Hamilton Harbour shoreline survey – 2006

Jesse Gardner Costa, Celeste Y.L. Rémillard, Andrew Doolittle, and Susan E. Doka

Central and Arctic Region
Fisheries and Oceans Canada
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, ON
L7S 1A1

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Fisheries and Oceans Canada
867 Lakeshore Road
Burlington, ON
L7S 1A1

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Under the Great Lakes Action Plan, Fisheries and Oceans Canada conducted a survey of the entire Hamilton Harbour shoreline in 2006. This report documents the methods used to conduct the shoreline survey, the attributes used to classify the shoreline, the methods used to create georeferenced shoreline layers, and a summary of the lengths of classified shoreline. This information was gathered to inform Hamilton Harbour Beneficial Use Impairment (BUI) #14, as well as provide a geodatabase shoreline layer for future habitat assessments. We estimated the length of Hamilton Harbour to be 60.3 km and that most of its shoreline is artificial (83.3% or 50.2 km), with natural areas and islands making up 7.7% (4.7 km) and 3.3% (2.0 km), respectively. We estimated that 9.3 km of the harbour shoreline has been modified for restoration, 16.0 km if we include the Remedial Action Plan estimates of Cootes Paradise and Grindstone Creek, and an additional 2.3 km if we include post-2006 modifications for restoration. Currently, our estimates do not meet the BUI subtarget of >15 km of improved shoreline, but the data in this report will serve as weight of evidence towards the BUI's assessment. This report serves as a record of data and methods and a reference point for the state of the shoreline of Hamilton Harbour in 2006. We recommend a simpler criteria with strict predefined classifications for any future surveys to be conducted in the harbour.

RÉSUMÉ

Gardner Costa, J., Rémillard, C.Y.L., Doolittle, A., Doka, S.E. 2020. Hamilton Harbour shoreline survey — 2006. Can. Tech Rep. Fish. Aquat. Sci. 3381: vii + 37 p.

Dans le cadre du Plan d'action des Grands Lacs, Pêches et Océans Canada a effectué un relevé de toutes les rives du havre Hamilton en 2006. Le présent rapport présente les méthodes employées pour effectuer le relevé des rives, les caractéristiques utilisées pour classer celles-ci, les méthodes appliquées pour créer des couches géoréférencées des rives ainsi qu'un résumé des longueurs des rives classées. Ces renseignements ont été récoltés pour évaluer l'altération de l'utilisation bénéfique (AUB) n° 14 du havre Hamilton et constituer une base de données géographiques des couches des rives en vue de futures évaluations de l'habitat. Selon les estimations, la longueur du havre Hamilton est de 60,3 km, la majeure partie des rives du havre est artificielle (83,3 % ou 50,2 km) et les zones naturelles et les îles constituent respectivement 7,7 % (4,7 km) et 3,3 % (2,0 km) des rives. Il a été estimé que 9,3 km des rives du havre ont été modifiés à des fins de restauration. Ce chiffre passe à 16,0 km si les estimations du Plan d'assainissement du Cootes Paradise et du ruisseau Grindstone Creek sont incluses et un 2,3 km peut être ajouté si les modifications effectuées après 2006 à des fins de restauration sont aussi comprises. En ce moment, les estimations ne correspondent pas au sous-objectif de l'AUB de plus de 15 km de rives améliorées, mais les données contenues dans le présent rapport serviront de poids de la preuve pour l'évaluation de l'AUB. Le présent rapport constitue un recueil de données et de méthodes et un document de référence sur l'état des rives du havre Hamilton en 2006. Nous recommandons un critère plus simple avec des classifications prédéfinies précises pour toutes les futures enquêtes qui seront menées dans le havre.

INTRODUCTION

Hamilton Harbour is an embayment located at the western end of Lake Ontario (Figure 1 and 2). Due to intense urban development and anthropogenic activities in the last 100 years, Hamilton Harbour's ability to support aquatic life has been significantly impaired (COA 1992). In 1987, the International Joint Commission designated Hamilton Harbour as an Area of Concern (AOC) to provide resources for the harbour's recovery, coordinated through a Remedial Action Plan (RAP). The Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada (DFO), assists in coordinating and implementing the RAP through research, monitoring, and scientific advice.

DFO's work in Hamilton Harbour focuses on ecosystem and fish habitat modelling to evaluate the recovery potential of the ecosystem, enabling the RAP team to plan recovery actions to meet established fish habitat and population targets for both upper and lower trophic levels. Since the establishment of the RAP team in 1992, beneficial use impairments (BUIs) were created to identify issues and recovery targets. Delisting objectives for the harbour were developed for the BUIs identified. Our focus was BUI #14: Loss of Fish and Wildlife Habitat, which included delisting sub-targets such as when the "improved littoral shore (0–5 m depth) measures ≥15 kilometres" (Hamilton Harbour RAP 2012).

Much of the shoreline of Hamilton Harbour has been hardened, either with vertical walls or armour stone. Restoration efforts starting in the 1990s have naturalized parts of the shoreline, with the intent of creating useable habitat for fish and wildlife (O'Connor 2002). To update the knowledge of the existing shoreline features, a field crew was deployed in 2006 to identify shoreline attributes. Tasks included characterizing the shoreline, developing geospatial layers to be used for current and future fish habitat modelling, and determining the length of shoreline (km) for the RAP's habitat shoreline BUI delisting sub-target. This document serves to identify the methods used to collect and classify shoreline data collected in 2006, provide an update on the state of the Hamilton Harbour shoreline to the RAP, and inform the RAP team on the progress towards the littoral shoreline sub-target.

To fill gaps where spatial data was sparse for Hamilton Harbour nearshore habitat information, DFO conducted a shoreline survey in 2006, with supplemental data collected later in 2007 and 2008. DFO's survey efforts aimed to complement previous shoreline classifications of Hamilton Harbour, including the north shore survey of Hamilton Harbour (conducted in 1992 by Conservation Halton) and the Environmental Atlas of Lake Ontario from Environment and Climate Change Canada (Environment Canada 1993). The intent of the 2006 survey was to provide an updated characterization of features of the Hamilton Harbour shoreline that affect fish habitat suitability. In addition, offshore sediment samples were also collected to support the visual shoreline survey (Appendix - Table A1).

The shoreline survey data collected in Hamilton Harbour also aided in creating geodatabase layers for a fish habitat supply analysis model known as the Habitat and Ecosystem Assessment Tool (HEAT). HEAT is used to assess habitat suitability and habitat supply for freshwater fish populations (DFO 2019). Identifying, classifying, and mapping substrate in Hamilton Harbour is a necessary prerequisite to modelling fish habitat with the HEAT model.

Data for the HEAT model was collected from various sources over several projects in an effort to compile a comprehensive representation of the offshore and nearshore zones of Hamilton Harbour. A Hamilton Harbour fish habitat geodatabase was constructed to store, integrate, and process the spatial habitat data that is required to support the HEAT model (Doolittle et al. 2010). The geospatial data framework that was developed will serve as a common storage and management framework for geographic information and spatial data for the Hamilton Harbour AOC. The attribute data collected in this report has been added to the geodatabase and is specifically used in substrate layers for the harbour (on the shoreline, as well as to help infer substrate composition into the water), and as baseline conditions for evaluating shoreline modifications/restoration efforts and their benefits to fish habitat.

METHODS

STUDY SITE

Hamilton Harbour (43°14'N, 79°51'W; Figures 1 and 2) is located on the west end of Lake Ontario, connected by the Burlington Ship Canal. It has a mean depth of 13 m, a maximum depth of 26 m, and a surface area of approximately 21.5 km^2 (Gertzen et al. 2016). Historically, Hamilton Harbour featured extensive marshlands and diverse fish habitat. However, in the last 100 years, increased urbanization and residential development in proximity to the harbour has dramatically altered the shoreline and degraded water quality (COA 1992).

SHORELINE SURVEY AND MAPPING

Surveys included field collection and a visual inspection along the shoreline to create a contiguous transit along the shoreline of Hamilton Harbour. The shoreline assessment was conducted on May 11, 15, 19, and 23 in 2006. Shoreline attributes (defined in the next section) were documented onto the shoreline survey form (Figure 3) and included the bearing to shore from the start location of a segment, using a Garmin 60 CSx GPS (Garmin Ltd., Olathe, Kans.). In addition to recording the shoreline attributes, each shoreline segment was photographed with an Olympus D800 digital camera, assigned a segment number and a photo number, and visually assessed. New segments were created when the field crew encountered a large transition in shore type. The criteria for "large transition" was subjectively identified by the field crew. When data were validated after a survey, segment transitions were typically identified through changes in composition (substrate) or structure type. Poor weather conditions impacted data collection, so some segments were mapped based on Google Maps ortho-imagery (with maps as close to the time of the initial survey) after the survey. All final data are

projected in NAD 83, UTM zone 17N, at an observed water level of 74.2 m (International Great Lakes Datum 1985).

Coordinates for each shoreline segment were created in ArcGIS™ (ESRI Inc., Redlands, Calif., U.S.A.), from the shoreline transition points created from the GPS coordinates and bearing data documented in the field. These transition points became the start and end points for each of the shoreline segments identified in the harbour (Figure 4). These segments were then validated by cross referencing the same geographical segment with the use of an existing Ontario Ministry of Natural Resources ArcGIS™ shapefile that was uploaded to Google Earth to identify inconsistencies. If a gap was identified, the next step in processing included aerial photography, field photographs, and analysis of adjacent segments. Due to the composition complexity of some shoreline segments, these supplemental data were used to determine the most dominant composition in the given segment to characterize features present at the Hamilton Harbour shoreline, with a primary focus on factors that affect fish habitat suitability.

In addition to the shoreline survey, sediment samples were collected via Ponars for the survey year as well as in 2010, 2011, and 2012. Samples were collected to complement shoreline substrate classifications from the shoreline survey, as well as inform our internal GIS substrate layers. Sub-samples of Ponars were stored in the lab and analyzed for particle size and loss on ignition and used to inform any gaps within the shoreline survey. Details of sample locations, sediment processing, and summarized results can be found in the Appendix (Table A1, Figure A1).

SHORELINE ATTRIBUTES AND CLASSIFICATIONS

A detailed protocol for the shoreline survey was developed to characterize and identify major changes in shoreline attributes (“Shoreline State,” “Shoreline Composition,” “Shore Structure,” “Adjacent Land Use,” and “Vegetation”) along Hamilton Harbour. The protocol included identifying attributes to cover the topographic and bathymetric composition within the 5-m littoral zone, based on Mason and Booth (2004). Data for each segment were collected concurrently. Therefore for each segment, bearing, photo documentation, and shoreline attribute classification were taken prior to moving on to the next segment. Priority classification of shoreline attributes was given to the land/water interface and the vegetation present at the shoreline. Each shoreline descriptor was mapped and measured in ArcGIS™ and represented as a length in kilometres and a percentage of the total sample, for each attribute classified.

Although our intent was to identify a dominant classification for each shoreline attribute, the complexity of some segments (with mixed classifications) made it difficult to define dominant classifications in many segments. As a result, field crews often wrote in mixed classifications on the field sheets. A decision was made post-survey to consolidate redundant classifications from the shoreline survey. After cross-referencing site photos with shoreline surveys, some of the original 234 segments had classifications modified, added, or removed to ensure consistency in the classification scheme across all segments. For example “Grass” was created for the Vegetation attribute to consolidate classifications that were written in by the field crew, such as “grass, few scattered shrubs, few trees”, “grass, sparse trees”, and “tall grass”.

Shoreline State

The Shoreline State attribute was classified in the field notes as “Artificial”, “Natural”, or “Island” (Table 1). Artificial was defined as having been converted from its hypothesized historical state unaffected by human activity, even if changes made were to protect the shoreline from further degradation. An example would include classifications such as “Shoreline Rip-Rap,” where concrete rubble lines the shoreline to slow erosion. Natural was considered to be an area that was mostly devoid of human-made structures, was largely vegetated, and would have been historically present in the Hamilton Harbour shoreline. Island was used for areas separate from the mainland that were built up/human-made, such as the shoals near Bayfront Park.

Shoreline Composition

The “Shoreline Composition” attribute was classified at the land-water interface for each segment. Using an adapted Wentworth classification of substrate types (Bain and Stephenson 1999) (Table 2), all substrate types smaller than or equal to gravel were classified as “Soft,” and particle sizes greater than or equal to cobble (Table 2) were classified as “Hard.” Size ranges were further binned into 11 different categories that were used by the field crew for classification. In areas of more complex shoreline substrates, the most dominant substrate category was used. For example, if both clay/silt and boulder substrate types were observed within a given segment, the shoreline survey form specified to choose one or the other, based on whichever was most abundant. Survey crews also documented multiple types of substrate at the shoreline to provide additional insight into the variability of shoreline substrate.

