# Bringing the Latest Science to the Management of Michigan's Coastal Dunes

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**Michigan Environmental Council**
**May 2015**

## Support

Financial assistance for this project was provided, in part, by the Michigan Coastal Zone Management Program, Office of the Great Lakes, Michigan Department of Environmental Quality (MDEQ), under the National Coastal Zone Management Program, through a grant from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

The statements, findings, conclusions, and recommendations in this report are those of the authors and do not necessarily reflect the views of the Michigan Department of Environmental Quality and the National Oceanic and Atmospheric Administration.

## Project Management

The Michigan Environmental Council (MEC), a 501(c)3 non-profit organization created in 1980, functioned as project coordinator and fiscal agent for this effort; however, it is first and foremost a partnership of researchers, practitioners and academic experts, many of whom work in and study Michigan's coastal dunes as their primary research focus. MEC developed this project explicitly to bring together experts to advance the state of scientific knowledge and hopefully support the work of the Michigan Department of Environmental Quality (MDEQ) in its charge to to protect, preserve, restore, and enhance the world's premier freshwater coastal dune system.

In addition to conducting new, primary research through both independent and collaborative efforts, members of the research teams and advisory committee met together four times during the grant period to review and critique existing information, develop and refine research methodologies and refine final work products. MEC hopes and believes the relationships and collaborations formed or strengthened through the course of this project will have a lasting impact in bringing our ever-expanding and improving scientific knowledge to bear on governmental and societal decisions about our dunes.

## Project Oversight

The Advisory Committee for this project included: **Alan F. Arbogast** (Michigan State University), **Steve DeBrabander** (Michigan Department of Natural Resources), **Elizabeth Brockwell-Tillman** (P.J. Hoffmaster State Park), **Brad Garmon (**Michigan Environmental Council), **Alisa Gonzales-Pennington** (Michigan Department of Environmental Quality), **Christopher Graham (**Michigan Natural Areas Council), **Edward C. Hansen** (Hope College), **Richard K. Norton** (University of Michigan), **John J. Paskus** (Michigan Natural Features Inventory), and **Robert B. Richardson** (Michigan State University).

## Acknowledgements

The impressive cast of academic experts and practitioners contributing to this project leveraged their scientific/technical expertise with minimal financial support, many making substantial in-kind contributions to the project through discounted hourly rates or significant *pro bono* work on the project. We are grateful and extend our sincere thanks to the following researchers, collaborators and contributors:

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We would also like to acknowledge the invaluable contributions of the following experts, each of whom provided project guidance, review and comments on methodologies, and review of project deliverables. Again, much of this work was done *pro bono*, or with minimal financial support.

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## Executive Summary

Michigan's world-class coastal dunes provide ecologic, geologic and economic value to our state's coastal communities. They attract new residents and millions of visitors to our shorelines. In the process, they challenge us to weigh our enjoyment of the dunes against the need to protect them and live in greater harmony with their dynamic, evolving character.

Calls for scientific studies and additional information to aid in our efforts to manage Michigan's coastal dunes were common even before state the created laws specific to them. Most recently, when policymakers revised the critical dune statute in various ways in 2012, they included a call for application of "the most comprehensive, accurate, and reliable information and scientific data available" to government decisions (Part 353, Section 324.35302(a)(iii)).

This project sought to advance that cause and improve our understanding of our coastal dune resources in three specific ways:

- **Defining and delineating the coastal sand dunes in a GIS environment.** What precisely is a coastal sand dune? Where are they? What is their current status in terms of ownership and management? How have they changed or been altered over time?
- **Understanding the sensitivity of the geomorphology and ecology of the coastal dunes.** What processes and activities are necessary to define and support an inherently dune-based ecology and physical form? How are these aspects impacted by human activities and development within the dune environment?
- **Exploring alternatives, options and strategies for managing coastal dune resources.** How did Michigan's approach to dune management originate and evolve, and how does it compare to other efforts around the country? What are the characteristics, perceptions and outcomes of this approach within Michigan's coastal dune communities?

The researchers addressed these questions through four discrete research projects:

- Creating a **systematic digital inventory** of Michigan's dunes using Geospatial Information Systems approaches;
- Developing **geomorphological and ecological models** to help assess likely impacts of various potential dune development approaches, including exploration of the potential for mathematical modeling to assist in estimating potential future impacts;
- Conducting a **historical, legal, and comparative review** of management approaches, including a comparison of other state programs and a survey of local officials;
- Reviewing emerging research on dune ages and dynamics and their **implications for risk and resilience** related to development in the dune context.

Most of this work was done by scholars employing scientific methodologies in a formal research context. This independent research was augmented by quarterly meetings of the researchers and the project advisory committee where methodologies were reviewed, discussed and refined. A significant element of the project also involved surveying local government leaders involved in the dune permit review process to gauge interest and support for various aspects of local dune management, providing a direct connection of this academic research to the more practical

requirement of implementing management approaches that support protection, enjoyment and use of the dune by local communities.

The project coordinator (MEC) collaborated with the advisory committee and researchers to write this project report, summarizing the research (much of which is currently being refined for submission and eventual publication in peer-reviewed journals), tying it together and providing recommendations to improve the science-based management of our coastal dune resources. This summary report, including recommendations, will also be presented to MDEQ officials and other relevant state decision makers for consideration and discussion.

The project recommendations, discussed and presented more fully in Part 3 of this report, are summarized as follows:

1. Expand and encourage awareness and use of geographic information in dune management, especially the new Michigan Dunes Inventory (MDI) GIS, by developing a new GIS layer to delineate Michiagn dunes, and by offering training sessions and model projects for state and local governments and non-governmental partners.
2. Incorporate the latest science into current dune management programs, particularly with regard to minimizing stabilization of dynamic or mobile dune complexes.
3. Convene a workgroup of state and local leaders to clarify and articulate the ideal role for both state and local government in dune management.
4. Fund additional scientific studies to determine the appropriate scale (local, regional, statewide) for measuring and managing ecological impacts to the dunes.
5. Close the most critical information gaps regarding the sensitivity of dune species and ecological communities to habitat fragmentation, using both professional and citizen science strategies.
6. Incorporate more risk and resiliency considerations into Michigan's dune management programs at the state and local levels, based on emerging understanding of dune age and the drivers of large-scale (geographic and temporal) dune dynamics.
7. Foster a stronger coastal dunes stewardship ethic and education program through outreach and engagement efforts, seeded by use of the "Understanding Michigan Dunes" journal map.
8. Convene a one-day summit to articulate goals and a statewide strategy for identifying and securing, through voluntary fee-simple purchase or conservation easements, some of the largest of the remaining high-quality, undeveloped coastal sand dunes.
9. Incorporate additional best practices from other state and provincial dune management programs into Michigan's approach, such as: a) clearly defining the state vs. local governmental roles, b) adding considerations for risk management in dunes, in addition to providing natural and scenic protections, and c) increasing public-private partnerships for stewardship.

MEC has also packaged the component parts of this project, including additional research, appendices, and a wealth of historic, legal, academic and practical studies and reports together, and made the information publicly accessible on our website: http://www.environmentalcouncil.org/coastaldunes. We plan to employ MEC's social and

traditional media capacities—including Face book and Twitter feeds, e-mail lists, electronic and print newsletter and website—to share this information with the public.

In the future, MEC plans to seek additional resources and opportunities to host public meetings in order to share the information and tools developed through this project widely with a concerned public, and to use the results of this project as a starting point for facilitating and applying additional research.

## Introduction

The history of Michigan's management of its coastal dune resources demonstrates that bringing "the latest science" to bear on this challenge has long been viewed as a critical need, if not always a top priority. The state's first dune-related law, passed in 1976, called for a host of new research projects to be completed to improve our understanding and management approaches (PA 222 of 1976). The first major revision and expansion of the law in 1989 also called for scientific studies to be completed, including a review of the maps that comprised the dune atlas (Public Acts 146 and 147 of 1989). The review was delivered a year later, but was not incorporated into the law (a topic discussed in greater detail later in this paper).

In reviewing calls for using science to address these dune challenges, a few dominant themes clearly emerge, including: 1) repeated requests for a fuller and more sophisticated inventory of the coastal dunes; and 2) suggestions for developing some kind of ecological sensitivity or impact analyses to help measure and understand the basic thresholds and capacities of plants and animals dependent on the dunes. For example, Marlene Fluharty, then a member of the state's Natural Resource Commission, wrote in a 1985 edition of Michigan Natural Resources Magazine, "There is a critical need for a standard set of criteria for professional land managers and planners to identify the relative sensitivity of the dunes complex. Such a sensitivity index would then help to identify the types of activity or development that could take place without impairing or destroying this irreplaceable resource" (p. 27).

A comprehensive 1987 University of Michigan Master's student thesis project suggested that "Michigan's dunes should be comprehensively inventoried and analyzed" by creating a "map of the entire system of dune system" that would, among other things, "document existing land uses in the dunes" (Beede VI-2). It also suggested the state needed to "design and/or develop a comprehensive dune system map, including geological, ecological, administrative, and other features" (Beede VI-4) .

For better or worse, these same primary research needs—a better dunes inventory with geographic capabalilites, and more sophisticated tools for understanding the sensitivity and thresholds of dune ecologies—remained top priorities for leading dune researchers when our current project was being developed nearly 30 years later. Both items became central to the current effort presented here. In addition, as highlighted in Section 2.4, more recent research, particularly over the last 20 years, has advanced our understanding of the age and geomorphic history of the dunes. The insights, based on increasingly sophisticated dating of soils and sands, have begun to alter in fairly dramatic ways many of our foundational concepts of the dunes.

It has also become clear that insights from social and political science have a role to play, especially in understanding the institutional and governmental systems that must be engaged in any successful dune management program. These would include the roles of local and state governments, regulatory and voluntary options, and best practices from other regions and municipalities hosting coastal sand dunes. We explored this realm with a new survey of local officials (Section 1.4) intended to better gauge their needs and appetite related to dune management, as well as undertaking a new review of related dune management programs in other states and provinces (Section 2.5).

The most recent changes to Michigan's dune management law (PA 297 of 2012) repeated the science theme that has been a consistent hallmark of dune law in Michigan since the initial legislation in 1976. While not explicitly calling for new dune research, the 2012 amendments recognized the importance of science for effective dune management, specifically calling for the application of "the most comprehensive, accurate, and reliable information and scientific data available" in fulfilling the Act's purpose (Part 353, Section 324.35302(a)(iii)).

This project and summary report is a direct response to that call, summarizing the results of a collaborative effort to make science a fuller partner in the management of our dunes. In the decades since Michigan's first coastal dune law was enacted, scholars have certainly advanced the state of scientific knowledge about Michigan's world-class coastal dunes, including sharpening our understanding of when and how dunes formed, their role in supporting native species and natural features, and the factors influencing their highly dynamic nature.

Our efforts here are intended to better provide Michigan with this information, summarizing the best and most up-to-date picture of the dunes themselves, pushing the science forward, and finding the best, most useful, and most interesting innovations among the various management programs and systems in place to support dunes in Michigan and elsewhere. The goal is to enable the state and its coastal communities to engage in true, science-based management of this unique and vital coastal resource.

