecting historic photos from the last 100 years from state and academic archives and from members of the public. These photos would then be replicated either by citizen scientists or by researchers at MSU. Obtaining these photo pairs allow researchers to observe and catalog natural and anthropogenic changes within these landscapes. Part of the impetus for this objective was a belief that human involvement/pressures (i.e. sand mining, housing/municipal development) were a primary driver for changes within dune systems. Through extensive photo collection and replication, the project team documented prolific natural plant succession along the Lake Michigan shoreline as well as examples of the impact of human development on dunes. Additional, localized research is needed to more fully illustrate and understand the impact of development.

This project also attempted to better understand how Michiganders understand and perceive various aspects of dune morphology and management actions that may impact dunes. As mentioned, the *#HowYouDune* survey generally revealed a misunderstanding among respondents of the types of ongoing and past management activities and the various actions that may alter a dune landscape. To better understand perceptions and understanding, the project team deployed the use of ‘mental mapping’ (Part 2). Mental mapping is a common tool used within social sciences to take a deep dive into how an individual, or groups of individuals, understand a particular issue/topic. Our team deployed this tool, in conjunction with several regional meetings, to elicit feedback and perspectives from Michiganders. Ultimately the mental mapping results could play a central role in informing state and local officials for how best to communicate and message dune management strategies.

Both the photograph and mental mapping activities were bolstered by the engagement of citizen scientists throughout Michigan. The process for engaging citizens scientists is detailed in Parts 1 and 3. MEC was encouraged by the response to previous grants and the *#HowYouDune* survey and believed citizen science provided a promising way to translate enthusiasm from the general public on dunes into meaningful science and data collection.

In addition to accomplishing these core objectives, MEC and partners successfully planned and executed a dunes symposium in October 2019. This event built off the 2017 Freshwater Dunes Summit, which focused on understanding the value of Michigan’s coastal dunes. For the 2019 symposium, MEC focused on communicating the outcomes of the current project to decision makers and dunes activists. Over 55 planners, stakeholders, and residents attended this event in Lansing and heard summaries of both the photo analysis and mental mapping portions of the project. The symposium also featured presentations from federal and NGO partners on invasive species management and a panel of state and local decision makers on the different needs and opportunities within dunes management.

The objectives and deliverables of this project intentionally built off of the expanded knowledgebase obtained in previous Coastal Zone Management grant efforts. MEC focused on new methods for conveying information and our scientific knowledge of coastal dunes processes to both the general public and decision makers. We believe the outcomes of this project are important steps towards more comprehensive and holistic management and understanding of these incredible and unique landscapes.

Part 1: Visualizing Physical Changes of Michigan’s Coastal Sand Dunes

Background

The coastal sand dunes along Lake Michigan provide the bucolic background for dozens of communities and often are a centerpiece in the state of Michigan’s *Pure Michigan* tourism campaign. Sleeping Bear Dunes National Lakeshore, with its distinctive perched dunes, was even listed as “The Most Beautiful Place in America” by *Good Morning America,* in 2011. In the last 20 years, due to the work of scientists from institutions and universities across Michigan, much is now known about the age and evolution of these features in the context of past climate changes and lake-level fluctuations. What is less known is the behavior and evolution of these dunes in the historic period, specifically since 1900. Questions abound regarding the response of these dune systems to shorter-term temporal phenomenon and whether any trends can be detected within the last 100 years. Understanding these processes will also shed light on past drivers of geomorphic change.

Fortunately, using the established practice of repeat photography, the gaps in knowledge regarding the historic behavior of Lake Michigan’s coastal sand dunes can begin to be addressed. This section of this report outlines the efforts of the *Sands of Time* project—a partnership between the State of Michigan, its Department of Environment, Great Lakes, and Energy (EGLE), Michigan Environmental Council, Michigan State University, and citizen scientists across the state—to document changes in coastal dune systems using repeat photography. Participants in the project obtained historical photographs of coastal dunes along Lake Michigan and attempted to recapture in 2019 the same photographs of the same locations, analyzing the differences and similarities between the paired photographs.

According to our analysis, the dune landscape has changed markedly in the past 120 years. At many sites, vegetation has expanded a great deal within the dune system since 1900. In addition to this expansion of plants, which tends to stabilize dunes, some sites bear the unmistakable imprint of human hands, primarily the expansion of housing in the landscape. Whatever the cause, few coastal dune sites along Lake Michigan appear today as they did in the past. Nearly all sites examined experienced change to a degree, and some locations, as geographically diverse as Grand Beach in the south and Sleeping Bear Dunes in the north, demonstrated substantial alterations of the landscape in the historical period.

This report will review the origins of Lake Michigan’s coastal sand dunes, explore the known research regarding coastal sand dune response in the historical period, discuss the methodology of this study along with the history of repeat photography for scientific use, and document the results of the project, highlighting key repeat photographs. Then, we will analyze the results and discuss next steps for research. The study area for this report is the entire extent of coastal sand dunes on the state’s Lake Michigan shore, encompassing slightly more than 100,000 acres

(Figure 1). From this expanse, our project will then focus on a select number of repeat photography sites representative of the changes occurring in the coastal dune environments.

Figure 1. Study area: Lake Michigan Coastal Dunes (Source: EGLE, ESRI)

Overview of Lake Michigan's Coastal Sand Dunes

Origins and Prehistoric Period

Convention held throughout most of the 20th Century that Lake Michigan's coastal sand dunes largely formed during the Nipissing phase of the ancestral Great Lakes. During this period ~5,500 years ago (Thompson et al., 2011), the Great Lakes drained through the isostatically rising North Bay channel in central Ontario, rather than through Lake St. Clair and the Detroit River (in the southeastern corner of the state) as they do now. This uplifting outlet resulted in a several-meter rise in the water level of Lake Michigan (Baedke and Thompson, 2000) resulting—it was commonly thought—in perched dunes and sandy deposits well above and inland of the current lakeshore (Dorr and Eschman, 1970). Lake Michigan retreated to within a few meters of current levels within 1,000 years. The coastal dune features lining the shore were thought to be the remnants of this Nipissing environment and were surmised to have been largely stable since then (White et al., 2019).

Beginning around 2000, new research suggested a different chronology for Lake Michigan's coastal dunes. Rather than the product of a singular event tied to a distinctive lake-level phase, chronological reconstructions of dune fields from numerous studies show a much more complex history. By dating eolian sand deposits via optically stimulated luminescence methods and buried organics with ^{14}C , researchers learned that some dunes indeed began forming during the Nipissing period (Arbogast et al., 2002; Arbogast et al., 2004; Lovis et al., 2012), but others, such as Rosy Mound near Grand Haven, formed well afterward at approximately 2,900 years ago (Arbogast and Loope, 1999). Moreover, many sites show evidence of multiple periods of dune stability and subsequent growth. The picture that emerges from these studies shows a geomorphically young landscape that has developed in a complex fashion since ~5,500 years before present, undergoing several phases of growth and stability in that time (Lovis et al., 2012).

Excellent examples of this phenomenon occur along the entire shoreline. At Warren Dunes near St. Joseph, evidence indicates multiple periods of stabilization followed by activity. Within dunes there, buried layers of soil and vegetation dating from the Nipissing phase exist between layers of sand (Arbogast et al, 2004). This stratigraphy shows that phases of dune construction or activity occurred in many phases and were followed by periods of stability, which allowed for soil development and the associated expanse of vegetation in the area. Farther north at Torch Lake, dating techniques revealed that at least two major periods of dune construction took place since the Nipissing period, interrupted by at least one long period of stabilization (Lovis et al., 2012, pg. 195).

All of these more recent studies demonstrate the dynamic nature of Lake Michigan's coastal dunes. These landscapes are akin to complex systems, which, in this case, respond to changes in lake levels and climate. For example, the dune building phases captured in these studies seem to correspond to known intervals of higher lake levels and cooler climates (Arbogast and Loope, 1999; Loope and Arbogast, 2000; Arbogast et al., 2002; Lovis et al., 2012, pgs. 114-122). Conversely, periods of stability seem to correspond to periods of lower water levels on Lake Michigan. This complexity suggests the coastal sand dunes along the Lake Michigan shoreline are not simply static backdrops from vacation photographs, but active landforms that are responding even now to changing environmental conditions.

Historical Period

While the origins and general evolution of Lake Michigan's coastal dunes are well understood, less is known about the behavior of Lake Michigan's coastal sand dunes since 1900. Given the statistical uncertainty associated with conventional dating techniques, which can sometimes be on the order of ~300 years in Michigan's coastal dunes, it is difficult to associate specific dune-forming episodes (e.g., sand deposition) in the prehistoric past to individual lake levels or climate episodes with high confidence. Thus, some uncertainty naturally exists with respect to the specific causal mechanisms for coastal dune behavior in the past. In order to fully understand the factors that contribute to coastal dune evolution, it is necessary to visualize historic changes to see how they correlate with known environmental variables that were observed or measured.

Unfortunately, few studies have been conducted that assess the patterns of coastal dune behavior since 1900 along Lake Michigan. Of those conducted, most focus on the process of wind-blown sand transport and deposition at specific sites (e.g., Van Dijk, 2004; Hansen et al, 2006; Hansen et al., 2009). Only one study has examined the nature of change in dunes over a broad geographical area. This study, conducted by White el al. (2019) employed remote sensing techniques of aerial photographs to analyze the changes in Lake Michigan coastal dune vegetation in select locations between 1938 and 2014. The study examined coastal dunes at 14 state parks and Sleeping Bear Dunes National Lakeshore along the Lake Michigan shoreline. At every location, vegetation had expanded since 1938, extending over previously barren sand dunes. This expansion of vegetation, White et al. (2019) concluded, was possibly linked to a general increase in precipitation since 1940 over the Lower Peninsula of Michigan based on climatological data from Muskegon.