Shore Structure

The “Shore Structure” attribute was considered modified shoreline and was developed with classifications to define the hardened structures within a segment. “Boat Launch/Slip” was defined as a ramp with a gradual grade that can be used to move boats in and out of the water. “Cobble/Rubble/Boulder” were areas with large sections of dumped rocks such as islands or armoured shorelines where, in most instances, shoreline had been developed for erosion prevention. Piers, wharfs, and sunken barges were included as part of the definition of “Vertical Seawall”. In considering piers and wharfs for the Vertical Seawall classification, we followed the U.S. Army Corps of Engineers (2002) definition of wharf: “A structure built on the shore of a harbour, river, or canal so that vessels may lie alongside to receive and discharge cargo and passengers”, and not their definition of pier: “A structure, usually of open construction, extending out into the water from the shore, to serve as a landing place, recreational facility, etc. rather than to afford coastal protection or affect the movement of water”.

“Shore Rip-Rap” sections were concrete or cement combined with other grain-sizes such as boulder or gravel. Anchored docks and floating docks were displayed as the same structure type (“Dock/Floating Dock/Slip”). Silt, clay, and sand were not classified within Shore Structure since the focus of this attribute was physical structures and not the dominant substrate.

Adjacent Land Use

A list of seven land use types ranging from undeveloped to industrial were used for classifying the Adjacent Land Use attribute (Table 3). “Industrial/Commercial” included all lands used by a business, “Parks/Recreation” included any maintained city parks or trails, “Residential” was defined as homes and lawns of private properties, “Undeveloped/Open Space/Forest” included all unmaintained or vegetated areas (including Holy Sepulchre Cemetery), “Transportation” included lands used by or immediately adjacent to roads, lastly, “Agricultural” included any farm lands.

Vegetation

The Vegetation attribute was visually classified (grasses, trees, shrubs, and emergent vegetation) from the type of vegetation associated with the shoreline within a 5-m predetermined buffer (Table 1). “Grass” along the shoreline encompassed all types of grass species including manicured, low, tall, or mixed grass species. “Shrub/Tree” consisted of tall, low, and medium, ranging in sizes >1.5 to 0.5 m and any variety of trees present, as well as species that were not identified in the survey; this classification essentially captures upland vegetation. "Emergent" included any Riparian or wetland plant species. Final classifications were determined by the visual assessment of presence/absence of vegetation at the time of data collection.

Shoreline State reclassification

We also wanted to provide additional summary information regarding potential restoration sites (or useable habitat), without having to reference more complex attributes, we reclassified the Shoreline State attribute post-survey to include an indication of shoreline hardness. “Artificial Hard”, “Artificial Soft”, “Natural Hard”, “Natural Soft”, and “Not Classified” were added to aid in identifying areas that may be used by wildlife, such as soft areas, regardless of whether they were artificial or natural.

Using Shore Structure, Shoreline Composition, and Adjacent Land Use attributes, we identified whether an area was hard or soft, and in some cases if an area was Natural or Artificial if the area was not already classified as such in the field survey. Some shoreline segments required additional cross referencing for reclassification, which was verified by the original data collected through photographs and on field sheets (Figure 3).

Using the same classification scheme used for the Shoreline Composition attribute, “Artificial Hard” was considered modified shoreline (seawalls, industrialized shoreline) with large particle size substrate, generally including cobble, rubble, and boulder (Table 2). “Artificial Soft” was based on attributes such as artificial beaches or other particle sizes (equal to or smaller than gravel, Table 2). “Natural Soft” areas consisted of particle sizes equal to or smaller than gravel (Table 2). These included zebra mussels, sand, and clay/silt. “Natural Hard” included unmodified shorelines with naturally occurring cobble/rubble/boulder. Areas that were of unknown composition were “Not Classified.”

Modified for Restoration

An assessment of “Modified for Restoration” was used to highlight the intent of a project rather than identify the ecological importance. This attribute was classified post-survey to provide context relative to the habitat BUI # 14. Areas Modified for Restoration were identified first through engineering drawings provided by Werner Plessl (City of Hamilton, Hamilton, Ontario, personal communication, 2019), then validated by expert opinions from the Hamilton Harbour RAP team (K. O’Connor, RAP coordinator, Hamilton, Ontario, personal communication, 2018; J. Vanden Byllaart, RAP researcher/writer, Hamilton, Ontario, personal communication, 2019; J. Hall, RAP coordinator (retired), Hamilton, Ontario, personal communication, 2019). Future assessments of fish habitat suitability, including assessments using the HEAT model, will determine the effectiveness of modifications for restoration and identify habitat that fish use.

Rehabilitation work in Windermere Basin has been identified as a restoration action by the RAP team. However, these restoration actions were completed after 2006 and are therefore not considered further for this report (even though Windermere Basin is spatially represented in the maps and total shoreline; it is expected the shoreline could be predominantly Natural Soft). Windermere Basin data is being updated in 2019 to delineate the current shoreline as well as create a digital elevation model for the area.

The contents of this report do not include the extensive database of geospatial layers, raw data, and imagery, but if you would like to access this information, please contact Susan Doka: Susan.Doka@dfo-mpo.gc.ca

RESULTS AND DISCUSSION

SHORELINE SURVEY AND MAPPING

Two hundred and thirty-four (234) individual shoreline segments were identified from the initial survey (numbered 1–207, 250–271, and 281–285), georeferenced, and classified based on shoreline type. An additional 32 segments were delineated post-survey to identify islands, breakwalls, and other structures for a total of 266 shoreline segments (Figure 4). At least one photo was taken for each shoreline segment. Site photos were used as an additional visual reference for shoreline classifications, as well as a cross reference for field notes.

SHORELINE ATTRIBUTES AND CLASSIFICATIONS

A total of 60.3 km of the Hamilton Harbour shoreline was classified (Table 3). Figures 5 to 11 show the composition of each shoreline attribute for the harbour, and Table 3 provides the total kilometres and percent representation of each classification across 266 segments. Some attribute categories were not observed during the survey (e.g., Agriculture for the attribute Adjacent Land Use). The following sections outlines the major observations for each shoreline attribute.

Shoreline State

Most of the Hamilton Harbour shoreline was identified as Artificial (83.3% or 50.2 km), with Natural areas in the northwest corner of Hamilton Harbour and the Island classification making up only 7.7% (4.7 km) and 3.3% (2.0 km) of the shoreline segments, respectively (Table 3 and Figure 5). The natural shoreline is concentrated primarily in the northwest corner of the harbour (known as Carol's Bay), while much of the rest of the AOC has been industrialized and developed since the 1800s (O'Connor 2002). The definition of a natural shoreline is challenging in this context, and largely depends on reference points in time as most if not all of Hamilton Harbour has been modified or impacted by anthropogenic activity. We defined Natural as an area that would have been historically (around 1800) present in the Hamilton Harbour shoreline; set as a benchmark in Minns (1997) as a time prior to significant anthropogenic impacts. We lack the historical data to validate this cutoff, however, this definition is useful to identify areas that lack human-made structures, or any major effects from humans (Minns 1997).

Shoreline Composition

Steel/Concrete Wall was the dominant classification and represented 39.3% (23.7 km, Table 3, Figure 8) of the Hamilton Harbour shoreline, followed by cobble and then clay/silt (10.2 km and 6.1 km, respectively). Though walls can be found throughout much of the harbour, most are found on the southern shore in industrial slips. No exposed bedrock was identified in Hamilton Harbour and 5.1 km of shoreline in Hamilton Harbour could not be classified using the current classification scheme. Desjardin Canal for example, had multiple composition types, and the field crew had difficulty classifying the segment. Data from classifications used in this survey will be used for future spatial products to infer substrate of the harbour into the water, where data gaps exist.

Shore Structure

Of all Shore Structure classifications outlined in the survey, Wall/Vertical Seawall made up the majority of the shoreline (43.1%) with 25.9 km (Table 3 and Figure 9). Approximately 10.9 km of shoreline were not classified due to segments lacking any form or solid structure (areas such as beaches, open fields, or riparian zones were captured in other attribute classifications) or because segments did not match any of the predetermined classifications.

Since most of the harbour was Artificial for the Shoreline State attribute, and 42% of the harbour was Industrial/Commercial for the Adjacent Land Use attribute, it is unsurprising that one third of the entire harbour was made of hardened/vertical walls. These walls were identified in both the Shoreline Composition (Steel/Concrete Wall) and Shore Structure (Wall/Vertical Seawall) attributes. There was, however, a discrepancy in the estimates of wall for each attribute: 23.7 km of wall for Shoreline Composition, and 24.5 km of wall for Shore Structure—a difference of 0.8 km. This is due to the combined definition of certain attributes that were not defined specifically enough in the survey

design process. The wall estimate for Shore Structure was greater than the estimate for Shoreline Composition, likely because the Shore Structure classification included any walls, regardless of material (steel, wood, concrete, plastic, stone), whereas the Shoreline Composition classification only included concrete and steel walls. As well, some of the structure classifications (mainly the wall classification) were completed post-survey, by ortho-imagery and may have led to over- or under-estimations of composition classifications during the process.

Adjacent Land Use

As expected, the shoreline was made primarily of Industrial/Commercial land use (42.0% or 25.3 km), followed by Parks/Recreation (22.5% or 13.6 km) as the second largest land use classification (Table 3 and Figure 10). Most of the industrialized shoreline was found along the southern shore, while parks and naturalized areas were located primarily on the western shore. The southeastern shore runs along the Queen Elizabeth Way highway, with trails along the southeast corner classified as Parks/Recreation, and the Burlington Skyway Bridge in the middle of the eastern shore classified as transportation. Eleven (11.1%) percent (6.7 km) of shoreline could not be classified for land use either due to lack of access (visually) to the property or because of unclear land usage.

Vegetation

Grass made up the majority (47.6% or 28.7 km) of the shoreline, whereas vegetation that provides habitat for fish and wildlife, such as trees and emergent vegetation, made up less than a fifth of the shoreline (15.7% or 9.4 km and 1.0% or 0.6 km, respectively) (Table 3 and Figure 11). Grass was distributed widely around all of Hamilton Harbour, whereas wetlands (classified as Emergent) were not well-represented across the Hamilton Harbour shoreline; open and riverine wetlands were observed just once while barrier and sheltered wetlands were not observed. If Windermere Basin is added to the BUI tally of littoral shoreline, the estimate of Emergent will increase as it is a wetland. One third (35.8% or 21.6 km) of the shoreline was Not Classified because it lacked any vegetation, mainly along the southern shore. Windermere Basin is included in the map and Table 3 as Not Classified as it was not surveyed in 2006, although we are aware it is vegetated and will be updated in the future.

Shoreline State reclassification

Table 3 and Figure 6 show the total length of Artificial and Natural areas grouped by shoreline substrate hardness. Artificial Hard made up the majority of the harbour (70.8% or 42.7 km), followed by Artificial Soft (12.4% or 7.5 km), Natural Soft (7.1% or 4.3 km), and Natural Hard (0.7% or 0.4 km). Artificial Soft shorelines with human-made beaches or berms of gravel or clay were found primarily in three locations in the harbour: in the Bayfront restoration areas (beaches on the southwestern shore); in the northeastern restoration areas (softened shore banks); and in the southeastern shore (slips in industrial areas of the harbour). Areas that were Modified for Restoration were completed with the intent of improving habitat for fish and wildlife, but the Artificial Soft

areas along the southern shoreline may be an unexpected source of potential useable habitat.

To aid in identifying restoration actions and potential habitat within Hamilton Harbour's shoreline, “Soft” and “Hard” qualifiers were added to the Shoreline State Artificial and Natural classifications to help predict areas that may be of use to fish and wildlife. Softened shorelines, areas such as wetlands or beaches, often have gentler slopes and are typically able to support vegetation that are of use to fish and wildlife (Uzarski et al. 2005). Hardened shorelines are often associated with steep walls and no riparian vegetation and support fewer and potentially less diverse wildlife communities (Dugan et al. 2008). If Natural and Artificial were considered without the qualifiers, it would be assumed that only 4.7 km of Natural shoreline would be useful to fish and wildlife. Considering soft shorelines and created islands, 13.2 km of shoreline (4.1 km Natural Soft, 0.6 km Natural Hard, 7.5 km Artificial Soft, and 2.0 km of Island) were delineated and are of potential use for fish and wildlife. These soft shoreline estimates partly overlap with the areas Modified for Restoration, though soft shorelines also identifies unmodified areas that may currently be used by fish and wildlife, or if left unmaintained may become naturalized in the future.