# Part 1: Role of Science and Policy in Dune Management Efforts

## 1.1 Role of Science in Dune Policy

Science has been intimately woven into Michigan's sand dune laws since the beginning. Prior to passage of the state's original 1976 Sand Dune Protection and Management Act, the state had published at least one geologic pamphlet on the dunes, 1962's "Michigan's Sand Dunes – A Geologic Sketch," written by Robert W. Kelley and published by the state's Geologic Survey Division (Kelley 1962.). This, in turn, included references to a 1942 study completed for the Michigan Academy of Science, Arts and Letters: "The Dunes of Lake Michigan and correlated problems," by I.D. Scott.

The 1976 Sand Dune Protection Act, however, was the state's first foray into requiring permits for mining and in formally designating some dunes as in need of protection. In anticipation of

broader regulation and because "basic technical information on sand dunes and adjoining land uses was so deficient," the legislation also required the MDNR to undertake additional study and conduct an inventory of sand dunes in Michigan, to be delivered by July, 1977 (Wyckoff 29). That report was to include:

- "An economic study of the current and projected sand dune mining practices in the state, showing where the sand is marketed, its uses, and the amount of sand reserves.
- A geologic study of sand areas within the state, other than Great Lakes and dune areas, that would contain sufficient reserves and have properties suitable for use as foundry core and molding sands or for other uses of sand.
- Sand dune areas or portions of sand dune areas that, for environmental or other reasons, should be protected through purchase by the state or other persons or interests, or easements including the acquisition of mineral rights by the state, and a priority list of sand dune areas to be acquired by the department.
- An identification and designation of barrier dunes along the shoreline, showing their effect on aesthetic, environmental, economic, industrial, and agricultural interests in the state.
- Methods for recycling or reusing sand for industrial and commercial purposes, along with alternatives to the use of dune sand and its economic impact.
- Recommendations for the protection and management of sand dunes for uses other than sand mining" (PA 222 of 1976, Section 281.653(3)(a-f)).

Several of these studies were completed, such as the alternatives study and an economic study of the sand dune mining industry in Michigan (Investigation 20). Preliminary identification of so-called "barrier" dunes was done as part of a study completed three years later, in 1979, by W.R. Buckler through Michigan State University's Remote Sensing Project. The study provided a "dune morphology classification" for the state's Great Lakes shoreland areas based on dune form, height, relative position and relationship to the "underlying formation" (Buckler 1979). Dune assemblages were identified and mapped according to this classification in priority areas. (A fuller description of Buckler's use of the term "barrier dune," which differs from the typical use of term in ocean coastal environments, can be found in Wyckoff p. 23).

Several of the requested studies, however, remained outstanding in 1984, when Michigan Governor James Blanchard tasked the Michigan Department of Natural Resources (MDNR) with developing a program to again address the dunes (Feb. 8 letter to MDNR Director Skoog, as quoted in Wyckoff). The Natural Resources Commission, an appointed body which provided oversight to the Department of Natural Resources, soon established a Citizen's Sand Dune Advisory Committee to "develop, review, and evaluate proposals for protection and management of sand dunes" (Wyckoff 43).

Again as summarized by Wyckoff, the Committee's report was issued in January 1985 and encouraged legislation for protecting sand dunes in private ownership and also recommended a set of ideas to consider in future legislation. Many of these concepts would later be reflected in state statute and become sources of contention, debate and future legislative debate and revision. They included:

1. “A citizen committee of concerned interests should develop the criteria and land use standards required by the legislation, with public involvement.
2. The criteria and land use standards should be established through the administrative rule process.
3. Local units of government should have the opportunity to protect sand dunes through adoption of zoning regulations which equal or exceed the standards set forth in the administrative rules.
4. The Department of Natural Resources should review all local zoning ordinances to assure that they meet the established criteria and standards. The Department should provide assistance to local governments in developing zoning ordinances.
5. The Natural Resources Commission should adopt regulations applying to development and use of sand dunes where:
    a) A local zoning ordinance does not meet the state standards, and the local government will not adopt an acceptable ordinance;
    b) An acceptable local ordinance has not been adopted within 5 years; or
    c) The local government elects not to adopt an acceptable ordinance.
6. An appeal process should be specified for local governments to contest a decision by the Department of Natural Resources.
7. During the period of time from enactment of the legislation to approval of the zoning ordinances, the local governments should notify the Department of proposed land developments in sand dunes. The Department should be allowed 60 days to respond to the proposal. If a local government does not have a zoning ordinance in effect, the Department should be able to review and approve projects during this interim time period” (Wyckoff 43).

The Committee’s report was adopted unanimously by the Natural Resources Commission, and its recommendations referred to as an “action plan.” Governor Blanchard called for additional sand dune protection in his 1986 State of the Union address.

Also in 1986, Mark A. Wyckoff, president of the Planning & Zoning Center, Inc., published “Managing Sand Dune Development in Michigan: State & Local Options,” in support of the continuing effort of the state MDNR to address sand dune development. His report provided definitions and context, explored various values associated with sand dunes, explored how development within sand dunes areas was currently addressed at the state and local levels, articulated interest group and public viewpoints on dunes, and highlighted alternative management approaches from other state programs. Notably, his report concluded with a call for “sound technical information” to be the basis of a “comprehensive statewide approach to sand dune management” (Wyckoff 71).

However, he also noted that “the lack of important, but not as yet collected information should not prevent the rapid development of comprehensive state sand dune policy—beginning with strengthening sand dune legislation. Waiting until more information is collected before acting will only insure that miles and miles of sensitive dune lands will be transformed to other uses without adequate assurance that unnecessary degradation of the natural dune environment will be prevented” (Wyckoff 71).

That report was followed a year later by another, even more lengthy study from the University of Michigan, the "Michigan Sand Dune Management Project" (Beede et al. 1987). Developed as a Master's thesis project, it provided a regional analysis which included a theoretical statewide dune policy, an historical overview of the definition and extent of Michigan's dunes, and demographic and economic factors; and land use and ownership classification systems.

As mentioned in the introduction, this 1987 University of Michigan project suggested an ecological classification system, including an ecosystem approach and case study, and ecologically based design recommendations (e.g., shoreline, hydrologic, dune formations, and vegetation processes). The report's conclusions also recommended specific actions to be undertaken by the State of Michigan, including: 1) that Michigan's dunes should be comprehensively inventoried and analyzed; 2) the state should "constrain development to meet the carrying capacity of dune systems based on comprehensive geological, ecological, aesthetic, and socio-political considerations;" and 3) the state should implement "a comprehensive regulatory and management scheme," including regulation of residential development (Beede VI-2).

More ecological information emerged in 1988 when another University of Michigan Master's degree thesis noted that 50 percent of dunes in private ownership were likely to be developed by 1996, with 31 percent of that being considered ecologically valuable. The report, *A Handbook for Managing Michigan's Endangered Private Dune Lands*, discussed and analyzed several types of development in dunes, and presented a method for identifying different categories of dune areas—endangered, disturbed, and wind prone. The report also covered ecological principles associated with coastal dunes, impacts of development, and proposed ecologically based management guidelines for development. Also included in the report were coastal maps of all designated sand dunes along Lake Michigan (Boven et al, 1988).

Two final research projects related to dune management are worth special note here, though both are discussed in more detail in Section 1.2. The "Atlas of Michigan Critical Dunes" was developed by the State of Michigan and adopted in February 1989, prior to passage of that year's expanded Sand Dune Protection Act (PA 146 and 147 of 1989). This Atlas primarily provided maps delineating the designated critical dune areas as defined by the MDEQ's Land and Water Management Division, which would administer the Act once the Atlas was codified in law later that year.

In that Atlas, critical dune areas were defined based on an "analysis of barrier dunes, soil surveys, geomorphologic dune features, topography, and exemplary dune association plant communities as designated by Michigan Natural Features Inventory." (Lusch 2). The lines encompassing these areas were drawn on paper maps and later digitized. The areas often included only a portion of a parcel, making the critical dune designation a feature on the landscape, more like a wetlands determination, rather than a general classification applied to an entire property. Using this approach, the critical dune designation was applied to approximately 74,000 acres out of the approximately 275,000 total acres of coastal areas identified as sand dunes in PA 222 of 1976.

The dune law was also later reorganized as part of a 1994 legislative reauthorization and amendment process. At that time, an addition to the law called for a follow-up, scientific review of the accuracy of the 1989 Atlas of Critical Dunes, to be completed within one year, including recommendations to the legislature for any changes to the Atlas or the underlying criteria used to delineate dunes. Michigan State University's Center for Remote Sensing was contracted to conduct the evaluation. David Lusch et al.'s *Final Report: Evaluation of Critical Dune Atlas Designated Under Part 353 Sand Dune Protection and Management of the Natural Resources and Environmental Protection Act 1994 PA 451*, was published in June 1996 and provided to the Michigan legislature in October 1997. The extensive report revisited and clarified various questions that had arisen as a results of earlier attempts at delineation, including a revised definition of "barrier dune" (Lusch 10).

Lusch's final report recommended changes on 60 of the original 1989 Dune Atlas's 72 total pages. It culminated in a recommendation to add approximately 12,000 acres of dunes to the Critical Dune Atlas, and to delete 230 acres that were deemed not to qualify and which, the report suggested, should not have been included in the original Atlas. The legislature did not take action to revise the Critical Dune Atlas, so the boundaries remain as originally drawn into the Atlas by the MDNR in 1989.

While by no means exhaustive, this list of studies and projects gives a taste of the tension between science and policy that has been part of Michigan's approach to sand dune management from the earliest efforts. To further explore this connection, it is worth taking a specific look at the history of legislation related to dune management, and some of the legal challenges that have arisen.

## 1.2. Michigan Dune Legislation: Timelines and Provisions

*1976 Sand Dune Protection and Management Act*

As previously mentioned, the State of Michigan began regulating activity in coastal sand dunes in 1976. The law dealt specifically with industrial sand mining for use in foundries and other commercial purposes. This law defined a sand dune area as "that area designated by the department [of Natural Resources] that includes those geomorphic features composed primarily of sand, whether windblown or of other origin and that lies within 2 miles of the ordinary high-water mark on a Great Lake." The areas regulated by the Act in relation to mining were termed "designated dunes," which MDNR staff further defined as "a land mass which exhibits the physiographic features of a dune-type ecosystem."

*1989 Legislative Amendments*

The Michigan legislature amended the 1976 "Sand Dune Protection and Management Act" (PA 222 of 1976, dealing specifically with industrial sand mining) in 1989 with the passage of the Sand Dunes Protection and Management Act (PA 146 and PA 147 of 1989, expanded to deal specifically with residential and commercial development in the dunes).

According to the history of the dune legislation on the MDNR website, passage of the law "came after years of effort by Governor James J. Blanchard, a number of legislators, representatives of local governments, environmental groups, the Natural Resources Commission, and the MDEQ" (Coastal Dunes, MDNR 2015). The fight, specifically the advocacy on the part of the Michigan United Conservation Clubs and the West Michigan Environmental Action Council, even elevated the issue to the pages of the New York Times in August of that year (Stoffel, 1989).

The Act was passed in the 1988-1989 legislative session and put greater emphasis on local government administration of the Act. It also codified in law the critical dune areas as mapped in the Atlas of Critical Dunes in February, 1989. Regulated activities within the designated dune areas included construction of buildings, septic systems, water wells, driveways, all excavation and filling, and vegetation removal. The law prohibited development on dune slopes greater than 25 percent without a special exception, and on the lakeward facing slope of the first significant dune features closest to the lakeshore in critical dunes.

