Sub-Indicator: Hardened Shorelines

Overall Assessment

Status: Fair

Trend (2009 – 2020): Deteriorating

Rationale: This report is the first opportunity at a comprehensive, binational status and trends assessment of the hardened shorelines of the entire Great Lakes since 2009. Using the source data that is now currently available to create derived hardened shorelines classification datasets (see Methods section) it is possible to provide an assessment of the status and trend for the hardened shorelines sub-indicator at the basin scale. The years provided for the Trend are based on the underlying source data and not derived datasets. Based on the amount of increased hardened shorelines since the 2009 reporting cycle it is apparent there is a deteriorating trend across most of the basin, with the only exception at this time being in Lake Superior. However, when newer data is made available, especially on the US side of Lake Superior, similar deteriorating trends may be present after the recent high water level period experienced across the Great Lakes basin.

Lake-by-Lake Assessment

Lake Superior

Status: Good

Trend (2009 – 2015): No Trend

Rationale: Lake Superior was assessed for hardened shorelines on the United States side only in the 2022 reporting cycle. The 2025 State of the Great Lakes reporting cycle is the first opportunity to compare basin wide results to the 2009 reporting cycle.

Lake Michigan

Status: Good

Trend (2009 – 2015): Deteriorating

Rationale: The status for Lake Michigan still remains Good from the 2009 to 2022 reporting cycle, but there has been an increase in the percentage of hardened shorelines in the combined moderately and highly protected shoreline classifications from 11.5% in 2009 to 16.6% in 2022 (Tables 1, 2, and 3), resulting in a Deteriorating trend.

Lake Huron (including St. Marys River)

Status: Good

Trend (2009 – 2015): Deteriorating

Rationale: The status for Lake Huron and the St. Marys River remains Good from 2009 to 2022 reporting cycle, but there has been an increase in the amount of hardened shorelines in the combined moderately and highly protected shoreline classifications from 2.7% in 2009 to 11.7% in 2022 (Tables 1, 2, and 3), resulting in a Deteriorating trend.

Lake Erie (including St. Clair-Detroit River Ecosystem)

Status: Poor

Trend (2009 – 2020): Deteriorating

Rationale: The status for Lake Erie and its connecting channels still remains Poor from the 2009 to 2025 reporting cycle, and there has been an increase in the percentage of hardened shorelines in the moderately and highly protected shoreline classifications from 39.0% in 2009 to 56.9% in 2022 but revised to 56.3% in 2023 (Tables 1, 2, and 3), still resulting in a Deteriorating trend.

Lake Ontario (including Niagara River and International section of the St. Lawrence River)

Status: Poor

Trend (2009 – 2018): Deteriorating

Rationale: While Lake Ontario was considered Fair in the 2009 State of the Great Lakes hardened shorelines sub-indicator report at 21.0% for the combined moderately and highly protected shoreline classification (Tables 1 and Table 3), the status for Lake Ontario and its connecting channels was classed Poor in the 2019 reporting cycle and again in the 2022 reporting cycle. There has been an increased amount of hardened shorelines in the moderately and highly protected shoreline classifications now at 40.6% (Table 2 and Table 3), resulting in a Deteriorating trend.

Status Assessment Definitions

Good: >80% of the shoreline reaches have minor to no protection (20% or less of the shoreline is moderately or highly protected)

Fair: 70-80% of the shoreline reaches have minor to no protection (20-30% of the shoreline is moderately or highly protected)

Poor: < 70% of the shoreline reaches have minor to no protection (30% or more of the shoreline is moderately or highly protected)

Undetermined: Data are not available or are insufficient to assess status condition of the ecosystem components.

Trend Assessment Definitions

Improving: Net decrease or no net increase in the percentage of hardened shorelines in the highly protected or moderately protected categories.

Unchanging: No change in the amount percentage of hardened shorelines in the highly protected or moderately protected categories.

No Trend: Data are available for a 10-year or longer period, but the trend is not statistically improving or deteriorating due to high variability in the data.

Deteriorating: Net increase in the percentage of hardened shorelines in the highly protected or moderately protected categories.

Undetermined: Metrics do not indicate a clear overall trend or data are not available or are insufficient to report on an overall trend.

The defined parameters are intended to support an assessment of relative change over time and represents an initial suggestion for establishing preferred conditions. However, further discussion and refinement of the categories is required to reflect improved understanding of shoreline hardening and ecosystem impacts. These status and trend definitions apply to both the individual lake assessments and the overall assessment. The lake assessments are based on the available shoreline data for each lake, and the overall assessment is based on the available shoreline data for all of the Great Lakes. The Ecological Condition section below outlines some of the challenges with attempting to define reference conditions for hardened shorelines.

Endpoints and/or Targets

The target for this sub-indicator is to observe no net increase in the amount of hardened shoreline along any of the Great Lakes or connecting channels.

Sub-Indicator Purpose

- To assess the amount of shoreline altered by the construction of artificial shore structures, such as sheet piling, revetment, rip rap, and other erosion control and shore protection structures.
- To infer the potential harm to natural coastal processes, aquatic-dependent life, water quality, and shoreline habitat from conditions created by artificial shore structures.

Ecosystem Objective

Shoreline conditions should support natural dynamics and healthy coastal ecosystem habitats for aquatic and terrestrial plant and animal life, including rare and threatened species.

This sub-indicator best supports work towards both General Objective #5 and #9 of the 2012 Great Lakes Water Quality Agreement which states that the Waters of the Great Lakes should, “support healthy and productive wetlands and other habitats to sustain resilient populations of native species” and “be free from other substances, materials, or conditions that may negatively impact the chemical, physical, or biological integrity of the Waters of the Great Lakes”. Replacing natural shorelines with hardened and armoring structures alters natural coastal processes and the habitats created by these processes. Examples of the negative impacts from shoreline armoring include the erosion of coastal wetlands, increased wave energy reflected off of sheet piles leading to rapid rates of change to natural shorelines, and providing areas for the spreading of invasive species like Dreissenid mussels.

Methods

How to measure the linear distance of shorelines, often referred to as the coastal paradox, has often challenged coastal scientists and introduced various levels of uncertainty with any type of shoreline calculations. Factors that influence these calculations include the starting point of reach delineations, segment length (e.g. 100 meters or 1 kilometer), sinuosity, and the natural dynamics (erosion, deposition, water level fluctuations) associated with shorelines over time.

Often aerial imagery or other remote sensing data are used and the vintage of source imagery data and other ancillary data only provide a snapshot in time of where and what type of shoreline is present, especially in regards to natural shorelines. In some of the Great Lakes multiple years' worth of imagery is needed to complete a derived hardened shorelines classification product (see Table 4). In the past State of the Great Lakes Hardened Shorelines sub-indicator reports, one-kilometer reaches have been used to quantify the amount of hardened shorelines present in the Great Lakes. However, without knowing the exact starting point of these reach delineations of various datasets for each of the Great Lakes, there can be a shift spatially in the classification between two different datasets for the same shoreline.

To account for the positional changes of dynamic shorelines, a one kilometer by one-kilometer Great Lakes shoreline reference grid was generated along the entirely the Great Lakes shoreline. This grid serves as a way to measure the linear shoreline distance within each grid cell and is not tied to any specific shoreline classification delineation method or dataset (Figure 8). This allows for the comparison of shorelines from different time periods, different datasets, and is agnostic of shoreline segmentation lengths.