Modified for Restoration

There was an attempt to differentiate natural areas from habitat enhancements (Modified for Restoration); however, it was difficult to distinguish created habitat from either Natural or Artificial means and so we left our original classifications. Without prior information on the extent of restoration actions, field crews could only describe restoration areas by other attributes, such as substrate or composition. As such, the restoration maps were created only from expert opinion, and not collected field data (Figure 7). All attribute layers’ metadata have been merged to query any specific attribute data about any restoration area, however, the data collected in the field was not and cannot be used to verify expert opinion for the map created for those restoration areas (Figure 7).

In the northeastern shore of the harbor, 2.1 km of shoreline was identified as Modified for Restoration (Table 4, Figure 7). Discrepancies between the drawings and actual modifications were not verified (J. Hall, RAP coordinator (retired), Hamilton, Ontario, personal communication, 2019), however, ortho-imagery was used to delineate shoreline in areas above water level datum (74.2 m, Table 5).

Bayfront Park, Waterfront Trail, and their associated islands in the southwest corner of Hamilton Harbour were modified with a large pathway and human-made islands for bird habitat for a total of 4.4 km of shoreline (Table 4, Figure 7). As the largest shoreline modification for the harbour, the Bayfront area spans several modifications, shoreline varies from hard shoreline of armour stone to soft sandy beaches. Pier 4 Park and Hamilton Pier are adjacent to the Pier 4 marina (south shore) and include 0.6 km and 0.4 km of modified shoreline, respectively. Pier 7 is still under development (W. Plessl, City of Hamilton, Hamilton, Ontario, personal communication, 2019), currently with 0.5 km of projected modified shoreline. Another 1.0 km of proposed restoration work is

planned for 2023 in Macassa Bay and Piers 5 to 7 (0.5 km modified post-2006) and will create a continuous modified shoreline from Desjardin Canal to Pier 7 (Figure 7).

Combining expert opinion, engineering drawings, and historical GIS layers, we estimated there was approximately 9.3 km of Modified for Restoration shoreline in the harbour as of 2006 (Table 4, Figure 7). Modifications made after 2006 (including proposed future projects) will add another 2.4 km of shoreline. Cootes Paradise and Grindstone Creek shoreline lengths have been estimated in the Hamilton Harbour RAP 2012 update report (Hamilton Harbour RAP 2012) and add an additional 2.3 km and 2.1 km of Modified for Restoration shoreline to the AOC (Table 4). Table 4 will aid in any future BUI status updates/assessments; we estimate there will be a total of 16.0 km of shoreline Modified for Restoration once all restoration actions are complete. Combined with the length of Natural shoreline in the harbour (4.7 km), there is 20.7 km of potential shoreline suitable as wildlife habitat once all restoration projects are complete. Windermere Basin (2.8 km) was not included in the total shoreline as it was not surveyed in 2006 and should be discussed with the RAP group whether it constitutes part of the harbour BUI targets.

CAVEATS AND FUTURE WORK

The 2006 Hamilton Harbour shoreline survey provided detail of the physical properties and current state of the nearshore area in Hamilton Harbour at the land-water interface, at a finer scale than previous surveys (the North Shore Survey by Halton Conservation and the Environment and Climate Change Canada Environmental Atlas of Lake Ontario [Environment Canada 1993]). The output from our shoreline survey is a comprehensive catalogue of the shoreline's physical properties in 2006. The results have already been used to generate maps and polylines for Hamilton Harbour that can be used for future surveys and projects (including habitat suitability modelling) and will be included in the current Hamilton geodatabase from Doolittle et al (2010).

If a future shoreline survey is to be completed, field surveys should minimize over-classification of shoreline of attributes. While the shoreline survey form used was a useful guide for classifying different shoreline attributes, the data collected following the form's classifications did not effectively represent the Hamilton Harbour shoreline; the high frequency of "Other" classifications on the survey form consequently required the reclassification of attributes post-survey. Using a combination of geospatial data and site photos, we were able to cross-reference shoreline classifications to address data gaps from the field survey.

Future shoreline surveys should also consider using geotagged photos captured by cameras with GPS capability to decrease observation bias in visual assessment. Subjectivity and observer bias exist in all visual assessments, however, we minimized the variability in classification by cross-referencing post-survey results and creating new classifications not represented by the initial assessment. Ortho-imagery analysis in conjunction with geo-referencing was also helpful in verifying the survey results. A

combination of site photos and ortho-imagery was helpful in adding landmark buildings and waterbody features.

In addition, it is suggested that a field survey with strict buffer guidelines be applied in future surveys. Priority classification of shoreline attributes were given to the land-water interface and the vegetation present at the shoreline, though some attributes required surveying beyond the shoreline within a buffer from the waterline (e.g., sand at shoreline, but armour stone was present within 3 m of the actual shoreline resulted in confusing classifications between attributes and had to be cleared up post-survey). A non-defined buffer also increased the number of multi-classifications that then required consolidation during analysis. The ability to cross reference boat-to-shoreline attributes is best suited with on-site classification and a buffer will keep the survey focused. Subjectivity can be a concern in any visual classification studies, therefore future shoreline surveys should focus on the land-water interface with a predetermined buffer from the waterline for assessment.

Defining a clearer objective about the end-user use of any collected data will help to focus which attributes need to be classified and how much detail is necessary. Future surveys should use this study to refine a priori classifications as well as create a decision tree on how to proceed if new/combined classifications arise. Utilizing a refined classification scheme would reduce the variability of interpretation of changes over time and reduce the effort needed to update a comprehensive shoreline map to inform BUI delisting and HEAT use.

CONCLUSION

This report provides a baseline of Hamilton Harbour shoreline conditions in 2006. The results from this survey will be helpful for planning any future assessment of shoreline modifications in Hamilton Harbour. For the Hamilton Harbour RAP, we estimated 9.3 km of shoreline had been Modified for Restoration in the harbour. Currently, our estimates of areas Modified for Restoration do not meet the Hamilton Harbour RAP BUI #14 sub-target of >15 km of improved shoreline. However, the data in this report will serve as weight of evidence towards future assessments of this BUI. Combined with our estimates of Modified for Restoration (9.3 km), the RAP's estimates of Cootes Paradise and Grindstone Creek (4.4 km), post-2006 modifications for restoration (2.3 km), and natural areas (4.7 km), there could be 20.7 km of naturalized shoreline to provide habitat for fish and wildlife. Future HEAT modelling will evaluate these areas to assess their effectiveness at providing habitat for fish in the harbour.

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Table 1. Classifications of attributes on the shoreline survey form used to identify shoreline types.

Attribute	Classification	Sub-class	Description
Shoreline State	Artificial		converted from its hypothesized historical state, unaffected by human activity, even if changes made were to protect the shoreline from further degradation
	Natural		an area that was mostly devoid of human-made structures, was largely vegetated, and would have been historically present in the Hamilton Harbour shoreline
	Island		areas separate from the mainland that were built up/human-made
Shoreline Composition [a]	Steel/Concrete Wall [b]	Hard	vertical, hardened walls; particle sizes are equivalent to bedrock and hardpan clay in the modified Wentworth Scale (Table 2).
	Island		identified island areas separate from mainland, did not identify the composition of the island, usually gravel or cobble
	Wood [b]	Hard	wooden docks or walls; particle sizes are equivalent to bedrock and hardpan clay in the modified Wentworth Scale (Table 2).
	Armour stone/Boulder [b]	Hard	boulders[b]; very large rocks; cannot sample; particle size >250.0 mm (Table 2); armour stone is used as a synonym for boulders and highlights the use of the stone for erosion protection
	Rubble [b]	Hard	large Rocks; cannot sample; particle size 151.1–250.0 mm
	Cobble [b]	Hard	particle sizes greater than or equal to cobble 65.1–150.0 mm
	Gravel [b]	Soft	all substrate types smaller than or equal to gravel 2.0–16.0 mm
	Sand [b]	Soft	fine particulates; can sample 0.06–1.9 mm
	Silt/Clay [b]	Soft	very fine particulates, usually organic or can be molded; can sample <0.06 mm
Shore Structure	Boat Launch/Slip		a ramp with a gradual grade that can be used to move boats in and out of the water
	Cobble/Rubble/Boulder		areas with large sections of dumped rocks such as islands or armoured shorelines where, in most instances, shoreline had been developed for erosion prevention
	Vertical Seawall		piers, wharfs, and sunken barges were included as part of the definition of “vertical seawall”
	Shore Rip-Rap		concrete or cement combined with other grain-sizes such as boulder or gravel
	Dock/Floating Dock/Slip		Included anchored docks and floating docks

Attribute	Classification	Sub-class	Description
Adjacent Land Use	Residential		homes and lawns of private properties
	Industrial/Commercial		all lands used by a business
	Transportation		included lands used by or immediately adjacent to roads
	Parks/Recreation		included any maintained city parks or trails
	Undeveloped/Open Space/Forest		included all unmaintained or vegetated areas (including Holy Sepulchre Cemetery)
	Agricultural		included any farm lands
Vegetation [c]	Grass		encompassed all types of grass species, including manicured, low, tall, or mixed grass species
	Shrub		consisted of tall, low, and medium, ranging in sizes >1.5 to 0.5 m
	Emergent (wetland)		wetland areas (barrier/sheltered/open/riverine) with vegetation
	Trees		included any variety of trees present; species were not identified in the survey
Shoreline State [d] Reclassification	Artificial Hard		modified shoreline (seawalls, industrialized shoreline) with large particle size substrate, generally including cobble, rubble, and boulder (Table 2)
	Artificial Soft		areas that have been altered based on attributes such as artificial beaches or other particle sizes (equal to or smaller than gravel; Table 2)
	Natural Hard		areas that are believed to be in their natural state; consisted of particle sizes greater than gravel (Table 2), naturally occurring cobble/rubble/boulder/bedrock
	Natural Soft		areas that are believed to be in their natural state, or as close as possible; i.e., riparian zones, wetlands; consisted of particle sizes equal to or smaller than gravel (Table 2), and included zebra mussels, sand, and clay/silt.
	Islands		identified island areas separate from the mainland; did not identify the Shoreline State of the island (often artificial)
Modified for Restoration [e]			used to highlight the intent of the project rather than identify the ecological impact.
All Attributes	Not Classified		areas of unknown classification; included in every attribute.

[a] Shoreline Composition determined at the land-water interface for each segment
[b] Adapted Wentworth classification of substrate types (adapted from Bain and Stevenson 1999)
[c] Vegetation visually classified from the type of vegetation associated with the shoreline within a 5-m buffer
[d] Shoreline State was reclassified post field survey, considering the attributes Shore Structure, Shoreline Composition, and Adjacent Land Use to provide additional summary information regarding potential restoration sites (or useable habitat) without having to reference more complex attribute combinations

Table 2. Adapted Wentworth classification of substrate types by size (adapted from Bain and Stevenson 1999).

Substrate type	Description	Particle size (mm)
Bedrock	Exposed slate or granite; cannot sample	
Hardpan clay	Highly compacted clay; cannot sample	
Boulder	Very large rocks; cannot sample	>250.0
Rubble	Large rocks; cannot sample	151.1–250.0
Cobble	Moderate sized rocks; may not sample	65.1–150.0
Pebble	Small rocks; can sample	16.1–65.0
Gravel	Coarse particulates/rocks; can sample	2.0–16.0
Sand	Fine particulates; can sample	0.06–1.9
Silt	Fine particulates, usually organic; can sample	<0.06
Clay	Fine particulates, can be moulded; can sample	<0.06
Organics	Woody debris, vegetation, humus	

Table 3. Shorelines classification, total length, and % representation of attributes for Hamilton Harbour in 2006.