The Act also restricted the amount of vegetation that could be removed. It required that critical dune applications include a written statement assuring that the cutting and removal of trees and vegetation on the site would be done according to instructions from the local conservation district. The districts could encourage applicable silvicultural practices and require plans from the applicant for mitigating the removal of trees or vegetation by providing assurances, called Vegetation Removal Assurances, that more trees and vegetation would be planted than were removed by the proposed use.

The law, as contemplated in the earlier NRC Citizen's Advisory Committee recommendations, included a model ordinance and provided an option for local governmental units (e.g., counties, townships, villages, and cities) to step forward and administer the Act within their jurisdiction. If the local governing entity chose not to administer the act, the state would handle critical dune permitting in that jurisdiction through the MDEQ (Sand Dune Protection, MDEQ 2015).

The Village of Pentwater in Oceana County voted to administer the Act in 1989 (Brown 1989). After the Act was passed, informational workshops were held in critical shoreline dune areas to explain the new law and encourage local jurisdictions to take on administration of the regulation. As of March 1990, 12 local jurisdictions out of 91 eligible counties, townships, villages, or cities with critical dunes expressed interest in administering the Act. (Benoche, 1990). According to Martin Jannereth, former Chief of the Lakes, Streams, and Shorelands Section of the MDEQ, the number of local jurisdictions—primarily townships—opting to administer the Act was consistent at around 12 into the 1990s. Until 2012, this number included Emmet County, the only county to take on the task.

*1994 Legislative Amendments (1996 Review Committee and Atlas Update Report)*

The 1989 Sand Dunes Protection and Management Act also came with an automatic sunset date of 1993, and was thus revisited by the state legislature in 1992. Legislative hearings were conducted, and were notable for property owners and developers attending the hearings and harshly criticizing the Act–some going so far as to compare the MDNR to "pirates" for taking

private property rights, and having unleashed a “tidal wave of despotic action” (Sand Dunes Protection 1992).

The law was reauthorized in 1994, with a handful of amendments to repeal the sunset provision, increase the slope allowance to 33 percent (up from 25 percent), add an appeals process for critical dune property owners, and provide more leeway for local jurisdictions to grant special variances.

The 1994 reauthorization was also impacted by the total reorganization of the state’s environmental acts into the Natural Resources and Environmental Protection Act or NREPA (PA 451 of 1994). Under this newly reorganized statute, the sand dune mining portions of the previous Public Act 222 of 1976 became Part 637, the “Sand Dune Mining” title, under the larger NREPA. The portions of the act dealing with development, as passed in 1989, became Part 353, the “Sand Dunes Protection and Management” title under NREPA. At present, the MDEQ’s Office of Oil, Gas, and Minerals administers Part 637 (MDEQ Sand Dune Mining), while the MDEQ’s Water Resources Division manages Part 353 (MDEQ Critical Dunes).

The 1994 amendments also authorized two follow-up actions: a review of key provisions in the law, and the additional study to confirm the accuracy of the critical dune designations in the Atlas. The June 1996 report, *Final Report: Evaluation of Critical Dune Atlas Designated Under Part 353 Sand Dune Protection and Management of the Natural Resources and Environmental Protection Act 1994 PA 451*, and a report of the Sand Dune Review Committee were provided to the Michigan legislature in October 1997 (Report).

That same month, 22 state senators wrote a letter to the DEQ seeking additional information about the Lusch study, focusing primarily on its recommendation that approximately 12,000 acres of additional dunes be designated as “critical” and added to the Critical Dune Atlas. The senators questioned the methodology of the evaluation and raised concerns about additional management burden if these lands were added, sought information about the quality of these lands, and for an estimate of the increased liability for the state based on “regulatory takings” suits (Gast et al., 1997).

MDEQ Director Russell Harding responded to the senator’s concerns in a letter dated February 25, 1998. While supporting and validating the research study’s methodology —he wrote that the MDEQ “is confident that the map set is accurate and the criteria used are appropriate”—Harding also stated that the MDEQ did not believe the study’s recommendations to add 12,000 acres to the Atlas should be adopted. “Upon a thorough review of the study,” Harding wrote, “the DEQ is confident the existing 70,000 acres of designated Critical Dune Areas adequately identifies Michgan’s most unique and fragile sand dunes.” The MDEQ’s view was that the study’s proposed additional acreage constituted a “secondary set of sand dunes” because they were located farther inland from the shore (Harding 1998). The letter thus suggested the legislature might prioritize the recommendations in the Lusch study by adding to the Critical Dune Atalas only the 3,000 acres “directly adjacent to the Great Lakes shoreline,” thus reducing any additional administrative cost to the department. As mentioned previously, the legislature did not take any action to revise the Critical Dune Atlas based on the Lusch study, and the Critical Dune area boundaries remain as they were drafted in 1989.

*2012 Legislative Amendments*

In the summer of 2012, a proposal to amend the Act was presented, citing among other things the takings risk they contended was facing the state (Hayden 2012). The amendments were adopted as Public Act 297 of 2012. The legislation included:

- Consideration of impacts from permitted activity on the "diversity, quality and function" of dunes. Notably, the legislation did not define these terms, leaving the MDEQ to work on defensible ways to implement a program utilizing them ( MDEQ Water WoRDs 2013)
- Addition of language to the purpose section requiring a balance between protecting the state's critical dunes with the expected benefit of economic development.
- Removal of language that specified any alteration to a dune could occur only when "the protection of the environment and the ecology of the critical dune areas for the benefit of the present and future generations is assured."
- Addition of an imperative "shall" in the Act, requiring permit approval unless the MDEQ proves significant damage to the public interest in its denials. An imperative "shall" was also included to apply to most driveways and accessibility measures.
- The ability to build on the lakeward facing slope of the first significant dune feature.
- Streamlined permitting for certain renovations.
- Removal of the ability of local governmental jurisdictions to adopt stricter critical dune regulations than the state.
- Public hearing requests limited to residents living within two miles of the project site.
- Removal of the requirement for local conservation districts to conduct Vegetation Removal Assurances.
- Maintenance or replacement of existing utility lines, pipelines, and other utility facilities that existed on July 5, 1989 were exempted from permitting. (MDEQ Questions and Answers 2015)

While it is too early to draw conclusions as to the overall impact of the 2012 amendments, some changes are evident. Emmet County, the only county ever to adopt and administer the Act, repealed its local ordinance following passage of the amendments (Hubbard 2012). County officials summarized their reasons in a presentation at a January 3, 2013, Emmet County Planning Commission meeting:

> "The Emmet County Zoning Ordinance currently regulates Critical Dunes as identified by the State of Michigan. In August, 2012, the state legislature adopted 2012 PA 297, which modified 1994 PA 451 Part 353 Sand Dune Regulations. Staff, including Civil Counsel, reviewed the revised statute and attempted to modify the existing Zoning District Overlay standards to comply with the state law. During review of the state law and current Zoning Ordinance, discrepancies were discovered between the Michigan Zoning Enabling Act and the new Dune standards.
>
> "The new law no longer allows a local zoning ordinance regulating critical dune areas to be more restrictive of development than the Michigan Department of Environmental Quality model zoning plan, including the standard of review of permits or variances in the model plan. The new law requires notifications of public hearings in a manner that conflicts with the Michigan Zoning Enabling Act. The new law gives a local enforcing

> agency the burden of proving environmental impacts upon which a permit denial is based. The new law potentially increases costs to local enforcing agencies" (Emmet County 2013).

At present, there are three jurisdictions still administering the Act: the City of Bridgman, in Berrien County; Beaver Island (Peaine and St. James Twps) in Charlevoix County, and Pere Marquette Township in Mason County (MDEQ List 2014).

As with the decline in local jurisdictions choosing to administer the dune law since 2012, it also appears that fewer conservation districts are involved in critical dune permitting since the amendments to the law were approved. Permit applicants are still required to provide a Vegetation Removal Assurance (VRA), but since 2012 these can be obtained from various entities other than a conservation district, such as private consulting firms. Researchers working on this project attempted to contact by phone all lakeshore conservation districts, and in doing so found that the majority of districts have experienced a significant decrease in requests for VRAs since the 2012 changes went into effect. Berrien County, for example, conducted approximately 20 VRAs per year prior to the 2012 amendments, but only conducted four VRAs in 2014.

This project did not undertake specific research on permits issued after the 2012 amendments, or on impacts from those decisions. However, while conducting online research into the Act's history and through the local government official interview, two instances came to light where a new development was permitted or proposed on the lakeward-facing slope of the first foredune—a type of development that would not have been permitted prior to the 2012 amendments. One such development was identified by the township supervisor of Cross Village, Gene Reck, during a phone interview in which he noted that a development was approved beyond the lakeward facing slope of the first foredune, in front of homes that were permitted prior to the 2012 amendments (Reck, 2015). According to news reports, a similar project has been proposed in the community of Michiana, located within the states of Michigan and Indiana (Chambers 2014).

## 1.3. Local Government Perspectives on Coastal Dune Management

In the winter of 2015, local government officials (either supervisors or mayors) in the 60 local jurisdictions with state-designated critical dunes were surveyed for the purposes of this project. They were asked to provide their viewpoints on the management of Michigan's overall coastal dune system. The online survey was completed by 33 local government leaders and included an open-ended question soliciting additional viewpoints on Michigan's system of coastal sand dunes, an option to participate in a follow-up phone interview, and an opportunity for respondents to indicate whether or not they wished to receive an update on the project. The results of the survey and interviews are available on the project website and as Appendices A and B of this paper.

In general, the survey results point to a broad and consistent appreciation of the dunes among local elected leaders. Nearly all survey respondents indicated that Michigan's coastal dunes are either "very important" or "somewhat important" to their local economies. The results also suggest that local officials continue to lean heavily on traditional "planning and zoning

regulation," viewing it as the most important tool available to local governments for managing the dunes—80 percent ranked planning and zoning regulations as either the highest or second-highest priority among five options. 88 percent ranked "education and outreach to owners and managers of coastal dune properties" and "more robust education and local volunteer stewardship" as among the lowest two priorities, suggesting that local leaders may be skeptical of voluntary approaches to dune management (MEC Survey Questions 1, 4).

Consistent with those findings, regulatory approaches (as opposed to ownership) were also a clear winner among locals, with 68 percent ranking "a strong state permitting program to regulate development in coastal dunes" as among the top two most effective programs at "protecting Michigan's coastal dune resources." Another 68 percent ranked "strong local government zoning to regulate development in coastal dunes" among the most effective approaches.

When asked about the value of public ownership of dunes, there was a notable preference for state ownership over local ownership (35 percent ranking state ownership as first or second-most effective, compared to 16 percent ranking local ownership as first or second-most effective) and a strong preference for fee-simple ownership over acquisition of development rights (58 percent ranking "acquisition of development rights in coastal dunes" as the least effective program). This could potentially reflect a lack of understanding of development rights programs, a theory born out by some of the personal interviews with local leaders conducted after the survey was administered (MEC Survey Question 3).

The kinds of information local government leaders are most interested in obtaining to improve dune management tended to focus on the practical aspects of dune development. The top three information needs of the locals were:

1) "Best practices for building and developing in coastal dunes" (62.5 percent),
2) "Risks and natural hazards related to building and development in coastal dunes" (53 percent), and
3) "How coastal dune activity and sand movement is impacted by building and development" (50 percent).

