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B Eli abe h A. Pendle on, E. Rober Thieler, and
S. Jeffre William [1]

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recent studies show that the current drop in lake levels (since 1998) are the largest since the Dust Bowl of the 1930's, and are likely a result of higher than average air temperatures over the Great Lakes (Assel and others, 2004). Impacts associated with expected lake-level falls over the next

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vulnerability has been determined and the possible impacts associated with water-level change are considered. Although this methodology can be applied anywhere that physical change is likely to occur as a result of changing water level, the kinds of change that may occur (i.e. exposure of polluted marine sediments, loss of wetland, erosion of river mouths, lower-groundwater levels)) are not addressed and should be considered by planners in the context of resources utilization and preservation. This report illustrates that CPI methodology can be applied along three lakeshores within the Great Lakes. The application of the data for planning purposes is a function of the nature of potential environmental change and whether such change is desirable from a resource management perspective.

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well older, higher shorelines from glacial lakes (Teller and Thorleifson, 1983). There are six historic lighthouses within Apostle Islands National Lakeshore as well as cultural resources associated with Native Americans, voyageurs, quarrying, loggers, farmers, and fisherman. For more information on Apostle Islands National Lakeshore see:

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The **Rate of Relative Sea Level Change** variable is derived from the change in annual mean water elevation over time as measured at water level recording stations within the Great Lakes. The rate of lake-level change for Lake Superior from 1918-2003 is about +0.4 mm/year and is ranked as low change-potential (Figure 1B) (GLERL, 2006). The rate of lake-level change for Michigan-Huron for the same time period (1918-2003) is +4.0 mm/year, and is ranked as moderate change-potential (Figure 1A) (GLERL, 2006). A reason for the difference in the historical magnitude of lake-level change between Michigan-Huron and Superior is that since 1914 outflow for Lake Superior has been regulated by the International Lake Superior Board of Control. Because lake levels have historically been rising through the 20th century, but are predicted to fall as a result of changing climate in the 21st century, change-potential was established based on lake level change (rise or fall) instead of only lake level rise (Figure 9A, Figure 9B, Figure 9C). Data from climate models suggest that Michigan-Huron levels could be declining at an average rate of 13 mm/year by 2090, and Superior could fall at a rate of 8 mm/year by 2090 (U.S. Global Change Research Program, 2000). Based on historical data and predictive models, Michigan-Huron tends to have greater lake-level variability than Lake Superior (U.S. Global Change Research Program, 2000). Establishing change-potential ranking based on lake-level change captures the variability in historic and future lake-level trends, and identifies the most dynamic systems as likely being the most vulnerable.

Mean Annual Significant Wave Height is used here as a proxy for wave energy which drives coastal sediment transport. Wave energy is directly related to the square of wave height:

$$E = 1/8 \rho g H^2$$

where E is energy density (wave energy per unit area) , H is wave height, ρ is water density and g is acceleration due to gravity. Thus, the ability to mobilize and transport coastal sediments is a function of wave height squared. In this report, we use hindcast nearshore mean significant wave height data for the Great Lakes for the period 1976-95 obtained from the U.S. Army Corps of Engineers Wave Information Study (WIS) (Hubertz and others, 1996). The model wave heights were compared to historical measured wave height data obtained from the NOAA National Data Buoy Center to ensure that model values were representative of the study area. Mean wave heights for the Apostle Islands NL, Indiana Dunes NL, and Sleeping Bear Dunes NL vary between 0 m (sheltered areas, very low change potential) to over 1 m (exposed areas, very high change potential) (Figure 10a, Figure 10B, Figure 10C).

Mean Annual Shoreline Ice Cover is linked to the protection from storms that an ice-covered coastline receives during the winter months (Forbes and others, 2004). Ice can also cause severe erosion and property damage especially in river settings or around structures not able to withstand ice push (Forbes and others, 2000). For this study, ice cover over decadal time scales is considered a protective agent in reducing storm erosion along the shoreline. Annual ice cover data were obtained from NOAA's Great Lakes Environmental Research Laboratory Annual Ice Cover Atlas (Assel, 2003) (Figure 11). Of the three national lakeshores in this report, the Apostle Islands experience the longest period of annual ice cover, between 60 and 105 days per year (moderate change-potential). Sleeping Bear Dunes and Indiana Dunes experience between 30-45 days per year of annual ice cover (high change potential) (Figure 12A, Figure 12B, Figure 12C).

coastal change-potential index for Indiana Dunes NL. The CPI scores are divided into low, moderate, high, and very high change

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The data within the coastal change-potential index (CPI) show variability at different spatial scales for Indiana Dunes NL. Variables such as regional coastal slope (very high), lake-level change (moderate), and mean annual ice cover (high) are constant within the park (Figure 8B, Figure 9B, and Figure 12B). The variable for shoreline change is low to high as determined from historic shoreline recession rates (Stewart, 1994) (Figure 7B). The significant wave height variable

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Gornitz, V. and White, T.W. 1992, A coastal hazards dataA22 Tw 19.4/MCID 19r016 T03 Tc -0.0igane.-0.8e03 T

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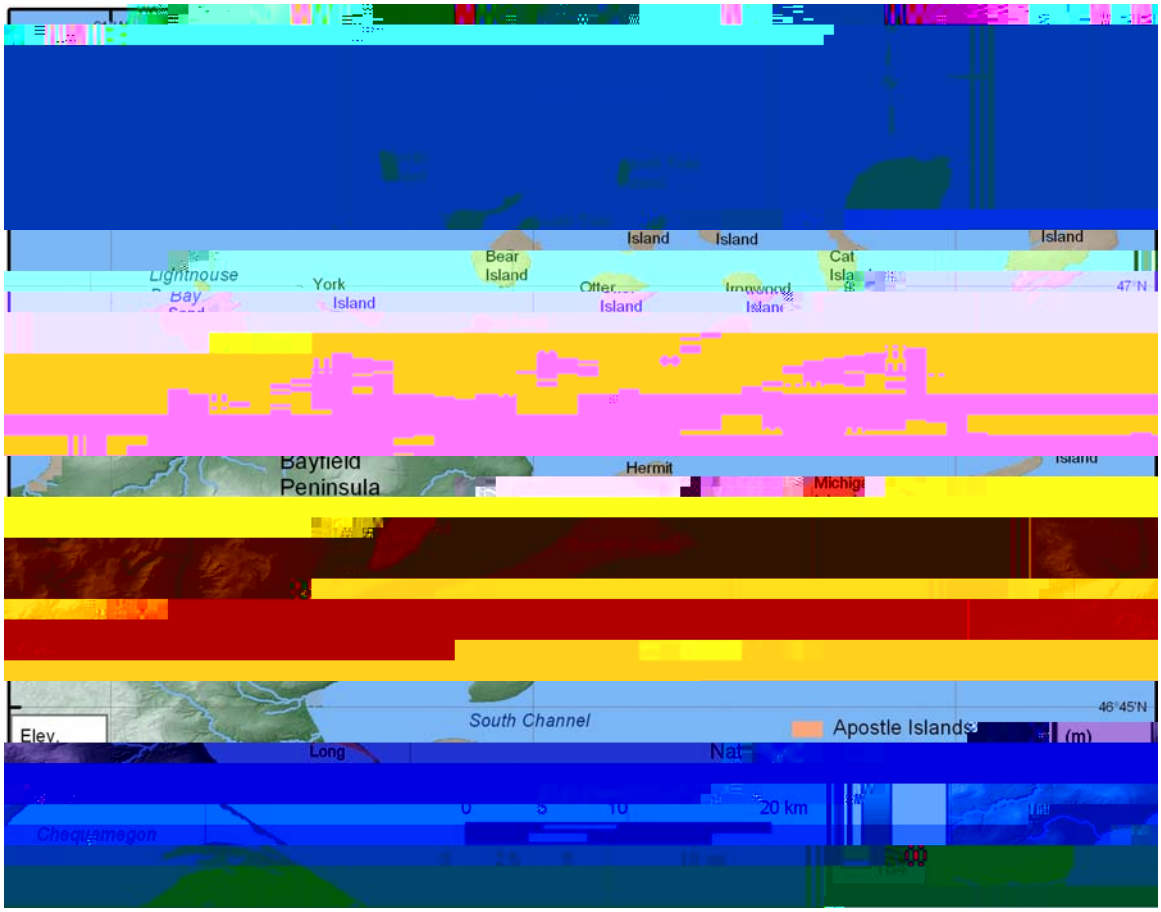
Figure 2. Location of Great Lakes National Lakeshore: Sleeping Bear Dunes, MI; Indiana Dunes, IN; and Apostle Islands, WI.



F **3A.** De ailed map of Apo le I land Na ional Lake hore.