Attribute	Classification	Length (km)	Total Representation (%)
Shoreline State	Artificial	50.2	83.3
	Natural	4.7	7.7
	Not Classified	3.4	5.7
	Islands	2.0	3.3
	Total	**60.3**	**100.0**
Shoreline Composition	Steel/Concrete Wall	23.7	39.3
	Cobble	10.2	16.9
	Clay/Silt	6.1	10.1
	Sand	5.8	9.6
	Not Classified	5.1	8.4
	Armour Stone/Boulder	4.1	6.7
	Islands	2.0	3.3
	Gravel	1.7	2.8
	Rubble	1.0	1.7
	Wood	0.7	1.2
	Total	**60.3**	**100.0**
Shore Structure	Wall/Vertical Seawall	24.5	40.7
	Cobble/Rubble/Boulder	12.3	20.5
	Not Classified	12.1	20.0
	Shore Rip-Rap	10.3	17.1
	Dock/Floating Dock/Slip	0.7	1.1
	Boat Launch/Slip	0.4	0.7
	Total	**60.3**	**100.0**
Adjacent Land Use	Industrial/Commercial	25.3	42.0
	Parks/Recreation	13.6	22.5
	Not Classified	6.7	11.1
	Residential	6.2	10.3
	Undeveloped/Open Space/Forest	5.2	8.6
	Transportation	3.3	5.4
	Agricultural	0	0
	Total	**60.3**	**100.0**
Vegetation	Grass	28.7	47.6
	Not Classified	21.6	35.8
	Trees/Shrub	9.4	15.7
	Emergent (wetlands)	0.6	1.0
	Total	**60.3**	**100.0**
Shoreline State reclassified	Artificial Hard	42.7	70.8
	Artificial Soft	7.5	12.4
	Natural Soft	4.3	7.1
	Not Classified	3.4	5.6
	Islands	2.0	3.3
	Natural Hard	0.4	0.7
	Total	**60.3**	**100.0**

Table 4. Total length (km) of shoreline modifications for restoration for Hamilton Harbour Area of Concern (Hamilton Harbour AOC). Estimates are calculated for the shoreline at the time of survey (2006), modifications made after 2006, and shoreline estimates for areas of the Hamilton Harbour AOC beyond the main harbour; areas were estimated by the Remedial Action Plan (RAP) in the 2012 update (Hamilton Harbour RAP 2012).

2006 Shoreline Modifications for Restoration	**Length (km)**
Bayfront Park	1.9
Hamilton Pier	0.4
LaSalle Park	1.8
Northeast Hamilton Harbour	2.1
Pier 4 Park	0.6
Waterfront Trail	2.5
Total	**9.3**
Post-2006 Shoreline Modifications for Restoration	
Farr Island (reconstruction - 2010)	0.4
Macassa Bay (to be completed 2023)	1
Pier 7 Shoreline Improvements	0.5
Piers 5-7 Redevelopment (to be complete 2023)	0.5
**RHC Pike Spawning (2003)*	*1.2*
**Windermere Basin (2006 shoreline)*	*2.8*
Total	**2.3**
2012 RAP Shoreline Estimates	
Cootes Paradise Marsh	2.3
Grindstone Creek Marsh	2.1
Total	**4.4**

**Areas in red* were not included for the sum of km of shoreline and should be discussed by the RAP whether these should be included for the Beneficial Use Impairment shoreline sub-target. See Figure 7 for locations in Hamilton Harbour.

Table 5. Water Levels collected from Environment Canada's Station 13150 in May, 2006.

Days of Collection	Observed Water Level (m)	Datum (m)	Water Level (m)
11-May-06	0.664	74.2	74.9
15-May-06	0.646	74.2	74.8
19-May-06	0.685	74.2	74.9
23-May-06	0.672	74.2	74.9

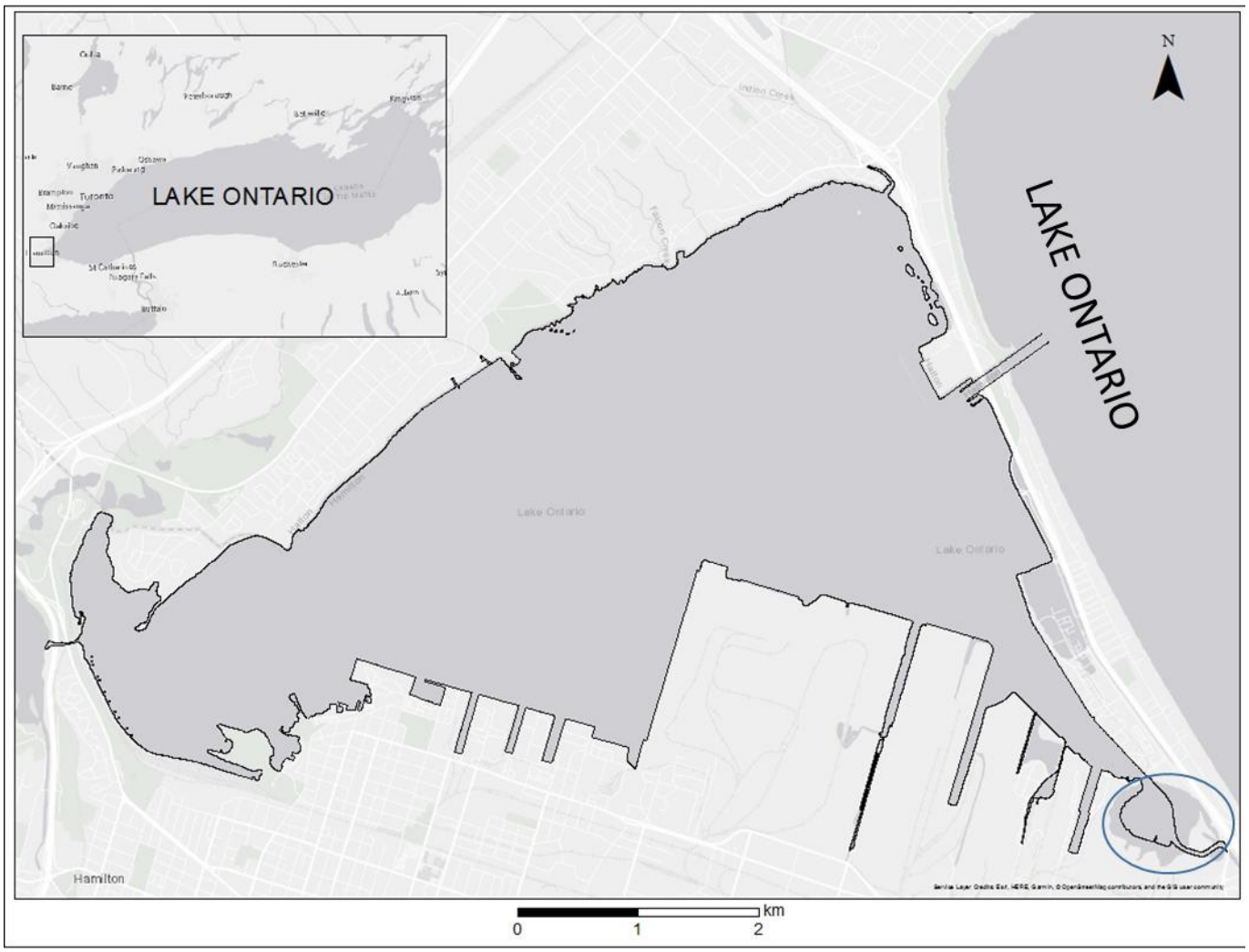


Figure 1. Hamilton Harbour 2006, surveyed shoreline. Windermere Basin is included in the shoreline layer (circled in blue in the southeast corner), however, it was not classified during the survey.

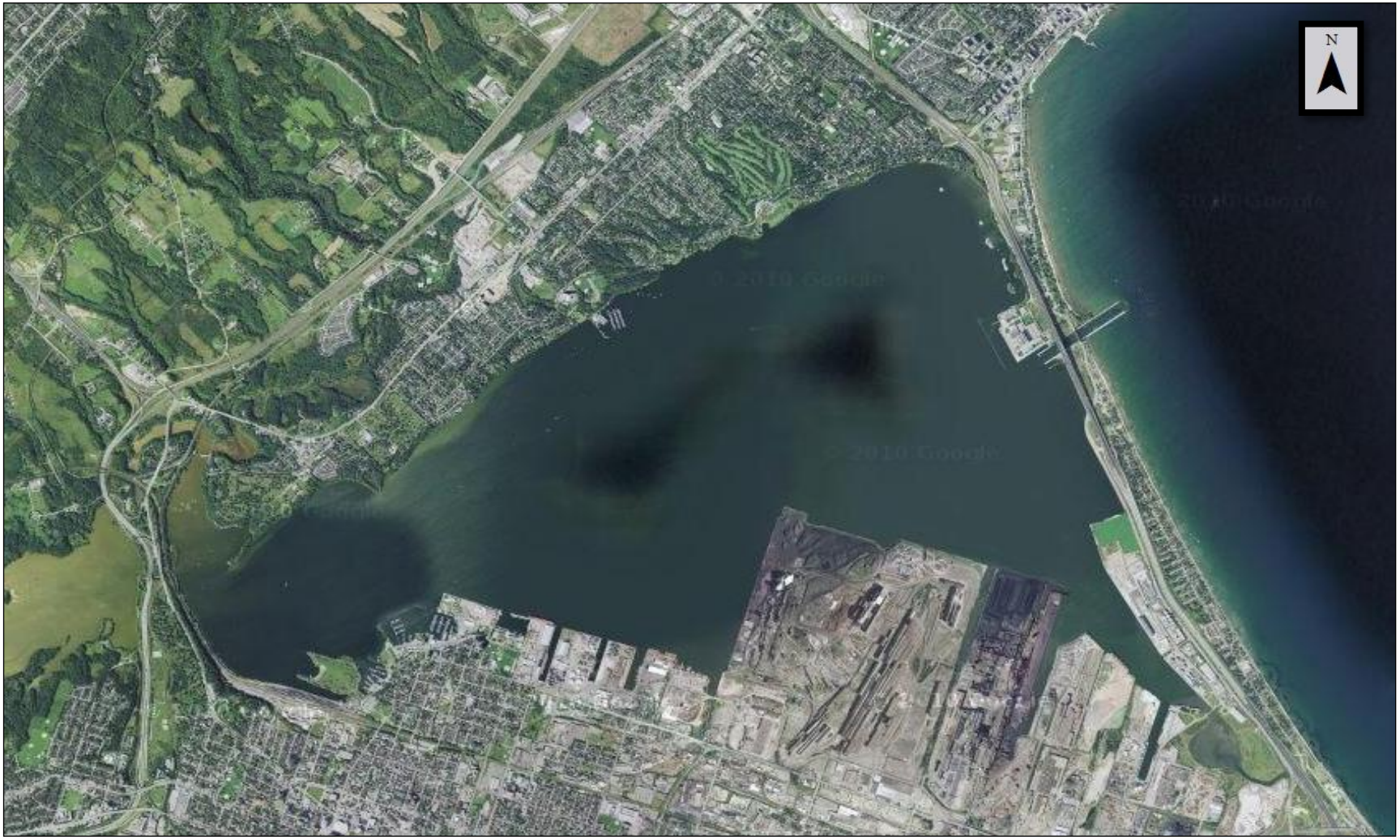
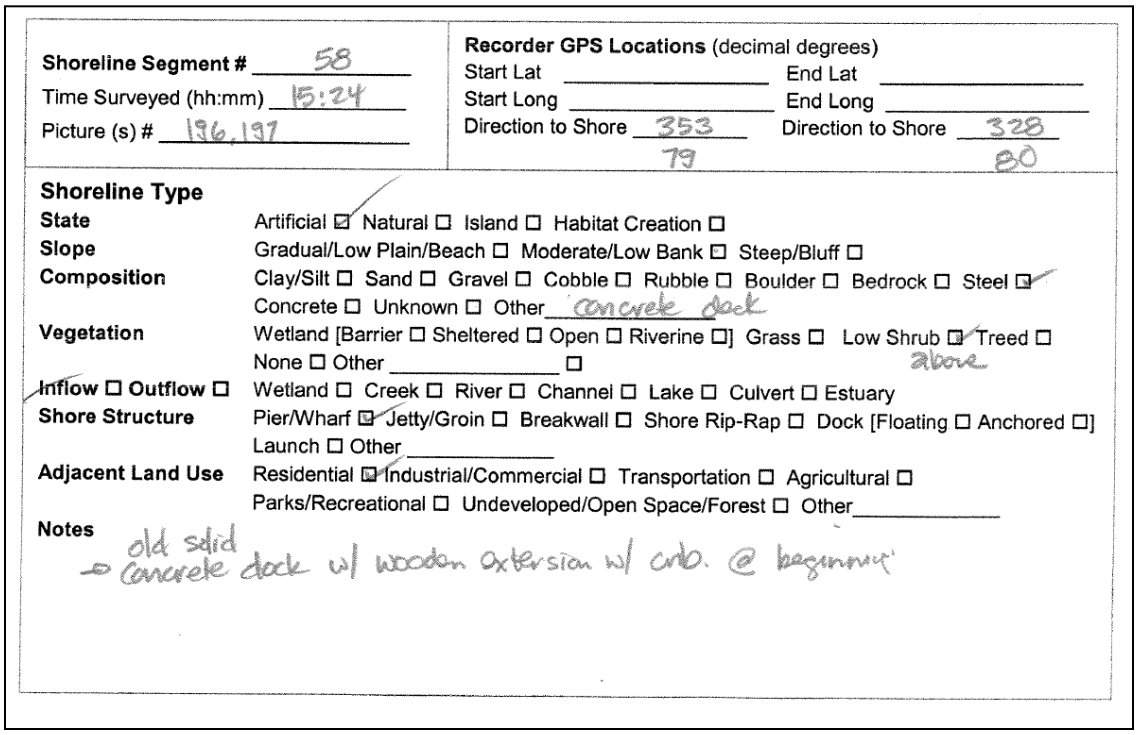


Figure 2. Aerial view of Hamilton Harbour (43°14'N, 79°51'W) located at the western end of Lake Ontario (Google Earth 2010).