This finding corresponds to studies conducted elsewhere that link dune behavior to complex, interrelated factors. Kocurek and Lancaster (1999) referred to sand dune environments as systems controlled by primarily three variables—the supply of sand, the availability of that sand for transport by wind, and the potential of the wind to transport said sand. The availability of sediment represents the exposure of sand to wind and is controlled by surface characteristics, including vegetation, according to Kocurek and Lancaster (1999). In turn, the ability of vegetation to grow and the strength of the wind are functions of climate. All of these factors and others, along with human intervention, conspire to produce the dune systems seen on the Lake Michigan coast today.

The approach by White et al. (2019) to determine trends in dune behavior in Michigan is somewhat similar to approaches undertaken elsewhere. A study of the changes in large dune features in the Indiana Dunes over a 70-year period was accomplished through an analysis of repeat aerial imagery (Kilibarda and Shillinglaw, 2015). That study found that a large dune known as Mount Baldy had moved inland 135m, but that the most active periods occurred during high water levels on Lake Michigan and periods of beach erosion. An additional study of coastal sand dune blowouts on Cape Cod used aerial imagery and a geographic information system (GIS) procedure to track changes in the coastal dune behavior (Abhar et al., 2015). The study concluded that, again, a number of interrelated factors, such as the frequency of intense storms and human intervention affected vegetation growth and dune stability and proved that the practice of repeat photography was useful in eolian environments. Another study from coastal Wales demonstrated that ground-based repeat photography also could be a powerful tool in determining dune behavior. A series of repeat photographs taken from several coastal locations showed a dynamic dune landscape in which vegetation expanded in some areas and sand was active in other areas (Millington et al., 2009).

The results of White el al. coupled with other research (e.g., Millington et al., 2009; Abhar et al., 2015; Kilibarda and Shillinglaw, 2015) into recent dune behavior suggests that employing the practice of repeat photography is a useful approach to determining trends in coastal dune systems. With the exception of the study of coastal dunes in Wales, most of the studies, including the White el al. (2019) paper in Michigan, utilized aerial images rather than ground-level photography. Given the nature of Lake Michigan's coastal dunes as a vacation playground, it was hypothesized that a treasure trove of ground-level historical photographs existed across the state and beyond, whether in libraries, archives, or shoeboxes tucked away in closets. It was this hypothesis and the need to continue to fill gaps in coastal dune behavior along Lake Michigan in the historical period which partly guided this project. Yet, the use of repeat photography is not as straightforward as pointing a camera at a sand dune and pressing a button; the practice has a long and colorful history in the Earth sciences that highlight its great potential and challenges.

Repeat Photography in Science

Earth scientists, regardless of the discipline, struggle with measuring landform change across all temporal scales. Whether the changes occur quickly, such as stream bank erosion during a flash flood, or more slowly, such as the development of soil, measuring changes on the Earth often challenge and elude the observational capabilities of the human eye and brain. Yet, the processes which shape our world continue unceasingly, presenting a real-time challenge to scientists. Limnologist John J. Magnuson described this phenomenon as the "invisible present" (Magnuson, 1990), while geographer Garry Rogers characterized it as "intervening unseen events" (Rogers et al., 1984).

Several scientists have addressed this challenge by adopting repeat photography into their work. The first known attempt to use multiple photographs taken in one place over a period of time to document scientific phenomena occurred in 1888 in Switzerland. There, Sebastian Finsterwalder, a professor of mathematics and geometry at the Technical University of Munich, began taking multiple photographs of alpine glaciers from the same location (Hattersley-Smith, 1966; Rogers et al., 1984). He used his background in mathematics to statistically measure changes in the photo pixels and, from this analysis, he crafted a theory of steady-state glacial flow.

From Finsterwalder, the use of repeat photography in the physical sciences grew steadily. Eventually, efforts were made to retrace the steps of early geographers toting cameras and recapture the early photographs—iconic images taken by geographer-photographers from the 19th Century such as Grove Karl Gilbert, John Karl Hillers, William Henry Jackson, and Timothy O'Sullivan, a protégé of Matthew Brady (Rogers et al., 1984). Most of these efforts were concentrated on documenting geographic phenomena in the western United States, in places such as the Grand Canyon, Yellowstone National Park, and glacier fields in Alaska. The practice only recently has begun to be applied east of the Mississippi River, where foliage often blocks clear photographic pathways.

Yet, as the practice grew, other challenges became clearer. Some of these issues pertain to the mechanism at the heart of the practice itself—the camera. Photographs can be misleading, altered, unrepresentative of an area at large, focused on the photographer's biases in subject matter and location, or tend to encourage an artistic tendency in a photographer's mission, which may or may not be appropriate for scientific work (Rogers et al., 1984).

Even after accounting for all of these issues with regards to repeat photography and the camera, there were additional issues in the field that had to confronted, from the interminable to the mundane. For example, a field scientist can spend a number of hours on site attempting the match a new photograph with an earlier one, hopelessly trying to pair angles, weather, and light often in vain (Rogers et al., 1984). Some original photo sites might be found in the field, the surrounding landscape having been altered too dramatically. Nevertheless, if practiced with an acknowledgement of these and other issues, repeat photography can prove to be a powerful tool in the analysis of landforms in the historical period.

Methodology

Process

This project aims to utilize repeat photography to answer questions related to coastal sand dune behavior along Lake Michigan's eastern shore in the historical period. To accomplish this, we developed a process to collect historical photographs, evaluate each photograph's usefulness, recapture the photos in the field, and analyze the results (Figure 2). The process involved libraries, archives, citizen scientists, several lengthy trips to perform repeat photography, and software to analyze photographs digitally. The first step in this process was to locate caches of historical photographs.

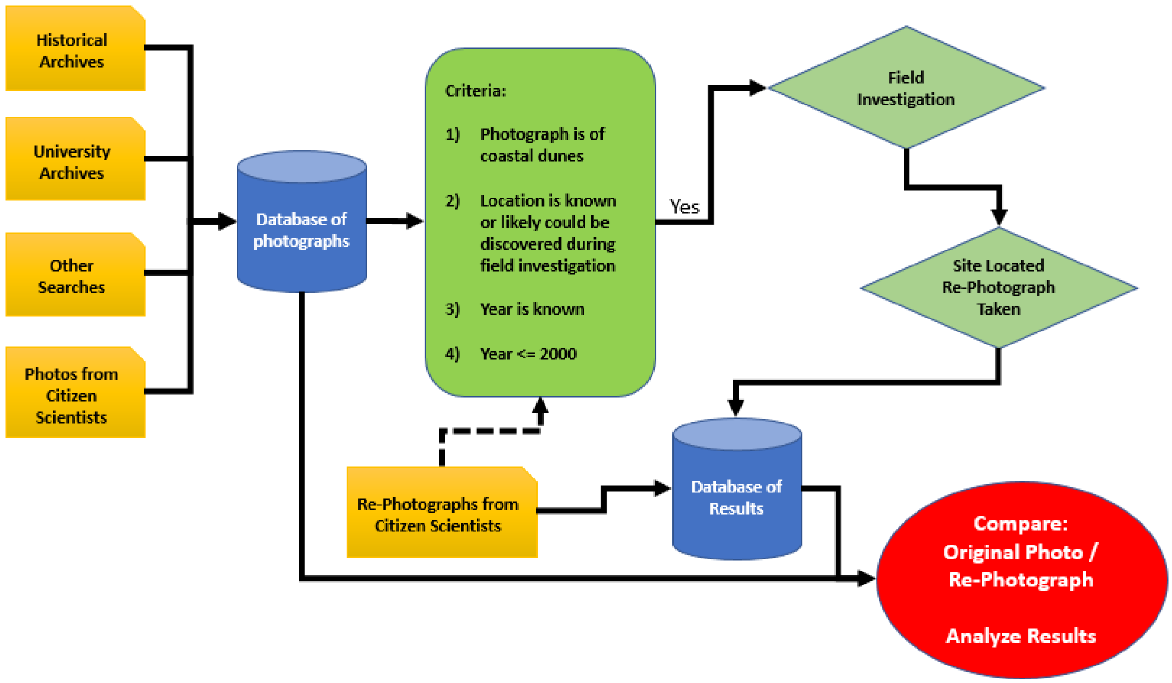

Figure 2. Repeat photography workflow process.

Data Collection

Historical photographs of Lake Michigan's coastal dune landscape were located in a variety of places. An effort was made to search several known archives, including those in counties along the Lake Michigan shoreline. The primary sources for historical photographs were the Archives of Michigan, the Bentley Historical Library at the University of Michigan, the Photographic Archive at the University of Chicago, which included images from scientist Henry Chandler Cowles' coastal Michigan field trips, and the Saugatuck-Douglas Historical Society Museum. Another fruitful repository of historical dune photographs came from EGLE, where several binders of photographic slides were discovered which documented coastal conditions from approximately 1965 to 1995.

Once suitable photographs were gleaned from these repositories, they were subsequently downloaded digitally into a database if online or a picture was taken of the photo with a digital camera. Additional photographs in various media were forwarded to researchers from citizen scientists. Eventually, 207 photographs were considered as potential candidates to be recaptured as part of this project. For a candidate to be viable, however, its precise location must be identifiable and the photograph must be of good quality. Additionally, for the purposes of temporal analyses, it was necessary to know the approximate year the photograph was taken.