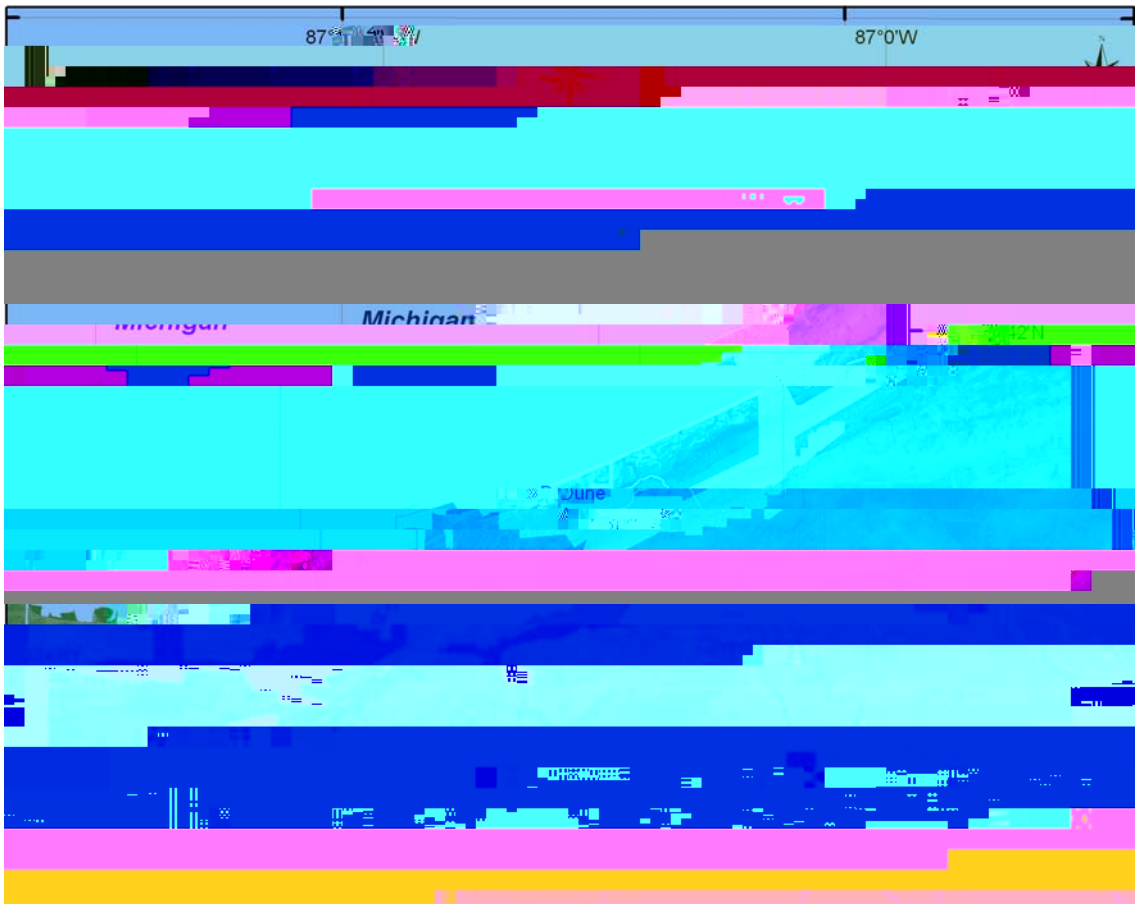
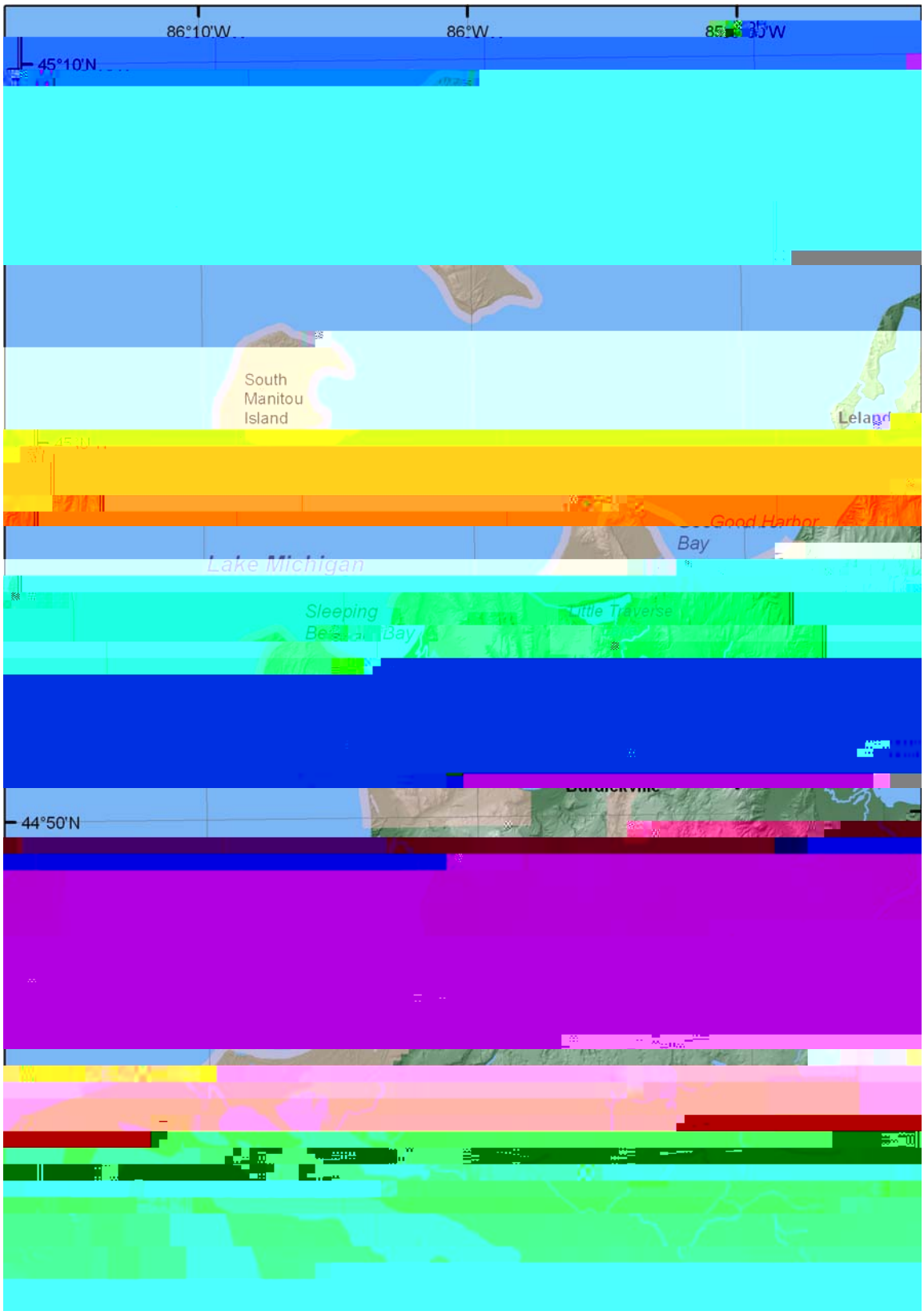


Figure 3B. Detailed map of Indiana Dunes National Lakeshore.



F f 3C. De ailed map of Sleeping Bear D. ne Na ional Lake hore.

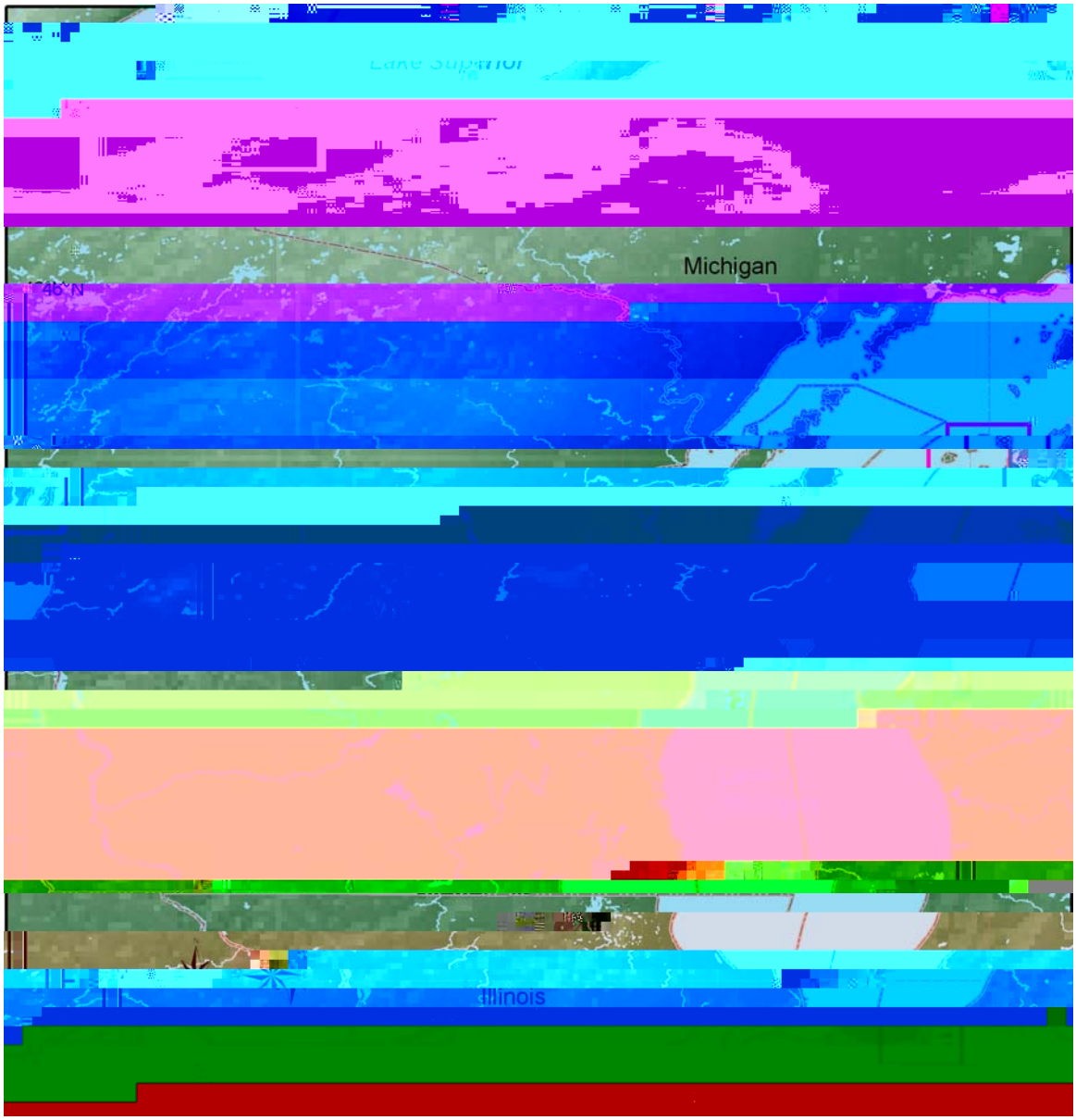


Figure 4. Index map of shoreline grid for Sleeping Bear Dunes NL, Indiana Dunes NL, and Apostle Islands NL.