Shoreline Segment # 58
Time Surveyed (hh:mm) 15:24
Picture (s) # 196, 197

Recorder GPS Locations (decimal degrees)
Start Lat _____ End Lat _____
Start Long _____ End Long _____
Direction to Shore 353 / 79 Direction to Shore 328 / 80

Shoreline Type

State Artificial ☑ Natural ☐ Island ☐ Habitat Creation ☐

Slope Gradual/Low Plain/Beach ☐ Moderate/Low Bank ☑ Steep/Bluff ☐

Composition Clay/Silt ☐ Sand ☐ Gravel ☐ Cobble ☐ Rubble ☐ Boulder ☐ Bedrock ☐ Steel ☑
Concrete ☐ Unknown ☐ Other concrete dock

Vegetation Wetland [Barrier ☐ Sheltered ☐ Open ☐ Riverine ☐] Grass ☐ Low Shrub ☑ Treed ☐
None ☐ Other _____ ☐ above

Inflow ☐ Outflow ☐ Wetland ☐ Creek ☐ River ☐ Channel ☐ Lake ☐ Culvert ☐ Estuary

Shore Structure Pier/Wharf ☑ Jetty/Groin ☐ Breakwall ☐ Shore Rip-Rap ☐ Dock [Floating ☐ Anchored ☐]
Launch ☐ Other _____

Adjacent Land Use Residential ☑ Industrial/Commercial ☐ Transportation ☐ Agricultural ☐
Parks/Recreational ☐ Undeveloped/Open Space/Forest ☐ Other _____

Notes
→ old solid concrete dock w/ wooden extension w/ crib. @ beginning

Figure 3. Examples of a completed shoreline survey form for segment 58. Data collected in 2006 field season.

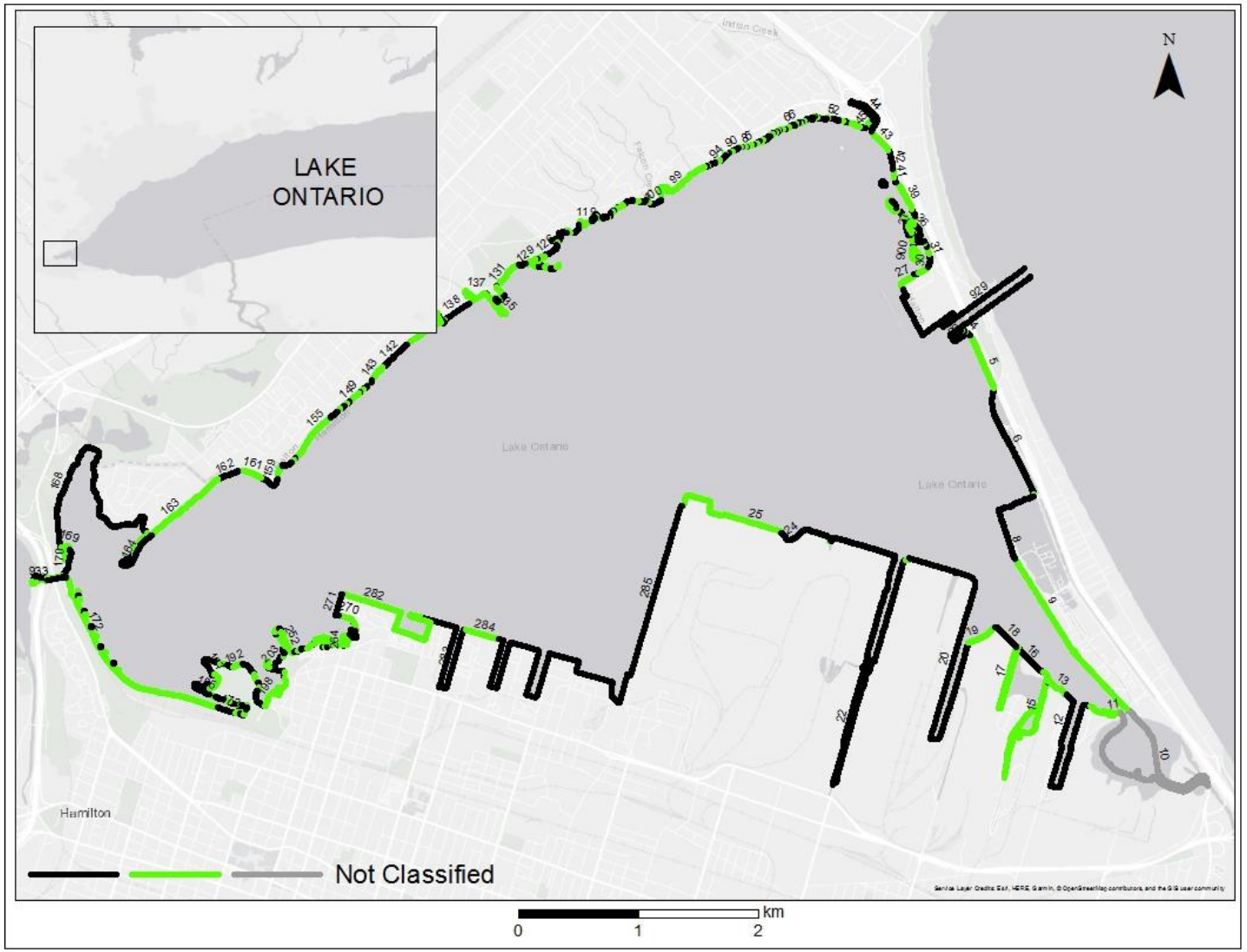


Figure 4. Map of Hamilton Harbour 2006, shoreline with 266 segments identified. These segments are associated with the layer data and attributes that were collected in the field between May 11 to 23, 2006. Segments are represented in two colours for display purposes to show the changing segments where data were collected.

Figure 5. Hamilton Harbour 2006, classifications for the Shoreline State attribute. Red bars with white spaces denote the extent of survey.

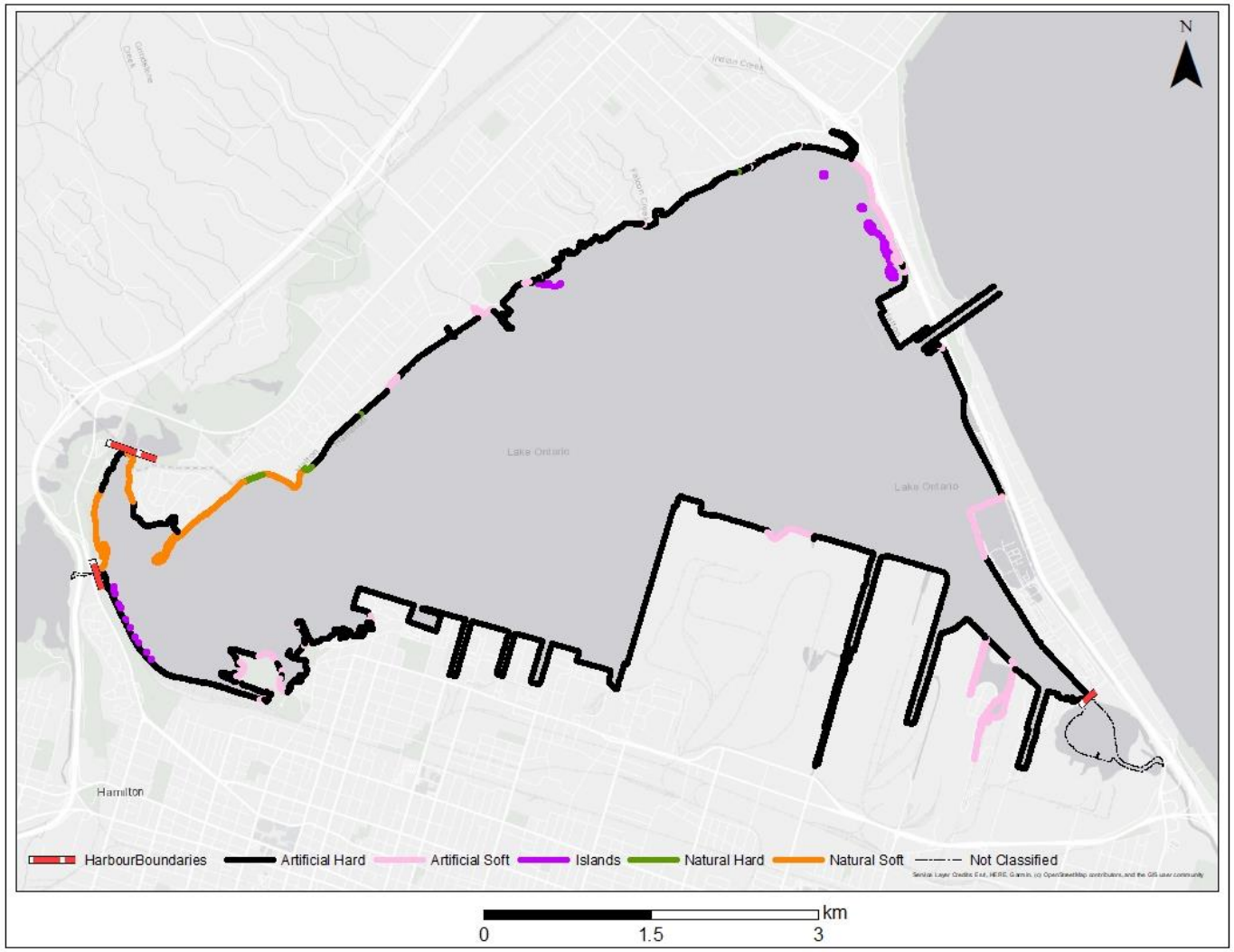


Figure 6. Hamilton Harbour 2006, Shoreline State attribute (artificial, natural, and island) combined with substrate hardness (Hard or Soft). Red bars with white spaces denote the extent of survey.