Of the 207 candidates for repeat photography, approximately 180 photographs were selected for field investigation. All 207 candidates were documented in a database with information such as the year of the photograph, the image source, photographer (if known), year, and a description of the likely location, which was determined either through archival notes associated with the photograph or through an investigation using online and topographic maps. For example, some place names, such as Palisades Park and Eiffel Tower Dune, are not commonly used by the public, but a search of maps online and offline revealed that these sites are located near Covert and Grand Beach, respectively. Data regarding these 180 candidates for field investigation were also added to a geographic information system (GIS) to aid in site location once in the field. These geographic data attached to these candidate sites later helped in the creation of an online story mapping website which would contain information about the best repeat photography results (See Results Section).

Unfortunately, given the length of time of this project, it is likely that some caches of historical photographs were missed. This is partly due to the vast scope of our study area, which included Michigan's lakeshore from the Indiana border to the Mackinac Bridge, plus any of the state's Lake Michigan islands. Further, there are gaps and biases in our coverage of historical coastal dune photographs, due to the nature of photography itself. Photographs are taken where people are—and the more people, the more photos. There would also need to be an incentive to preserve old photographs. Thus, we have abundance of historical photographs from Sleeping Bear Dunes—a popular vacation destination and part of the National Park Service—and Holland, a relatively large town on Lake Michigan's coast with a vibrant history. We have no photographs from the relatively remote Nordhouse Dunes area. While it is possible, there is no guarantee that any additional archives could have yielded further images. This is where citizen scientists hopefully would provide an additional dimension to our database.

The Role of Citizen Scientists

Citizen science is one of the most promising approaches to translate interest in a conservation issue into useful action and engage community members in collecting data in support of advancing science. This project presented an excellent opportunity for the project team to tap into the passion and interest of residents displayed in the #HowYouDune survey to inform the collective understanding of dune landscapes.

The project team proposed to engage citizen scientists specifically for collecting historic photographs and repeat photograph pairs of Michigan's coastal dunes. MEC, project partners, and others helped promote this effort over the course of three months.

The process for collecting photos was important in order to maintain scientific integrity of the overall project. To better ensure the photographs collected were usable, the project team developed a protocol for historic and repeat photo submissions (Appendix A & B). For historic photos, submitters were asked to provide specific site information including but not limited to, a map of the location, map coordinates, or landmark references and the date of the photograph. The location was particularly important in order to accurately generate a photograph pair. It was also important for the photo to focus on the dune itself rather than the people visiting the site. Historic photos were submitted through MEC's website (www.environmentalcouncil.org). MEC and MSU sorted through all submissions and selected a subset of photos that could be repeated (i.e., could be located and had an associated date).

A specific protocol was also developed for collecting repeat photograph pairs. As detailed elsewhere in this section, this process was highly sensitive and required a great attention to detail. In the tutorial, the project team described the process of finding the historic photo location, the equipment needed, and tips for shooting the scene. Photo pairs were submitted through MEC's website. This protocol could be utilized by future citizen scientist efforts along Michigan's coastal dunes. In order to make this protocol transferable to other research endeavors, the project team adapted the protocol to also include general guidance for how to interact with dunes in a low impact, responsible way.

Despite detailed instructions and extensive media coverage, only a few viable photos were submitted by citizen scientists. Of the dozens of historic photos submitted, only one met the criteria to be usable for repeat photography. The majority of unusable photos either did not have a specific location identified and/or the photo did not focus on the dune landscape and instead focused on a person or object in the foreground.

Throughout the course of the project, no viable repeat photo pairs were submitted through citizen science efforts. Unlike the historic photos which lacked the necessary detail, residents simply did not submit photo pairs (usable or not). While the project team is not sure what deterred citizen scientists we assume it was due in large part to the complexity and rigor necessary to achieve a usable repeat photograph pair. Citizen scientists may have felt intimidated or lacked the time necessary to engage on this aspect of the project. The project team did not receive any questions from citizen scientists about the protocol or needing clarification on the process so the assumption is that few even attempted this activity. Future projects may consider identifying a committed group of citizen scientists who are ready to engage in repeat photography activities.

Future efforts to engage citizen scientists could learn from this effort in several ways:

1. Develop, implement, and message a very rigorous protocol for photo collection. The majority of unusable photos lacked information specified in the protocol.
2. Extensive outreach through traditional and social media is key to driving interest in citizen science engagement.

Acquisition of Modern Photographs

As stated above, 180 photographs were selected for field investigation. A total of seven field trips were made to the Lake Michigan coast to visit the locations where these photographs were originally taken. An eighth field trip was planned to Beaver Island, but logistical difficulties prevented a visit. Some photograph locations proved somewhat easy to find, while others were never located. At each site, however, considerable time was spent to find the location where the original photograph was taken. In a dynamic dune environment, which is sometimes characterized by mobile eolian sand or an expansion of vegetation, this was often difficult and sometimes required hiking for hours. High lake levels in Lake Michigan during the summer of 2019 inundated some study sites, such as at Holland State Park. At times, the human-built environment also had altered the landscape significantly, making it difficult to find the original site. An example of this is Lighthouse Dune at New Buffalo, which once stood at the mouth of the Galien River, which has since become a modern harbor. Occasionally, access to the original photo location was denied due to the presence of restricted beachfront communities. Given the mobile nature of eolian sand, it was also sometimes difficult to determine the precise location because of dune dynamics in the intervening years.

Once the approximate location of the photograph was found, care was taken to obtain the correct focal height, or camera's distance above the ground, angle, and light. Three cameras were used to take multiple photographs, including a 1974 Bell & Howell FD35 film camera, a Nikon Coolpix S6000 digital camera, and a personal cellphone. Multiple pictures from a variety of angles and focal lengths were taken with each camera. The pictures were uploaded to the database for analysis.

Analysis of Paired Photographs

Once the 2019 re-photographs were captured for each viable site and uploaded into a database, the images were cropped to align as best as possible. As mentioned above, Finsterwalder and others (Hattersley-Smith, 1966; Rogers et al., 1984), used a pixel to pixel comparison between photographs at the same sites to quantitatively measure differences in glaciers in the Alps. Yet, Finsterwalder set up his own photo stations from which to take photographs and knew the precise location, focal length, and angle of all of his original photos. Thus, he could make a quantitative pixel-to-pixel comparison between multiple years. In this project, the latitude and longitude of the original photograph locations was not known, nor were the focal lengths or camera angles. Yet, as Kull (2005) noted in his study of vegetation change on Madagascar, the lack of precise photo stations does not hinder the ability to provide a measurable analysis of the differences between original and recaptured repeat photographs. Well-developed heuristics and clear, descriptive categories can still provide the analytical element necessary to determine trends between the photographs and across the study area, even if this is not a pure quantitative approach. Moreover, the mobile nature of eolian sand, with its high potential for landscape change, renders repeat photography difficult, as even the ground where the original photographs were taken may have dropped and risen several meters in the ensuing interval. This project does not seek to force a quantitative schema on the results where one cannot be supported, nor to build a qualitative category system to assess change; this can be performed in the future. Nevertheless, the results mostly provide a clear trend across the coastal dune systems of Lake Michigan in the state.

Results

Of the 180 sites analysts visited or attempted to visit, approximately 60 proved appropriate for photographic re-analysis. Not all of these approximately 60 sites provided compelling results. Some re-photographs were taken where dense foliage now existed, resulting in repeat photographs of mere leaves. Still, an analysis of the approximately 60 paired photographs showed that 25 sites yielded compelling comparisons. These 25 best paired photographs will populate the project's website. Figure 3 contains a map of these 25 best locations.

In most of the paired photographs, two distinct trends emerged—one extensive, the other less so. In most of the historical photographs, bare sand is abundant in the image, while in the 2019 re-photographs, vegetation has expanded considerably. This expansion of grasses and, in some cases, invasive species, trees, and other woody vegetation is a significant trend. At some of the sites, the presence of vegetation allowed the landscape to aggrade, or become slightly convex, due to the ability of grasses and trees to trap additional mobile sand. The other, less ubiquitous trend involves the advent of the human-built environment, in the form of beachside homes, barriers, buildings, roads, and trash. This human intervention is not seen at all or even most sites, but it is pronounced south of Warren Dunes, around Holland, and Muskegon. Figures 4 and 5 show representative locations where the expansion of vegetation from the earlier historical photographs is significant by 2019, while Figure 6 of Grand Beach shows both the expansion of vegetation and human structures.

