A Physical and Spatial Assessment of Remediated Submerged Habitats within the Thunder Bay Area of Concern

Thesis completed in partial fulfillment of a Masters in Environmental Studies.

Lakehead University

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Abstract

The designation of Thunder Bay's Harbour as an Area of Concern (AOC) by the International Joint Commission prompted the need for Remedial Action Plans to improve historically significant habitats (RAP, 1991; RAP 2004). In an attempt to restore, protect, conserve, and prevent further ecosystem degradation, a series of projects were developed with site-specific objectives to benefit the Thunder Bay AOC. The removal of contaminants, habitat compensation engineering, and species introduction was implemented to enhance the productivity of littoral zones and reduce areas of degraded habitat along the industrialized shoreline (RAP, 1991; RAP 2004). A multi-methodological approach is applied in this study to assess the physical and spatial habitat characteristics of six rehabilitation projects executed by the Thunder Bay Remedial Action Plan team (RAP) including McKellar Embayments, Neebing-McIntyre Floodway, Northern Wood Preservers Alternative Remediation Concept, Sanctuary Island, Current River, and North Harbour. A habitat classification framework is applied to utilize specific habitat indicators to rank sites based on their fisheries value and role in littoral zone regeneration and recovery. The majority of the projects were successful in improving habitat complexity, receiving a moderate to high ranking in the habitat classification. Further improvements in buffer zone extent, diversity, and thickness would benefit the aquatic ecosystems and would improve overall habitat scoring. River habitats, such as Neebing-McIntyre, require more extensive work to achieve outlined restoration goals as the embayment features did not have the desired outcome. Continued monitoring and management will ensure the success of these sites and provide evidence to support ongoing habitat restoration efforts in the Remedial Action Plan Program.

1.0 Introduction

The Great Lakes Water Quality Agreement was signed in 1978 as part of a commitment to restore and maintain the chemical, physical and biological integrity of the Great Lakes (Environment Canada, 1987; IJC, 1987). A total of 43 polluted areas were designated as Areas of Concern (AOC). Of those, 17 locations were in Ontario, with Thunder Bay being a primary location along the north shore of Lake Superior (RAP, 1991; RAP 2004). Prior to water quality and habitat degradation, Goodier (1981 and 1982) documented the historical presence of significant fish spawning habitat for the major commercial species within the Thunder Bay harbour (RAP, 1991). However, after the 1880s, Thunder Bay's growing industrial activities and urban development have resulted in severe environmental pollution and habitat degradation to the North Shore of Lake Superior (RAP,1991; RAP, 2004). During this time, Thunder Bay became the second-largest grain handling port in Canada with several pulp and paper mills along the waterfront (Winch et al., 2013, RAP, 2004). Development was not without consequence. High volumes of navigational dredging, pulp, and paper chemical waste disposal, hardening of the shoreline from industrial docks, and infill to create new industrial property degraded the natural habitat. This resulted in reduced species diversity and abundance, a loss of recreational opportunities, and a decline in aesthetic values (Environment Canada,1987; RAP 2004). To compensate for this major loss, the development of Remedial Action Plans led to projects with specific goals and objectives to rehabilitate historic aquatic habitats with the long-term target of environmental management and protection (Lee, 1995; Foster and Harris 2009).

Thunder Bay was identified as an AOC due to the impairment of 10 out of 14 Beneficial Use Impairments (BUIs) defined by the International Joint Commission and Great Lakes Water Quality Agreement (RAP, 2004). Beneficial Use Impairments are specific environmental conditions that have been impacted by anthropogenic influence, causing a change in chemical, physical, or biological integrity (RAP,2004; ECCC, 2017). Remedial Action Plans focus on addressing designated beneficial use impairments and developing restoration designs using a range of habitat rehabilitation and conservation techniques (Kelso and Hartig, 1995; Hall et al., 2006). These habitat enhancement projects have attempted to restore and recreate nearshore aquatic habitat, stabilize wetlands, restore diversity, and increase the abundance of fish and wildlife (RAP, 2004). Thunder Bay Remedial Action Plans have prioritized the improvement of water quality and sediment conditions while compensating for habitat loss by enhancing existing ecosystems (RAP, 2004; ECCC, 2017). A cooperative effort from the public, industry, and government is required to address specified impairments and industrial impacts. Input is provided from local public advisory councils to assist in defining goals and remedial options for degraded habitats within the Area of Concern (Hall et al., 2006; Foster, 2012). The expectation of these rehabilitation projects is to mitigate beneficial use impairments and to contribute to the delisting of the harbour as an area of concern.