Information about the "economic impacts of tourism and recreation associated with coastal dune landscapes" also scored fairly high at 40 percent, while the lowest-scoring need, interestingly, was information about "how coastal dune ecology (wildlife and plants, such as habitat fragmentation and introduction of invasive species) is impacted by building and development." This resource was favored by only 25 percent of the respondents (MEC Survey Question 6).

Again, the complete results of the survey and interviews are available on the project website and as Appendices A and B of this paper.

# Part 2: Advancing the Science of Dune Management

## 2.1 Creating a Systematic Coastal Dune Inventory

The initial goal of this portion of the project, as articulated in a grant proposal to the Coastal Zone Management Program, was to create "the first cumulative inventory of our dunes,

including information on parcel sizes, slopes, landscape features, land cover, development and fragmentation information, etc." The survey and resulting "maps and tools" were intended to "help decision makers understand the strengths and weakness—challenges and opportunities—of our overall dune management regime" by making more information available to regional and local planning entities regarding the "assets within their own geographies and how those assets relate to the overall system." Ideally, it was also hoped that the assembled data would support other new or improved models and analysis tools by providing "a fuller picture of the diversity, distribution, ecological function and geomorphic character of the dune system at the parcel, local, regional and statewide scales, enabling new characterizations, comparisons, and more informed prioritizations of management strategies than are currently available."

A group of researchers located at Calvin College in Grand Rapids undertook this challenge, and worked throughout 2014 and into early 2015 to systematically inventory the coastal dunes along the Michigan shoreline by compiling available information into a GIS database which enables geospatial analysis and visualization.

The project engaged a team of researchers in the Calvin College Department of Geology, Geography and Environmental (GEO) Studies. The project manager, Dr. Deanna van Dijk, took care of project administration and directed the content focus on Michigan dunes. GIS expert Dr. Jason VanHorn directed the search for available GIS data, built the structure and tools of the GIS database, and brought data into the GIS. Three undergraduate research students worked part-time on the project, with a focus on investigating available GIS information. Katie Burkley concentrated on pursuing various types of data on Michigan dunes, including published dune research results and study locations. Brian Hilbrands and Audrey Hughey focused on the availability and process of including aerial imagery in the GIS.

The work group focused throughout this project on four primary objectives:

- To investigate available GIS information on Michigan coastal dunes,
- To compile collected data into an organized GIS database focused on Michigan coastal dunes,
- To include geospatial analysis and visualization tools in the GIS database, and
- To build a journal map application for public education on Michigan dunes.

The resulting "Michigan Dune Inventory GIS" online application focused on Michigan dunes is available online at http://gis.calvin.edu/MDI; "Understanding Michigan Dunes," an online application in the journal map theme can be accessed via the GIS system, or independently at http://arcg.is/1sW1woh. The project was also presented at the annual meeting of the Association of American Geographers in Chicago, Illinois, in April 2015 (VanHorn, J.E. and D. van Dijk 2015), and efforts are underway to publish the research in peer-reviewed scholarly journals.

*Investigating Available Information and Building the GIS Interface*

Given the project objective of building a GIS database combined with a goal of making the GIS database broadly accessible, the project team developed criteria for identifying which information was available for possible inclusion in the GIS database. The information needed to:

a) Include data about the dunes: The focus of this criterion was whether the data could help in understanding the dunes and their context.
b) Be available in GIS format: Data needed to be available as shapefiles, geodatabase, or convertible formats like KML so that it could be included in the GIS.
c) Be hosted as a REST service: Representational State Transfer (REST) provides easily incorporated transferable formats for geospatial data on the internet and can be pulled into GIS applications.
d) Have documented metadata: To ensure use and quality of the dataset we required metadata documentation.
e) Provide hosting permission: Some layers of spatial data are accessible and usable but not licensed to be served elsewhere. Thus we found some limitations to hosting data that is downloadable and useable but not with license to host.

During the investigation of ideas and suggestions for possible information sources, project researchers recorded notes for the above criteria for each source investigated.

Project researchers used the results of investigating all possible ideas to identify the set of GIS information that could be included in the GIS database. Many interesting pieces of information were rejected for inclusion because they either did not appear in GIS format, did not have REST services, did not have adequate documentation of metadata, or did not give permission to be hosted on another site. Types of data that were available in several different places were compared to identify which source fit best with the criteria above and the project goals.

It was determined that an online GIS environment would be built to provide free access to dune geospatial data. Thus the Michigan Dune Inventory GIS was conceived more thoroughly and the subsequent layers that had been gathered or discussed were incorporated. The MDI involved a complete ground-up development process for the interface as well as content layers, including decisions about design, architecture, and delivery and eventually the evaluation, revision, adjustment of prototypes of the GIS, as well as associated applications and tools.

More than 130 versions of the GIS were developed through the process before the design and interface was finalized. In January 2015, the MDI GIS was released online after beta testing and successful use by students and researchers. As of April 2015, working Version 1.319 was available at http://gis.calvin.edu/MDI/.

*Creating the Journal Map*

In addition to making data and tools available to any user with online access through the Michigan Dune Inventory GIS, the workgroup also wanted to make dune knowledge more accessible to the general public. After considering several options, a detailed journal (story) map application was determined to have the greatest potential for reaching a broad audience and utilizing the resources of the MDI GIS.

The over-riding goal of the application was to further the educational outreach aspects of dune knowledge and dune appreciation. Specific objectives for customizing a journal map template to tell the story of the Michigan dunes were:

- To answer the question, “What are the dunes?”

- To define detailed aspects of Michigan dunes in two- and three- dimensions, such as a) types of dunes found in Michigan, b) dune processes, c) dune history and changes, and d) significance of the dunes.
- To make connections with dune research and the analysis/visualization capabilities of the MDI GIS.

Dr. VanHorn provided the technical expertise needed to choose an appropriate journal map template, customize the template for Michigan dune information, and build the journal map using a combination of content and appropriate visualizations. Dr. van Dijk provided content in the form of text and appropriate visuals (where images were not readily available through the MDI GIS). The starting content and storyline were taken from a "Lake Michigan Coastal Dune" website developed by Dr. van Dijk roughly ten years earlier. As the journal map application developed, the content was updated with recent data and research results, and the storyline was modified to better fit the new application format.

*Results of Dune Inventory GIS and Journal Map*

The MDI GIS allows users to investigate the dunes of Michigan by accessing a variety of environmental and social layers at multiple scales. It provides new ways of visualizing the dunes, and includes information for understanding Michigan dunes and their context, including their physical, ecological and cultural characteristics; historical changes in dune characteristics and land use; ownership patterns; regulatory status; and research on the dunes. Because the information is presented in the form of GIS layers, location information and spatial patterns of data are included.

As an online, interactive and free GIS application, accessibility is only limited by a few constraints (e.g., current browser, basic Internet connection on a computer), thus enabling geospatial investigation of the dunes and analysis of the coastal dune areas that may have previously been limited to entities with professional-level GIS staff and software. It provides a user-friendly and attractive interface intended to make data and tools available to users with limited GIS knowledge

However, the MDI GIS also provides a range of more sophisticated applications for users to learn about the dunes (e.g. Elevation Profile app) and the ability to analyze data using measurement tools and several apps for specialized purposes. Measurement tools permit the user to identify the *location* of a point, measure the *distance* of a line, and measure the *area* of a polygon. (Point, line and polygon are specified by the user.) Users can also find specific locations using the *address match* application. The *elevation profile* application enables the user to see a representation of the topography along a line specified by the user. The *viewshed analysis* application shows the user all the locations that can be seen from a user-selected point (assuming a denuded landscape). The *add your data* application lets the user add GIS shape files to the map. The added layer is temporary and does not remain with the MDI as a permanent layer, and while the layer is added it is not visible/accessible to anyone else.

The data layers and applications of the MDI GIS suggest it could be a useful and accessible tool for different users and needs, including: local governments that currently do not utilize

professional GIS tools for understanding and managing dunes in their jurisdictions; and local stewardship, volunteer or other non-governmental entities seeking to engage in dune management.

The "Understanding Michigan Dunes" journal map application is available directly at http://arcg.is/1sW1woh and it is embedded in the MDI GIS under the Apps tab. The application is an interactive mapping tool that allows a story to be told section by section with interactive map displays, text, charts and graphs, and multimedia video. The intended audience includes the many investigators or potential users of the MDI GIS—including youth in K-12—who might have limited knowledge of the dunes.

"Understanding Michigan Dunes" gives users a contextual understanding of dune geomorphology and how to understand the dune complex along Michigan shorelines. There are several interactive maps that provide spatial information and increase knowledge through the use of maps and additional content. The content of the application is frequently updated based on Calvin College GEO Department research and investigation by faculty and students from ongoing research, classroom projects, and from literature reviews.

As an educational tool, the journal map application shows potential for becoming a powerful public outreach tool for understanding and appreciating Michigan dunes. Even while the application was in development, user responses were overwhelmingly positive. The users were impressed by the combination of a compelling story focused on the Michigan dunes and the powerful visualization tools that enable users to explore features that are being described. Potential uses for the application include being linked to a variety of websites related to Michigan dunes (such as state agency, conservation and advocacy group websites). For example, MDNR personnel are considering making the application available to state park visitors on tablet computers in visitor centers.

*Data Challenges and Future Needs*

The initial project proposal included the gathering and use of aerial imagery. In the past, aerial imagery in the United States has been expensive and was built into the plan budget. But in the last eight years there has been a significant shift by the United States government under the National Spatial Data Infrastructure to provide as a singular focused approach, as much publically paid for government data, including aerial and satellite imagery, for free or little cost. This was a bit of a surprise, as it was expected that some aerial imagery would be available, but most would need to be purchased for dune areas around Michigan.

Instead, using online tools like Earth Explorer (earthexplorer.usgs.gov) the team was able to download 392GB of aerial imagery. Unfortunately, the aerial imagery was often non-georeferenced. Notwithstanding the painstaking time to download, extract, georeference and georectifiy older aerial imagery, the team found the dune areas of older times especially difficult to reference because of the lack of basepoints (tic points) to which known locations can be matched.

Therefore, the team chose three counties to focus on as a way to pilot what might be done and how effective it might be toward dune investigation. Under Dr. VanHorn's guidance, Brian Hilbrands and Audrey Hughey completed all Earth Explorer downloading of aerial imagery for three test counties: Ottawa, Oceana, and Leelanau. Aerial imagery were available for those counties since the 1930s. However examining the exact dates of imagery and when it was flown in each respective county revealed that there was an incongruity of dates flown when comparing it among the other counties. Therefore, we chose three time periods that were as congruous as possible so that users can see change in the coastal land for those three counties during the same basic historical time periods. Dr. VanHorn finished processing aerial georeferenced imagery for Leelanau, Oceania, and Ottawa counties as was needed when student researchers were no longer working on the project (summer 2014).

After extensive investigation of parcel data, the team concluded that the following challenges prevented its inclusion in the MDI GIS:

- Not all counties along Lake Michigan have GIS capacity and only half the counties have parcel data available for purchase;
- Available parcel data is too expensive, averaging $1650 for 5000 parcels (for counties which have data available for purchase);
- Parcel data which can be purchased has significant restrictions on how the purchaser can use the data. For example, Grand Traverse and Ottawa County make GIS data available for free for research purposes, with the stipulation that the data cannot be shared with anyone beside the researcher unless a license agreement is purchased.

In lieu of parcel-level data, the *add your data* application was developed within the MDI to let a user add their own GIS shape files to the map. With this feature a user with access to parcel data for a particular area of interest could add those shape files to the map to investigate patterns of interest. As noted previously, the *add your data* upload is temporary and does not remain with the MDI as a permanent or even accessible layer by anyone else.