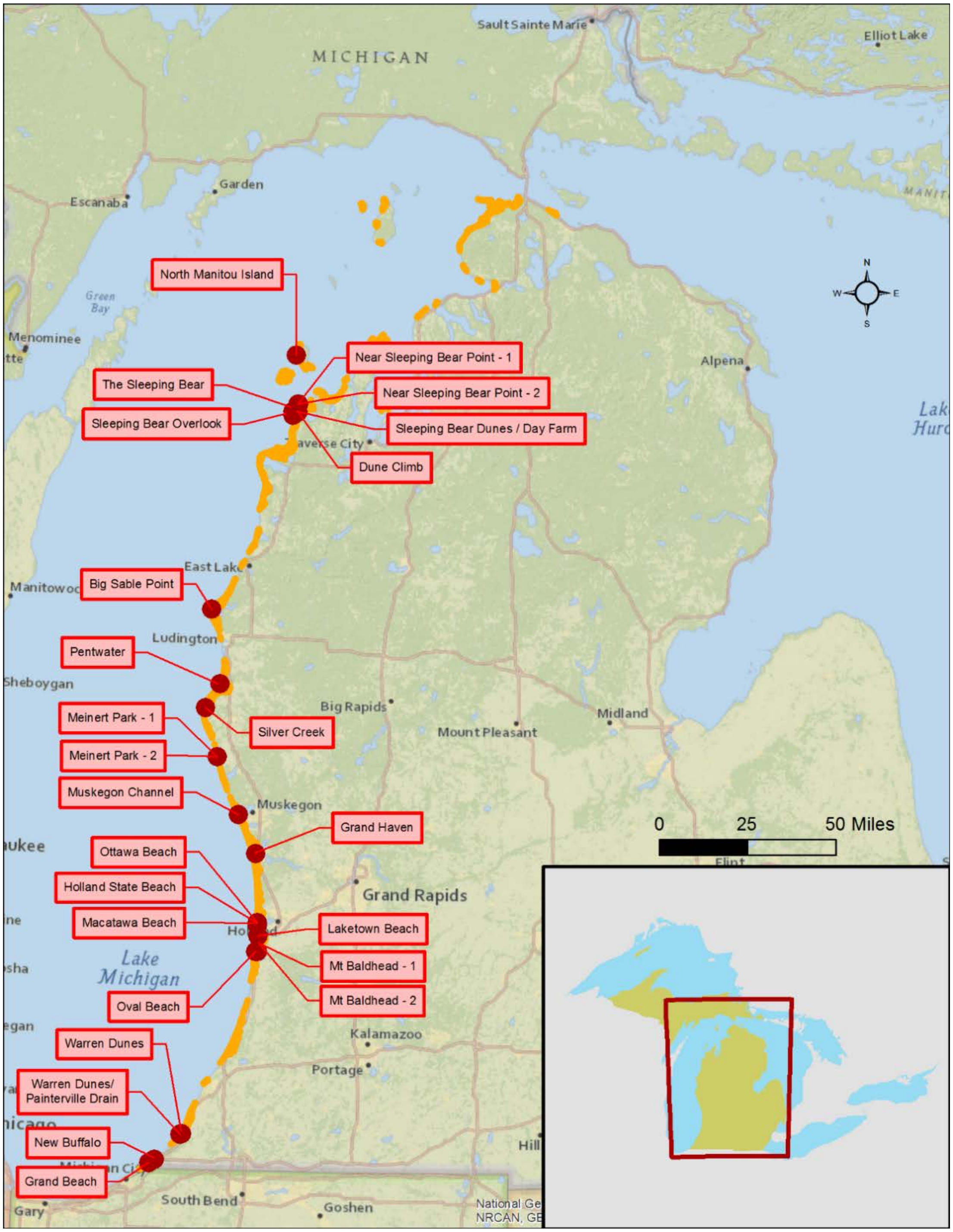

Figure 3: Statewide repeat photography results (Source: EGLE, ESRI).

Figure 4. Repeat photography results from Laketown Beach from 1989 and 2019, showing expansion of vegetation (photo sources: EGLE, Kevin McKeehan).

Figure 5. Repeat photography results from near Sleeping Bear Point from 1915 and 2019, showing expansion of vegetation (photo sources: University of Chicago, Kevin McKeehan).

Figure 6. Repeat photography results from Grand Beach from 1987 and 2019, showing expansion of human development and vegetation (photo sources: EGLE, Kevin McKeehan).

Michigan Coastal Dunes Repeat Photography Map

The Michigan Coastal Dunes Repeat Photography Map is available via the project website at www.environmentalcouncil.org/learning_to_live_in_dynamic_dunes. The website features the overview map of paired photographs and the 25 best pairs such as the examples shown in Figures 4-6. Each of the 25 sites is featured on a separate page that includes a description of the site, the photo pair, a small detail map, a Google map linked to the latitude and longitude of the site, and where available, a Google map street view link.

Discussion

Expansion of Vegetation

Most of the re-photographs from the 60 sites show an expansion of vegetation over dune areas that once were patches of bare sand. Coastal sand dunes are complex, dynamic systems responding to multiple factors such as climate and weather. The study of Mount Baldy in Indiana by Kilibarda and Shillinglaw (2015) proposed that the dune's status was tied to water levels on Lake Michigan and beach erosion, both of which are partially a function of climate and weather. Likewise, the study of vegetation expansion over sand dunes in Michigan state parks along Lake Michigan proposed that the increase in ground cover may be tied to a general increase in precipitation in the region since 1940 (White el al., 2019).

The causal factors driving vegetation expansion at our sites may be the same as these two studies. The same 80-year precipitation increase noted in White el al. (2019) at Muskegon would have been present at most, if not all, of the sites in our study. Moreover, the climatic and weather phenomena driving geomorphic change at Mount Baldy near Michigan City, Indiana, would not be foreign at our sites, especially those in the south near Grand Beach and Warren Dunes.

Yet, other factors may also be at play and need to be investigated going forward. These include whether previous bare sand areas were extensively logged just prior to the original photograph. If these areas were indeed deforested, then perhaps the expansion of vegetation seen in the 2019 re-photographs is the slow temporal response of the landscape to that event. There is some evidence that dune areas around Saugatuck were deforested for timber following the Great Chicago Fire of 1871. Other factors include the suppression of fire, as wildland fires were a fixture of pre-settlement and frontier Michigan, a fact expressed in events like the Great Thumb Fire of 1881 that killed 282 people. By suppressing fire on the landscape, it is possible this allowed vegetation to expand. The advent of invasive species adapted to colonizing and thriving in disturbed bare eolian sand may also be an important factor.

All of these factors—changes in climate, severe storms, logging, suppression of fire, and growth of invasive species—may have a role in the expansion of vegetation across coastal dune systems in Lake Michigan. Many of these, such as climate and fire, are linked, but it is likely that some factors are more important than others. The increase in average annual precipitation since 1940 at Muskegon from approximately 60cm to nearly 100cm by 2010 cannot be ignored. In an eolian environment where soils are sandy, available water is critical to the development of soil and plant life. It is possible, but not yet proven, that a threshold in annual precipitation was crossed sometime between 1940 and 2010 that fostered the conditions for successive colonization of dune soil by vegetation. As photographs from the 1980s at Meinert Park and Laketown Beach (Figure 4) in our study show, it is possible that this theoretical threshold was breached post 1990 as bare sand is still evident. Also a factor is the proportion of this precipitation as snow and the amount of time snow was on the ground. In summary, all of this provides the impetus for further investigation.

Encroachment of the Human-Built Environment

At the conception and outset of this project the team anticipated observing pronounced changes in dune landscapes as a result of development. The encroachment of the human-built environment is best seen from photographs at Grand Beach, Holland, and Muskegon.

These photographs clearly indicate that dune landscapes in those areas developed a great deal. Personal observation and anecdotal evidence indicate that similar impacts have occurred along much of the shoreline, especially in the southeastern reach of the coast. Nevertheless, our photographic results do not reflect the expected findings at the outset of this study. We strongly believe that the apparent lack of developmental impact illustrated here is a result of sampling bias related to our ability to locate initial photographs that could be effectively and accurately replicated. Further research is necessary to determine if more representative pairs can be obtained.

Conclusions

This project sought to apply the practice of repeat photography to help fill gaps in our understanding of coastal sand dune behavior on the state’s Lake Michigan shoreline. We scoured archives and leveraged the knowledge of citizen scientists to build a database of historical photographs from which we were able to capture 25 compelling re-photographs during the Spring and Summer of 2019. Upon examining the 25 matched photographic pairs, we determined that vegetation had expanded across patches of formerly bare sand at most sites and that the human-built environment encroached significantly upon some locations. These trends, especially the former, require further study to determine which factors are driving these changes. The most likely factor appears to be an increase in precipitation in the region since 1940, but this is not proven and may not be the only factor.

In addition to the study results, which are compelling in the context of determining drivers of dune behavior over time, we learned a great deal about process. First, we were somewhat surprised by the relative lack of initial photographs that were suitable for replication. Given the tremendous popularity of the lakeshore and its dunes, we assumed that hundreds of suitable photographs could be quickly acquired from state and local archives that could be used in this analysis. Although we have a sufficient number to show distinct patterns of environmental change, we would have preferred to have more, especially in developed areas. In fact, that is not the case, which begs the question: “Where are those photos?” It could well be that they rest in the hands of individuals who could have filled the role of citizen scientists. In that regard, we were secondarily surprised that very few individuals wanted to fulfill that role. These shortcomings indicated to us that a much more thorough effort needs to be made over a longer period of time to acquire a genuinely full cache of photographs for a comprehensive examination of dune change in the historical period.

Part 2: Michiganders’ Perceptions of Dunes: Mental Mapping

Introduction

Coastal sand dunes provide an array of important benefits that are supported by coastal geomorphic processes and location-specific ecosystems, including social and economic benefits to humans. For example, dunes that are relatively undeveloped provide a natural laboratory for scientific research; they provide coastal protection and erosion control; and they serve as habitat for biological diversity. In addition, coastal sand dunes provide attractive landscapes for recreation and tourism activities; they have cultural heritage value; and they also generate economic impacts that support local communities. Coastal sand dune ecosystems are ecologically important, but their specific values and uses are understudied, poorly understood, underappreciated, and often ignored in policy decisions (Everard et al., 2010; Barbier et al., 2011).

Scientists refer to these kinds of benefits as *ecosystem services*, which are usually interpreted to imply the contributions of nature to a variety of goods and services. Ecosystem services are the benefits people obtain from ecosystems, and the range of ecosystem services can be classified under three different categories:

1. *goods*, or the products obtained from ecosystems, such as resource harvests, water, and genetic material;
2. *services*, or ecological functions, such as water purification, erosion control, climate regulation, and habitat provision; and
3. *cultural benefits*, or the intangible benefits of recreation, tourist attractions, gathering places, nature-inspired art, spiritual renewal, and heritage values.