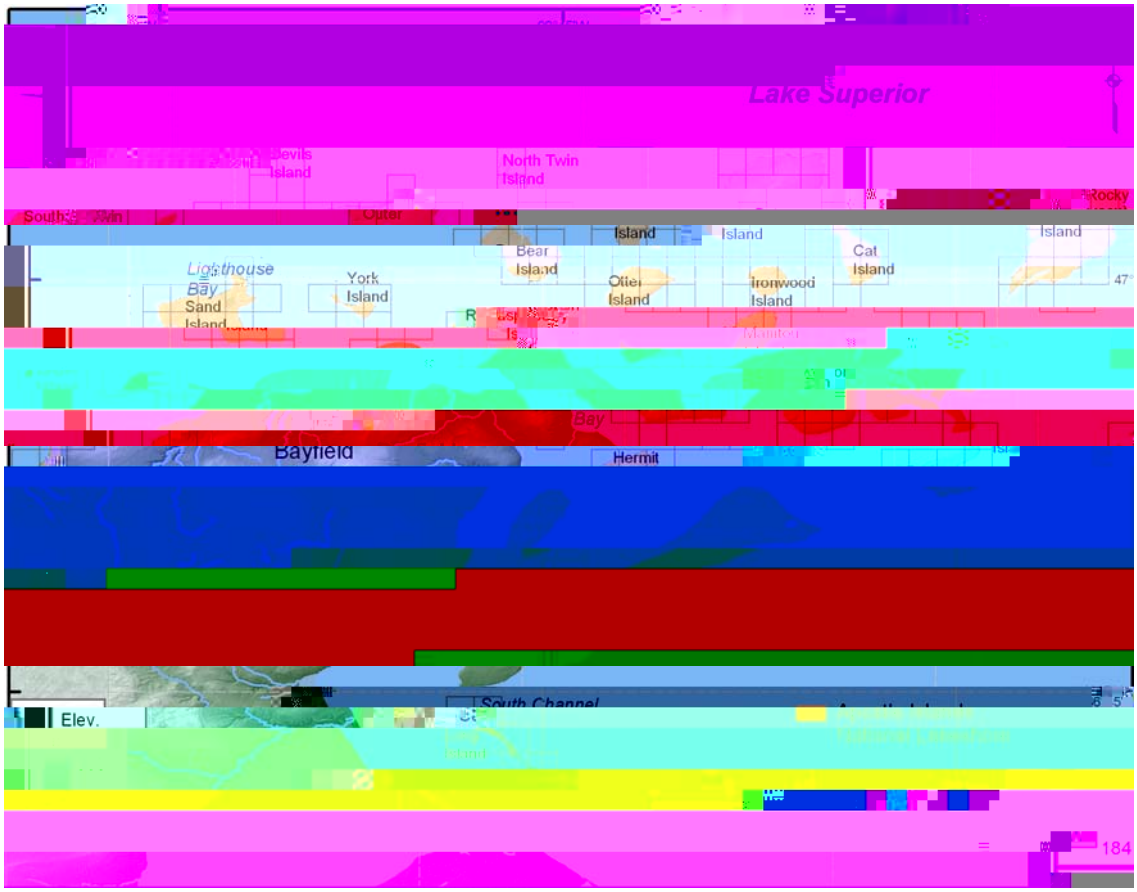
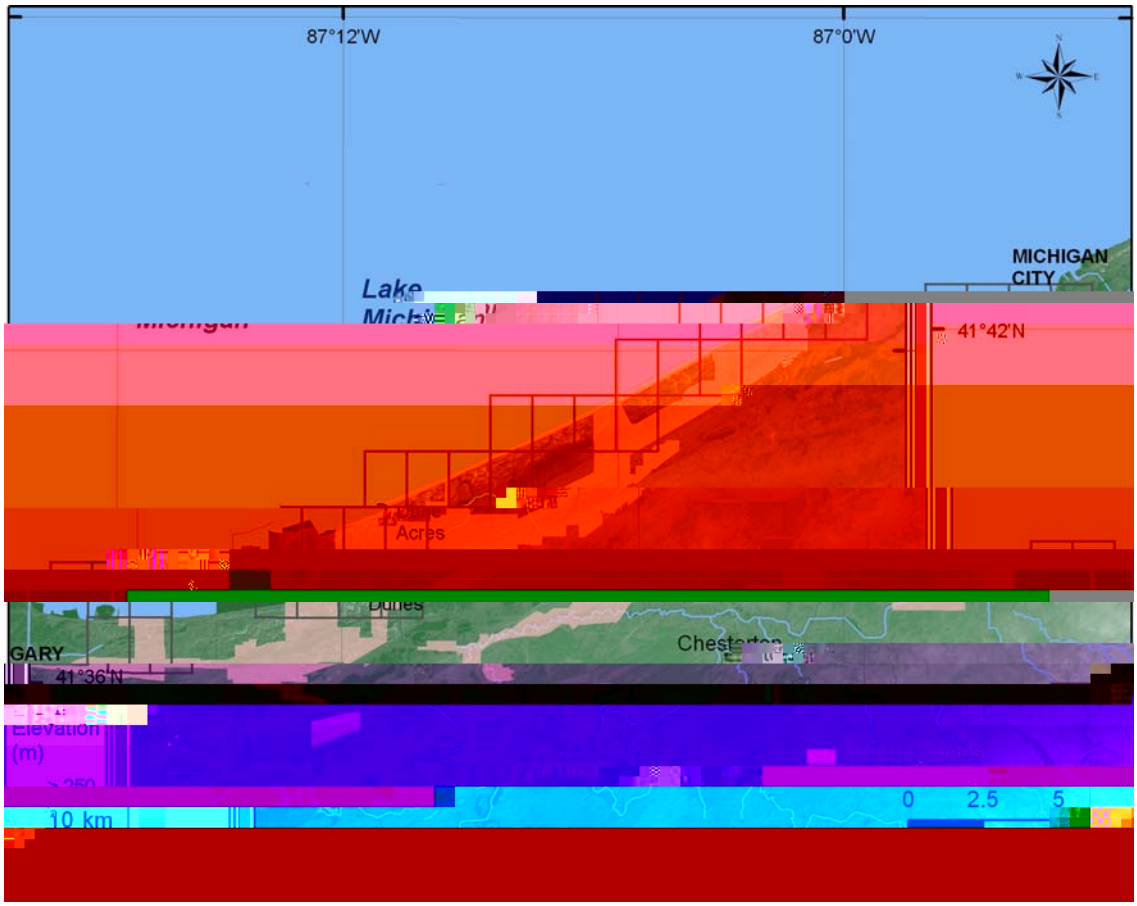


Figure 5A. Shoreline grid for Apostle Islands NL. Each cell is approximately 1-minute and represents a shoreline segment for which each variable is defined.



F **5B.** Shoreline grid for Indiana D ne NL. Each cell i appro ima el l-min e and repre en a horeline egmen fo

F t 5C. Shoreline grid for Sleeping Bear D. ne NL. Each cell i appro ima el l-min. e and repre en a horeline egmen for hich each ariable i defined.

Figure 6A. Lakeshore geomorphology for Apostle Islands National Lakeshore. The colored shoreline represents the variations in coastal geomorphology within the park. High change-potential geomorphology includes gravel and sand beaches not immediately backed by bluffs. Moderate change-potential geomorphology consists of alluvial fans and sand beaches backed by bluffs. Low change-potential geomorphology includes medium bluffs and rock outcrops.