To maintain continuity with past reporting, the hardened shoreline percentage break values and classification categories (Shantz 2011) have been adopted and applied to the grid cell values. To determine the hardened shoreline classification category for each of the Great Lakes shoreline reference grid cells, the sum of hardened classified shorelines lengths within a grid cell are divided by the total length of shoreline within the grid cell to determine the percentage of hardened shorelines per cell.

Hardened shorelines, or shoreline armoring, as classified in this report include any placement of material used to armor the shoreline including rip rap, sheet pilings, bulkheads, revetments, and other ad hoc materials along the shore to offer protection from waves and water level changes. Below are the hardened shoreline classification categories:

- Highly protected (70-100% hardened)
- Moderately protected (40-70% hardened)
- Minorly protected (15-40% hardened)
- Minimal Protection (< 15% hardened)

While the 2019 U.S. Great Lakes Hardened Shorelines Classification (NOAA 2019) does include artificial coastal perpendicular structures such as jetties, groins, breakwaters, piers, and docks, these features were not included in the hardened shorelines calculations. Additionally, islands were also excluded from the analysis, see Data Limitations.

Discussion

Various ecological conditions are influenced by shoreline hardening including changes in coastal aquatic and terrestrial habitats, changes in littoral sediment transport, reductions in ecosystem services and changes in surface and ground water interactions (Gittman et al. 2016). The degree of negative impact to aquatic and terrestrial life and alterations to sediment transport rates in the coastal zone will vary depending on the structure type, design and condition including changes in water levels. Some types of hardened shoreline when not properly sited or engineered without consideration for the surrounding environment may lead to even more severe impacts.

Armoring of the shoreline is often performed to protect property from the impacts of waves and help to slow erosion, but do not necessarily protect against erosion from overland runoff or insufficient structure set back requirements, both of which could be better addressed through other strategic management practices. These armoring structures can additionally be of concern if they are not properly installed and maintained over time. Proper planning, engineering, and design criteria for site specific placement are needed, but often armoring placement is rushed in response to rapid changes that are being seen in the Great Lakes. While some types of armoring can provide habitat for wildlife (see USACE ERDC 2012 and Gittman et al. 2016), many structures in the Great Lakes need retrofits or replacement to provide this type of habitat and could benefit from greater coordination and cost sharing. Working towards a blend of grey (traditional armoring) and green (nature based) shoreline protection structures must be considered to address the increase in hardened shorelines that is currently being observed in the Great Lakes.

Since the hardened shorelines sub-indicator report in 2022, an interagency effort was completed to generate an updated baseline shoreline dataset for the United States portions of the remaining Great Lakes. Additionally, an effort to create and digitize a baseline dataset for the Canadian portion of the Great Lakes has been completed (see the Additional Information section). The combined data from the Canadian and United States sides and their respective connecting channels now allows for a more recent and complete picture of hardened shorelines across the Great Lakes. Additionally, the imagery used for the hardened shorelines analysis was collected just prior to the recent period of high water levels (~2017 to present) in all of the Great Lakes. We are seeing with the recent period of high water levels in all of the Great Lakes there has been a quick response by armoring of the shorelines to protect property, houses, and other critical coastal infrastructure.

Currently there is limited documentation present in the Great Lakes on addressing recommended shoreline hardening and armoring constraints and understanding long-term impacts at the basin wide and lake wide scales. Based on the hardened shoreline analysis of each lake basin for this report, Lake Huron, Lake Michigan and Lake Superior are classified as being in Good status while Lake Erie and Lake Ontario are classified as being in Poor status based on a descriptive point of reference using the baseline Great Lakes (previously known as SOLEC) estimates of the extent and intensity of shoreline hardening (Shantz 2011).

The challenge is defining an appropriate target value regarding shoreline hardening and understanding that each lake, and its connecting channels, are different and unique based on the ecosystem services provided within each basin. The current assessment categories only provide a general estimate of the extent and intensity of shoreline hardening. They do not reflect an assessment of the ecosystem status and its sensitivity or impacts due to hardened shorelines in each lake. Rather, the estimate of the extent and intensity of shoreline hardening can help infer potential harm to natural coastal processes, aquatic-dependent life, water quality, and shoreline habitat.

Lake Superior

Lake Superior currently has a status of Good at 5.2% (Table 3, combined Highly and Moderately protected percentage). Much of the Lake Superior is classified as natural since little to no shoreline armoring has been applied due to the geologic setting where there are several miles of shoreline composed of bedrock with smaller wetland complexes. The shoreline armoring that has occurred in Lake Superior is primarily associated with the more urban and marine transportation settings including the Twin Ports of Duluth, Minnesota and Superior, Wisconsin; the Soo Locks near Sault Ste. Marie; and the various smaller harbors (Figure 3). However, with the recent increase in water levels there has been increased demand for shoreline structure permits. In Minnesota there has been a 1700% increase in permits from 2014-2020 with only two being issued in 2014 and 36 in 2020 (Perello et al. 2020). Prior to 2014, from 2010-2013, there were no permits applied for in Minnesota (Perello et al. 2020).

Most of the new shoreline structures include breakwater, rip rap, seawalls, and gabion basket retaining walls. On the Wisconsin Lake Superior shoreline, a similar story has happened between 2010 and 2019 with a 1633% increase in shoreline structure permits (Perello et al. 2020). Most of the shoreline structures being placed in Wisconsin include bulkheads and rip rap. It will be interesting to see how the coastal ecosystem responds to this sudden increase in shoreline structures due to high water levels and how it adjusts accordingly when water levels do start to drop again. Similar in Michigan there have been reports on increased permitting for shoreline structures, but comprehensive numbers were not available for this report.

On the Canadian side, less than 5% of the total length of shoreline has been hardened. Like the United States, shoreline armoring is associated with urban and marine settings but due to the mostly unpopulated Canadian shoreline, is largely restricted to two urban areas. In Sault Ste. Marie, Ontario alteration has occurred along the waterfront and in Thunder Bay, Ontario alteration has occurred at both the waterfront and the mouth of the Kaministiquia River (Mission and MacIntyre Rivers).

Lake Michigan

Based on the hardened shorelines classification data for Lake Michigan its status is currently Good at 16.6% (Table 3, combined Highly and Moderately protected percentage), however, it is less than four percent from changing to Fair status (20-30% of the shoreline is moderately or highly protected). Much of the hardened shoreline in Lake Michigan occurs in the southwest extending from Milwaukee, Wisconsin southward towards the Chicago, Illinois metro area and also in the vicinity of Green Bay, Wisconsin (Figure 4). There are also smaller areas of hardened shoreline development associated with the various harbors and small towns along the shore of Lake Michigan.