This section of this report outlines the efforts of the *Valuing Michigan’s Coastal Dunes* project – a partnership between the State of Michigan, its Department of Environment, Great Lakes, and Energy (EGLE), the Michigan Environmental Council, Michigan State University, and citizen scientists across the state – to conceptualize and understand the uses and values of coastal sand dunes in Michigan. Using an innovative online survey approach, the #HowYouDune Coastal Sand Dune survey deployed during 2017 allowed participants to identify the location of where they visited in Michigan’s coastal dune landscapes, log the type of activity they engaged in during these visits, and answer a series of questions about visitor spending and the cultural and social values they attribute to the coastal sand dunes. More than 3,600 respondents to the survey provided information about the importance of Michigan’s coastal sand dunes to their quality of life. The primary reason for visits to dunes is recreation, which is considered to be among the list of cultural ecosystem services (Everard et al., 2010; Barbier et al., 2011).

Some of the ecosystem services of coastal sand dunes have been identified and measured, including coastal protection, erosion control, carbon sequestration, nutrient cycling, recreation, and other cultural services (Read, 1989; Everard et al., 2010). Coastal protection is arguably one of the most valuable services provided by sand shore ecosystems especially in the face of extreme storms and water level rise (Barbier et al., 2011). Beaches and sand dunes provide sediment stabilization and soil retention in vegetation root structure, thus controlling coastal erosion and protecting recreational beaches, shorefront properties, tourist-related business, agricultural land, and wildlife habitat. In addition, coastal dunes provide raw materials (e.g., sand), water storage, and carbon sequestration. Coastal dune ecosystems also provide maintenance of wildlife in the form of habitat for fish, birds, ungulates, and other species.

Many of the ecosystem services provided by coastal sand dunes in Michigan are valuable in part because of their uniqueness and global importance. There are more than 230,000 acres of coastal sand dunes in Michigan, which is the greatest amount of land area in freshwater coastal dunes in the world. These dunes support an array of threatened and endangered animal and plant species, several of which are dependent on the movement of windblown sand for long-term survival, and they support numerous habitats, including open sand dunes, interdunal ponds, and temperate forests.

Coastal sand dunes in Michigan provide areas for a variety of recreation activities that attract millions of visitors each year. Boating, fishing, swimming, diving, walking, beachcombing, and dune walking are among the numerous recreational and scenic opportunities that are provided by beach and dune access (Barbier et al., 2011). Little is known about the social and economic values of coastal ecosystem services, particularly these coastal sand dune landscapes (Everard et al., 2010), and the lack of reliable estimates of these services has been described as “worrisome” (Barbier et al., 2011: 185).

Many of the ecosystem services provided by sand beaches and dunes are threatened by human use, development, invasive species, pollution, and climate change (Brown and McLachlan 2002; Zarnetske et al. 2010; Hacker et al., 2012). The human drivers of change in beaches and dunes primarily include loss of sand through mining, development and coastal structures (e.g., marinas), vegetation disturbance, pollution and litter, and biological invasion (Barbier et al., 2011). In particular, the removal or disruption of sand and vegetation coupled with increased storm intensity and water level rise threaten critical services provided by coastal dune ecosystems, specifically those of coastal protection and coastal freshwater provision. In the Great Lakes Basin, the dynamic nature of lake water levels, coastlines, and storm intensity calls for adaptive management of dunes ecosystems under changing climate conditions (Gronewold et al., 2013).

There have been few studies of the perceptions of visitors and stakeholders in coastal sand dunes in Michigan. A visitor study conducted at Sleeping Bear Dunes National Lakeshore involved the distribution of questionnaires to visitors at eleven different locations in 2009 (Holmes et al., 2010). Visitors were asked about their perceived importance of protecting several resources and attributes, and 96 percent of respondents rated clean water as “extremely important” or “very important.” Respondents also rated protection of clean air (95 percent), scenic views (95 percent), and sand dunes (94 percent) as “extremely important” or “very important.”

In this part of the project, an approach known as mental modeling (or mental mapping) was used to gather information about how citizens and stakeholders perceive the benefits of coastal sand dunes in Michigan, and the threats to the integrity of dunes ecosystems. Mental modeling is based in Fuzzy-Logic Cognitive Mapping (FCM), a parameterized form of concept mapping that allows for the development of qualitative static models. FCM represents knowledge by defining three characteristics of a system:

- The components of the system;
- The positive or negative relationships between the components; and
- The degree of influence that one component can have on another, defined using qualitative weightings (e.g. high, medium, or low influence).

The purpose of this study is to better understand the values and perceptions of Michigan's dunes by dune users and stakeholders. This will help inform the development of better coastal dune management by government agencies, conservation groups and university researchers. Mental modeling approaches aim to engage stakeholders in developing a shared understanding of a problem or issue of social concern. Concept maps were developed to represent how individuals perceive coastal sand dunes, and these maps were translated into semi-quantitative, dynamic meta models that represent the integrated beliefs of groups. The results reveal the collective perceptions of dunes stakeholders, and their values and priorities have implications for coastal zone management and conservation of coastal sand dunes in Michigan.

Methods

This study builds upon the #HowYouDune online survey conducted in 2017, in which 3,610 respondents provided their perceptions of the values of dunes and their relative importance. Survey respondents were asked to voluntarily provide their email addresses for follow-up research activities, and a sub-sample was randomly selected for invitation to participate in the mental modeling exercise.

Individual concept maps were constructed using *Mental Modeler*, a modeling software that helps individuals and communities capture their knowledge in a standardized format (http://www.mentalmodeler.org). *Mental Modeler* was developed to support group decision-making, allowing users to collaboratively represent and test their assumptions about a system. Additionally, it has also been applied as a social science research tool to measure the individual or shared mental models that often underlie human decision-making. *Mental Modeler* has been used in a variety of social and environmental contexts, including adaptation to climate change, disaster planning, and community-based natural resource conservation.

These models can be used to examine perceptions of an environmental or social problem or to model a complex system where uncertainty is high and there is little empirical data available. In addition to fostering a highly informed and widely shared understanding and vision for the dunes, these models can help us build, test, and simulate various scenarios for decision-making and policy approaches that can be shared, refined, and carried forward to help guide discussions of managing development in highly dynamic coastal environments such as sand dunes.

Mental models were developed and collected via two primary channels. First, workshops were held in four locations in Michigan, and individuals were invited via email by MEC through several professional networks. Participants were provided instructions for developing their concept maps using paper, adhesive notes, and drawings that represented the direction and magnitude of relationships between concepts. Upon completion of the workshops, individual concept maps were constructed in the *Mental Modeler* software. Second, individuals were randomly selected from the list of email addresses provided in the #HowYouDune online survey, and they were invited to participate in a webinar where they received training and instructions for building their mental maps using *Mental Modeler*. All mental models included four required starter components that were drawn from open-ended comments in the online survey. These components were: (i) dune quality, (ii) scenic beauty, (iii) access, and (iv) development. The data underlying individual mental maps were combined and analyzed to develop semi-quantitative, dynamic metamodels that represent the integrated beliefs of groups.

Four regional modeling workshops were held in Michigan in 2019 with the aim of developing mental maps of coastal sand dunes. Individuals were invited by Michigan Environmental Council via email using mailing lists, social media, and other professional networks. The location, date, and number of participants at each workshop is provided below in Table 1.

Table 1. Mental modeling workshops.

Date	Location	Number of participants
May 17, 2019	Douglas	8
May 23, 2019	Chikaming Township	16
June 5, 2019	Dexter	18
June 24, 2019	Lansing	18

Individuals were instructed that participation is voluntary and that all information shared will be anonymous. They were told that they would receive a $20 gift card for participating in the workshop. Participants were asked to indicate their willingness to participate in the workshop on a consent form (see Appendix C). Prior to receiving the modeling instructions, participants were asked to complete a brief survey that included some demographic information (see Appendix D). While the demographic information provided the project team with a general understanding of participants (e.g. age, education) the information was not a necessary component in the metamodel analysis and as such was not utilized.

Participants were informed about the purpose of the workshop and the objectives of the study, and they were provided with some basic information about mental models and some examples. They were given instructions for developing their own mental models, including four starter components that were required for each mental model. These four starter components were defined as:

- Dune quality—Quality of the dunes environment or dunes ecosystem
- Scenic beauty—Natural beauty of the dunes
- Access—Recreational access for leisure
- Development—Includes construction of roads, homes or marinas

Participants were instructed to brainstorm additional components that are related to these four starter components, and to draw these relationships on paper using arrows indicating the direction of impact. They were then instructed to indicate the strength or magnitude of the relationship using positive and negative symbols, per the labels in Table 2.

Table 2: Symbols representing magnitude of relationships in mental models.

Type of relationship	Positive	Negative
Very positive/negative	+ + +	- - -
Moderately positive/negative	+ +	- -
Somewhat positive/negative	+	-

Participants were given large sheets of paper, adhesive notes, and pens to complete the exercise. Most participants completed their mental models in about 30-40 minutes. After the mental modeling activity, Dr. Arbogast delivered a brief presentation on the dynamic nature of sand dunes and their unique characteristics in Michigan. At the end of the workshops, mental models were collected and reviewed for accuracy, and incomplete or unusable mental maps were discarded. Interns at Michigan Environmental Council were trained in the use of *Mental Modeler*, and they reconstructed all of the valid mental models in the software for analysis in a standardized format.

Forty respondents to the #HowYouDune online survey were randomly selected for invitation via email to participate in mental modeling webinars. Two webinars were held on June 27 and July 9, and participants were given instructions for using the *Mental Modeler* software to develop their own mental models of coastal sand dunes in Michigan. Instructions for constructing mental models were the same as in the workshops, including the four starter components. Participants submitted their completed mental models as an email attachment. A total of 17 mental models were submitted by webinar participants.