Beyond parcel data, there are several other layers that would aid the MDI investigator, such as LIDAR quality for high-resolution elevation detail. The USACE has LIDAR and the team at Calvin College has acquired it. However, due to the unique extent of Michigan dune systems along the eastern shore of Lake Michigan toward the inland, the USACE LIDAR does not adequately incorporate Michigan dunes for helpful analysis. For most locations, the LIDAR only shows a small part of the dunes directly along the shoreline and misses the greatest extent of the dunes.

Several layers in the MDI GIS show specific dune areas (e.g., Critical Dune Areas boundaries or shorelines with low or high dunes), but there is no available dune GIS layer to identify all of the dunes in Michigan. Without such a layer, fundamental questions about the dunes can only be estimated or answered locally. Furthermore, appropriate stewardship questions cannot be fully answered without knowing the cumulative extent and other characteristics of dunes in Michigan.

## 2.2. Developing a Schematic Ecological Impact Model

The Ecological Impact Modeling group developed two sets of models for this project: first, a series of schematic flowcharts for evaluating the impact of different coastal development scenarios on the physical and ecological processes in coastal dune complexes; and second, a mathematical model of Pitcher's Thistle (*Cirsium pitcheri*) population dynamics. This section discusses the first model, the schematic flowcharts. The mathematical model is discussed in the following section. 2.3 "Developing a Mathematical Impact Model Using Pitcher's Thistle."

Authors and primary researchers on this portion of the project include Jacquelyn Plowman, Suzanne DeVries-Zimmerman, and Edward Hansen of the Department of Geological and Environmental Sciences at Hope College, Holland, Michigan, and Charles F. Davis, III, of Davis Associates Architects & Consultants, Inc., in Chicago, Illinois. As of May 2015, their study, "How the Dunes Work: A Review of the Dynamics of Michigan's Coastal Dunes" is currently in a prepublication research draft. As such, it should be considered preliminary and is not for distribution or citation. The project was also presented at the annual meeting of the Geological Society of America in Vancouver, British Columbia, Canada in October 2014 (Plowman et al., 2014), and efforts are underway to publish the research in peer-reviewed scholarly journals. A copy of the final journal article will be made available on the project website following publication of the paper.

*Research Approach*

Based on the original project design, the ecological impact modeling team undertook two primary tasks to create the schematic flowcharts. First, they worked to develop a matrix to define the key physical/biological parameters and limiting factors for a range of ecological features and communities in the coastal dune system. Second, the team set out to create and evaluate a set of development scenarios that incorporated site design elements and strategies employed in permitted or proposed construction projects on critical dune sites. Eleven initial residential development scenarios were developed using lot and home site configurations commonly seen in critical dune areas (such as cul de sac style; multiple houses with shared driveways; linear clusters; multi-family "congregate" clusters; and traditional grid style).

The impact evaluation approach utilizes a set of decision-making flowcharts to present a schematic model of how the primary physical (geomorphological) and ecological processes work in the Great Lakes' coastal dune system. Based on these schematic flowchart models, it becomes possible to evaluate the potential impact of a proposed development on the dune's physical and ecological processes and functions. Five of the eleven residential development styles were selected for evaluation of potential development impacts using the physical and ecological flowcharts.

The group's research on this topic first describes the physical and ecological processes characteristic of the coastal dunes along Lake Michigan and then discusses the flowchart tool and the criteria needed to utilize the tool. It also identifies data or research gaps that limit our ability to assess quantitative impacts of development for certain attributes. Lastly, the full report

discusses the respective development scenarios, including the nature of the dune, its ecology, and the configuration of the development, and the impact of that development scenario on the dune and its ecology. These conclusions range from semi-quantitative to qualitative in nature, as there was insufficient information in the scientific literature to quantify many of the parameters in the flowcharts. The many data gaps in coastal dune research along the Great Lakes found through this research are also noted, providing suggestions to guide future research.

*Key Dune Physical Processes*

Wind and sand supply are the principle factors influencing dune development and movement. It is largely through altering these two factors that people impact dune mobility. In order to build dunes, winds capable of transporting sand must be able to flow over a sand supply area and then onto an area on which the sand can be deposited.

The largest sand source on the Great Lakes is the beach, and the strongest winds blowing over this source are onshore winds, often those associated with storms. Dune growth begins with obstructions that break the force of the wind near the sand's surface and cause sand to be deposited in low shadow dunes around that obstruction. Sand supply is an important limiting factor in dune development because it often outweighs the ability of strong winds to transport sand (van Dijk, 2014).

Pavement also impacts the wind and sand supply, and, therefore, can influence sand transport. Pavement decreases the amount of sand supply by covering areas of open sand with an impermeable surface. However, pavement tends to increase the ability of winds to transport sand downwind from the pavement by decreasing the friction between winds and the surface. This means that winds traveling over pavement tend to increase in velocity, and will be able to transport sand higher in the slipstream, and for a longer distance. Also, saltating (bouncing) grains will bounce higher off pavement and into the higher velocity/energy zone of the slipstream, again, potentially causing more sand to be transported further. Larger areas of pavement have the greatest potential to increase sand transport compared to locations with narrow areas of pavement. Smaller areas of pavement do not tend to significantly increase wind velocity. Therefore, the distance of sand transport is not increased.

Dunes are also impacted by gravity. The movement of sediment downhill under the influence of gravity and in the absence of flowing water, flowing ice or wind, is known as mass wasting. While wind is the main dune-forming agent, mass wasting also modifies dunes. Human-induced mass wasting can have a smaller impact on a dune. It is also possible for people to affect directly the topography of the dunes by removing or adding sand, thereby changing the dune's height or the angle of its slopes. Disturbance of a dune at slopes near the angle of repose (~30 degrees) can lead to the movement of sand downhill in avalanche lobes. Sediment disturbed on slopes at less than the angle of repose will tend to settle downhill at a greater rate than it will settle uphill, leading to a net down slope movement. This is the general principle behind the slow down slope movement known as creep. The steeper the slope, the greater this down slope movement will tend to be.

*Key Dune Ecological Processes*

The concept of succession is critical to understanding ecological processes in the dunes. Succession is the sequence of changes in the species makeup of the ecological community occurring over time in an area (Smith and Smith, 2009). An ecological community is the collection of all the populations of different species within an area.

An idealized successional sequence on the open dunes begins with a newly exposed or created surface, such as a fresh patch of bare sand. The first plants and animals colonizing this area comprise the pioneer community. Over time, the pioneer community modifies its environment. In the case of open dunes, the pioneer plant species significantly slow the movement or deposition of sand and this decreased rate of sand burial is one of the primary drivers of successional change in the open dunes community (Cowles, 1899; Olson, 1958; Johnson and Miyanishi, 2008). Each vegetative community also can modify the soil chemistry, leading to a change in the community.

However, the primary driver of ecological succession in the coastal dunes is sand burial (Maun and Peruman, 1999; Maun, 2004). Most of the pioneer or open dune plant species are dependent on a certain amount of sand movement. However, the growth of vegetation on a dune decreases and slows the movement of sand, eventually stabilizing it. The resulting stable dune conditions create an unsuitable environment for the original pioneer community and new species colonize the area, establishing a different ecological community or a new sere. This process continues until a climax community is established. In the climax community, dying plants and animals are replaced by plants and animals of the same species so the species composition or ecological community does not change with time. In many areas along the eastern shore of Lake Michigan, the climax community is a beech-maple or mesic forest with some hemlock (Kost et al., 2007).

Maintaining the respective dune communities requires the existence of a variety of ecological communities within the larger dune complex and among adjacent dune complexes. Plants from one community must migrate by seed or rhizome dispersal to new suitable environments to reestablish and maintain those communities. However, this interdependence is fragile. Climatic and topographical changes often vary considerably within a dune system and the communities change with these conditions. Hence, the diversity of communities, their relative sizes, and the distance between them can be crucial to their continued existence. Individual species require a minimum patch size, so smaller patches contain a subset of species from larger patches (Fahrig, 2003).

During development, linear infrastructure such as roads and driveways reduces the size of and isolates habitat patches, and increases the amount of edge environment (Varela et al, 2006). This affects both diversity and survival, as these smaller patches usually contain fewer species (Debinkski and Holt, 2000). In addition, linear infrastructure reduces the ability of plants to colonize new patches of habitat as existing habitat becomes unsuitable due to succession. Larger barriers, such as housing developments, can cause a greater separation between communities. Although separation does not have the same effect on all species, it does generally reduce biodiversity of the ecosystem (Fahrig, 2003).

*Results of Development Scenario Analyses*

After testing the schematic flowcharts on a series of hypothetical development scenarios in different coastal dune settings, some conclusions were drawn. Overall, the amount of dune mobility, and therefore the amount of sand burial, especially in open dune areas, decreased with development. Ecologically, pioneer and sensitive species that are dependent on sand burial were lost due to the resulting dune stability from development. The amount of dune mobility in back dune areas did not change, as there was little to no mobility prior to development. Hence, ecological changes in these factors in the back dunes were not as pronounced as these dunes are vegetated with later successional communities adapted to very low to no sand burial rates on their leeward and windward sides. Other ecological concerns, such as forest fragmentation and the spread of invasive plants and animals, can only be qualitatively addressed at this time due to the lack of scientific research in the coastal dunes on these issues. Erosion due to stormwater runoff from roadways and driveways was included in the flowcharts, but not analyzed as part of this study. However, this process is also an important consideration in the dune environment. Development also fragments and increases the distance connecting similar ecological communities. This may decrease the likelihood that certain ecological communities will persist locally.

*Conclusions, Information Gaps and Needed Research*

The team used current scientific understandings of the geomorphic and ecologic processes in the Great Lakes' coastal dunes to create a two-part public policy decision-making flowchart. The first part evaluates a development's impact on the dune's physical processes in three categories: dune mobility, erosion by gravity, and pavement effects. The second part evaluates the development's impact on the type and number of ecological communities and species composition within those communities. This method provides a useful means to assess the impact between different development scenarios and between different coastal dune settings.

However, this scheme constitutes an initial or preliminary approach, ranging from qualitative to semi-quantitative in nature. Much research remains to be done in order to fully quantify the effects of development within these dunes. One of the key findings of this study was the identification of areas where more research is needed.

More information is needed on essentially every evaluation criterion of the matrix. However, data on the effects of habitat fragmentation on the sustainability of the different ecological communities of the coastal dune environments are especially lacking. Unfortunately, at this time, key information for Great Lakes coastal species is unavailable and research on this topic is very sparse. Although it is vitally important to understanding the ecological systems of the coastal dunes, research on patch size, species dispersal, fragmentation and related topics for the Great Lakes' coastal dunes species has not been pursued and much research is needed to fill this knowledge gap.

Furthermore, little to no research has been done on the number of individual plants needed to sustain a viable population of a species in a particular community. In general, ecological research

shows that the fewer existing members of a species there are, the less likely it is for that species to remain viable and/or extant. However, the threshold where this occurs for individual species, and even ecological communities, in the Great Lakes' coastal dunes is not known.

Further research is also required to assess quantitatively how much distance can separate similar communities before a species in one community cannot reach the next community or reach a suitable environment to create a new community. Each species within a community must be considered individually to gain a complete and accurate understanding of how the increased distance and/or separation between communities affects the likelihood of maintaining that community.