Habitat monitoring is essential to ensure effective progress towards specified remediation goals and the eventual delisting of the Area of Concern. Consistent with a “No Net Loss” philosophy, the collection of baseline data can affirm gradual rehabilitation progresses and prevent any habitat decline (Smokorowski et al., 2015). This study aims to contribute to the long-term monitoring of Thunder Bay’s nearshore habitats by classifying current habitat conditions and providing recommendations for continued improvements of six rehabilitation projects implemented by the Thunder Bay Remedial Action Plan including McKellar Embayments, Neebing-McIntyre Floodway, Northern Wood Preservers Alternative Remediation Concept, Sanctuary Island, Current River and North Harbour (Figure 1). A habitat classification framework was utilized to evaluate key habitat indicators and rank sites based on their fisheries value and role in littoral zone regeneration and recovery. Ensuring the maximum return on these habitat investments and understanding the mechanisms which contribute to a successful restoration will benefit future remediation efforts in Thunder Bay and across the Great Lakes (Allan et al., 2015).

Figure 1:Remedial Action Locations within the Thunder Bay AOC. (Esri, DigitalGlobe 2019).

1.2 Purpose of this Research

Aquatic habitat is spatially and temporally dynamic, determined by the interaction of the structural and biological features within a hydrological regime (Maddock, 1999; Trebitz et al., 2011). The classification of habitat quality can confirm the value and role of habitat rehabilitation projects in ensuring sustainable fisheries (NRC et al., 2002). The development of baseline habitat data through an underwater survey that characterizes nearshore bathymetry, water quality, substrate structure, aquatic macrophyte abundance and diversity, and riparian buffer zone will assist in understanding the mechanisms which contribute to a successful restoration. The final product of this research will include high-resolution maps depicting these characteristics, recommend improvements occurring within these engineered structures, and classify habitat value based on current condition. In assessing a variety of indices and integrated spatial information, the study seeks to assist in habitat monitoring, contribute to environmental management decisions, and aid in visualizing and understanding the progress of each rehabilitation project.

The synthesis of the various data types collected during this study enhances our ability to understand, manage, and track the restoration progress of degraded habitats (Allan et al., 2015). A framework for ecological classification is provided while eliminating knowledge gaps and enabling scientific responses for future restoration projects and continued resource management. Understanding the spatial distribution, visualizing habitat relationships, and identifying the strengths and weaknesses of restoration efforts will benefit the long-term success of these previously degraded habitats. The data collected also provides a record in which to measure and compare continued waterfront development and monitoring. In assessing the progress of remedial actions and the level of recovery that is occurring from natural and human intervention, this study will promote the continued application of thoughtful habitat rehabilitation strategies and the conservation of recovering ecosystems.

1.3 Objectives of Research

- Characterize the bathymetry, submerged aquatic vegetation, substrate structure, water quality and buffer zones of six nearshore remediated environments in the Thunder Bay Harbour

- Map the spatial extent of submerged macrophytes and substrate structure by utilizing side-sonar imagery and ground-truth verification.

- Determine habitat recovery and fisheries value of rehabilitated habitats in the Thunder Bay Harbour by applying a Habitat Classification Framework.

2.0 Literature Review

Considerations for shoreline spatial planning and fisheries management are dependent on habitat heterogeneity and the protection of multiple habitats (Kritzer et al., 2016; DFO, 2016). Ensuring habitat connectivity, habitat complexity, and applying recommended management plans further prevents the degradation of habitat from anthropogenic influences (Kritzer et al., 2016). Habitat assessment within the Thunder Bay Area of Concern is crucial to the effective management of limited habitat resources and ensuring the efficiency of remedial action projects (Able et al., 1987; Environment Canada, 2013; DFO, 2016). The analysis requires a holistic understanding of aquatic habitats and utilizes modern methods of digitizing and data capture to produce precise geomatic maps and display a broad range of data. The focus of this literature review is to delineate the requirements of a sustainable habitat, essential habitat indicators, new methods of collecting habitat data, and habitat classification schemes used to assess rehabilitation success.