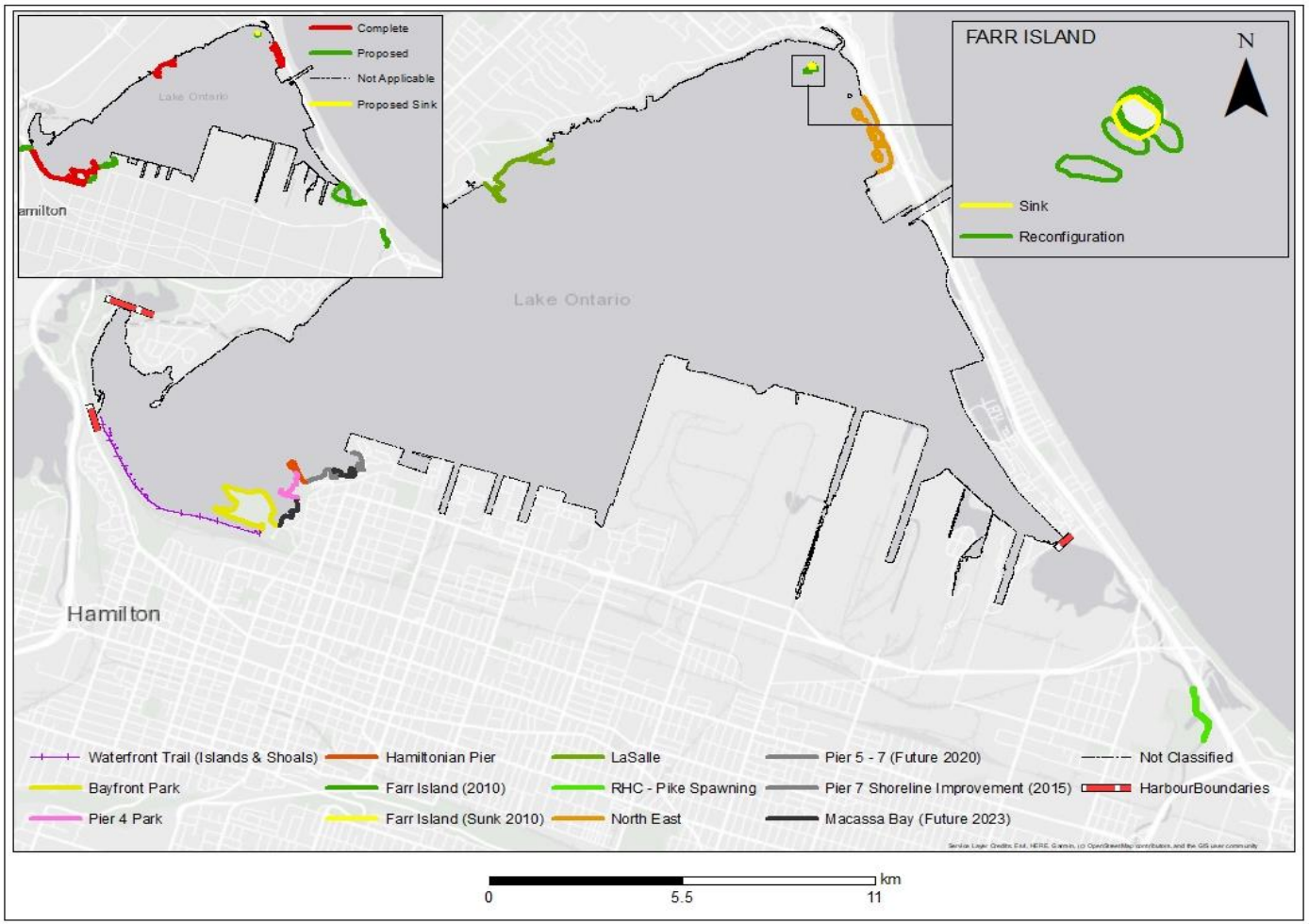


Figure 7. Hamilton Harbour 2006, modifications for restoration; see Table 4 for the lengths and date of each modification. Red bars with white spaces denote the extent of survey. The inlay in the left top corner shows the status of Modifications for Restoration as of 2006. “Complete” bars show projects that were finished before 2006, “Proposed” are projects completed or to be completed post-2006, and “Proposed sink” highlight the modification of Farr Island (J. Hall, Hamilton Harbour RAP coordinator (retired), Hamilton, Ontario, personal communication, 2019). Farr Island, where part of the island was sunk “Sink” to become a shoal, and the rest was raised to create an island “Reconfiguration”.

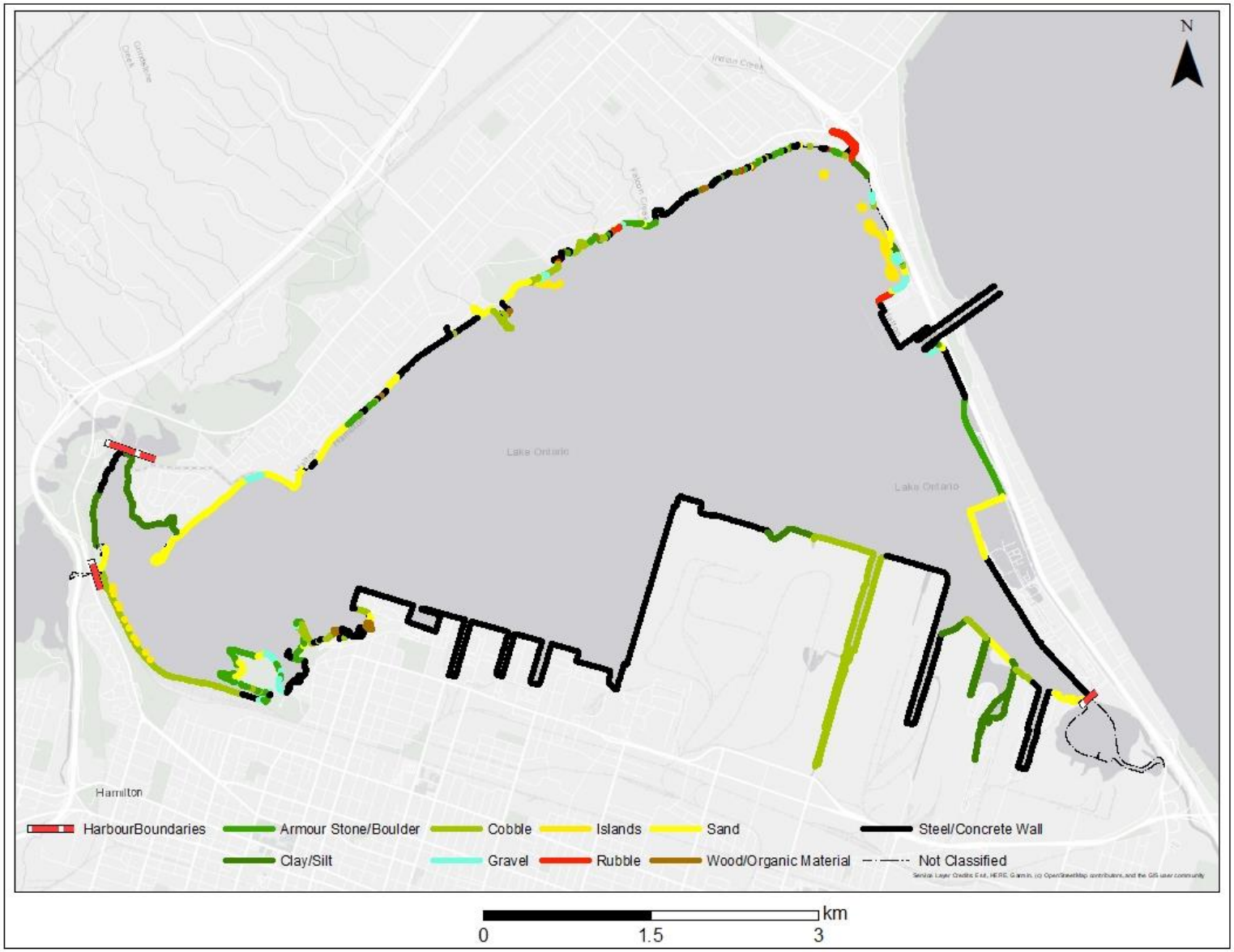


Figure 8. Hamilton Harbour 2006, Shoreline Composition. Values for classifications such as Armour Stone/Boulder were merged as they are similar to each other in granular composition. Red bars with white spaces denote the extent of survey.

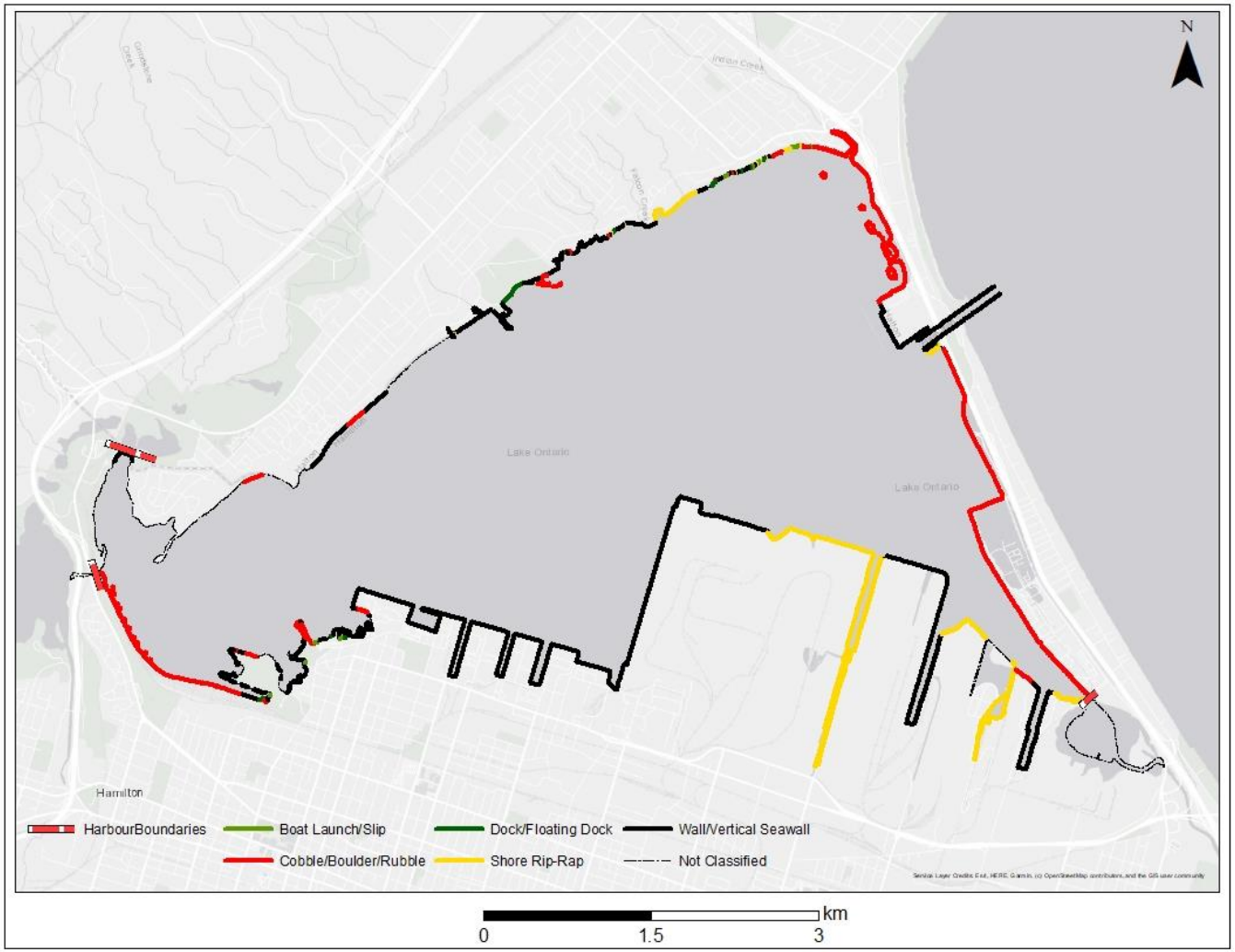


Figure 9. Hamilton Harbour 2006, Shore Structure. Red bars with white spaces denote the extent of survey.

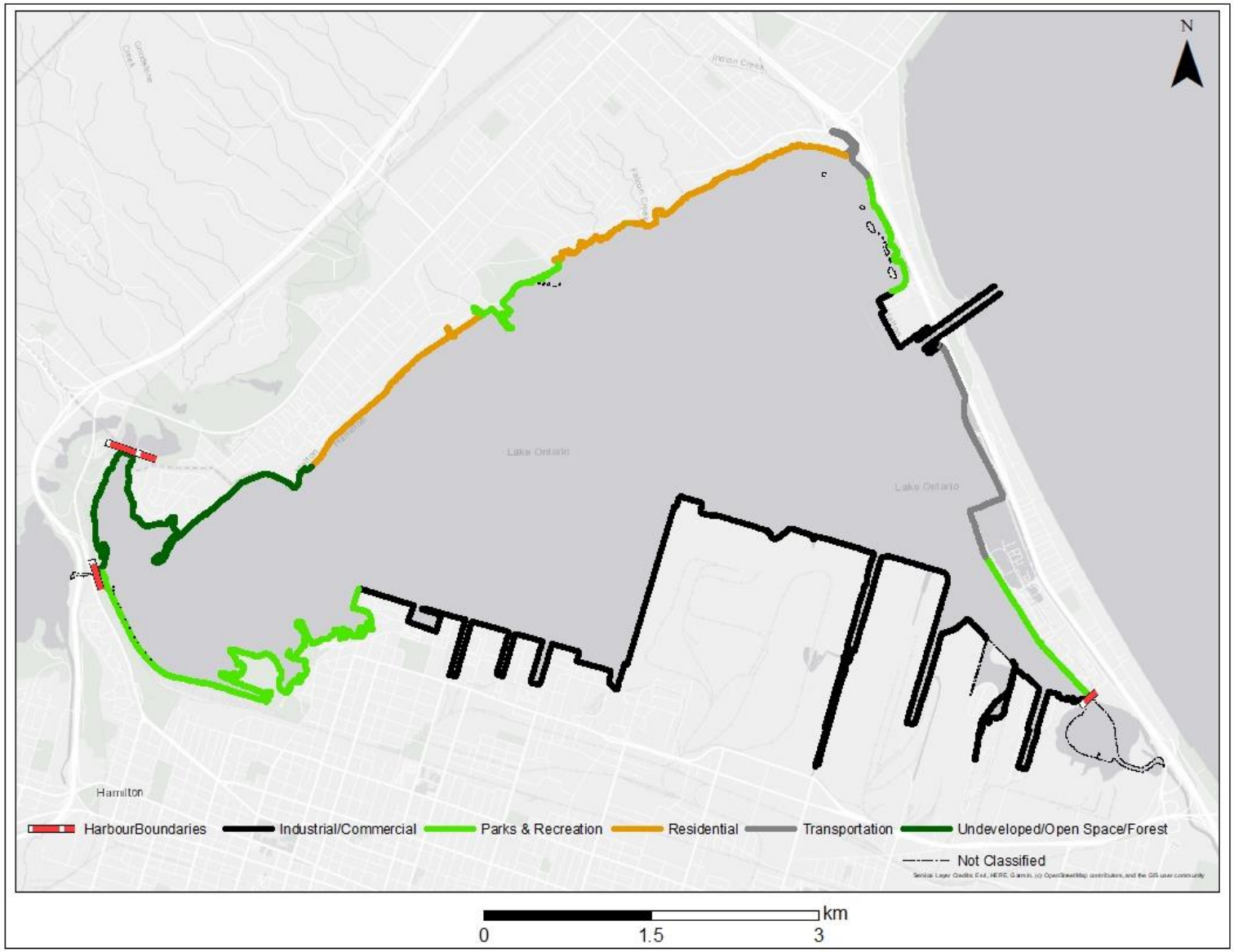


Figure 10. Map of Hamilton Harbour 2006: classifications for the Adjacent Land Use attribute. Red bars with white spaces denote the extent of survey.