While the hardened shoreline analysis completed for this report did not report on shoreline perpendicular structures, there are numerous structures present along the southwestern Lake Michigan shoreline (NOAA 2019). These shoreline perpendicular structures have been placed to help capture sediment moving southward along the shoreline in the hope of establishing pocket beaches which can have multiple benefits, including human recreation, open coastal space buffers and habitat restoration/protection. The recent period of high water levels has also caused significant changes to occur, impacting the remaining natural areas in southwestern Lake Michigan. The interplay between hardened shoreline structures and natural coastal ecosystems is of particular interest along Illinois Beach State Park where significant erosion has occurred south of the North Point Marina which is protected by rip rap and breakwaters (Figure 9). Project work is currently underway towards protecting the remaining panne wetlands present along this section of shoreline in Illinois. Since the release of the sub-indicator report during the 2022 reporting cycle additional in-water shoreline protection structures have been placed along Illinois Beach State Park. These structures have not been added into this reporting cycle as details around how to capture these in water structures within the analysis are still to be determined.

Lake Huron (including St. Marys River)

Based on the United States and Canadian data, Lake Huron currently has a status of Good at 11.7% (Table 3, combined Highly and Moderately protected percentage). Much of the hardened shorelines located in Lake Huron occur within Saginaw Bay; near Tawas City, Michigan; along the St. Marys River; southern Georgian Bay from Severn Sound to Colpoy's Bay; and the southern end of Lake Huron by Port Huron, Michigan, and Sarnia, Ontario (Figure 5). Much of the North Channel and Eastern Georgian Bay on the Canadian side is classified as natural since little to no shoreline armoring has been applied due to the geologic setting where there are numerous coastal wetlands and inlets located between bedrock headlands. When comparing the current status at 11.7% with the 2009/2011 status value of 2.7% (Table 3) there appears to be a 9% increase in the amount of hardened shoreline within Lake Huron and the St. Marys River Ecosystem. However, the comparison is not as straight forward given

the resolution of the datasets used for each time period and the method by which the amount of hardened shoreline was analyzed and quantified, see Measure, Data Limitations, and Additional Information sections.

Lake Erie (including St. Clair-Detroit River Ecosystem)

Based on the hardened shorelines classification data for Lake Erie and the St. Clair-Detroit Ecosystem its status is currently Poor at 56.3% (Table 3, combined Highly and Moderately protected percentage). When comparing the current status at 56.3% with the 2009/2011 status value of 39% (Table 3) there has been a significant increase in the amount of hardened shoreline within Lake Erie and the St. Clair-Detroit River Ecosystem. However, the comparison is not as straight forward given the resolution of the datasets used for each time period and the method by which the amount of hardened shoreline was analyzed and quantified, see Measure, Data Limitations, and Additional Information sections. It does appear that the density of armoring along the shoreline is increasing when comparing values in Table 1 with Table 2. However, since the overall length of categorized shoreline decreased due to the refined shoreline delineation, there is uncertainty as to whether the identified change represents a true increase or a difference in dataset methodologies. Much of the highly armored shorelines are associated within the connecting channels of the St. Clair-Detroit River Ecosystem and the more urban and marine transportation settings of western, southern, and eastern Lake Erie (Figure 6). On the Canadian side, the recent reassessment of the shoreline showed that there has been additional hardening, largely in areas where landowners have made attempts to protect beaches or infrastructure from water-level fluctuations. The amount of highly and moderately protected shorelines in Lake Erie and its connecting channels is of particular concern especially when trying to reconnect the lake with its coastal ecosystems. Given the shallow setting of Lake Erie and east to west orientation on the landscape it is prone to severe seiche impact events that can alter water levels several feet in the matter of hours. This can lead to coastal inundation and erosion which has resulted in the amount of shoreline armoring efforts present within this geography. Finding alternative “softer” protection solutions like nature-based shoreline protection or developing resilient shorelines through the Systems Approach to Geomorphic Engineering community of practice (SAGE 2021) are potential ways to work towards improving hardened shoreline trends in Lake Erie and the St. Clair-Detroit Ecosystem.

Lake Ontario (including Niagara River and International section of the St. Lawrence River)

Based on the hardened shorelines classification data for Lake Ontario, the Niagara River, and international section of the St. Lawrence River its status is currently Poor at 40.6% (Table 3, combined Highly and Moderately protected percentage). When comparing the current status at 40.6% with the 2009/2011 status value of 21% (Table 3) there has been a significant increase in the amount of hardened shoreline within Lake Ontario and its associated connecting channels. However, the comparison is not as straight forward given the resolution of the datasets used for each time period and the method by which the amount of hardened shoreline was analyzed and quantified, see Measure, Data Limitations, and Additional Information sections.

It does appear that the density of armoring along the shoreline is increasing when comparing values in Table 1 with Table 2. However, since the overall length of categorized shoreline decreased due to the refined shoreline delineation, there is uncertainty as to whether the identified change represents a true increase in hardening of shorelines or a difference in dataset methodologies.

Much of the highly hardened areas appear in western Lake Ontario from the Niagara River to Pickering, Ontario with some intermixing of highly protected and minor protection along Lake Ontario’s southern shoreline in New York (Figure 7). After the flooding that occurred in Lake Ontario in 2017 several homeowners and communities implemented shoreline armoring to protect properties from future coastal inundation.

Linkages

The hardened shoreline sub-indicator can be directly linked to other sub-indicators currently used to assess the Great Lakes basin. Those sub-indicators/indicators are:

Coastal Wetlands sub-indicators – the placement of hardened shorelines have a direct impact to coastal wetlands across the Great Lakes including modifications to fish spawning and feeding habitats, changes in coastal processes, and alter shorebird habitats based on physical modification to the shorelines. These changes from natural to hardened shorelines can also weaken aquatic habitat connectivity.

Watersheds Impacts and Changes in Physical Conditions sub-indicators – the hardening of shorelines can alter the coastal land water interface significantly where large scale anthropogenic shoreline modifications have occurred. This can lead to further erosion of unprotected lands and properties, and changes in local coastal landcover types . The armoring of shorelines can also diminish littoral drift, impacting river mouths and regional sediment management.

Cladophora sub-indicator (Nutrients and Algae) – the placement of nearshore large rip rap, boulders, and similar coarse materials used to harden the shoreline may allow for the development of Cladophora in areas that may not have been supportive of Cladophora growth (e.g. soft substrates) in the past by providing a solid substrate upon which the algae can attach.

Dreissenid Mussels sub-indicator (Invasive Species) – similar to Cladophora, the placement of nearshore large rip rap, boulders, and similar coarse materials used to armor the shoreline may allow for zebra mussels to inhabit areas that may not have supported zebra mussels in the past by providing a solid substrate upon which the mussels can attach.

Assessing Data Quality

Data Characteristics	Agree	Neutral or Unknown	Disagree	Not Applicable
Data are documented, validated, or quality-assured by a recognized agency or organization	X			
Data are from a known, reliable and respected generator of data and are traceable to original sources	X			
Geographic coverage and scale of data are appropriate to the Great Lakes Basin	X			
Data obtained from sources within the U.S. are comparable to those from Canada	X			
Uncertainty and variability in the data are documented and within acceptable limits for this sub-indicator report	X			

Data used in assessment are openly available and accessible	USA – Yes CAN - Yes	United States Great Lakes Shoreline Data: https://coast.noaa.gov/digitalcoast/data/hardened-shorelines.html Canada Great Lakes Baseline Shoreline Data: Canadian Great Lakes Baseline Coastal Habitat Survey - Open Government Portal (canada.ca) Canada Great Lakes Nearshore Assessment (continues to be updated) Great Lakes Nearshore Waters Assessment - Open Government Portal (canada.ca)

Notes on Accessing Data

To access the United States Great Lakes Shoreline Data you can either download the data directly using this link, https://coast.noaa.gov/digitalcoast/data/hardened-shorelines.html, or view online through the Great Lakes Hardened Shoreline Classification Web Feature Layer.