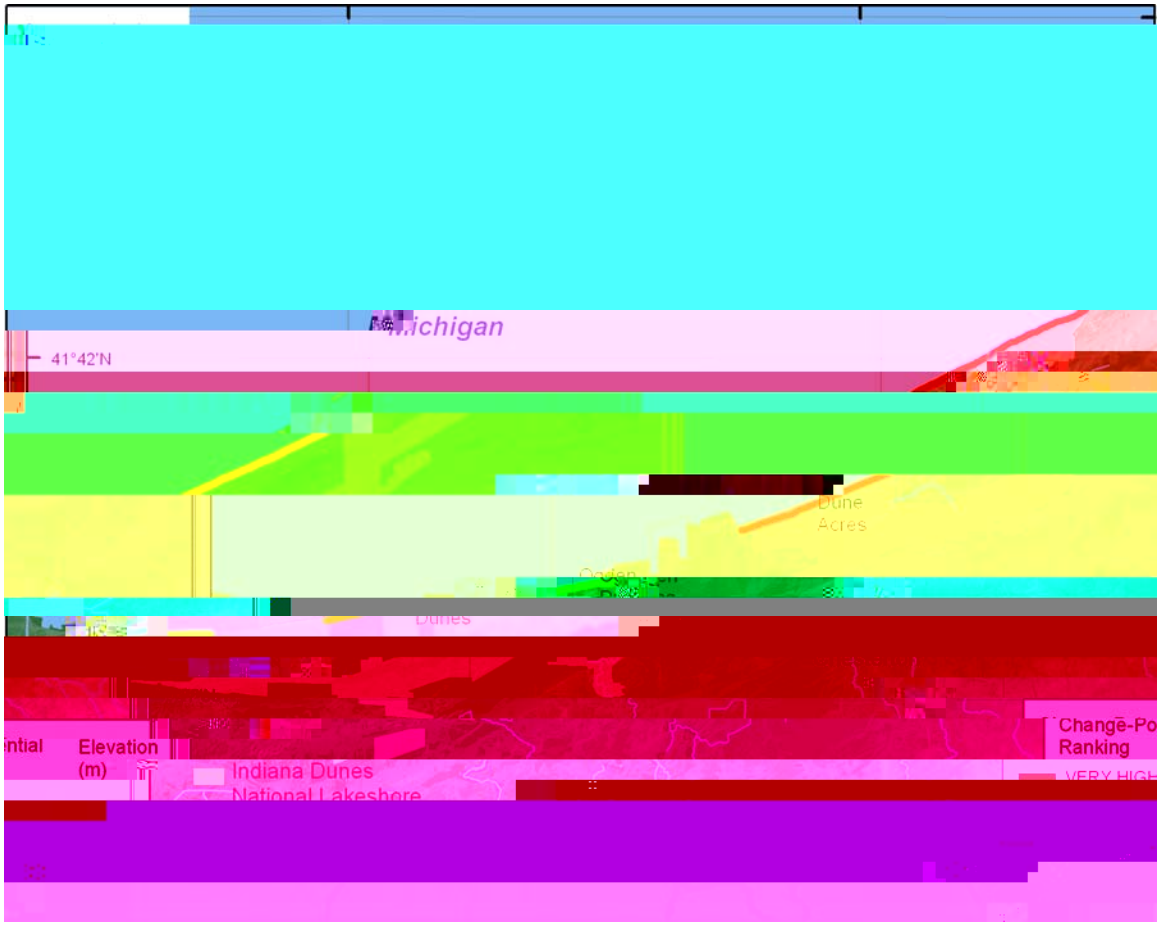


Figure 6B. Lakeshore geomorphology for Indiana Dunes National Lakeshore. The colored shoreline represents the variations in coastal geomorphology within the park. High change-potential geomorphology includes gravel and sand beaches not immediately backed by bluffs. Moderate change-potential geomorphology consists of alluvial fans and sand beaches backed by bluffs. Low change-potential geomorphology includes medium bluffs and rock outcrops.

Figure 6C. Lakeshore geomorphology for Apostle Islands National Lakeshore. The colored shoreline represents the variations in coastal geomorphology within the park. High change-potential geomorphology includes gravel and sand beaches not immediately backed by bluffs. Moderate change-potential geomorphology consists of alluvial fans and sand beaches backed by bluffs.

Figure 7A. Shoreline change for Apostle Islands National Lakeshore. The colored shoreline represents the estimated rate of shoreline change.

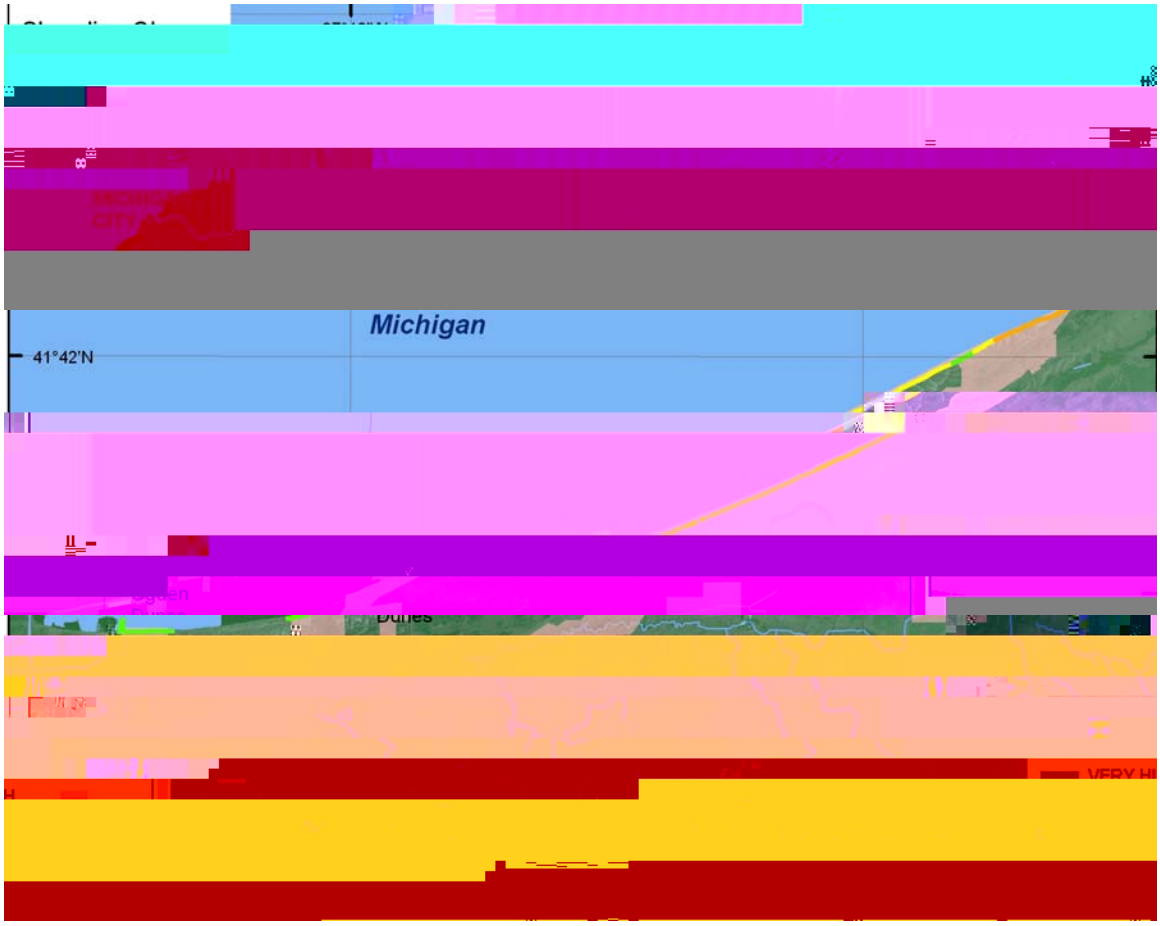
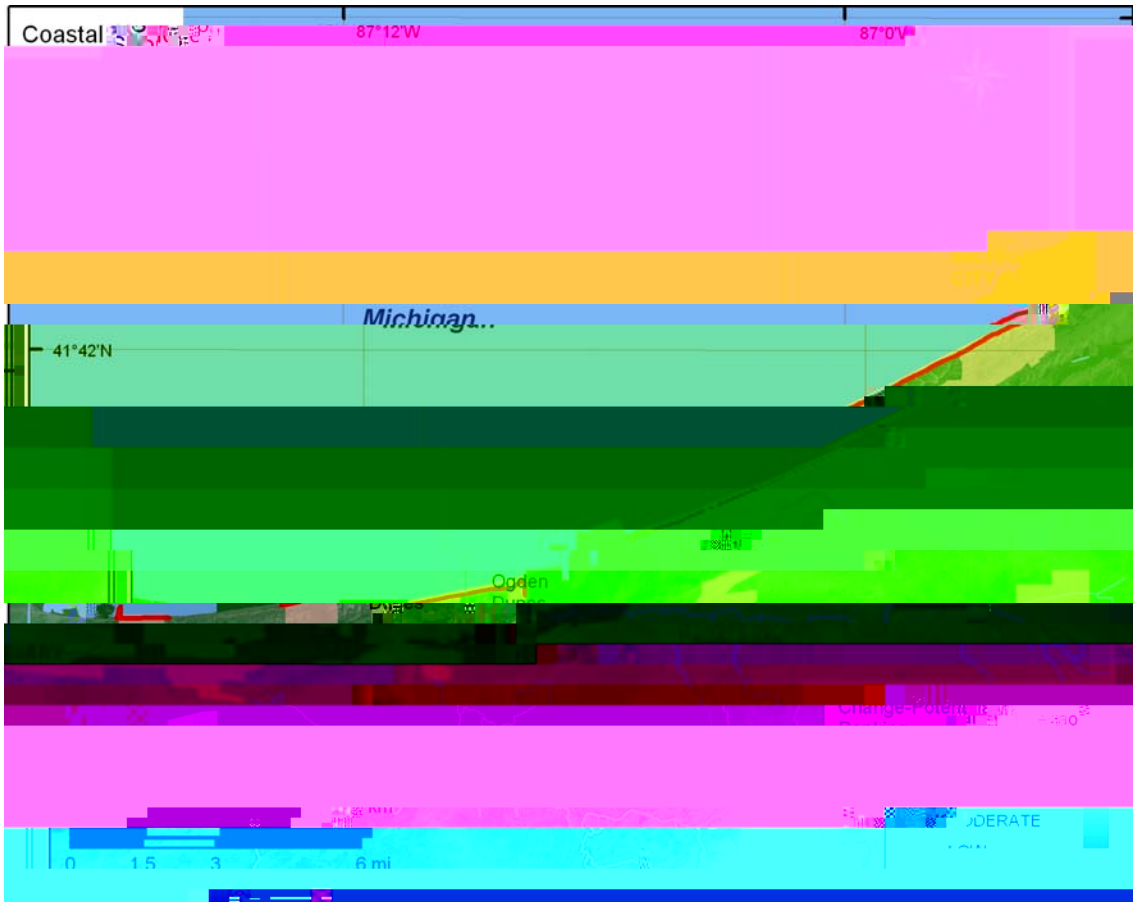


Figure 7B. Shoreline change for Indiana Dunes National Lakeshore. The colored shoreline represents the rate of shoreline change.