Figure 11. Hamilton Harbour 2006, classifications for the Vegetation attribute. Red bars with white spaces denote the extent of survey.

APPENDIX

HAMILTON HARBOUR SUBSTRATE SURVEY

Ponar sediment samples were collected and complement shoreline substrate classifications from the shoreline survey, as well as inform our internal GIS substrate layer. Sampling occurred across three time periods: May 2006 (*n* = 19*)*, May 2007 (*n* = 71*)*; and May 2008 (*n* = 16*)*. Prior to the survey, the shoreline of Hamilton Harbour was divided into line segments based on shoreline type as determined with previous substrate info. Subsets of line segments were then selected using stratified random sampling so that all substrate types were represented. This subset was used to pick point sampling Ponar locations (Figure A1).

Sediment samples were taken at the midpoint of each shoreline segment at depths of approximately 0.5–1.0 m. For segments longer than 1 km, samples were taken at midpoints every 500 m instead of at transition points between shoreline types. These data aided in identifying transition points along the shore where bearing information was incorrect. In total, 106 Ponar sediment samples were collected (or attempted if a sediment sample could not be collected) along the Hamilton Harbour shoreline (Figure A1).

When possible, visual assessments were conducted for each sample location to estimate percent composition of substrate using the following categories: bedrock, boulder, rubble, cobble, gravel, sand, silt, and clay. Ponar grabs were collected when the prevailing substrate had a particle size less than or equal to gravel (≤ 16 mm). Sub-samples of the Ponar (100 grams) were taken from the top layer and stored in white ointment jars in a cooler on the boat and subsequently stored in a refrigerator prior to quantitative analysis. Of the 106 sites visited, 51 were visually assessed (27 where the substrate particle size was larger than gravel, and 24 sites that could be sampled by Ponar, however, were not analyzed), and 55 sites were collected and analyzed. Additional notes were made if any of the substrate consisted of zebra mussels, which were later reclassified as gravel due to similar grain size.

To determine the particle size and carbon content of the sediment, two separate analyses were conducted: sieve analysis and organic content loss-of-ignition (LOI). Organic matter content is an determined by of measuring percent mass loss in sub-samples after heating samples to 500 ^{o}C for two hours. Sieve and LOI analysis were conducted for 55 sediment samples either by Great Lakes Laboratory for Fisheries and Aquatic Sciences (DFO; *n* = 36) or by Environment Canada (EC; *n* = 19 samples). The methods for DFO and EC sediment analyses were similar and outlined as follows:

DFO SIEVE METHODS - Samples were freeze-dried and broken down with mortar and pestle. Sediment was sieved into three different Wentworth grain sizes for processing: i) more than 2 mm sieve [gravel, large organic matter and debris (SO)]; ii) less than 2 mm and greater than 63 µm [very coarse sand to fine sand (SA)]; iii) less than 63 µm [silt and clay (ST/CL)]. Each sediment sample was shaken for 20 minutes, placed in

crucibles (metal container) and weighed. To remove additional moisture, samples were placed in a desiccator (moisture removal container) for approximately 24 hours. The sample was then re-weighed and the amount of each sediment type was calculated by subtracting the weight of the empty crucible from the weight of the sample and crucible. Percent composition was calculated as follows:

$$\%\,[ST/CL] = \frac{[ST/CL]\ g}{[SO] + [SA] + [ST/CL]\ g}$$

DFO LOI - Sieved samples of each grain size were standardized to an approximate weight of 2 grams and placed into a preheated muffle furnace at 500°C for approximately 2 hours. Samples were then transferred into a desiccator to cool for approximately 15 minutes, and then the combined ash /crucible weight was recorded for each grain size. Percent LOI was calculated using the following equation:

$$\text{Total \% LOI} = \left(\frac{[SOpre] - [SOpost])\ g}{[SOpre]\ g}\right) + \left(\frac{[SApre] - [SApost])\ g}{[SApre]\ g}\right) + \left(\frac{[ST/CLpre] - [ST/CLpost])\ g}{[ST/CLpre]\ g}\right)$$

g = grams
ST/CL = silt/clay
SO = organic matter
SA = coarse to fine debris/sand

EC SIEVE METHODS- Samples that were mostly sand and gravel (*n = 16*) were analyzed for percent composition using comparable methods to DFO for sieve analysis, grain size, and percent composition outputs. Samples were weighted, placed in a multi-stack sieve (with a maximum of 29 stacks), and shaken for 15 minutes. They were removed from the stack and weighed again. Samples that were primarily comprised of silt /clay (*n = 3*), were analyzed by laser diffraction analysis using a LA-950 Laser Particle Size Analyzer (Horiba, Japan).

EC LOI - For individual grain sizes, a few grams of moist sample were placed in a crucible and weighed. The samples were dried in an oven at 100 °C until fully desiccated. The crucible and sample were re-weighed, and the difference in weight was recorded as water content. The crucible and sample were placed into a muffle furnace, set to a temperature of 450 °C and left for 8 hours. The sample was removed from the furnace, allowed to cool, and re-weighed. The difference from the dry state yields the organic content. Percent LOI was calculated according to the equation below.

$$\text{Total \% LOI} = \left(\frac{[SOpre] - [SOpost])\ g}{[SOpre]\ g}\right) + \left(\frac{[SApre] - [SApost])\ g}{[SApre]\ g}\right) + \left(\frac{[ST/CLpre] - [ST/CLpost])\ g}{[ST/CLpre]\ g}\right)$$

g = grams
ST/CL = Silt/Clay
SO = Organic Matter
SA = Coarse to fine debris/sand

Sieve analysis was used most often to assess the particle size of samples (52 of 55 samples); however, this method does not distinguish between clay and silt. Samples that were not analyzed using diffraction analysis were assumed to be equal parts (50:50) clay and silt. Organic matter in the samples was reclassified to clay and silt

depending on the relative composition of each of the two types of substrate in the sample. For instance, if the sample had equal parts clay and silt; organic matter would be divided evenly between clay and silt.

Of the 106 sites, Shoreline Composition was dominated by small substrate: sand was the most frequently occurring substrate type (*n* = 80), followed by silt (*n* = 65), clay (*n* = 61), and gravel (*n* = 38). Larger substrates were much less common. Cobble occurred at 22 sampling sites while boulder and rubble were observed at only 5 and 7 sites, respectively. Gravel, sand, silt and clay were found at every analyzed sample site.

Percent loss of ignition (%LOI) was summarized for the 55 sediment analyzed (Figure A1). Percent loss of ignition ranged from 0.1% to 11.3% and the mean %LOI was 3.13%. This suggests that most sites had little organic content in the substrate. With consideration for fish habitat restoration, areas that have high clay/silt content are invaluable to submerged aquatic vegetation and consequently, many fish species.

A summary of the particle size analysis results can be found in Table A1.

Table A1. Sediment particle size and loss on ignition (LOI) analysis for samples collected from Hamilton Harbour between 2010–2012.

ID	Latitude	Longitude	Date	Analyzed	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	%LOI
1	43.280280	-79.885270	01/05/2011	Y	0.0	0.0	0.0	0.0	0.5	78.3	10.6	10.6	5.3
2	43.299188	-79.845065	01/05/2011	N	0.0	0.0	90.0	10.0	0.0	0.0	0.0	0.0	
3	43.298920	-79.844555	03/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
4	43.276502	-79.861818	03/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
5	43.274450	-79.867147	03/05/2011	N	0.0	40.0	60.0	0.0	0.0	0.0	0.0	0.0	
6	43.271535	-79.875132	03/05/2011	N	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
7	43.310280	-79.816790	10/05/2011	N	0.0	0.0	0.0	0.0	0.0	60.0	40.0	0.0	
8	43.310890	-79.817880	10/05/2011	N	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
9	43.311443	-79.808548	10/05/2011	N	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
10	43.280295	-79.882653	10/05/2011	N	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
11	43.280785	-79.881336	10/05/2011	Y	0.0	0.0	0.0	0.0	0.1	99.7	0.1	0.1	1.2
12	43.281738	-79.879857	10/05/2011	Y	0.0	0.0	0.0	0.0	0.1	99.5	0.2	0.2	1.5
13	43.281229	-79.884633	10/05/2011	N	0.0	0.0	0.0	0.0	0.0	20.0	60.0	20.0	
14	43.281952	-79.883455	10/05/2011	N	0.0	0.0	0.0	0.0	0.0	30.0	20.0	50.0	
15	43.282829	-79.888537	10/05/2011	N	0.0	0.0	0.0	0.0	0.0	20.0	60.0	20.0	
16	43.281801	-79.887768	10/05/2011	Y	0.0	0.0	0.0	0.0	4.4	79.2	8.2	8.2	7.1
17	43.277050	-79.886290	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	2.0	76.0	22.0	
18	43.276210	-79.885610	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	8.0	74.0	18.0	
19	43.270350	-79.874950	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	10.0	75.0	15.0	
20	43.270580	-79.876190	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	10.0	80.0	10.0	
21	43.270880	-79.876960	12/05/2011	Y	0.0	0.0	0.0	0.0	0.6	73.2	13.1	13.1	6.7
22	43.271030	-79.870060	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	12.0	76.0	12.0	
23	43.286570	-79.866700	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
24	43.296750	-79.852730	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	90.0	0.0	10.0	
25	43.307650	-79.826420	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	90.0	0.0	10.0	
26	43.269047	-79.786737	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
27	43.278590	-79.791380	12/05/2011	N	0.0	0.0	0.0	0.0	0.0	20.0	60.0	20.0	
28	43.310920	-79.807050	10/05/2010	Y	0.0	0.0	0.0	0.0	0.0	98.6	0.7	0.7	0.5
29	43.310490	-79.807700	10/05/2010	Y	0.0	0.0	0.0	0.0	0.0	97.3	1.3	1.3	0.4
30	43.309730	-79.808190	10/05/2010	Y	0.0	0.0	0.0	0.0	0.0	97.6	1.2	1.2	0.2
31	43.309690	-79.808670	10/05/2010	Y	0.0	0.0	0.0	0.0	0.0	96.0	2.0	2.0	0.5