After discarding incomplete or unusable mental models, a total of 72 valid models were collected among the five sub-groups of workshop and webinar participants (Table 3).

Table 3: Number of completed mental models from each sub-group.

Sub-group	Number of models
Douglas	8
Chikaming Township	14
Dexter	17
Lansing	18
Webinar	15
Total	72

The data from these individual mental models were downloaded as spreadsheet files for analysis at the sub-group and full sample (metamodel) levels. Metamodels developed from each of the five sub-groups is attached as Appendix E.

Results

The mental models of coastal sand dunes in Michigan included dozens of unique components that were integrated into the mental models by 72 individual participants. The frequency at which unique components appear in individual mental models reveals information about the shared perceptions of multiple participants across the sample.

The data were analyzed in terms of the frequency of components or nodes in individual mental models. Figure 7 presents a frequency histogram of mental model components and highlights those nodes that were included in at least 10 percent of the mental models of individual participants. Beyond the four starter components that were included in all mental models, *litter* was the most frequently included node, appearing in more than 40 percent of mental models. This highlights the importance of the problem of litter as a threat to dunes ecosystems. The next most frequent nodes were *erosion*, *wildlife*, *invasive species*, *education*, and *vegetation*, all of which appeared in more than 30 percent of mental models.

These frequencies suggest a moderately high level of understanding of dunes ecosystems and the impacts of environmental change. Other nodes such as *visitors*, *climate change*, *tourism*, and *habitat* were included in more than 20 percent of mental models. The frequencies of these nodes reveal some of the values and concerns that are widely shared among dunes stakeholders, and the prominence of these issues among the mental models of participants has policy implications for the management of coastal sand dunes in Michigan.

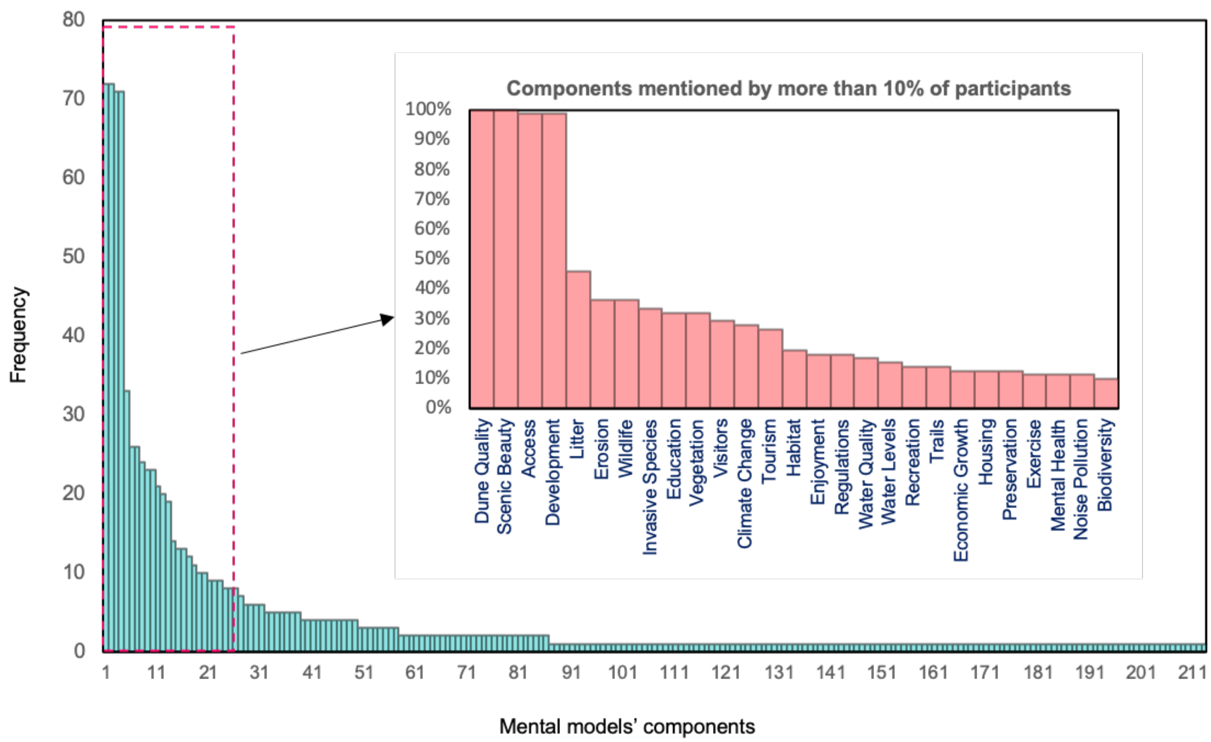

Figure 7. Frequency histogram of mental model components.

The data were also analyzed to generate metamodels to understand areas of shared agreement among participants with regard to particular values or concerns related to coastal sand dunes in Michigan. Figure 8 presents a core metamodel of nodes that were included in the mental models of individual participants in all five sub-groups (i.e., participants in four workshops and webinar participants). This model can be understood as an abstraction or simplification of the shared perceptions of coastal sand dunes among participants. The size of each node represents the degree of centrality, or the relative influence of particular nodes in a mental model and can be thought of in terms of relative importance of concepts to participants. Gray arrows represent positive relationships, while orange arrows represent negative relationships. The width of arrows represents the strength of relationships in terms of "very," "moderate," and "somewhat" positive or negative.

Not surprisingly, the four starter components (i.e., *dune quality*, *scenic beauty*, *access*, and *development*) reveal higher levels of centrality because they appear in every mental model and have the most connections to other nodes. The relatively wider, double-headed gray arrows between *scenic beauty* and *dune quality* imply the mutually supporting relationships between those two concepts. A similar relationship is depicted between *dune quality* and *wildlife*, and between *dune quality* and *habitat*, demonstrating that wildlife habitat is perceived to be a relatively important feature of dune quality to participants. There is a strong and mutually positive relationship between *tourism* and *access*, and between *preservation* and *access*, demonstrating how dunes in protected areas such as parks provide access for recreation and tourism. There is another strong and mutually positive relationship between *education* and *access*, demonstrating how access to dunes provide opportunities for environmental education and learning.

The concepts of *preservation* and *stewardship* are perceived as having positive impacts on *scenic beauty*. *Education* is perceived to have positive impacts on both *preservation* and *stewardship*, as well as on *habitat*, *wildlife*, and *vegetation*, which highlights the perception of the numerous positive benefits of education related to coastal sand dunes. There is a shared concern about *litter*, which is perceived to be driven by *tourism* and *visitors*. There is also a shared concern about *erosion*, which is perceived to be driven by *development*, *visitors, water levels*, and *climate change*. Participants emphasized the value of *regulations*, which are perceived to have positive impacts on *scenic beauty* and *dune quality*, and negative impacts on *litter*. This suggests that participants believe that regulations are effective tools for maintaining the values of dunes and their ecosystem services. *Tourism* is perceived to be positively associated with *development*, which in turn is perceived to have negative impacts on *wildlife*, *habitat*, *vegetation*, and *water quality*. Both *preservation* and *regulation* were perceived to have negative impacts on *development*, which suggests that these two approaches are seen as effective tools for mitigating the negative impacts of development on dunes ecosystems.

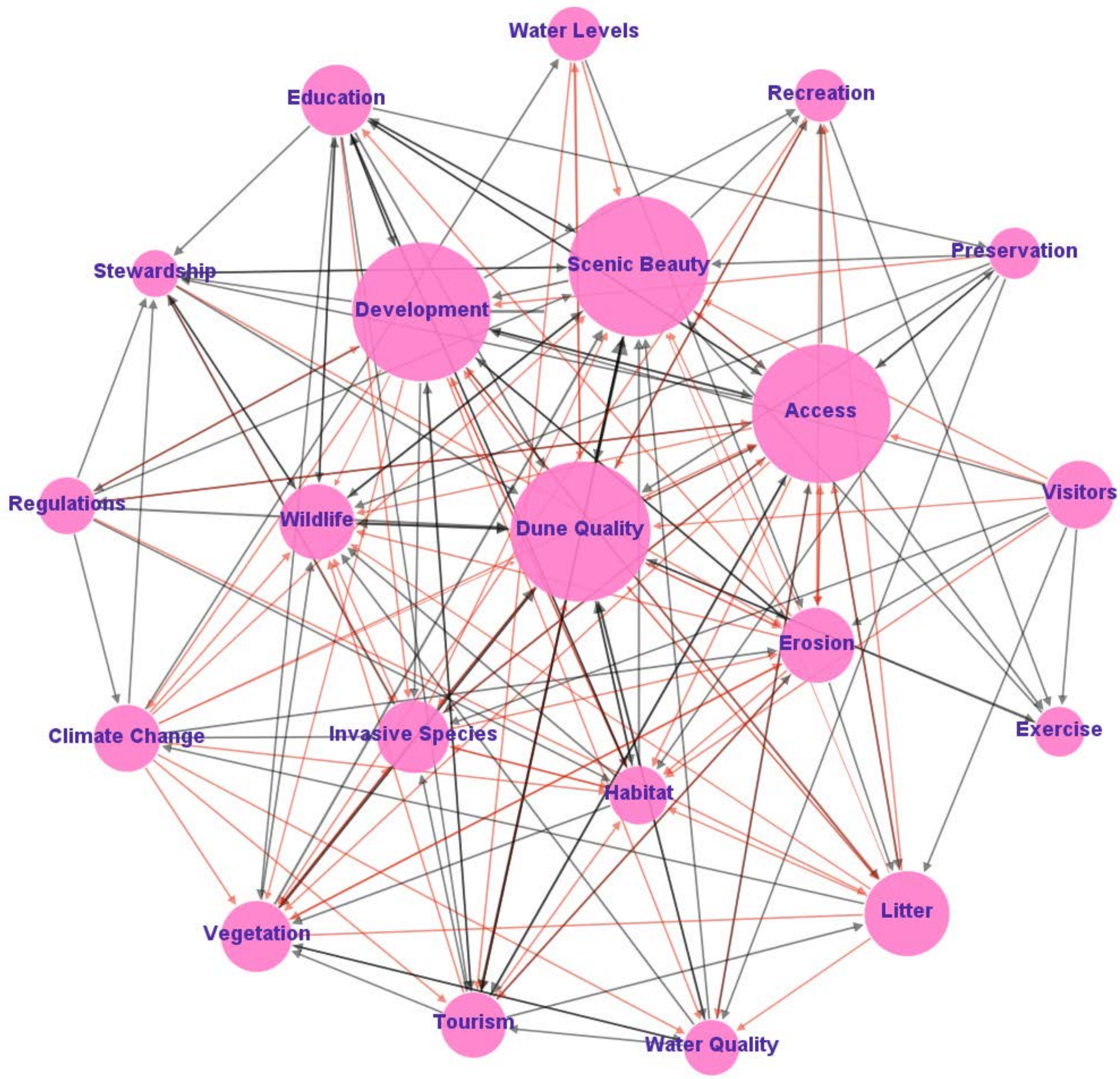

Figure 8. Core metamodel of nodes included in mental maps of all five sub-groups.