To access the Canadian Great Lakes shoreline data there are two options. You can see each lake-specific Nearshore Waters Assessment record and follow the links to download each geodatabase, in which there is a layer for Shoreline Hardening, using the Great Lakes Nearshore Waters Assessment - Open Government Portal (canada.ca). Data used exclusively in this assessment can be accessed through the Canadian Great Lakes Baseline Coastal Habitat Survey - Open Government Portal (canada.ca)

Data Limitations

1. The geographic scale for the updated information covers all of Lake Ontario (including the Niagara River and International section of the St. Lawrence River), Lake Erie (including St. Clair-Detroit River Ecosystem), Lake Michigan and Lake Huron (including St. Marys River) and Lake Superior.
2. All island shorelines were removed prior to performing the data analysis. The inclusion of islands in the future is something that should be discussed by the State of the Great Lakes reporting team in forthcoming report updates by determining which islands should or should not be included in future calculations.
3. The dependence on orthophotography and other imagery sources, while high in resolution, are only valid by their production date. It is expected that all imagery sets currently used will be updated on a five-year interval and classified accordingly to a well-documented shoreline classification schema.
4. While the use of a one kilometer by one kilometer Great Lakes shoreline reference grid is useful to quantify the hardened shoreline classification (see Methods section), this grid will need to be updated to include

additional cells, or removal of cells, for future sub-indicator report calculations. The grid was generated using the Great Lakes and St. Lawrence Albers projection (EPSG: 3175) and will be shared with the State of the Great Lakes reporting team for use in forthcoming report updates.

5. The procedure for identifying hardened shorelines was applied consistently on both the Canadian and U.S. shorelines. However, the identification and interpretation of hardened shorelines was influenced by the imagery availability and resolution which varied greatly along certain areas of the Canadian shoreline. The specific age of input imagery used for individual shoreline reaches has been attributed to the hardened shoreline vector dataset.
6. All perpendicular shoreline structures, including jetties and groins (groynes), were removed to help with ensuring that shoreline lengths were not over calculated, however, this did leave some parts of the hardened shoreline incomplete and with small gaps. Similarly, small inlets and slips were also removed leaving small gaps.
7. There continues to be introduced uncertainty with regards to shoreline length and differences due to variations in water levels at the time of imagery collection and classification. Since the sub-indicator is based on a relative difference in the percent of shoreline within various categories, it is still possible to make some comparisons, especially with the use of the Great Lakes shoreline reference grid (Data Limitations #5 and Measure section).

Additional Information

In 2019 a new vector shoreline of the United States Great Lakes Shorelines was released (NOAA 2019). This dataset was previously mentioned in the prior hardened shorelines sub-indicator report, developed and used in this report, and can serve as a baseline moving forward. The dataset consists of shoreline segments classified as either artificial or natural, along with structure type and condition. NOAA's Office for Coastal Management, in partnership with the US Army Corps of Engineers, contracted with Tetra Tech in the development of a higher resolution, applicable to a mapping scale of 1:2,000. The data were created by digitizing shoreline using National Agriculture Imagery Program imagery from 2014 through 2017 and comparing it with oblique imagery, lidar, and other ancillary datasets. The classification of the shorelines is based upon the Flood and Erosion Prediction System classification schema (Stewart 2002, Baird 2005, and AECOM 2012) with some modifications to account for additional shoreline classification needs. The classification schema and methodology used to create this dataset are well documented and efforts to create new or update existing datasets should ensure that classification methodologies are similar to these efforts to ensure continuity in reporting in the future.

The 2019 dataset allows for comparison on a lake-by-lake basis and also allows for a breakdown of shorelines by state and county to further understand local characterization of the shorelines within the United States. The dataset also further classifies what types of structures are in place (jetty, rip rap, sheet piling) and general condition (good, moderate, poor). This level of detail could help further the understanding on what types of impacts to shore habitat are associated with the different types of artificial shore structures. Oblique imagery and lidar have also been collected for several years now along the Great Lakes shoreline by federal, provincial and state agencies. These data could further be utilized together with the hardened shorelines data to understand the dynamics and connections between hardened and natural shorelines. These data should be considered in future reporting efforts, where appropriate, to help develop new metrics that further explain shoreline dynamics across the Great Lakes.

The Canadian shoreline hardening data was completed using best available imagery. For Lake Superior, Environment and Climate Change Canada (ECCC) utilized imagery (10 cm resolution) collected between July and

November 2018 as part of a nearshore LiDAR acquisition. Ontario's Imagery Program, Land Information Ontario (LIO), was accessed to delineate shoreline hardening on Lakes Huron, Erie and Ontario. ECCC utilized the most recent South Western Ontario Orthophotography (SWOOP), South Central Ontario Orthophotography (SCOOP) and Central Ontario Orthophotography (COOP) from LIO.

These Canadian aerial and orthophotography sets were used to digitize line segments as 'natural' or 'hardened', and classify each line segment based on the exposure categories of 'lake', 'sheltered', or 'connecting channel'. For example, classify line segments within embayments and tributaries as having 'sheltered' exposure and line segments exposed to lake wave energy as having 'lake' exposure. Shoreline hardening is one of several measures being completed under ECCC's Canadian Baseline Coastal Habitat Survey and Great Lakes Nearshore Waters Assessment. A completed dataset of hardened shoreline for the entire Canadian Great Lakes was completed in 2023.

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List of Tables

Table 1. Modified 2009 Baseline Great Lakes/SOGL hardened shoreline classification used in the 2011 State of the Great Lakes Hardened Shorelines sub-indicator assessment with connecting channels added in with their respective lake as reported in the Lake-by-Lake Assessment.

Source: National Oceanic and Atmospheric Administration (1997), modified (2022).

Table 2. Updated 2025 Great Lakes hardened shoreline classification values.

Sources: Environment and Climate Change Canada (2020, 2021, 2022b, 2023), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Note: Lake Superior is incomplete at this time on the Canadian side.

Table 3. Comparison between Modified 2009 Baseline Great Lakes/SOGL hardened shoreline classification and newer shoreline classification values.

Sources: 2009 Baseline - National Oceanic and Atmospheric Administration (1997), modified (2022), 2022 Update - Environment and Climate Change Canada (2020, 2021, 2022b, 2023), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Note: the difference between 2022 and 2025 reflects the new data coverage over the Canadian portions of Lake Superior and Lake Huron with updated data coverage over the Canadian portion of Lake Erie.

Table 4. Latest versions of completed hardened shorelines classification source data imagery years and year of derived classification for each lake by country. The derived products are what are used in determining the percentage of hardened shoreline. Please view individual derived datasets identified in the Reference section to find specific source data imagery years used for each stretch of shoreline within each lake and connecting channel.

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Sources: Environment and Climate Change Canada (2020, 2021, 2022b, 2023), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Basemap: Open Street Map.

Figure 2. Map of Great Lakes hardened shoreline protection status classification. Note that islands were not included in the hardened shorelines analysis. Map created June 2024.