ID	Latitude	Longitude	Date	Analyzed	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	%LOI
32	43.312550	-79.814870	10/05/2010	Y	0.0	0.0	0.0	0.0	0.0	94.4	2.8	2.8	0.7
33	43.311970	-79.814930	10/05/2010	Y	0.0	0.0	0.0	0.0	0.0	94.5	2.7	2.7	0.1
34	43.311040	-79.814890	10/05/2010	Y	0.0	0.0	0.0	0.0	0.0	97.9	1.1	1.1	1.1
35	43.310650	-79.814850	10/05/2010	Y	0.0	0.0	0.0	0.0	0.9	94.1	2.5	2.5	1.1
36	43.281410	-79.883130	11/05/2010	Y	0.0	0.0	0.0	0.0	0.2	95.9	2.0	2.0	2.3
37	43.284460	-79.888520	11/05/2010	Y	0.0	0.0	0.0	0.0	0.0	0.5	82.5	17.0	6.9
38	43.282540	-79.887760	11/05/2010	Y	0.0	0.0	0.0	0.0	0.0	0.3	71.0	28.7	11.3
39	43.280780	-79.887050	11/05/2010	Y	0.0	0.0	0.0	0.0	0.0	38.8	43.6	17.6	6.2
40	43.302510	-79.801090	11/05/2010	Y	0.0	0.0	0.0	0.0	0.5	96.9	1.3	1.3	1.7
41	43.302000	-79.802220	11/05/2010	Y	0.0	0.0	0.0	0.0	1.0	97.6	0.7	0.7	1.3
42	43.301540	-79.803170	11/05/2010	Y	0.0	0.0	0.0	0.0	0.1	99.2	0.3	0.3	0.5
43	43.301250	-79.803930	11/05/2010	Y	0.0	0.0	0.0	0.0	0.0	99.2	0.4	0.4	1.7
44	43.296370	-79.854540	17/05/2010	Y	0.0	0.0	0.0	0.0	0.0	91.6	4.2	4.2	1.1
45	43.295670	-79.854180	17/05/2010	Y	0.0	0.0	0.0	0.0	0.0	99.9	0.1	0.1	0.8
46	43.295600	-79.854100	17/05/2010	Y	0.0	0.0	0.0	0.0	0.0	97.7	1.1	1.1	0.9
47	43.311410	-79.805720	02/05/2011	N	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
48	43.299390	-79.848660	05/05/2011	N	0.0	0.0	70.0	0.0	0.0	0.0	30.0	0.0	
49	43.297320	-79.853320	02/05/2011	N	0.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	
50	43.310990	-79.815090	04/07/2012	Y	0.0	0.0	0.0	0.0	0.1	99.3	0.3	0.3	1.0
51	43.310700	-79.814840	04/07/2012	Y	0.0	0.0	0.0	0.0	12.8	84.4	1.4	1.4	2.4
52	43.312210	-79.814780	04/07/2012	Y	0.0	0.0	0.0	0.0	14.1	75.1	5.4	5.4	1.2
53	43.311570	-79.815190	04/07/2012	Y	0.0	0.0	0.0	0.0	0.5	97.7	0.9	0.9	0.7
54	43.312520	-79.814910	04/07/2012	Y	0.0	0.0	0.0	0.0	0.8	94.1	2.5	2.5	1.1
55	43.274590	-79.865010	05/05/2011	Y	0.0	0.0	0.0	0.0	4.0	79.3	8.3	8.3	5.6
56	43.278440	-79.887810	04/07/2012	Y	0.0	0.0	0.0	0.0	9.6	77.7	6.4	6.4	5.6
57	43.294990	-79.795650	05/05/2011	Y	0.0	0.0	0.0	0.0	0.3	99.6	0.0	0.0	0.9
58	43.272730	-79.879450	04/07/2012	Y	0.0	0.0	0.0	0.0	24.2	71.8	2.0	2.0	4.3
59	43.309260	-79.814820	04/07/2012	Y	0.0	0.0	0.0	0.0	0.6	84.9	7.3	7.3	2.6
60	43.279530	-79.887900	04/07/2012	Y	0.0	0.0	0.0	0.0	8.5	75.0	8.3	8.3	9.5
61	43.274930	-79.886010	04/07/2012	Y	0.0	0.0	0.0	0.0	21.2	73.1	2.8	2.8	7.0
62	43.275370	-79.884440	04/07/2012	Y	0.0	0.0	0.0	0.0	0.1	79.2	10.4	10.4	7.7
63	43.296778	-79.798550	05/05/2011	Y	0.0	0.0	0.0	0.0	25.7	73.2	0.6	0.6	2.0
64	43.307870	-79.814770	04/07/2012	Y	0.0	0.0	0.0	0.0	0.0	49.3	25.3	25.3	8.6
65	43.310540	-79.814820	04/07/2012	Y	0.0	0.0	0.0	0.0	6.1	90.5	1.7	1.7	2.9

ID	Latitude	Longitude	Date	Analyzed	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	%LOI
66	43.275050	-79.885670	04/07/2012	Y	0.0	0.0	0.0	0.0	7.9	80.6	5.8	5.8	7.5
67	43.275160	-79.885280	04/07/2012	Y	0.0	0.0	0.0	0.0	1.2	83.5	7.6	7.6	6.8
68	43.275290	-79.884740	04/07/2012	Y	0.0	0.0	0.0	0.0	0.4	91.9	3.8	3.8	6.8
69	43.298910	-79.844480	02/05/2011	N	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	
70	43.294620	-79.857550	05/05/2011	Y	0.0	0.0	0.0	0.0	11.3	87.5	0.6	0.6	1.7
71	43.270580	-79.874850	04/05/2011	N	0.0	0.0	20.0	0.0	80.0	0.0	0.0	0.0	
72	43.273140	-79.871960	05/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
73	43.270470	-79.870430	04/05/2011	N	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	
74	43.276345	-79.861148	05/05/2011	N	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
75	43.289930	-79.864450	05/05/2011	Y	0.0	0.0	0.0	0.0	13.8	86.0	0.1	0.1	1.3
76	43.303139	-79.840622	02/05/2011	Y	0.0	0.0	0.0	0.0	6.5	90.7	1.4	1.4	7.6
77	43.292671	-79.860178	05/05/2011	N	0.0	0.0	70.0	0.0	0.0	30.0	0.0	0.0	
78	43.273122	-79.875694	10/05/2011	N	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
79	43.274880	-79.867460	05/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
80	43.288790	-79.792980	05/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
81	43.302200	-79.839380	10/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
82	43.300450	-79.848070	02/05/2011	Y	0.0	0.0	0.0	0.0	0.7	97.5	0.9	0.9	0.7
83	43.286510	-79.868980	04/05/2011	Y	0.0	0.0	0.0	0.0	13.4	86.1	0.2	0.2	1.8
84	43.271560	-79.875380	04/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
85	43.273490	-79.867940	04/05/2011	N	0.0	0.0	0.0	0.0	50.0	50.0	0.0	0.0	
86	43.274040	-79.867680	10/05/2011	Y	0.0	0.0	0.0	0.0	79.9	18.0	1.1	1.1	1.7
87	43.283650	-79.794170	05/05/2011	N	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0	
88	43.293558	-79.858723	05/05/2011	N	0.0	0.0	40.0	0.0	30.0	30.0	0.0	0.0	
89	43.304890	-79.838360	02/05/2011	Y	0.0	0.0	0.0	0.0	0.1	79.4	10.3	10.3	1.1
90	43.306026	-79.833637	04/05/2011	N	0.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	
91	43.301550	-79.844420	05/05/2011	N	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
92	43.306922	-79.829148	02/05/2011	N	0.0	60.0	0.0	0.0	10.0	30.0	0.0	0.0	
93	43.309190	-79.825120	04/05/2011	N	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0	
94	43.310971	-79.820326	02/05/2011	N	0.0	0.0	0.0	0.0	90.0	10.0	0.0	0.0	
95	43.312440	-79.815460	04/05/2011	N	0.0	0.0	95.0	0.0	2.0	3.0	0.0	0.0	
96	43.313020	-79.809970	02/05/2011	Y	0.0	0.0	0.0	0.0	0.7	97.2	1.0	1.0	0.7
97	43.311880	-79.807360	04/05/2011	Y	0.0	0.0	0.0	0.0	1.6	95.4	1.5	1.5	1.0
98	43.272560	-79.868490	04/05/2011	N	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	
99	43.270505	-79.869285	04/05/2011	N	0.0	0.0	50.0	0.0	50.0	0.0	0.0	0.0	

ID	Latitude	Longitude	Date	Analyzed	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	%LOI
100	43.275770	-79.862630	05/05/2011	Y	0.0	0.0	0.0	0.0	4.5	81.5	7.0	7.0	5.0
101	43.275760	-79.866690	05/05/2011	N	0.0	0.0	0.0	0.0	0.0	33.0	34.0	33.0	
102	43.270600	-79.877740	04/05/2011	N	0.0	0.0	70.0	30.0	0.0	0.0	0.0	0.0	
103	43.275330	-79.886760	10/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
104	43.284870	-79.889800	04/05/2011	Y	0.0	0.0	0.0	0.0	0.0	31.2	34.4	34.4	3.0
105	43.283332	-79.884672	04/05/2011	Y	0.0	0.0	0.0	0.0	21.2	75.4	1.7	1.7	1.5
106	43.281090	-79.882610	10/05/2011	N	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
				Mean (%)	**0.0**	**2.8**	**15.7**	**4.2**	**7.7**	**54.4**	**10.4**	**4.9**	**3.1**
				St. Dev	**0**	**13.5**	**32.8**	**18.0**	**20.4**	**41.7**	**21.5**	**8.7**	**2.9**

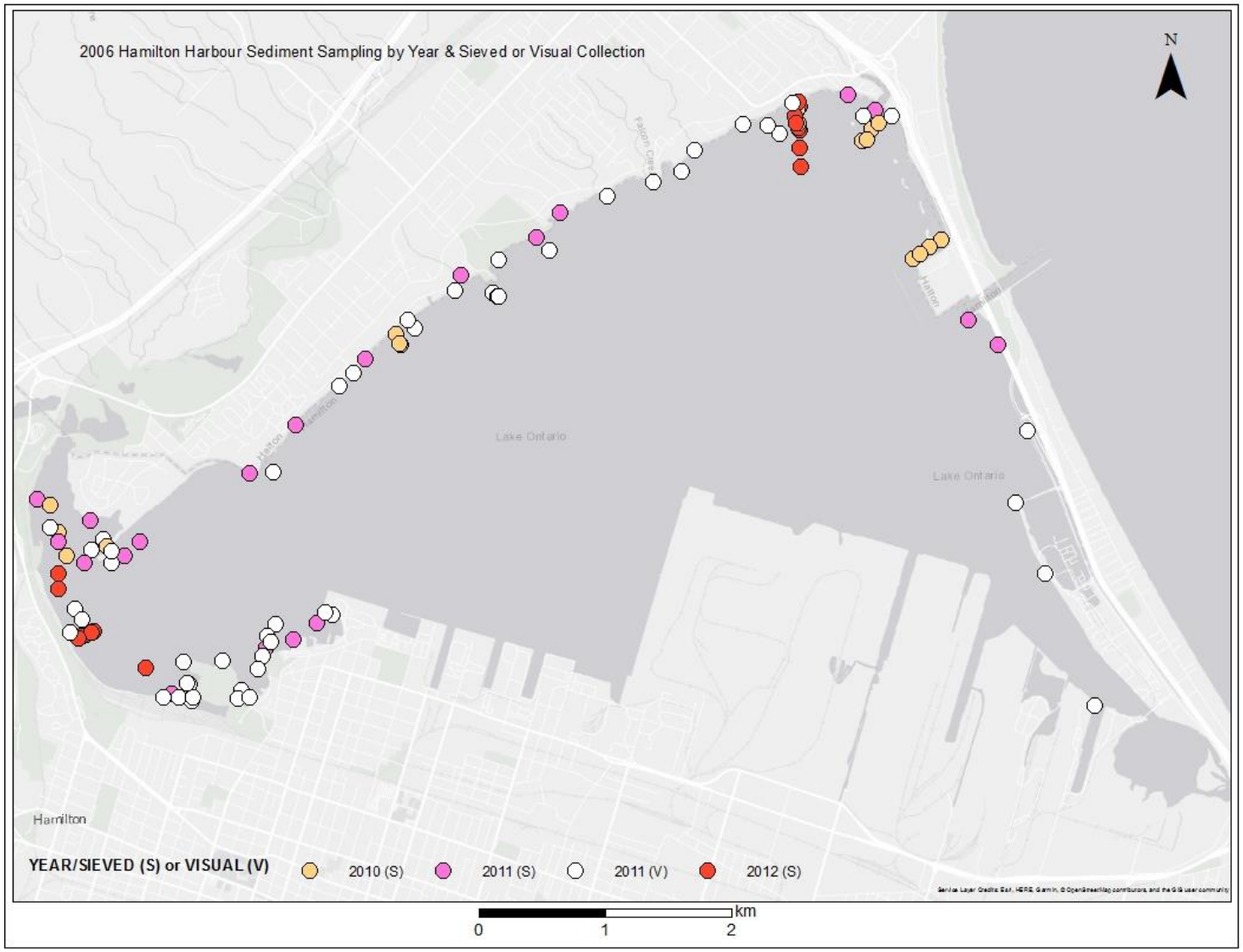


Figure A1. Map of Hamilton Harbour identifying the locations of point sediment samples collected for the shoreline survey to quantitatively describe shoreline substrate composition. A total of 106 samples were collected over three time periods, although visual sample assessment was only conducted in 2011.