2.1 Habitat Characteristics

Aquatic habitats have differing hydrologic regimes and vegetative structures that need to be considered for conservation planning and restoration design (Environment Canada, 2013). In accordance with “How Much Habitat is Enough” (HMHIE), a guideline for habitat rehabilitation created by the Ontario Ministry of the Environment, the Thunder Bay waterfront falls under the “Coastal Wetland” category due to the high volume of water, along with a mixture of floating and submerged aquatic vegetation (Johnson et al., 2007; Environment Canada, 2013). The Great Lakes have lost approximately 60 -80% of their historical coastal wetlands (Smith et al., 1991; Ball et al., 2003; Croft and Chow-Fraser, 2007), making it essential to identify, conserve and remediate remaining quality locations. Coastal wetlands are crucial for Lake Superior’s fisheries since 60% of fish biomass are associated with these heterogeneous habitats (Petzold, 1996). Coastal marshes are often used as nursery or feeding habitat; 41.6% of Great Lakes fish species (133 total) are considered coastal marsh species, with 31% relying on wetland habitat to survive (Environment Canada, 2013: p.18). The pursuit of the “optimal” habitat occurs in coastal locations with convoluted shorelines, complex basin morphometry, and high habitat heterogeneity. Remediation projects within the Area of Concern need to encompass these key elements into the design and require annual monitoring to ensure designated habitat goals are achieved.

Habitat complexity is a concept utilized in rehabilitation projects to eliminate structural simplification by creating artificial structures and alterations to facilitate greater habitat heterogeneity (Jasmine et al., 2014). Habitat complexity is multi-faceted, influencing species distributions, and trophic interactions through spatial scale, diversity, size, density, and arrangement of structural elements (Kovalenko et al., 2011). Habitat heterogeneity is essential for species to co-existence and should be a priority in the design and application of remedial action plans. While complexity differs across various aquatic ecosystems, remedial action designs need to focus on enhancing sub-surface complexity to increase habitat value and ecological functioning. The success of rehabilitated habitats is measured by improved biotic diversity, the density of macrophyte assemblages, and increased complexity of spatial and temporal parameters (Crowder and Cooper, 1982; Kolasa et al., 2011; Kovalenko et al., 2011). In an era of continual habitat loss, understanding the role of habitat complexity, ecosystem function and biodiversity can result in the remediation, protection, and preservation of critically important ecosystems (Kovalenko et al., 2011).

Habitat indicators (biotic and abiotic) provide a qualitative characterization of habitat and can be used as proxies to measure general ecological health (Cvetkovic and Chow-Fraser, 2011). Indicators are described as characteristics within the environment that, when measured, can designate habitat conditions, assess the magnitude of stressors, and gauge the ecological responses to degradation or remediation (Stalberg et al., 2009). The selection of indicators provides the initial development of a benchmark for future monitoring and assists in determining habitat functionality (Stalberg et al., 2009). Macrophyte colonization, substrate heterogeneity, and water quality are all essential indicators of wetlands that provide crucial information about the physical habitat, as well as spatial and temporal variability (Stalberg et al., 2009; Cvetkovic and Chow-Fraser, 2011). It is essential to have an established understanding of each indicator in order to assess their state and how it directly affects the habitat condition. Using a selection of indicators removes gaps in data and enhances interpretations that can contribute to a more effective framework for habitat monitoring (Stalberg et al., 2009).

2.1.1 Aquatic Vegetation

The presence and type of submerged aquatic vegetation is a standard indicator of healthy ecosystems, as their widespread distribution is highly dependent on surrounding environmental parameters such as substrate and water quality (Dennison et al., 1993; Croft et al., 2007). Studies have shown that complex habitats with higher macrophyte abundances support greater biota diversity, provide more abundant food resources, improve refuge from predation, and create additional habitat niches (Croft et al., 2007). Aquatic habitat health was examined at Chesapeake Bay, the study confirmed that submerged aquatic vegetation could be linked solely to environmental quality (Dennison et al., 1993). The results showed that aquatic macrophytes are an effective indicator for monitoring change within a habitat and provide a direct assessment of restoration progress (Dennison et al., 1993). The key role that macrophytes play in increasing the level of physical complexity and forming unique habitat structures is essential to the recovery of degraded habitats and should be monitored within Areas of Concern (Kovalenko et al., 2011).

Macrophytes provide essential ecosystem services for habitat development and benefit the rehabilitation of the physical environment (Randall et al., 1996). The effect macrophytes have on complex interactions between sediment dynamics and hydrodynamics is imperative for aquatic habitat success (Randall et al., 1996; Madsen et al., 2001). Aquatic vegetation assists in stabilizing shorelines, reducing erosion, and encouraging sedimentation (Madsen et al., 2001). Macrophyte beds increase the volume of sediment deposition due to their capacity to reduce the current velocities and attenuate wave energy (Madsen et al., 2001). Sedimentation reduces turbidity levels and increases substrate stability, preventing sediment from being easily displaced and resuspended into the water column (Madsen et al., 2001). Reduced turbidity increases the level of light penetration benefiting the growth of macrophyte stands to produce a more complex habitat structure. The physical environment benefits from these multifaceted interactions, and the results produce a more intricate habitat.