Figure 8A. Regional coastal slope for Apostle Islands National Lakeshore. The colored shoreline represents the regional slope of the land, 5 km landward and lakeward of the shoreline.



F 8B. Regional coastal slope for Indiana Dunes National Lakeshore. The colored shoreline represents the regional slope of the land, 5 km landward and lakeward of the shoreline.

Figure 8C. Regional coastal slope for Sleeping Bear Dunes National Lakeshore. The colored shoreline represents the regional slope of the land, 5 km landward and lakeward of the shoreline.

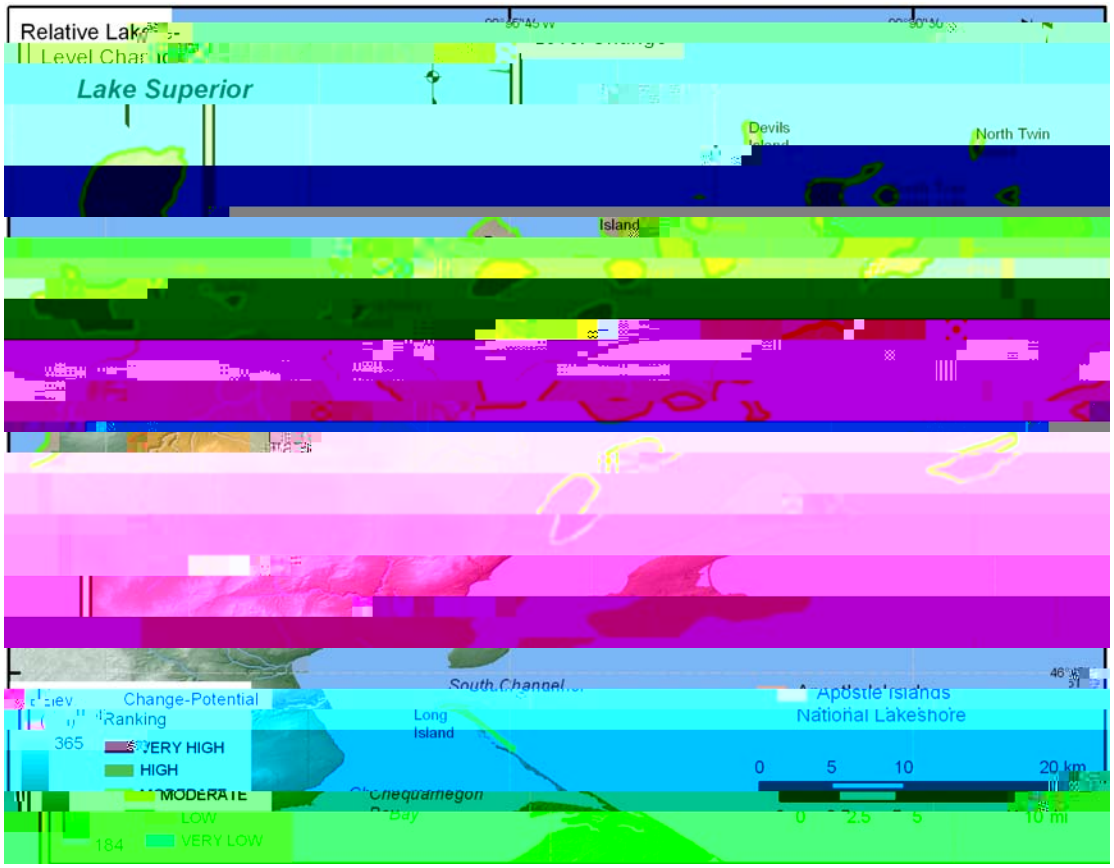


Figure 9A. Rate of relative lake-level change for Apostle Islands National Park.

Figure 9B. Rate of relative lake-level change for Indiana Dunes National Park.

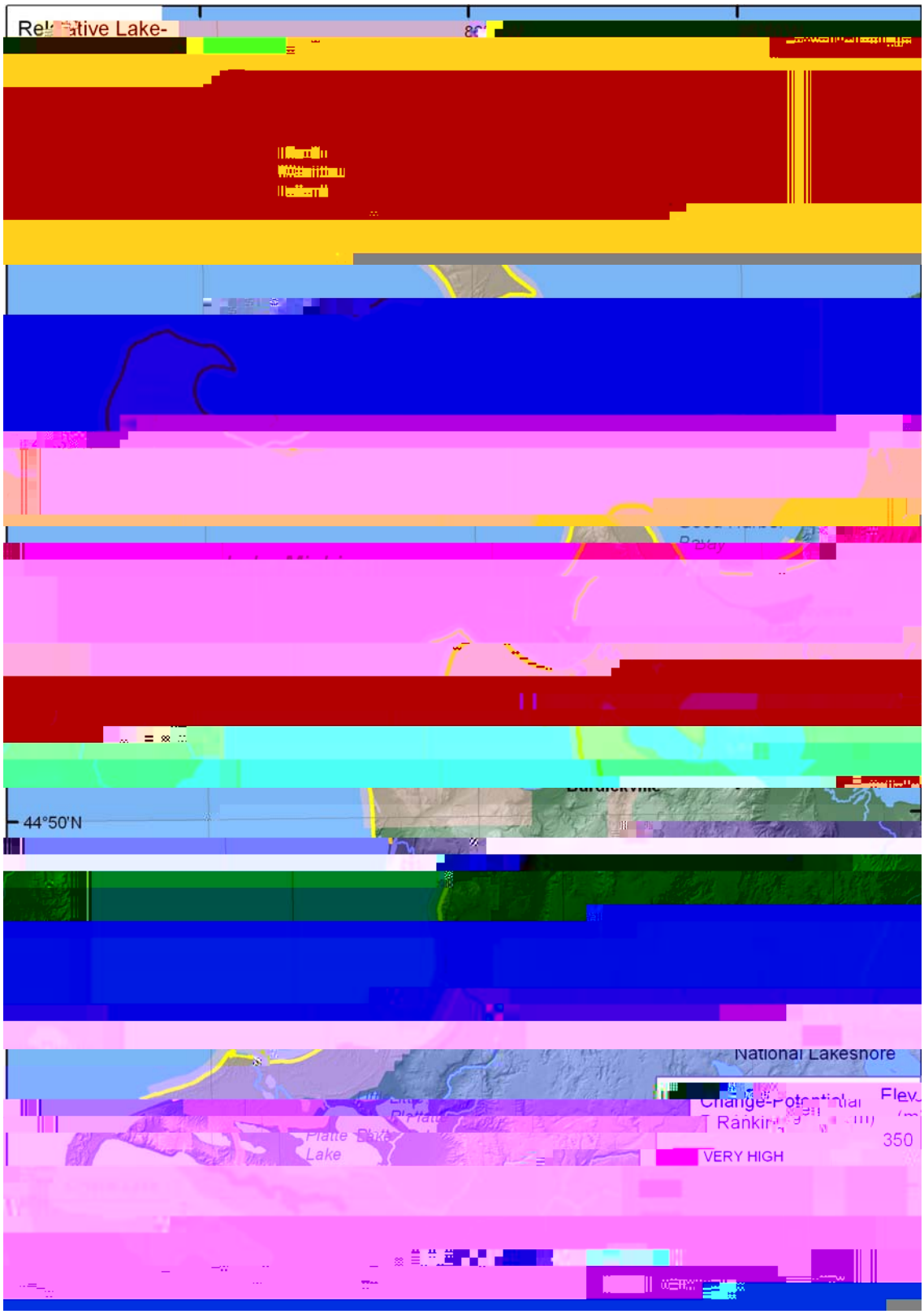


Figure 9C. Rate of relative lake-level change for Sleeping Bear Dunes National Park.