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Figure 4. Map of Lake Michigan hardened shoreline protection status classification. Note islands were not included in the hardened shorelines analysis. Map created June 2024.

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Sources: Environment and Climate Change Canada (2022b), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Basemap: Open Street Map.

Figure 6. Map of Lake Erie, including St. Clair-Detroit River Ecosystem, hardened shoreline protection status classification. Note islands were not included in the hardened shorelines analysis. Map created June 2024.

Sources: Environment and Climate Change Canada (2020), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Basemap: Open Street Map.

Figure 7. Map of Lake Ontario, including Niagara River and International section of the St. Lawrence River, hardened shoreline protection status classification. Note islands were not included in the hardened shorelines analysis. Map created June 2024.

Sources: Environment and Climate Change Canada (2021), National Oceanic and Atmospheric Administration (2019). Basemap: Open Street Map.

Figure 8. Map of the southern end of Lake Huron. This shows how the source hardened shoreline vector datasets are used to develop the one kilometer by one kilometer Hardened Shorelines Protection Status Classification. Map created June 2024.

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Sources: Google Earth imagery and bathymetric surfaces developed from Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) topobathy lidar. Credit: NOAA Office for Coastal Management.

Last Updated

State of the Great Lakes 2025 Report

Table 1. Modified 2009 Baseline Great Lakes/SOGL hardened shoreline classification used in the 2011 State of the Great Lakes Hardened Shorelines sub-indicator assessment with connecting channels added in with their respective lake as reported in the Lake-by-Lake Assessment. Source: National Oceanic and Atmospheric Administration (1997), modified (2022).

Lake / Connecting Channel	Highly Protected (%) (>70% protected)	Moderately Protected (%) (40-70% protected)	Minorly Protected (%) (15-40% protected)	Minimal Protection (%) (<15% protected)	Non-structural Protection (%)	Unclassified (%)	Total Shoreline (km)
Lake Superior	3.1	1.1	3	89.4	0	3.4	5080
Lake Michigan	8.6	2.9	30.3	57.5	0.1	0.5	2713
Lake Huron (including St. Marys River)	1.6	1.1	4.8	90.6	1.1	0.8	7073
Lake Erie (including St. Clair-Detroit River Ecosystem)	22.6	16.4	14.2	45.2	1.2	0.3	2581
Lake Ontario (including Niagara River and International section of the St. Lawrence River)	12.9	8.1	17.7	54.6	0	6	4527

Table 2. Updated 2025 Great Lakes hardened shoreline classification values. Sources: Environment and Climate Change Canada (2020, 2021, 2022b, 2023), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Note: Lake Superior is incomplete at this time on the Canadian side.

Lake / Connecting Channel	Highly Protected (%) (>70% protected)	Moderately Protected (%) (40-70% protected)	Minorly Protected (%) (15-40% protected)	Minimal Protection (%) (<15% protected)	Unclassified (%)	Total Shoreline (km)
Lake Superior	2.7	2.5	3.4	91.4	0.0	3556
Lake Michigan	11.0	5.6	5.8	77.6	0.0	2353
Lake Huron (including St. Marys River)	6.9	4.8	6.3	82.0	0.0	4324
Lake Erie (including St. Clair-Detroit River Ecosystem)	45.0	11.3	8.8	34.9	0.0	1878
Lake Ontario (including Niagara River and International section of the St. Lawrence River)	24.9	15.8	16.6	42.7	0.1	2225

Table 3. Comparison between Modified 2009 Baseline Great Lakes/SOGL hardened shoreline classification and newer shoreline classification values. Sources: 2009 Baseline - National Oceanic and Atmospheric Administration (1997), modified (2022), 2022 Update - Environment and Climate Change Canada (2020, 2021, 2022b, 2023), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Note: the difference between 2022 and 2025 reflects the new data coverage over the Canadian portions of Lake Superior and Lake Huron with updated data coverage over the Canadian portion of Lake Erie.

Lake / Connecting Channel	2009/2011 Combined Highly and Moderately Protected (%)	2022 Combined Highly and Moderately Protected (%)	2025 Combined Highly and Moderately Protected (%)
Lake Superior	4.2	5.3	5.2
Lake Michigan	11.5	16.6	16.6
Lake Huron (including St. Marys River)	2.7	10.3	11.7
Lake Erie (including St. Clair-Detroit River Ecosystem)	39.0	56.9	56.3
Lake Ontario (including Niagara River and International section of the St. Lawrence River)	21.0	40.6	40.6

Table 4. Latest versions of completed hardened shorelines classification source data imagery years and year of derived classification for each lake by country. The derived products are what are used in determining the percentage of hardened shoreline. Please view individual derived datasets identified in the Reference section to find specific source data imagery years used for each stretch of shoreline within each lake and connecting channel.

Lake / Connecting Channel	Canada		United States	
	Imagery Year(s)	Derived Product Year(s)	Imagery Year(s)	Derived Product Year(s)
Lake Superior	2015	2022	2014, 2015	2019
Lake Michigan	N/A	N/A	2014, 2015	2019
Lake Huron (including St. Marys River)	2015	2022	2014, 2015	2019
Lake Erie (including St. Clair-Detroit River Ecosystem)	2020	2023	2015, 2016, 2017	2019
Lake Ontario (including Niagara River and International section of the St. Lawrence River)	2013, 2014, 2015, 2018	2021	2014, 2015	2019