Lastly, critical thresholds beyond which the coastal dune ecosystems suffer significant or irreversible degradation have not been established. Evaluating this will first require defining the appropriate spatial scale. In other words, should the threshold be established on a local or more regional level? If local thresholds are considered, then the cumulative effects of degradation on the larger coastal system must be researched and evaluated. At this time, and despite the importance of this information in understanding the long-term health of the coastal dune ecosystems, these research questions do not appear to be under investigation.

## 2.3 Developing a Mathematical Impact Model Using Pitcher's Thistle

The conceptual models above would ideally be replaced by more precise and quantitative mathematical models. Presently, this is impossible due to our limited understanding of the precise nature of these processes and the complexity of their interactions.

Instead, the mathematical modeling arm of the project focused on developing detailed mathematical models of a relatively well-studied and ecologically important dune species, Pitcher's thistle (*Cirsium pitcheri*). Although our understanding of many of the factors influencing Pitcher's thistle populations is very limited, the existing literature is comprehensive enough to begin to develop well-supported models. As the results of future scientific studies become available, the models may be refined and restructured to make more accurate predictions.

The mathematical modeling arm of the Ecological Impact Modeling consisted of Brian P. Yurk and Anne McManis of the Department of Mathematics at Hope College, Holland, Michigan. The full report of this group, titled "Dune Ecology Modeling with Particular Emphasis on Pitcher's Thistle Populations," is in pre-publication draft form.

*Model Development*

The group focused on developing a mathematical model: a precise, simplified description of reality that reflects current understanding and assumptions about how natural processes evolve and interact. Mathematical models are useful for extending our best ideas about how natural processes work into predictions about the future states of a system. Thus, this work represents an

initial attempt to develop mathematical models that will be useful in evaluating dune development scenarios and other management issues.

The team developed three models to investigate population dynamics of Pitcher's thistle, a perennial monocarpic (flowers once) thistle endemic to the Great Lakes region where sand dunes are present. The team's hope is that developing mathematical models for one focal dune species will yield insights into the types of data that are needed to better understand Pitcher's thistle itself as well as other dune species.

The biology of this plant becomes particularly important for the study, as it germinates and grows as a seedling for one year before entering the rosette stage where it persists for 5-8 years before flowering once and dying. The transitions between these stages are important components of the impact modeling. Also important to note is that the emergence probability of Pitcher's thistle seeds depends on how deeply they are buried by sand. Variation in sand erosion and deposition patterns at a site become important factors for predicting impacts on the species.

The models developed for the project are nested in that each successive model incorporates most of the aspects of the previous models while adding complexity. The additional complexity allows for the incorporation of more factors that impact the population. However, the more complex models require more information. Furthermore, the model predictions are more difficult to understand with a more complex model, where teasing apart the influence of interacting factors can be difficult. Consequently, there are insights that can be gained with even the simplest of the three mathematical models:

- **Deterministic structured population model.** The simplest model developed ,this approach aggregates the population into classes based on size and maturity. Transitions between classes are modeled using transition probabilities estimated from Pitcher's thistle data.
- **Stochastic structured population model.** This model incorporates demographic stochasticity. With the stochastic model, we think of each individual as a distinct entity and determine its fate at each time step as the outcome of a random process. In analyzing the results of a stochastic model, it is important to run multiple simulations to produce a distribution of predictions.
- **Spatial model.** This model is a structured population model with demographic stochasticity, in which the locations of individual plants are tracked over time. The spatial effects that we include in the model are:
    - Burial impacts emergence probabilities (transitions from seed to seedling) of buried seeds according to the Chen and Maun model (4), seeds in erosional areas have a lower probability of emerging than seeds deposited on neutral surfaces (no burial or erosion), and seeds on neutral surfaces have a lower probability of emergence than seeds that are buried to a moderate depth.
    - The survivorship of seedlings into the rosette classes declines with increasing local marram grass density.
    - The survivorship of seedlings into the rosette classes declines with increasing local Pitcher's thistle density.

*Conclusions, Information Gaps and Needed Research*

The usefulness of a mathematical model for making predictions is determined by the quality of our understanding of the important processes that drive the behavior of the system. That understanding is reflected both in the model structure and in the parameters that are used to tune the model. Ideally, both the model structure and the parameter estimates are informed and directly supported by observations and measurements made in laboratory or field studies. Some parameters can also be estimated indirectly. However, models often depend on parameters that cannot be estimated either directly or indirectly using existing data.

This suggests the need for future work in the laboratory or the field. In this case, the model behavior can be investigated under a range of values of the unspecified parameters. This allows us to explore possible behaviors of the system and to estimate how sensitive the model predictions are to these parameters. This can result in important predictions and reveal the need for future scientific studies.

In this work, the team chose to focus on Pitcher's thistle, because it is an important endemic plant to Great Lakes sand dunes, and because there have been some field studies of Pitcher's thistle populations. A model of a different plant species or of a set of interacting species endemic to Great Lakes sand dunes would require a similar level of understanding of the processes that drive the population and community dynamics.

The models developed here also point to the need for additional studies of Pitcher's thistle populations along the Great Lakes shorelines. The structured population model at the core of all three models is based on Pitcher's Thistle data collected by Loveless, who measured plants at two field sites near the Sleeping Bear Dunes between 1979 and 1983. Loveless did not designate plant locations along with the demographic data, and in order to initialize simulations using a spatial model, the initial spatial distribution of the population must be known. Spatially varying factors that influence the population dynamics (e.g., burial levels, marram grass densities) must be specified as well. These data are also not available for the Loveless study.

The interactions between Pitcher's thistle and other locally dominant plant species (e.g., marram grass) have not been thoroughly studied. Spatial distribution patterns of Pitcher's thistle plants have been investigated, but the impacts of density dependence in Pitcher's thistle populations have not been investigated, and their seed dispersal patterns have not been studied quantitatively. Finally, though germination and emergence studies have been conducted with seeds buried by varying amounts of sand, the impacts of burial on other life stages are not well understood.

The spatial model developed here is capable of predicting Pitcher's thistle population dynamics under different development scenarios. Doing so, however, would require developing a map of the existing Pitcher's thistle population at the development site as well as a map of the changes that will occur as a result of the development scenario.

## 2.4 Emerging Science of Coastal Sand Dune Age and Dynamics

Alan F. Arbogast of Michigan State University provided additional analysis for this project, specifically by providing a summation and analysis of recent and emerging research into dune age and dynamics. That information is summarized below. His full paper, "The Emerging Science of Coastal Sand Dune Age and Dynamics: Implications for Regulation and Risk Management in Michigan," can be found on the project website at http://www.environmentalcouncil.org/coastaldunes..

Until the 1970s, it was generally assumed in the scientific community that the dunes had largely formed during the "Nipissing phase" of the ancestral Great Lakes. This high lake stage, which occurred ~5,500 years ago, occurred due to the complex interactions related to climate and crustal rebound following the most recent ice age. The upper Great Lakes (Huron, Michigan, and Superior) shared the same water plane at this time and were about 15' to 20' higher than present during the peak part of the high stand. As far as the dunes are concerned, it was assumed that they formed during or shortly after this time, largely because high amounts of sand were presumably eroded from lake bluffs and then blown by the wind to the nearshore environment.

More recent investigations focusing on the physical geography and geomorphology of the coastal dunes undertaken in the late 1990s have begun to change this view. The shift occurred in large part because dating techniques, such as radiocarbon ($^{14}C$) dating and optical stimulated luminescence (OSL) dating now existed that could more accurately estimate the age of the dunes. The discovery that many of the lake-fronting dunes contain a variety of buried soils (paleosols also suggested they did not form during a single period of time, as had been generally assumed, but rather grew in distinct stages that were separated in time by periods of landscape stability when relatively little wind-blown sand accumulated.

Results from this systematic dating program suggest that an early pulse of coastal-dune growth in Michigan indeed occurred during the Nipissing high stand ~ 5,500 years ago. Contrary to earlier assumptions, however, this period of dune growth was not the primary event in the history of the dunes. Instead, it very much appears that most dune growth occurred during two distinct periods of time. The first occurred between ~ 3500 and 2000 years ago, followed by a subsequent distinct episode of coastal stability over much of the Michigan shoreline for about a 1,000 years that resulted in the addition of little wind-blown sand to the dune system. Following this episode of extended stability, the second episode of dune growth took place between 1000 and 500 years ago. Some additional accumulations of wind-blown sand have even occurred in the past ~300 years into the historic period.

The reasons for these episodes of dune growth is still poorly understood, but is likely related to some combination of lake-level fluctuations, climate changes, and the incidence of strong storms (e.g., Arbogast and Loope, 1999; Loope and Arbogast, 2000; Arbogast et al., 2002; Arbogast et al., 2004; Hansen et el., 2010; Blumer et al., 2012; Lovis et al., 2012). Lake-level fluctuations may be important because they could have directly impacted the supply of sand that could be moved by the wind to form dunes.

The impact of climate may be best exemplified by the most recent period of extensive dune growth between ~1,000 and 500 years ago. This interval of time corresponds very well with the Medieval Warm Period, which is well documented in the Northern Hemisphere. This climate interval, which was likely somewhat drier in the Great Lakes region than the modern environment, could have changed the supply of sand in the dune system by reducing vegetation.

Additional evidence suggests that El Niño cycles could possibly play a role, with periods of stability occurring in centuries with relatively high occurrence of El Niño (Monaghan et al., 2013) because fewer strong storms may have occurred due to the configuration of the mid-latitude jet stream during those intervals. The precise interaction of these variables, *if* they occurred, and their response time(s), currently remains a mystery and thus a focal point for further research.

In addition to the reconstructed history of dune growth and stability, it is now understood that dune systems in the northern part of Michigan differ from their counterparts in the southern part of the basin as far as their position on the landscape is concerned. Dunes in the southern end of the basin tend to consist of large, overlapping parabolic dunes with active blowouts in many places. These dunes line the shore for many miles and also contain several paleosols, indicating that they have grown upward in an episodic fashion through time.

In contrast, northern coastal dunes tend to occur in distinct embayments, such as Little Traverse Bay, and consist largely of distinct ridges that contain relatively few parabolic forms. In addition, buried soils are rare in this area. This lack of parabolic dunes and buried soils in the north suggests that dunes in this part of the basin formed quickly, whereas those in the south grew vertically and have been reworked frequently through blowout formation. The central part of the lakeshore, between approximately Muskegon and Ludington, appears to be a transition zone, with a combination of ridges and overlapping parabolic dunes present (Hansen et al., 2010).

This geographical variation in dune form is likely related to the differential effects of crustal rebound following the most recent ice age. It is well understood that the landscape in northern Michigan continues to rebound slowly from the weight of the most recent glacier that covered the region between ~ 30,000 and 10,000 years ago. In contrast, the southern end of the basin may be slowly subsiding. As a result, dunes in the north have grown outward as new coastal surfaces rebounded above the water plane (Lovis et al., 2012). In the south, however, coastal dunes have been heavily eroded, resulting in their “cliffed” appearance.

*Implications for Dune Management*

The new understanding of coastal dune evolution in Michigan that has emerged in the past two decades could have significant implications for their management. In particular, this collective body of work clearly demonstrates that the coastal dunes should not be viewed as a singular body that formed largely during one interval of time thousands of years ago. Rather, they should be viewed as a complex system that is dynamic.