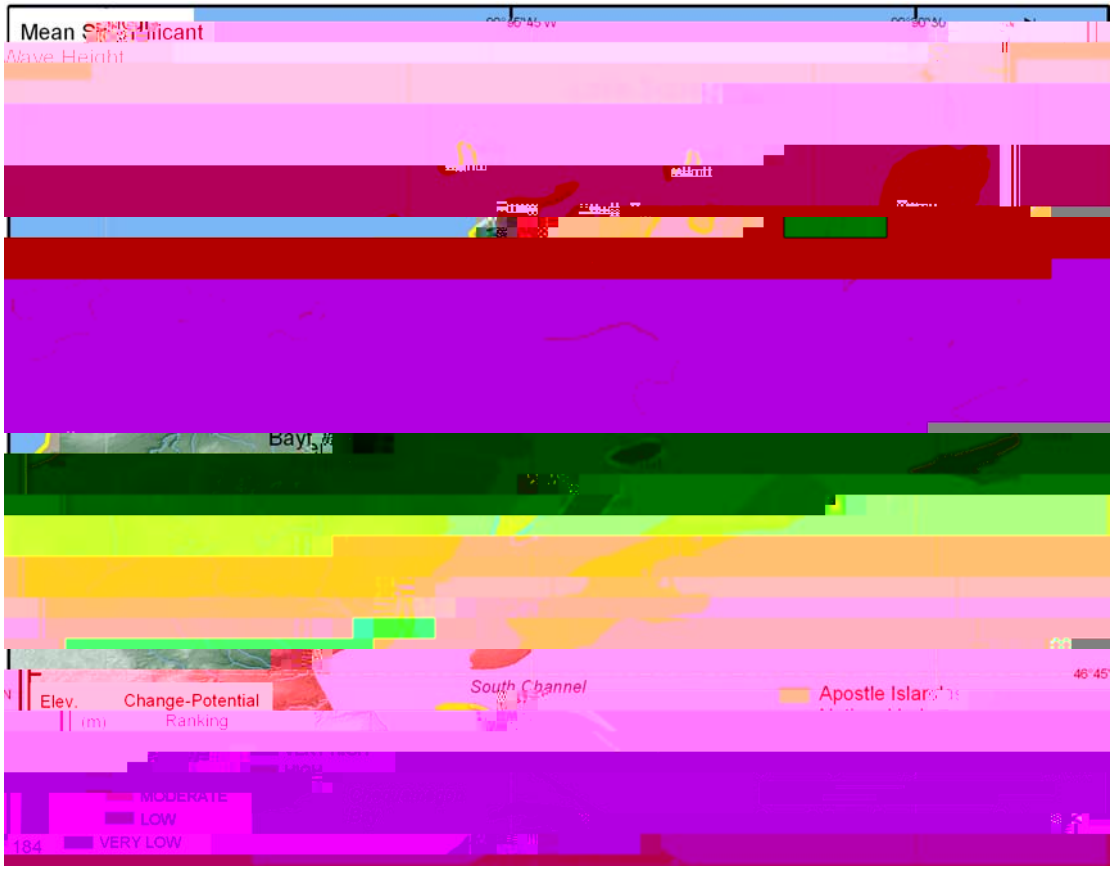


Figure 10A. Mean significant wave heights for Apostle Islands National Lakeshore. The colored shoreline represents the ranked mean significant heights within the park.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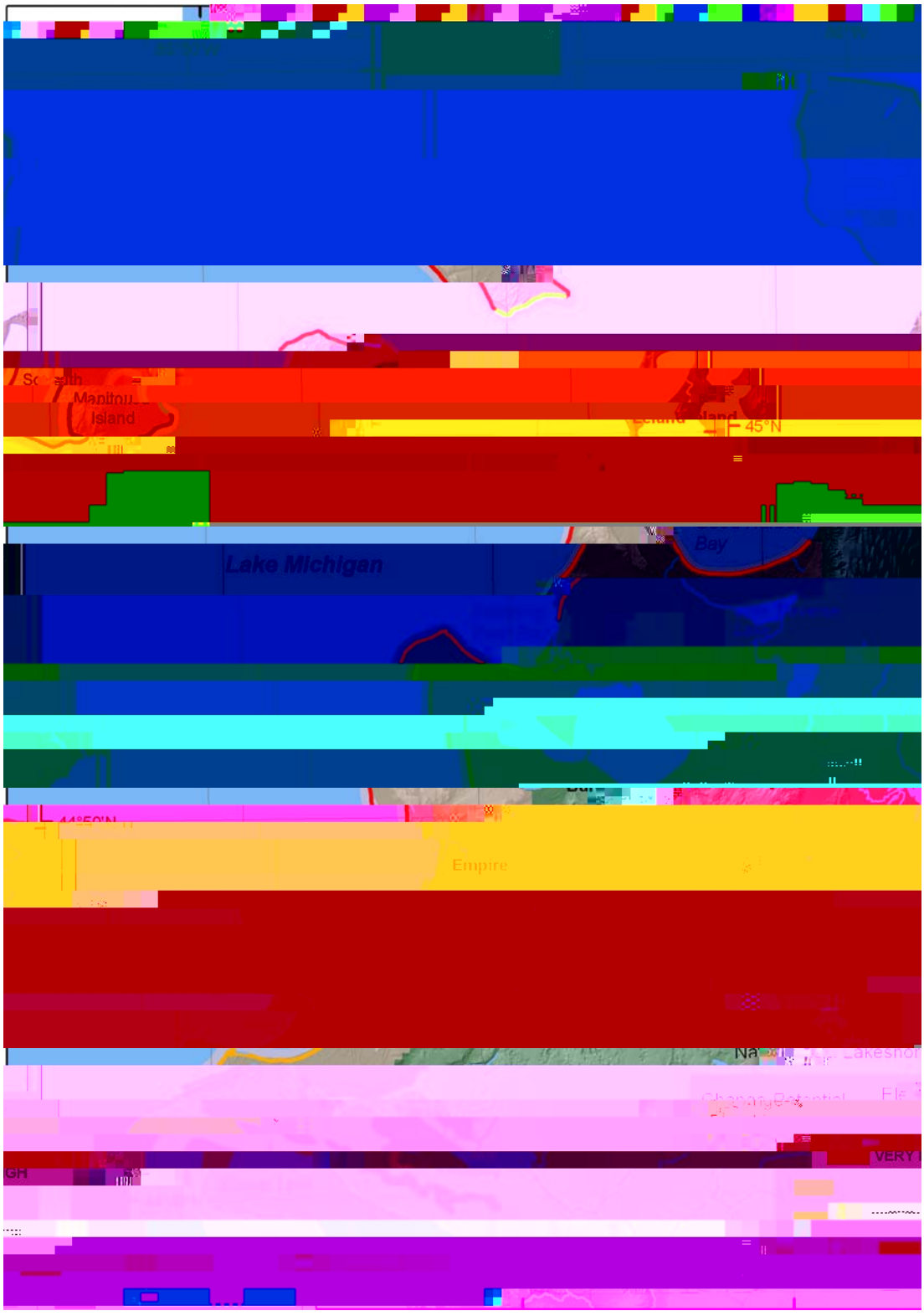


Figure 10C. Mean significant wave heights for Sleeping Bear Dunes National Lakeshore. The colored shoreline represents the ranked mean significant heights within the park.

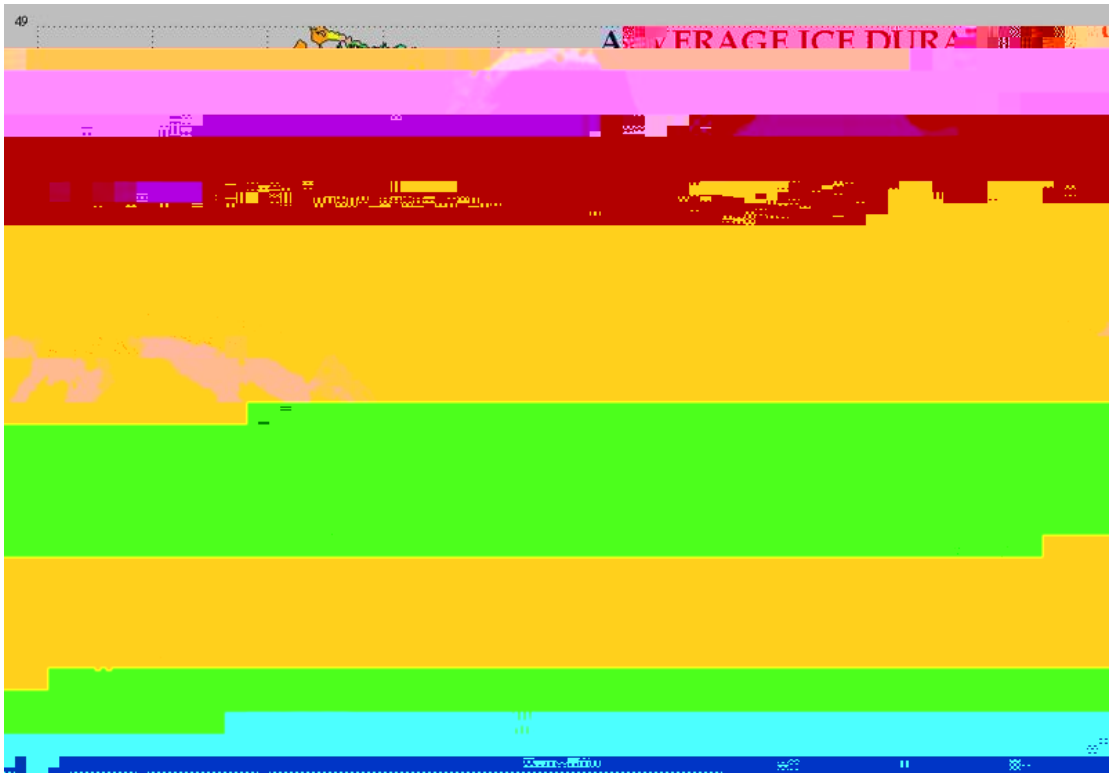


Figure 11. Mean Annual Ice Duration for the Great Lakes for Winters 1973-2002 (Assel, 2003).