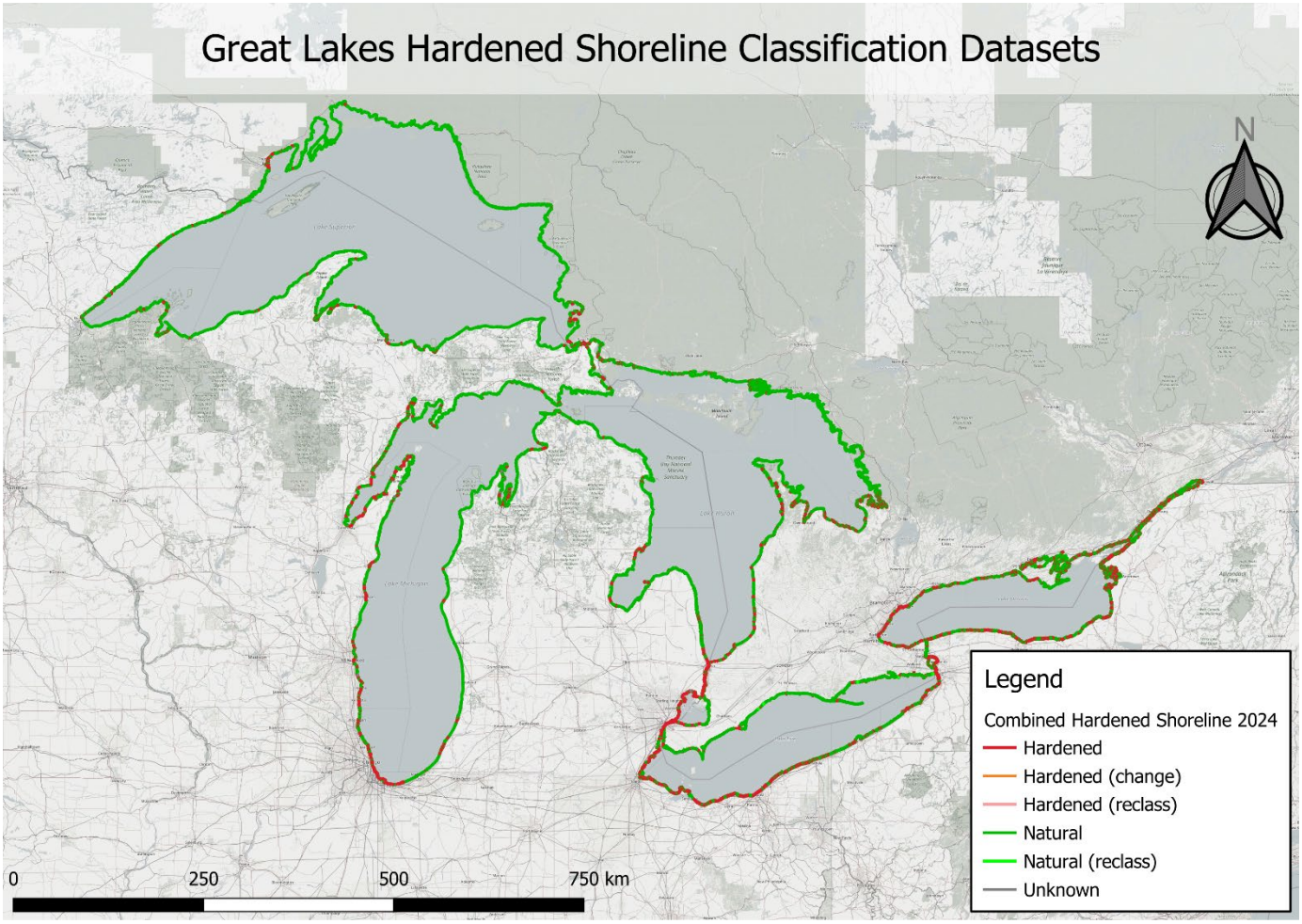

Figure 1. Map of Great Lakes hardened shoreline classification datasets used for Lake-by-Lake Assessment as of February 2024. Note that islands were not included in the hardened shorelines analysis. Sources: Environment and Climate Change Canada (2020, 2021, 2022b, 2023), National Oceanic and Atmospheric Administration (2019), Zuzek Inc. (2018). Basemap: Open Street Map.

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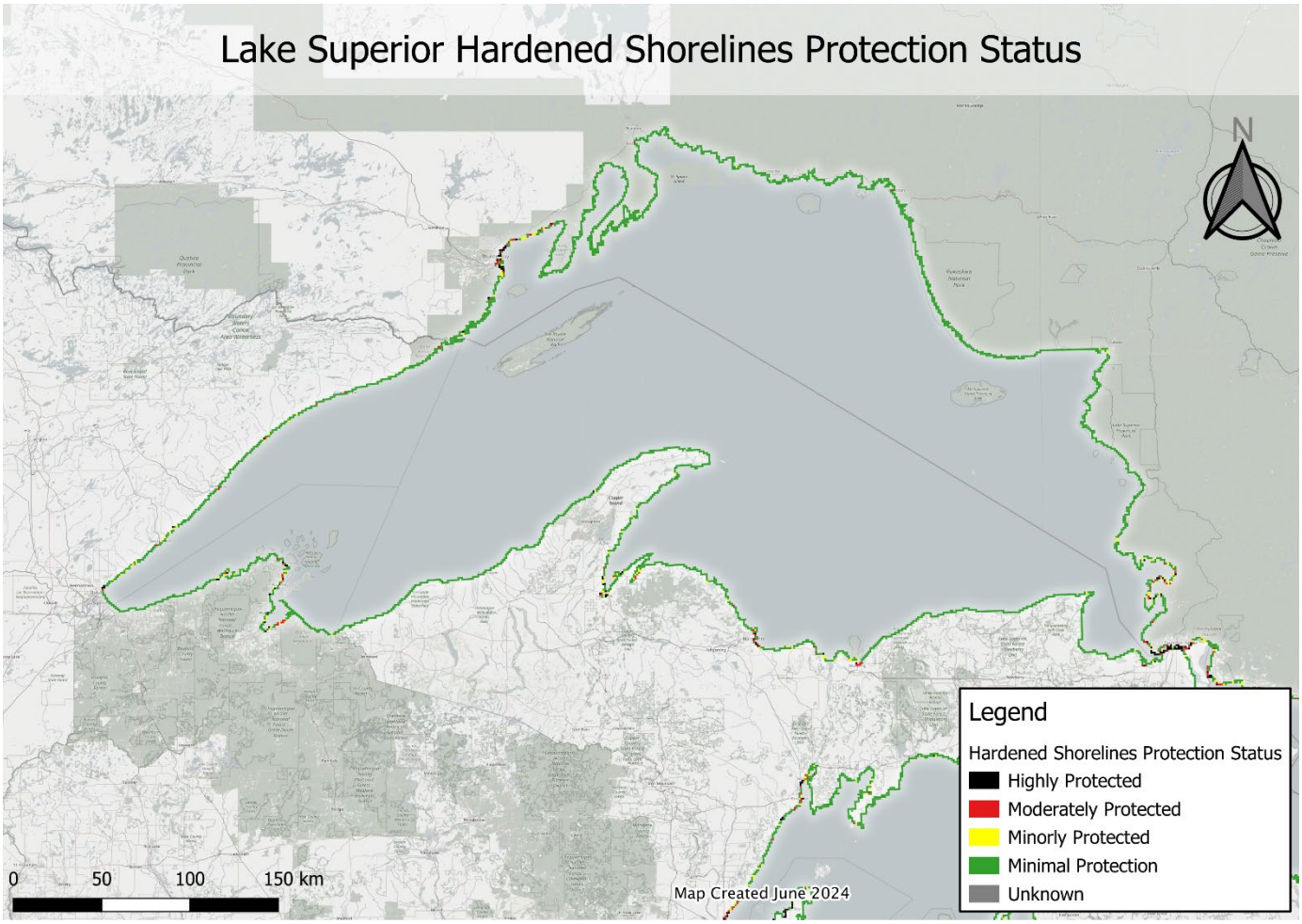