Coastal sand dunes have long been portrayed and often managed as fragile features to be preserved, rather than as dynamic systems to be accommodated. The legislative findings section

of the Sand Dune Management statute (Part 353), in fact, states that "the critical dune areas of this state are a unique, irreplaceable, and fragile resource." National news coverage during the run-up to passage of Michigan's controversial 1989 dune management law similarly reflected the scientific understanding of the time, saying this of the soon-to-be designated critical critical dunes: "Formed by the interplay of wind and water, sand dunes are particularly fragile and sensitive. Removal of vegetation for construction of a home, for instance, frequently results in a 'blowout,' in which the sand blows away down the shore—and often onto someone else's property" (Stofel, 1989).

While technically true – human and other impacts can and do destabilize individual dunes, with the result often a suddenly more unpredictable and frustrating landscape of actively blowing, drifting and migrating sand – the image of the dunes as a discrete and largely static feature in need only of careful handling fails to capture the full, dynamic and diverse nature of the dune system overall. Emerging information about the age ranges and dynamic nature of the full coastal dune complex suggests that other influences—changing lake levels, climatic variations, weather patterns—likely have a much larger impact on the dunes as a system.

This should not be taken as a recommendation to ignore or downplay human activities and development approaches that clearly can and do destabilize individual dunes and create costly challenges for communities and neighboring homeowners. Rather, the science suggests that our management programs should be revisited with a greater appreciation for relative dynamism and diversity of the system—particularly the role of large-scale dune destabilization, migration and alteration, which has and will happen within much shorter time frames than previously understood, and which is driven by factors not entirely understood yet. A dune management approach that took this view would likely treat dune development with an eye toward hazard risk mitigation, in addition to considerations of slope, environmental or aesthetic concerns.

At present, Michigan's dunes are managed as if all dunes are essentially the same from a geomorphic perspective and that singular variables such as slope attributes can be used as a simple and effective surrogate for dune management. Research demonstrates, however, that dunes should likely be viewed individually when it comes to their management, with consideration of variables such as landscape position, geography, and growth history in mind. By using such a holistic view of the dunes, it is then possible to understand that comparative dunes with similar slopes may or may not be very different with respect to their overall stability. Such an understanding, in turn, can lead to better decisions about the impact that development may have in the immediate area.

## 2.5 Comparing Coastal Dune Management Approaches

A review of dune management approaches of several other states, within the Great Lakes region, and those with ocean coastlines, was conducted in order to determine similarities and differences, and to identify potential programs and tools that could possibly be implemented in the State of Michigan. Side-by-side comparisons of these programs are contained in the report Appendix C and on the project website at http://www.environmentalcouncil.org/coastaldunes.

*Other Great Lakes States*

In the Great Lakes region, by far, the majority of coastal sand dunes are located in Michigan, with 275,000 acres on the Lake Michigan and Lake Superior shorelines (based on PA 222 of 1976). There are relatively small areas of dunes (both privately and publicly held) in Indiana, Illinois, and Wisconsin. Dunes in Wisconsin are encompassed in the 865-acre Whitefish Dunes State Park and 1,000-acre Kohler-Andrae State Park, which contains two and a half miles of beach. Dunes in Illinois are located in the Illinois Beach State Park. Its dune area is situated on about six and a half miles on Lake Michigan in the 4,000-acre park. In Indiana, the majority of the coastal dunes are located in the Indiana Dunes National Lakeshore. The 15,000-acre national park has 15 miles of Lake Michigan shoreline. There are no state regulations for coastal dunes in Wisconsin, Illinois, and Indiana. One of the largest stretches of dunes in the Great Lakes outside of Michigan is a 17-mile stretch on eastern Lake Ontario, owned and managed by the State of New York. An important program to note is the Eastern Lake Ontario Dunes Coalition, a public-private partnership focused on education, stewardship and overall management of the dune area. There are 35 partners in the coalition, including local, county, state, and federal entities. The coalition has issued a number of status reports, and has established a Dune Steward program to flag issues on the shoreline and to provide education to area residents and visitors.

*Ocean States*

Online research was done to determine ocean states with coastal dune management programs. Thirteen state programs were chosen to review, mostly due to the availability of information. The review of coastal dune management approaches in 13 states with ocean coastlines focused on the purpose of the law(s) authorizing coastal dune permitting, the extent of regulation, how regulatory areas are defined, regulated activities, permitting, the state role, and local role. Review of the detailed guidelines for construction and other types of activities in coastal dunes was beyond the scope of this report.

*State Comparisons*

There are distinct differences and similarities in the coastal dune management programs reviewed. In particular, there is a distinct difference overall between Michigan, with its freshwater coastline, and the other states, all with ocean frontage, in terms of the purpose of regulation and the ecology and extent of the dune systems.

The purpose of regulation for the ocean states generally encompassed a combined focus on coastal erosion and natural resource protection. Several had purposes that included ecological protection as a high priority, including North and South Carolina, Oregon, and Washington. Oregon's was the most evident, with language expressing protection of "an outstanding resource," in its legislative purpose. It was also the only state to include "resiliency" in its purpose, a recent approach to planning for coastal changes due to climate change. Most of the ocean states focused more on coastal erosion as their legislative purpose while including reference to protection of natural resources as a secondary goal. Many also included language referencing a balance between protecting the coastal system and human uses. Michigan's statute

was one of the most explicit in referencing a balance between the benefits of protecting critical dunes with the benefits of economic development and human use.

There are several different ways that states defined the dune areas under regulation, including language specific to local geography and mapping, delineation of construction or building lines providing boundaries where construction could and could not occur, and designation of special areas, such as in New York and Michigan. Oregon's defined coastal area also encompassed the watersheds associated with the shoreline. Some statutes provided a definition for dunes, but not all. Michigan was the only state to have an atlas of regulated dunes, with specific acreage, based on a study of the shoreline dunes.

The states also have considerable variance as to where the regulated areas are defined. A number were included in statute or rules. Several are depicted on maps, such as Michigan's Critical Dune Atlas. Some are also contained in the land use plans of local governments that have a permitting role.

Four of the state programs reviewed (Delaware, Florida, New Jersey, North Carolina) do not allow for a local government role in coastal dune management. In North Carolina, the state has permitting authority, but permits must be consistent with local land use plans. Georgia, Michigan, New York, and Virginia allow local governmental units to administer the regulatory program. However, local governmental ordinances in Georgia must meet or exceed the state program standards and provisions. In Michigan, local governmental ordinances cannot be more restrictive than the state regulatory program. Five states—Maine, Maryland, Oregon, Texas, and Washington—require local governmental entities to develop and adopt land use or other types of plans to regulate coastal development activities. In Texas, local governmental units are also required to adopt erosion control plans.

Comparing regulated activities in each state is challenging, as they each have different climates, topography, geography, and local economic development priorities. However, the activities regulated in most states included: land clearing, alteration of the areas (filling, sand removal, digging) vegetation disruption and removal) and construction of structures. It was not possible within the scope of this project to obtain and review specific information on regulated or exempt activities in the numerous local governmental programs.

There appears to be considerable variety in the way that states handle permitting programs and only the most general information was considered for this report. Each state has a lengthy and detailed list of permit guidelines and/or rules, which places a detailed comparison beyond the scope of this report. All states require permits or letters of approval for regulated activities in their coastal dune areas. Florida reviews potential impacts of activities in relation to the beach dune system, adjacent properties, vegetation, and marine turtles. Georgia has two permit processes—one for stable dunes and one for eroding, unstable dune areas. New York's permit standards look to the use – whether or not it is reasonable and necessary, and how it minimizes effects on natural protective features and natural resources. In the states that allow for or require local government regulatory programs, permitting must be consistent with state standards or requirements or approved individually by the state program. Michigan's permitting program is

the only program that mandates approval of permits unless harm to the dunes is proved by the regulatory authority, whether at the state or local governmental level.

*Key Takeaways of State Comparisons*

Michigan is distinctly different in regard to coastal dunes than other states in the Great Lakes region. Michigan has the greatest amount of dunes in the Great Lakes, especially acreage in private holdings, and its acreage is large even in comparison with many coastal dune areas in ocean states. Its dunes, situated on about 270 miles along a freshwater resource, are distinctly different, both in their origins and ecology, than ocean dunes.

Michigan's legislative purpose, as articulated in the statute and revised in 2012 (PA 297 of 2012), is also considerably different than ocean states, which have coastal dune regulatory initiatives primarily aimed at stemming coastal erosion from the storms and weather presented by the oceans. In the face of ocean front challenges, it may be easier to motivate the public and private property owners to support coastal dune protection. Michigan is also one of the few states that regulate very specific coastal dune areas versus the use of tidal and land boundaries, as do the majority of ocean states reviewed in this report. It may be more challenging, especially in relation to private property, to regulate specific areas versus the entire length of a shoreline.

One avenue to look to for improved coastal dune management may be the development of a stronger relationship with local governmental units that contain critical dunes. The majority of state environmental authorities in states on ocean coastlines appear to have a strong relationship with local governmental units as far as regulating coastal areas and dunes. There are elements of these programs that may prove useful models for Michigan, such as Texas, where local governments are required to provide permit applications to the state for review and approval or Washington, where a major role of the Department of Ecology is to provide technical assistance to local governments in relation to their land use plans and permitting.

At present, of the coastal dune management approaches reviewed for this report, Michigan's is the only one where local government regulation is not allowed to be stricter than the state. It is also the only state that mandates permit approvals, with the burden of scientific proof the responsibility of the regulatory agency.

# Part 3: Recommendations

Managing coastal dunes is not a simple task, and bringing the best information from science into the conversation about management and regulation has been a challenge central to Michigan's long history of coastal dune management approaches. Incorporating the best academic knowledge and scientific understanding of the dunes into the very human tasks of governance, management and use of those same dunes has been and remains a monumental task. Thus far, that challenge has been met with somewhat mixed results.

With this current round of research and assessment, we intended to compile the best available information about our state's dunes to provide a historical and social context for engaging with that information and understanding its relationship to management, and to provide a foundation

for future research, reflection and possibly revision of current approaches. With those goals in mind, we offer the following recommendations for consideration by the relevant funding entities, state and local leaders, and individuals and groups with an interest in Michigan's coastal dunes:

1. **Expand and encourage awareness and use of geographic information in dune management, especially the new Michigan Dunes Inventory (MDI) GIS, by developing a new GIS layer to delineate Michiagn dunes, and by offering training sessions and model projects for state and local governments and non-governmental partners.** The analytical power and capacity of the MDI GIS to improve the understanding of Michigan's coastal dunes on a local, regional and statewide level is immense. The MDI GIS allows users to investigate the dunes, provides new ways of visualizing the dunes, and includes information for understanding Michigan's dunes and their physical, ecological and social context. As an online, interactive and free GIS application, it provides a user-friendly and attractive interface intended to make data and tools available to users with limited GIS knowledge, while also providing a range of more sophisticated applications and the ability to analyze data using measurement tools and several apps for specialized purposes. This suggests it could be a very useful and accessible tool to support local governments that currently do not utilize professional GIS tools for understanding and managing dunes in their jurisdictions, as well as for supporting local stewardship, volunteer, or other non-governmental entities seeking to engage in dune management. *One significant area of need is to identify, define and delineate the spatial extent of coastal dune systems throughout the state in a polygon layer, which could then be incorporated into the MDI to significantly expand its usefulness in addressing fundamental research questions.*

2. **Incorporate the latest science into current dune management programs, particularly with regard to minimizing stabilization of dynamic or mobile dune complexes.** While scientific understanding of the dune environment continues to evolve, our research suggests several areas where "the most comprehensive, accurate, and reliable information and scientific data available" today does point to some specific, short-term management objectives that should be added to or reinforced in Michigan's programs. *Specifically these are: a) recognizing the inherent dynamism and mobility of dunes and dune complexes as among the most fundamental "functions" of dunes; b) avoiding the stabilization of mobile dune areas as a variety of dune areas (open, migrating and more stable) are necessary to maintain the diversity of ecological communities within the dunes; and c) encouraging development approaches that minimize fragmentation of dune habitats.*

3. **Convene a workgroup of state and local leaders to clarify and articulate the ideal role for both state and local government in dune management.** Finding the proper balance between state and local management responsibilities for dunes has been a challenge since the passage of the 1989 Act. At this time, there are three (out of a possible 60) local jurisdictions electing to administer the Act on a local level, and that number has dropped since 2012. Survey results indicate that local government leaders continue to believe that local zoning is one of the most effective tools for dune management, though they also rely heavily on state permitting as an important tool.