Additional concepts emerged as highly central to the metamodel when the project team accounted for mental map concepts represented in the majority of sub-groups (.e. at least three out of five sub-groups) rather than in all five sub-groups. Figure 9 represents a metamodel of these concepts.

As above, the size of each node represents the degree of centrality, or the relative influence of particular nodes in a mental model and can be thought of in terms of relative importance of concepts to participants. Gray arrows represent positive relationships, while orange arrows represent negative relationships. The width of arrows represents the strength of relationships in terms of "very," "moderate," and "somewhat" positive or negative.

Some of the same relationships appear in this broader metamodel, including the mutually supporting relationship between *scenic beauty* and *dune quality*. Several new concepts emerge, including the Americans with Disabilities Act (ADA), which prohibits discrimination against individuals with disabilities in all areas of public life and requires inclusion of features such as accessible parking spaces, routes, toilet facilities, and spectator seating areas (ADA, 1990). Participants perceived *ADA access* to be positively associated with *access*. Other components such as *trails* and *roads* are also perceived to be positively associated with *access*, which in turn is perceived to have a positive impact on *visitors*. *Biodiversity* is perceived to have a positive impact on *dune quality*, while *invasive species* is perceived to have a negative impact. Again, participants emphasized the value of *regulations*, which are perceived to have positive impacts on *dune quality*, while *ORVs* (off-road vehicles) are negatively associated with *dune quality*. This suggests that participants believe that regulations are effective tools for protecting the values of dunes and their ecosystems, which are perceived as threatened in part by the recreational use of ORVs. Participants emphasized the importance of dunes management in perceiving components such as *public land* and *stewardship* to be positively associated with *scenic beauty*, which is negatively affected by *erosion* and *invasive species*. In addition, participants find *visitors* to have a negative impact on *scenic beauty*, implying a preference for less crowded spaces for outdoor recreation. Components such as *dune quality* and *scenic beauty* are primary drivers of *enjoyment*, and in turn, *scenic beauty* was perceived to have a positive impact on *mental health*. Participants perceived *population* and *tourism* to be positively associated with *economic growth*, which contributes to *development*. In turn, development is perceived to be negatively associated with habitat, wildlife, and vegetation.

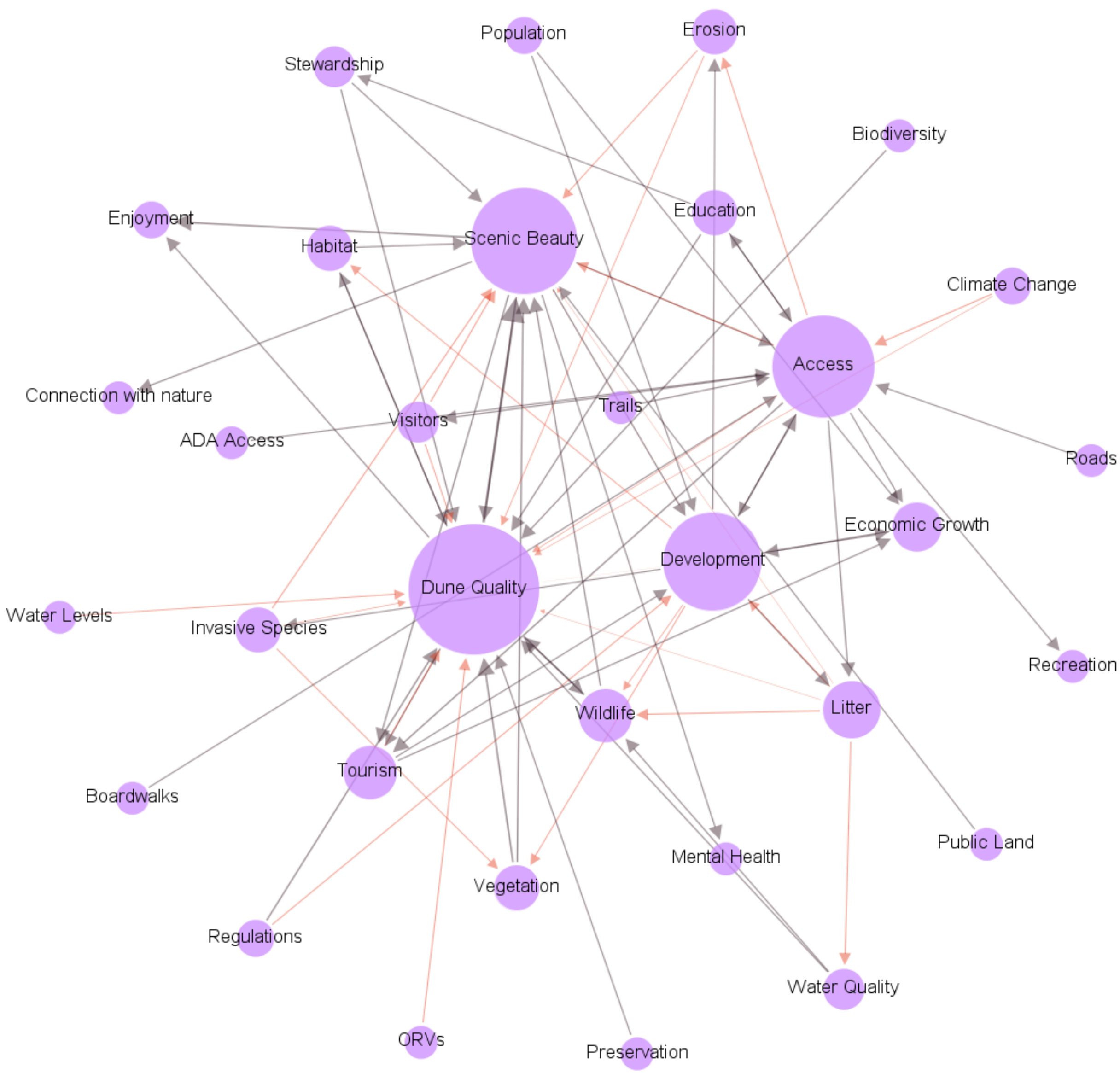

Figure 9: Metamodel of nodes included in mental maps in a majority of sub-groups.

In terms of the primary drivers associated with the four required starter components (i.e., *dune quality*, *scenic beauty*, *access*, and *development*), there were several areas of strong agreement among respondents regarding the benefits of coastal sand dunes and threats to the integrity of dunes. Table 4 presents the top three most frequent concepts that were included as having impacts on these four concepts as well as the top three concepts that were included as being impacted by these four concepts. Participants noted moderately negative impacts of *development* on both *dune quality* and *scenic beauty*. *Litter* was included as having somewhat negative impacts on both *dune quality* and *scenic beauty*. *Trails* and *ADA access* were included as having somewhat positive impacts on *access*, which reveals some of the important drivers of access among participants. Participants noted that *dune quality*, *scenic beauty*, and *access* were all positively associated with *enjoyment*, revealing some of the primary drivers of pleasure when visiting dunes for recreation. Both *scenic beauty* and *access* were perceived as being positively associated with *tourism*. *Development* was perceived as having moderately negative impacts on *dune quality* and *scenic beauty*, and somewhat negative impacts on *wildlife*. The perceptions of *development* as a starter component reveals a feedback loop with *scenic beauty*, which is perceived as having somewhat positive impacts on *development*, implying that the beauty of dunes is part of the attraction that leads to development. However, *development* is perceived as having somewhat negative impacts on *scenic beauty*, as new construction diminishes the aesthetic values of the natural dunes landscape.

Table 4. Primary drivers of change for four required starter concepts.