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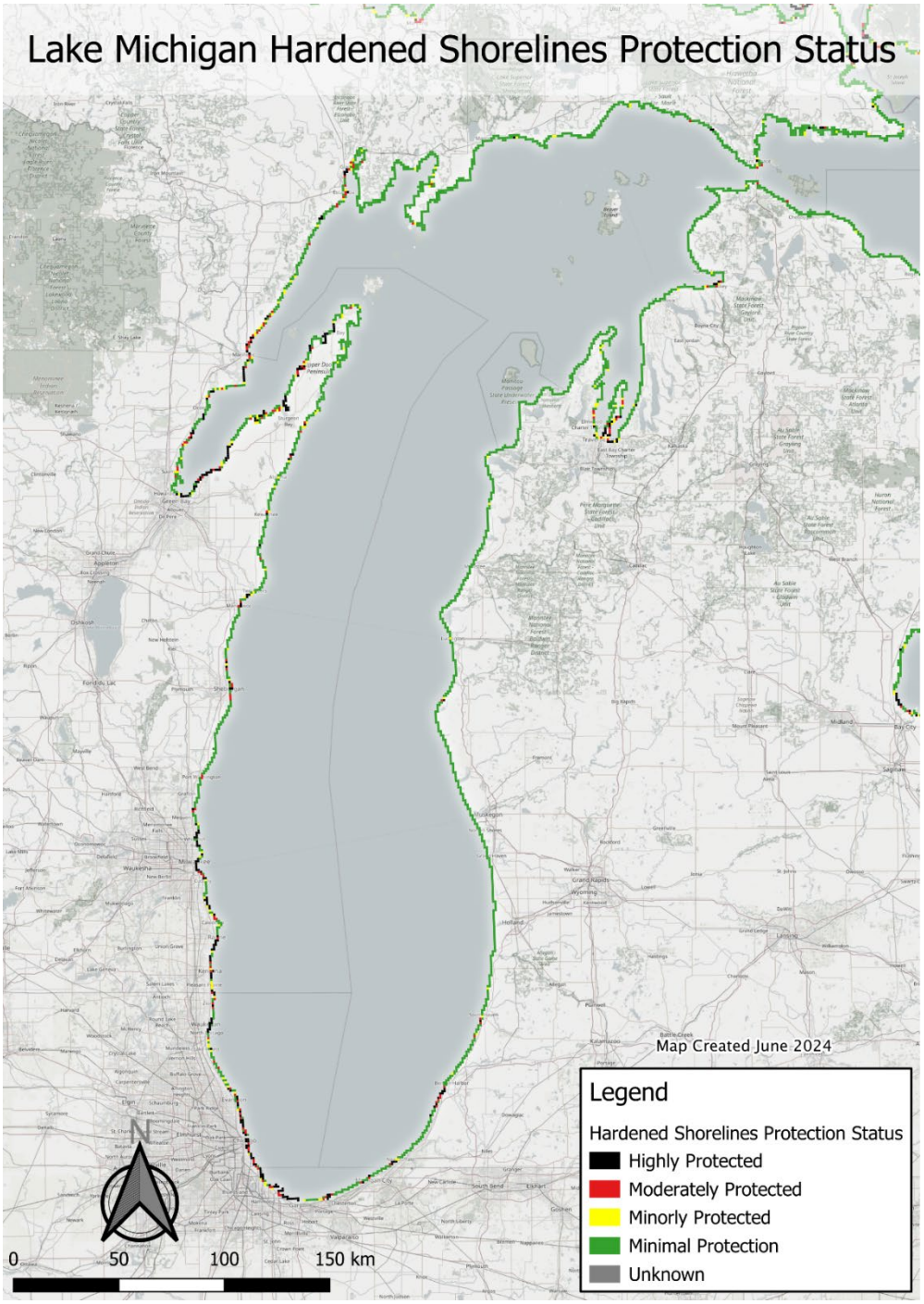

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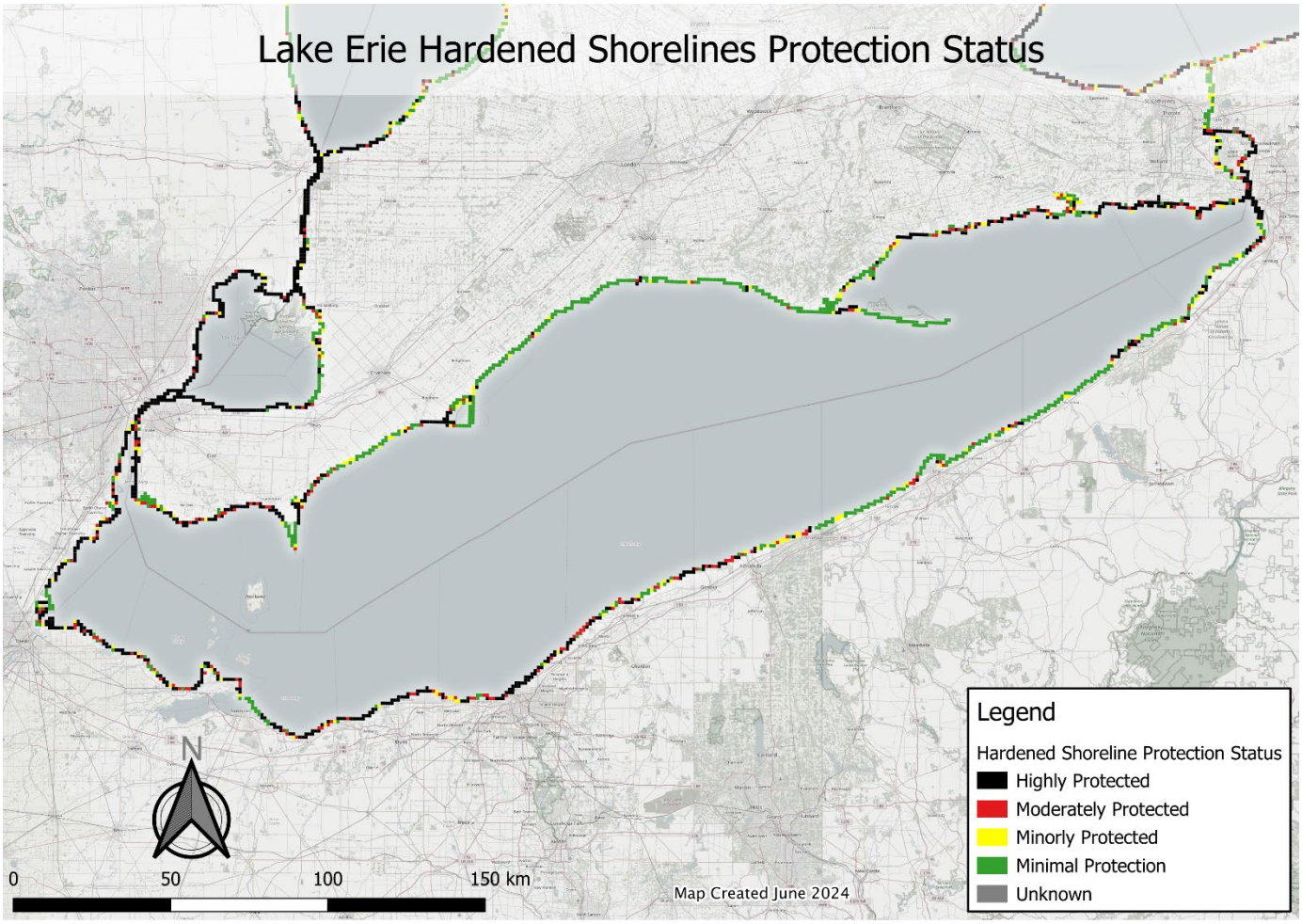