Meanwhile, other functions, such as acquisition and ownership of large, high-quality dune parcels may actually be seen as a more suitable role for the state as opposed to local governments. This has potential implications for the Department of Natural Resources and the Michigan Natural Resources Trust Fund (see Recommendation 8). Also, it appears that the 2012 statutory amendments have created some confusion regarding the role of local governments, adding a "no more protective than state" limiting provision that may conflict with the stated approach of the original statute. This confusion appears to have driven some local governments, such as Emmet County, out of the program (and raises the central question: why would a local government voluntarily undertake a program that provides no value beyond the state's program). There is an outstanding question if this provision actually conflicts with the state's other planning and zoning statutes. *All of this suggests the need for a thoughtful and systematic review of the proper and desired role of various levels of government in terms of meeting the goals of dune management.*

4. **Fund additional scientific studies to determine the appropriate scale (local, regional, statewide) for measuring and managing ecological impacts to the dunes.** Critical thresholds beyond which the coastal dune ecosystems suffer significant or irreversible degradation have not been established. If local thresholds are considered, then the cumulative effects of this degradation on the larger coastal system must be researched and evaluated. At this time, and despite the importance of this information in understanding the long-term health of the coastal dune ecosystems, these research questions do not appear to be under investigation. Similarly, data on the effects of habitat fragmentation on the sustainability of ecological communities of the coastal dune environments are especially lacking. *The first step in addressing this need is deciding the scale at which this threshold and the resulting ecosystem degradation should be understood and managed.*

5. **Close the most critical information gaps regarding the sensitivity of dune species and ecological communities to habitat fragmentation, using both professional and citizen science strategies.** Key information about coastal species—both plant and animal—is unavailable, and research on this topic is sparse. Although it is vitally important to understanding the ecological systems of the coastal dunes, research on patch size, species dispersal, fragmentation and related topics for the Great Lakes coastal dunes species has not been pursued and much research is needed to fill this knowledge gap. The emerging popularity of "citizen scientist" programs and the use of mobile platforms for capturing key data should also be explored as a means to close critical information gaps and simultaneously foster a citizen stewardship ethic (also see Rec. 7). The Michigan MDNR hosts one of the longest-running citizen science programs, the annual frog and toad survey, in the country. If carefully designed, such a model could be expanded to the key dune-dependent species and could have the potential to be very popular. *There are a variety of agencies and entities who should be engaged in developing and eventually coordinating a strategy to systematically approach this challenge, such as university researchers, the Michigan Natural Features Inventory, the Michigan Stewardship Network and the Michigan Dune Alliance.*

6. **Incorporate more risk and resiliency considerations into Michigan's dune management programs at the state and local levels, based on the emerging understanding of coastal dune age and the drivers of large-scale (spatial and temporal) dune dynamics.** An emerging body of science clearly demonstrates that the coastal dunes should not be viewed as a singular body that formed largely during one interval of time thousands of years ago. Rather, they should be viewed as a complex system that is dynamic. This science suggests that our management programs should be revisited with a greater appreciation for relative dynamism and diversity of the system—particularly the role of large-scale dune destabilization, migration and alteration, which has and will happen within much shorter time frames than previously understood, and which is driven by factors not entirely understood yet. A dune management approach that took this view would likely treat dune development with an eye toward hazard risk mitigation, in addition to critical considerations of ecological, slope, or aesthetic concerns. *The State of Michigan should review its High Risk Erosion Area (Part 323) and Sand Dunes Management (Part 353) programs with this information in mind, and should also seek opportunities to ensure this updated information is incorporated into programs currently working with local community resiliency planning efforts, such as the University of Michigan's "Restoring, Retrofitting, and Recoupling Michigan's Great Lakes Shorelands" program and the Land Information Access Association's "Resilient Michigan" program, projects also supported by the Office of the Great Lakes' Michigan Coastal Management Program.*

7. **Foster a stronger coastal dunes stewardship ethic and education program through outreach and engagement efforts, seeded by use of the "Understanding Michigan Dunes" journal map.** The world's largest collection of dunes on a freshwater resource is situated on Lake Michigan, providing the dunes' shoreline area with considerable ecologic, economic, and aesthetic value. However, we lack a statewide education infrastructure to highlight the significance of these coastal dunes and to foster appreciation and stewardship of them. The "Understanding Michigan Dunes" journal map could aid in such an effort, with additional links from websites connected to Michigan dunes (such as state agency websites, conservation and advocacy group websites) and/or by making available to park visitors as interactive displays on tablet computers. For example, MDNR personnel are considering making the journal map available to Michigan state park visitors on iPads in park visitor centers. In addition, a state-sponsored citizen science initiative focused on the dunes could improve knowledge while sparking increased community knowledge and stewardship. *The "Understanding Michigan Dunes" journal map application shows great potential for becoming a powerful new public outreach tool for understanding and appreciating Michigan's dunes.*

8. **Convene a one-day summit to articulate goals and a statewide strategy for identifying and securing, through voluntary fee-simple purchase or conservation easements, some of the largest of the remaining high-quality, undeveloped coastal sand dunes.** Identifying and taking a proactive approach to securing the highest quality, undeveloped sand dune areas has been a priority for many groups and agencies, including the National Park Service (1959) and Michigan's state government as outlined in the original 1976 sand dune law. This effort has not been undertaken on a strategic, statewide

basis to date. Our local government survey suggests that local leaders view state ownership of high-quality dunes as an effective approach to dune management. State park facilities with sand dunes are consistently the most-visited in the state, often experiencing long lines of visitors on summer weekends, many of whom have to be redirected to neighboring local and regional parks due to capacity issues. The MDNR adopted a comprehensive land strategy in 2013, including a goal of providing public access every five miles along the Great Lakes shoreline (MDNR Land Strategy 2013). The Michigan Natural Resources Trust Fund Board of Trustees has, in the past, made acquisition of coastal dunes a high-priority. Local land conservancies and parks departments continue to strive to secure additional acreages of lakeshore dunes. *These various themes, opportunities and programs should be brought into alignment through a strategic meeting of key partners, with the primary outcome being a strategic plan for securing the highest conservation-value areas of undeveloped dunes.*

9. **Incorporate additional best practices from other state and provincial dune management programs into Michigan's approach, such as: a) clearly defining the state vs. local governmental roles (**Rec. 3)**, b) adding considerations for risk management in dunes, in addition to providing natural and scenic** protections (Rec. 6)**, and c) increasing public-private partnerships for stewardship** (Rec. 8). Even though there are distinct differences between the coastal dunes in Michigan and the ocean states, there is much to learn from an examination of their laws, policies, programs and methods. Within the limited review done for this report, it is evident that there are valuable approaches from these other states to consider. Ideas we feel most worthy of exploring in the short term are state programs which: a) clearly define and share responsibilities between the state vs. local government levels of management; b) effectively meld considerations of both the risks associated with developing in a dynamic dune environment and protection of the natural and scenic value of the dunes (Michigan's approach separates these considerations into two distinct and separate programs); and c) offer examples of innovative public-private partnerships in areas of stewardship and education. *Specifically, the Eastern Lake Ontario Dunes Coalition is a potential model to examine for lessons in merging private, nonprofit, and local and state governmental efforts for sharing the burden of coastal dune management.*

## Conclusion

The group of researchers, practitioners, advocates and managers involved in this project collectively represents decades of diverse expertise, passion, and perspectives on Michigan's coastal dunes. When the group first convened on a snowy day in West Michigan in early 2014 and began to develop a strategy for tackling the daunting variety of challenging work encompassed in this report, they also took a few minutes to step back and consider their hopes and fears for this project, and for Michigan's dunes themselves.

Many of their hopes and fears for the dunes reflect a perspective largely mirrored by those who have seen and walked the dunes, both residents and visitors alike. There was a hope that these places will continue to exist for their great-grandkids to see and enjoy. There was a fear that Michigan may one day lose the heart and soul of these places, that their inherent "awesomeness"

may be diminished beyond recognition. There was a fear that the dunes would one day become so fragmented that natural ecosystem functions were no longer self-sustaining, that the dunes would thus lose their resiliency, their diversity of plant life; visions that they could be degraded into a monoculture of grass. There was a fear that the dunes would become a place harboring only small microcosms of the lost natural system that would be carefully stewarded – "ecosystem museums" - to view or do research on a scale not commensurate with the once-massive system. But there was also hope: a recognition and desire that we improve our understanding of the physical and ecological processes and their interactions within the coastal dune system, so that we could maintain a place where the dune species in all their diversity could flourish, and these natural systems sustain and even restore themselves.

And, as always, a desire to find a workable balance between protection and development arose out of a concern that the dunes become too privatized, lacking adequate public access—articulated most clearly as a fear that "Michigan may one day feel like Florida," with its endless miles of urbanized and suburbanized coastline. There was a desire that more people who live in Michigan now come to know and prize the dunes as much as those people who live outside of Michigan—many of whom first heard of this amazing complex when Michigan's Sleeping Bear Dunes was named the Most Beautiful Place in America by the Good Morning America television program in 2011 (Sleeping Bear 2011).

There was also a recognition that the dunes system really needed someone, perhaps state government, to identify and sustain a sufficient number and acreage of high-integrity dune complexes to provide representative distribution and quantity of key species. At its most basic, the question elicited a response in keeping with the goals that have hopefully been advanced through this project, improving our collective knowledge and the tools available for better coastal resource management.

And so, the group got to work. The result—after more than a year of research and crunching numbers, mining history and memories, reviewing numerous scientific studies, comparing and contrasting approaches—is summarized here. With support from the Office of the Great Lakes' Michigan Coastal Management Program, we developed these tools, conducted the research and performed assessments that we hope will assist state and local leaders in applying the most sophisticated, science-based understanding of our coastal sand dunes to their policy and permitting deliberations. By creating a more complete and comprehensive picture of Michigan's coastal dune system, and bringing our current knowledge of the ecological and geologic dynamics of the dunes front and center, this effort will assist Michigan in better recognizing, respecting and strategically protecting the species, habitats and landscapes that make our coastlines beautiful and unique.

We encourage you to dig deeper through the resources collected on the project website, and begin using and exploring the new tools, emerging science, and historical perspectives offered here. Michigan's coastal dunes are a unique world-class resource, rich in beauty and opportunity, change and challenge.

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