Concept	Effect	Concept	Effect	Concept
Development	--	**Dune Quality**	++	Scenic Beauty
Litter	-		+	Wildlife
Climate Change	-		+	Enjoyment
Development	--	**Scenic Beauty**	+	Enjoyment
Dune Quality	++		+	Mental Health
Litter	-		+	Tourism
Trails	+	**Access**	-	Dune Quality
Development	+		+	Tourism
ADA Access	+		+	Enjoyment
Litter	-	**Development**	--	Dune Quality
Scenic Beauty	+		--	Scenic Beauty
Population	+		-	Wildlife

Conclusion

Mental modeling can be a valuable tool in advancing understanding of how stakeholders perceive the benefits of coastal sand dunes and the threats to the integrity of dunes ecosystems. The components of mental models reveal important information about the perceived benefits of coastal dunes ecosystems and the threats to the integrity of these ecosystem services. In this study, dozens of unique components were integrated into the mental models of 72 participants in workshops and webinars, and at least 23 unique components appeared in more than ten percent of the mental models. As each new mental model is added to the database, the *saturation point* reveals the number of participants at which the maximum number of unique components is reached. The mental modeling data were analyzed to determine the saturation point for unique components or nodes. Figure 10 presents a frequency asymptote curve of total unique nodes (red) and unique concepts added with each additional participant (green). The analysis reveals a total saturation point at 61 of 72 participants, or approximately 84.7 percent. Beyond the asymptote or saturation line, data from the mental models of additional participants do not include additional unique nodes.

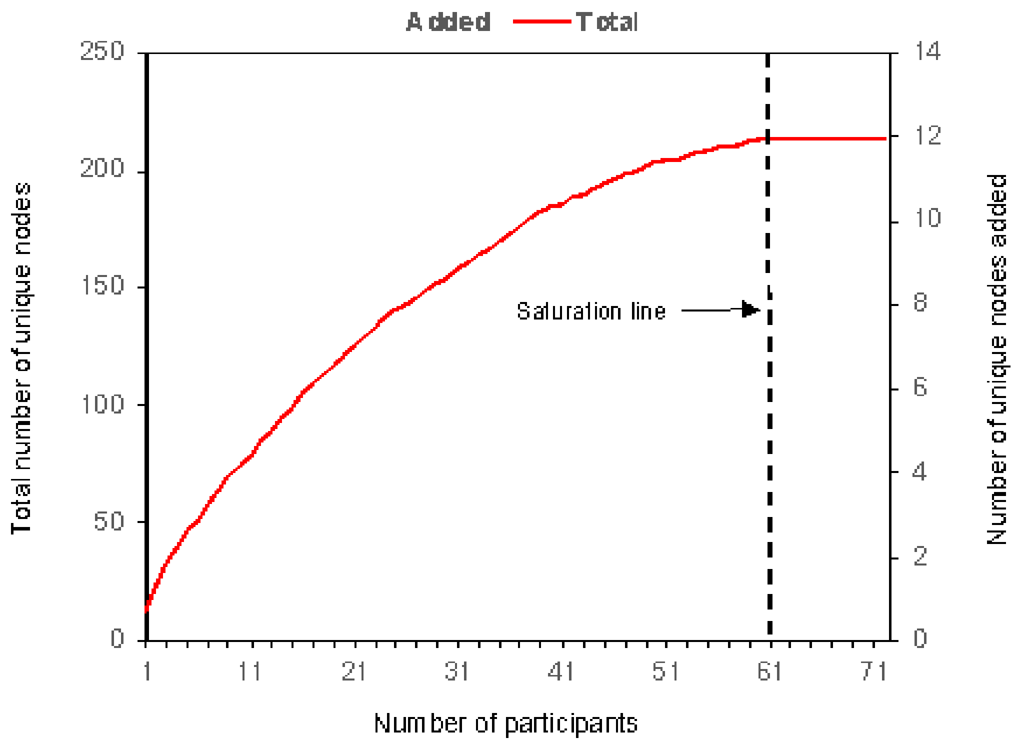

Figure 10. Saturation of mental model components or nodes.

The results also reveal high levels of frequency and centrality of four starter components, namely, dune quality, scenic beauty, access, and development. Other components are frequently included in individual mental models, including *litter*, *erosion*, *invasive species*, *wildlife*, *habitat*, *vegetation*, *education*, *preservation*, and *stewardship*, which highlights many of the perceptions of values and concerns associated with coastal sand dunes.

Metamodels reveal a shared positive perception of *dune quality*, *scenic beauty*, and *access*, which are generally seen to contribute to *enjoyment* and *tourism*, and in some cases, *mental health*. *Dune quality* is positively associated with *scenic beauty*, *wildlife*, and *habitat*. There is a shared perception that *education* is positively with both *preservation* and *stewardship*, as well as on *habitat*, *wildlife*, and *vegetation*, which highlights the perception of the numerous positive benefits of education related to coastal sand dunes. The concepts of *preservation* and *stewardship* are perceived as having positive impacts on *scenic beauty*, which has implications for the management of dunes ecosystems.

There is a generally widespread concern about *litter*, *development*, and *invasive species*, which are perceived to have a negative impact on *dune quality* and *scenic beauty*. There were also concerns about the impacts of *climate change* on *dune quality* and *access*. These findings are consistent with the literature, which suggests that the greatest threats to ecosystem services provided by sand beaches and dunes include human use, development, invasive species, pollution, and climate change (Brown and McLachlan 2002; Zarnetske et al. 2010; Barbier et al., 2011; Hacker et al., 2012). Participants emphasized the value of *regulations*, which are perceived to have positive impacts on *scenic beauty* and *dune quality*, and negative impacts on *litter*. This suggests that participants believe that regulations are effective tools for maintaining the values of dunes and the integrity of their ecosystems.

There is also a shared concern about *erosion*, which is perceived to be driven by *development*, *visitors*, *water levels,* and *climate change*. In general, *development* was perceived as negatively associated with *dune quality*, *scenic beauty*, and *wildlife*. The perceptions of *development* reveal a feedback loop with *scenic beauty,* which is perceived to be positively associated with *development*, and in turn, *development* has a negative impact on *scenic beauty*. Both *preservation* and *regulations* were perceived to have negative impacts on *development*, which suggests that these two approaches are seen as effective tools for mitigating the negative impacts of development on dunes ecosystems. These findings have implications for coastal dunes management and policy.

Part 3. Communications and Engagement

Michigan Environmental Council staff lead communications and engagement activities for this project, and successfully obtained media coverage and participants for project activities.

Citizen Scientist Photo Submissions

Our media campaign to solicit photos from citizen scientists garnered a wide array of attention from across the state and resulted in more than 70 photos submitted:

- WWMT: Become a citizen scientist by submitting your older Lake Michigan dune photos
- Grand Haven Tribune: Dune photos sought for research project
- WILX TV: Help track Michigan's sand dunes
- Manistee News Advocate: Researchers want your old Lake Michigan vacation photos
- Michigan Radio Stateside: Interview with Tom Zimnicki
- Fox 2 Detroit: Michigan Environmental Council: Send us your old coastal dune photos
- Traverse City Record Eagle: Wanted: Your old dunes photos; Sands of Time project studies Michigan's coastal dunes

Citizen Scientist Photography Protocols

The project team worked together to create the citizen scientist photo submission protocols for both historic and repeat photography, which was widely shared via several communications channels. The toolkit/protocol was featured on the MEC website with clear instructions and an easy to use form for uploading photos (see Appendix A & B).

Michigan Coastal Dunes Symposium 2019

We planned a day-long symposium with the goal of sharing preliminary results and cutting-edge science from the current project, and promoting civic engagement to support sound coastal dune management. The target audience was local and state planners and decision-makers for Michigan coastal dunes communities, as well as coastal dunes advocates, scholars and interested residents.

The following organizations were enlisted to help promote the symposium to their networks:

- Michigan Townships Association
- Michigan Municipal League
- Michigan Association of Planners
- Southwest Michigan Planning Commission
- Michigan State University Department of Geography
- Michigan State University Department of Community Sustainability
- Michigan Coastal Management Program
- Preserve the Dunes
- West Michigan Environmental Action Council

We also called on the project's advisory committee to share with their considerable networks:

- The Stewardship Network
- The Nature Conservancy in Michigan / Michigan Dune Alliance
- Heart of the Lakes

State lawmakers representing these key committees were invited via email, phone and in-person invitation drops:

- House Natural Resources
- House Commerce and Tourism
- Senate Environmental Quality
- Senate Natural Resources

Finally, we invited individuals who completed the #HowYouDune survey, and promoted on Facebook with a Facebook event and a two-week targeted ad campaign.

We were delighted to have ~75 people register for the event and 57 people representing our target audience participate in the symposium.

The *Michigan Coastal Dunes Symposium 2019: Learning to Live in Dynamic Dunes* was held in Lansing in October 2019 (for the symposium invitation and program, see Appendix F & G).

The Symposium featured presentations that focused on four main themes:

- how have Michigan's coastal dunes changed in the last 100 years;
- what impacts do our activities have on natural dune processes;
- how are dunes perceived by Michigan residents and communities; and,
- what criteria do local and state decision-makers use when making dunes planning and management decisions?

This highly successful event revealed two main points:

1. Dunes and the management of dunes generate strong interest and involvement from diverse residents across Michigan.

2. State and local decision makers recognize the need for more comprehensive and holistic guidance for coastal dune management and interactions with dunes. A panel discussion featuring Marcy Hamilton (Southwest Michigan Planning Commission), Jennifer Howland (City of Grand Haven), Kate Lederle (Michigan Department of Environment, Great Lakes, Energy), and Richard Norton (University of Michigan College of Architecture and Urban Planning) highlighted the need to have a more robust conversation around dune management/planning and how new research and understanding of dune processes might impact those planning decisions.

Appendix H provides a complete summary of all Symposium Q&A including the panel discussion from decision makers.

Conclusion

This project highlighted the complexity of both physical dune processes and how residents understand coastal dune systems. The complexity was illustrated in both the repeat photography and mental modeling portions of the project. Our work also reinforced the strong interest and passion that coastal dunes elicit within residents and that residents are increasingly concerned about efforts, or lack thereof, to conserve and manage dune landscapes at both the State and local level. The project team believes the outcomes of the photograph and mental mapping portions of this project could inform short and long-term planning strategies for governmental officials.

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