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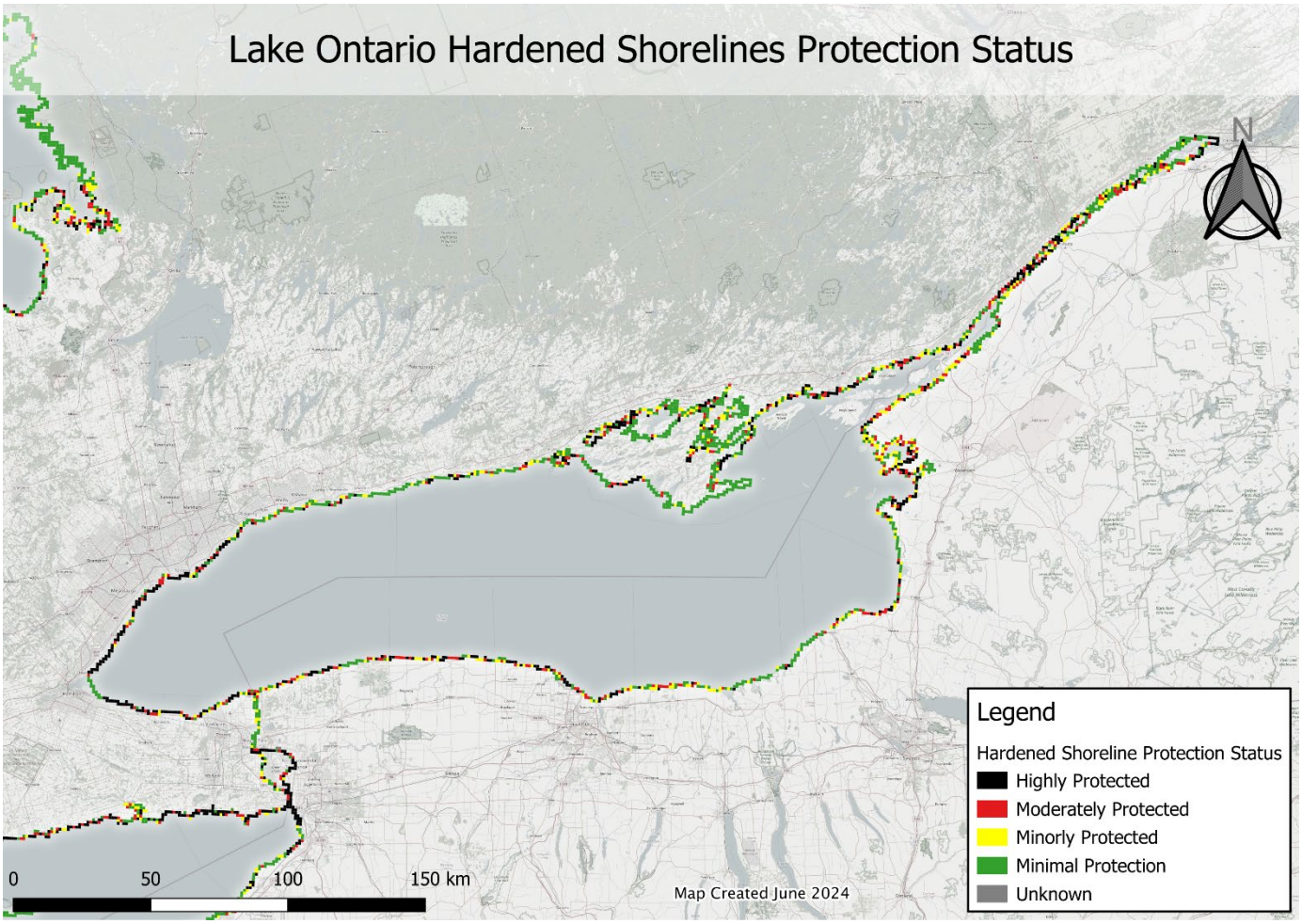

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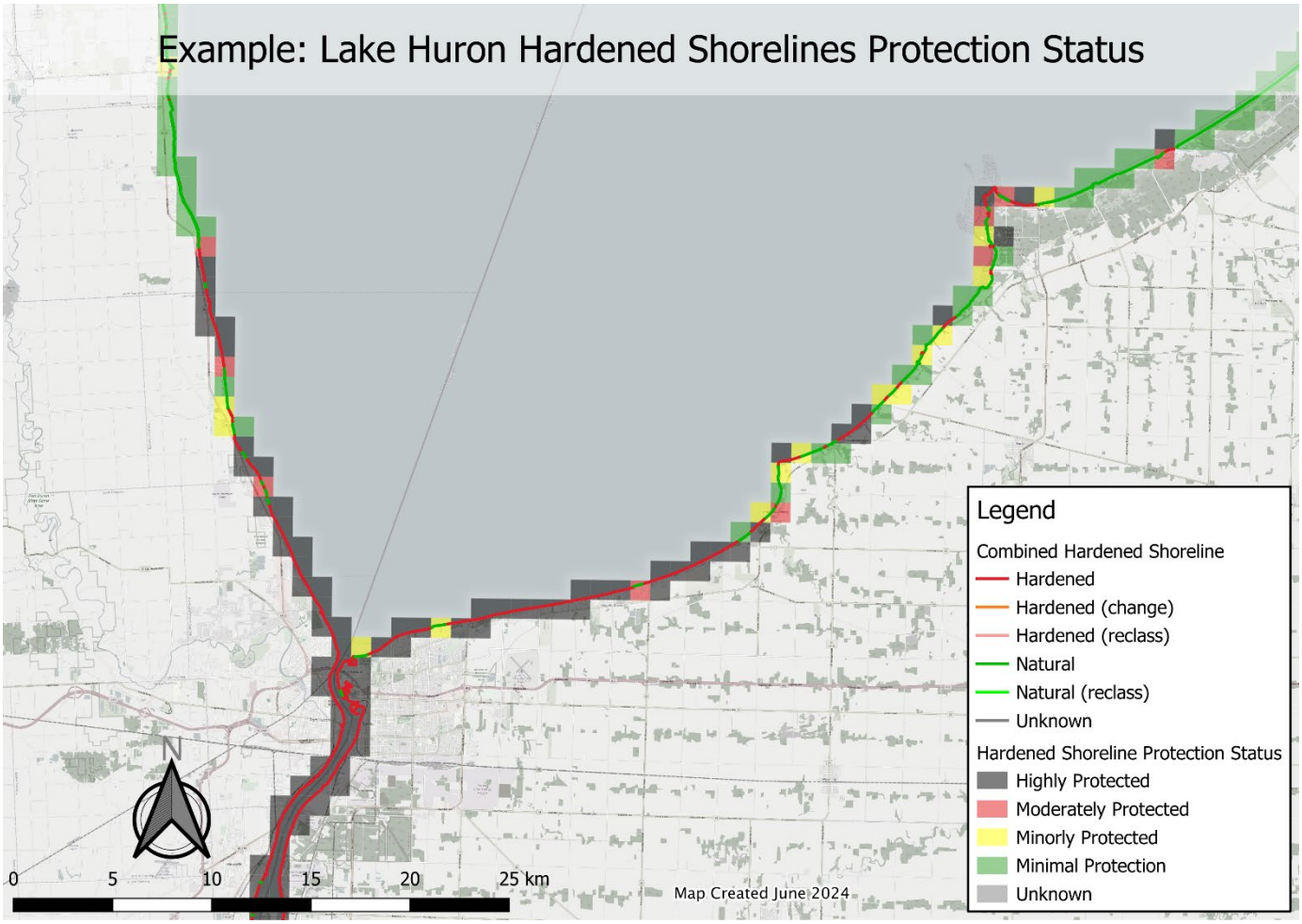

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