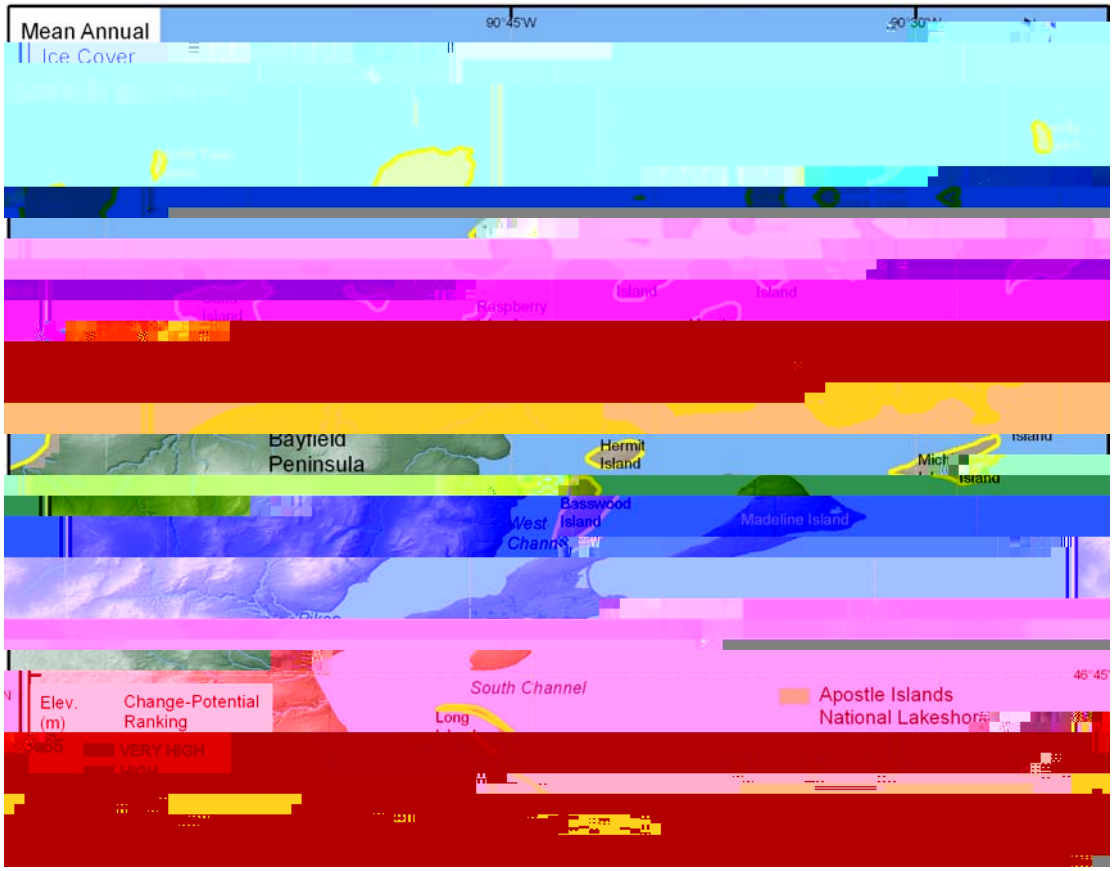


Figure 12A. Mean Annual Ice Cover for Apostle Islands National Lakeshore.

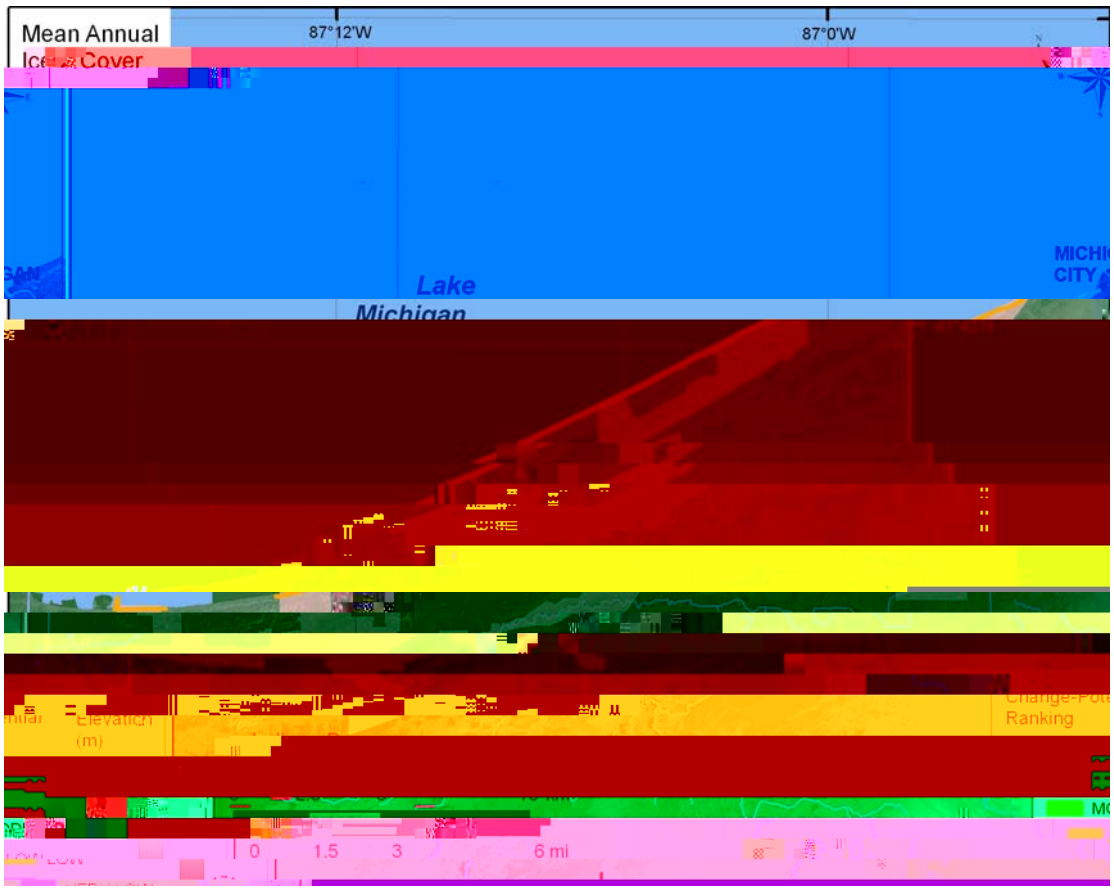


Figure 12B. Mean Annual Ice Cover for Indiana Dunes National Lakeshore.

Figure 12C. Mean Annual Ice Cover for Sleeping Bear Dunes National Lakeshore.

Figure 13A. Relative Coastal Change-potential for Apostle Islands National Lakeshore. The colored shoreline represents the relative coastal change-potential index (CPI) determined from six variables. The very high change-potential shoreline is located along sandy stretches where significant wave heights are highest. The low change-potential shoreline is located along bluffs where wave heights are low.

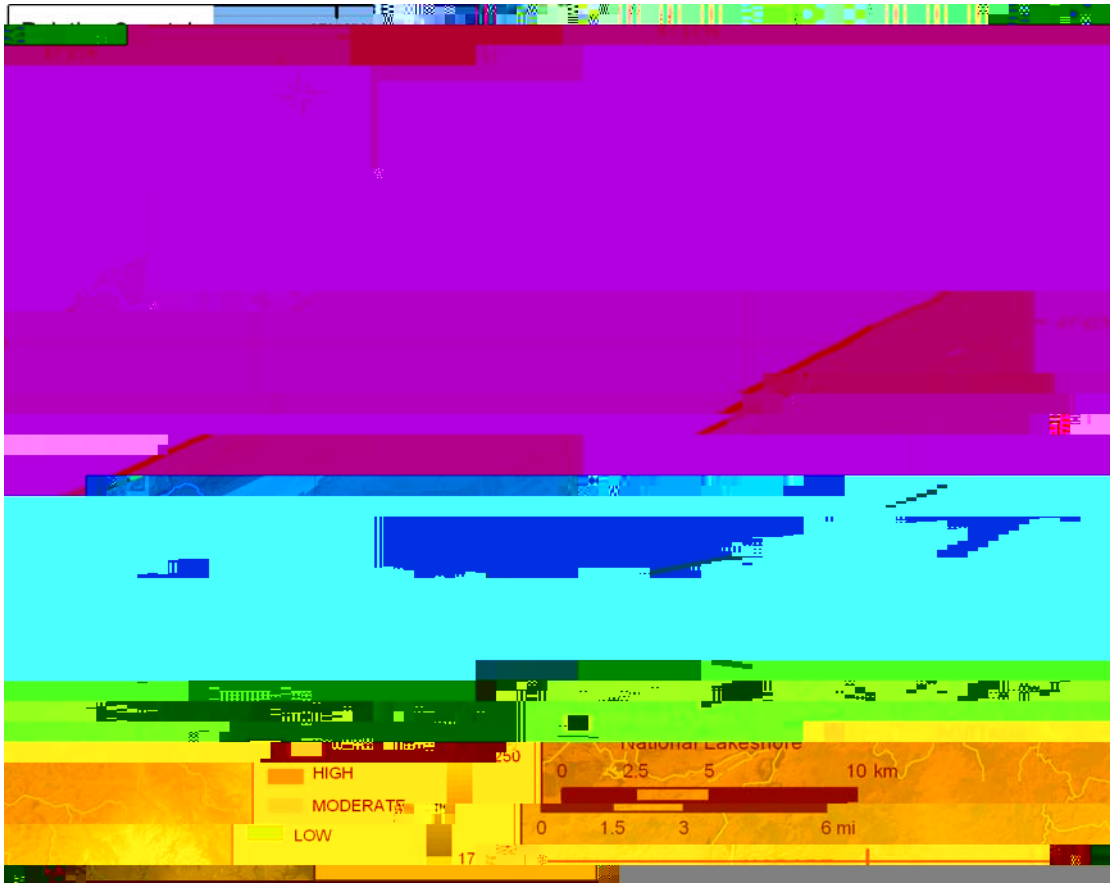


Figure 13B. Relative Coastal Change-potential for Indiana Dunes National Lakeshore. The colored shoreline represents the relative coastal change-potential index (CPI) determined from the six variables. The very high change-potential shoreline is located along sandy stretches of coast where shoreline recession rates are highest. The low change-potential shoreline is located along bluffs where shoreline recession is lower.

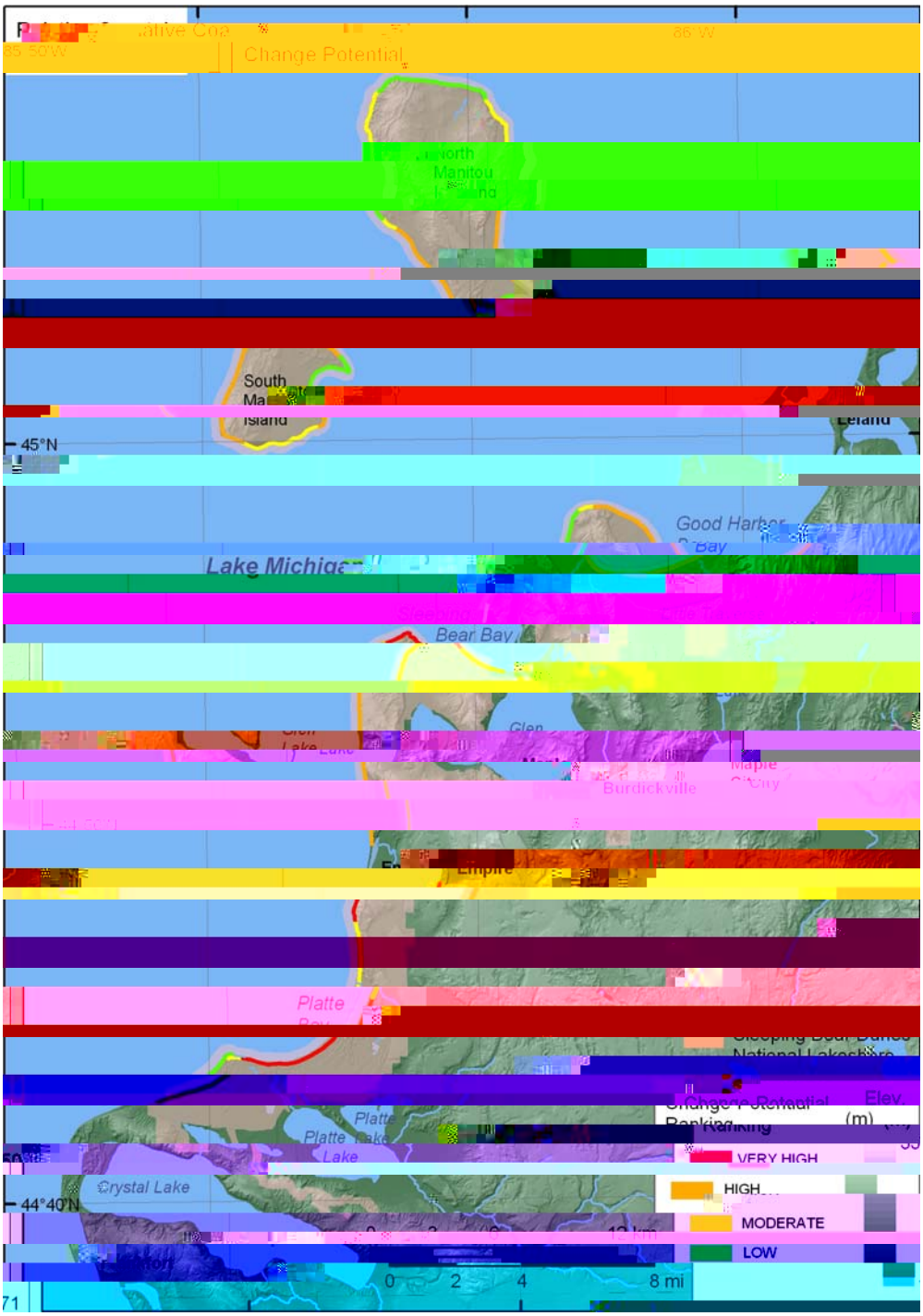


Figure 13C. Relative Coastal Change-potential for Sleeping Bear Dunes National Lakeshore. The colored shoreline represents the relative coastal

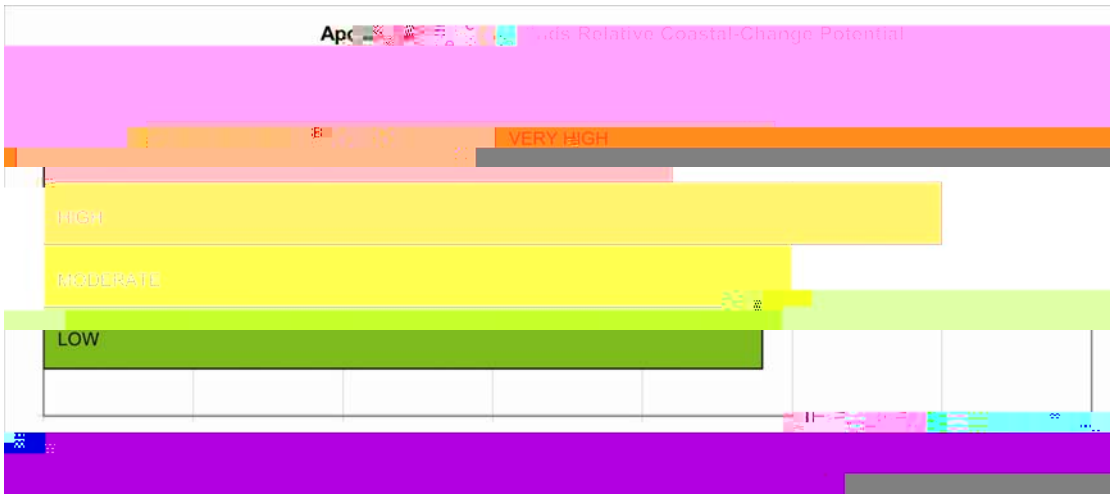
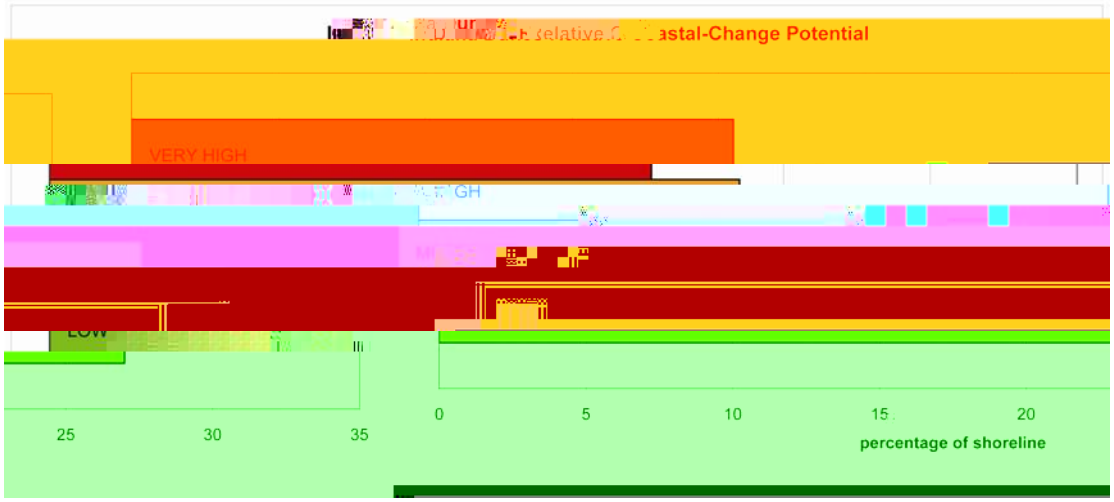


Figure 14A. Percentage of Apostle Islands NL shoreline in each CPI category.



F f 14B. Percentage of Indiana Dunes NL shoreline in each CPI category.

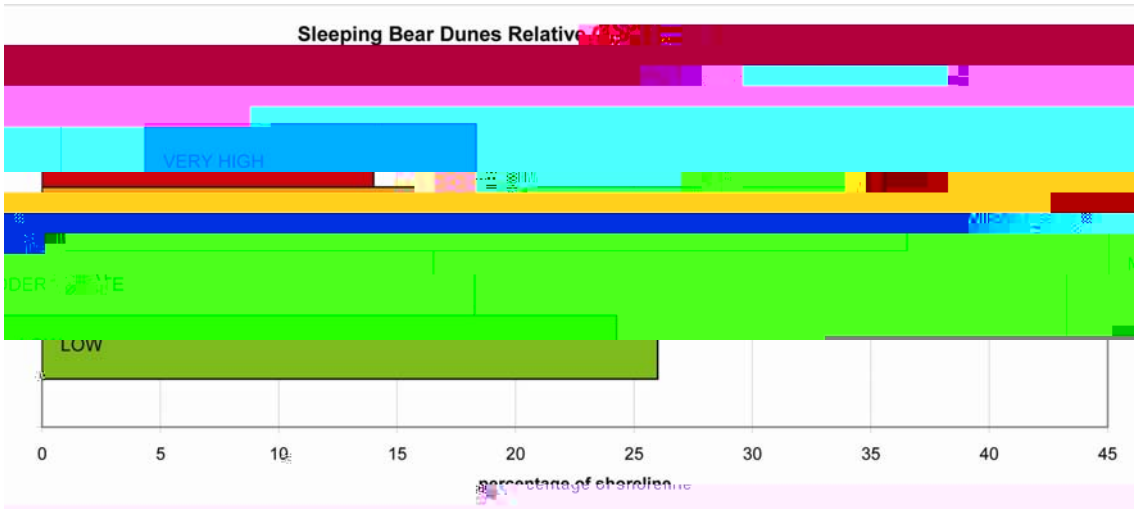


Figure 14C. Percentage of Sleeping Bear Dunes NL shoreline in each CPI category.

1. Range for Coa al Change Po en ial Ranking of Variable on he Grea Lake hore .

2. Source of Data

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GEOMORPHOLOGY	Aerial photography and surficial geology maps from state GIS organizations and NPS Natural Resource and GIS Programs	http://www.michigan.gov/cgi http://www.state.in.us/ingisi/ http://science.nature.nps.gov/nrdata/index.cfm
SHORELINE EROSION/ACCRETION (m/yr)	United States Great Lakes shoreline recession rate data (final report)	