Submerged macrophyte abundance plays a significant role in the functioning of aquatic ecosystems, influencing the inhibition of aquatic biota and species composition (Randall et al., 1996; Heck and Crowder, 2001). The density of aquatic macrophytes directly affects the sustainability of habitat communities as it influences predator and prey interactions (Crowder and Cooper, 1982; Thomaz and Cunha, 2010). In highly complex habitats, predators often have reduced efficiency in capturing prey due to dense vegetation inhibiting their ability to forage (Thomaz and Cunha, 2010). Conversely, low diversity and sparse structure result in a lack of refuges from predators leading to increased foraging activities, causing scarcities in prey (Valley et al., 2004). If submerged aquatic vegetation falls below 10%, the habitat cannot sustain the fish species dependent on them (Valley et al., 2004). The ideal percentage cover is between 40% to 60% as it provides optimal habitat for a variety of species of different sizes and requirements (Environment Canada, 2013; Valley et al., 2004). Habitats with adequate macrophyte colonization can increase the connectivity of the trophic network while providing food web stability (Huxel and McCann 1998; Thèbault & Fontaine, 2010).

Having a heterogeneous mix of plant types caters to the specific needs of numerous species that utilize them for predation, hiding, and spawning (Thomaz and Cunha, 2010). Native plants provide a higher quality of habitat for supporting diverse fish species. However, the cultivation of invasive species is better for a habitat than little or no submerged aquatic vegetation (Valley et al., 2004). Invasive species can be critical in habitat recovery or areas that no longer support the growth of native species (Thomaz and Cunha, 2010). However, the composition of macrophyte assemblages in a habitat can be influenced by invasive species altering biotic relationships among species. The displacement of native plants leads to reduced suitability of habitat for certain fish species (Thomaz and Cunha, 2010). Rapidly growing invasive species, such as Eurasian Watermilfoil or Curly-Leaf Pondweed, can create extensive homogenous surface canopies that have the effect of reducing sub-canopy species (Valley et al., 2004). Not only does this create inhospitable foraging environments, but they reduce levels of sunlight in the sub-canopy, lower levels of oxygen, and alter PH levels (Environment Canada, 2013). Although the presence of invasive species can enhance habitat complexity in recovering ecosystems, negative effects are expected when homogenization results in less structural complexity and diversity (Thomaz and Cunha, 2010).

Freshwater flora varies greatly in their structure, physiology, and ability to tolerate inorganic and biological stressors. Some macrophyte species have a higher tolerance (due to elevated levels of polymorphism and phenotypic plasticity) and can subsist environmental variation and stressors, continuing to thrive throughout the season (Lacoul and Freeman, 2006). Other species experience narrower tolerances, thereby becoming important proxy indicators of ecological stress or degradation (Lacoul and Freeman, 2006). Common stressors that limit macrophyte success include irradiance, salinity, ice cover, temperature, nutrients, pollutants, turbidity, and competition. Monitoring seasonal macrophyte species composition, stand shape and structure can provide vital information about habitat suitability, condition, and degradation (Madesen et al., 2001). This concept highlights the beneficial use of macrophytes as long-term and short-term habitat indicators, delineating if remedial efforts were beneficial or damaging to the habitat recovery (Lacoul and Freeman, 2006).

Croft and Chow-Fraser (2007) developed a basin-wide biotic index, The Wetland Macrophyte Index or WMI, to assist in evaluating the presence and degree of anthropogenic disturbance based on aquatic wetland macrophytes within the Great Lakes. The index assumes macrophytes will respond directly or indirectly to changes in water quality and the degree of impairment is reflected in taxonomic composition (Croft and Chow-Fraser, 2007). The WMI utilizes canonical correspondence analysis (CCA) to compare macrophytic abundances to environmental variables establishing plant indices that reflect aquatic 'health' (Croft and Chow-Fraser, 2007). Plants were organized based on their profile within the water column; emergent, floating, and submerged. Macrophytes are given U-values and T-values based on their position on the centroid along the CAA axis (Croft and Chow-Fraser, 2007). The U-value indicates the tolerance of a species to degraded water quality. Ranging from 1 to 5, a value of 1 would indicate that the location had high nutrient loading and high turbidity, whereas a value of 5 is associated with lower concentrations of nutrients and clearer waters (Croft and Chow-Fraser, 2007). T-values were estimated from the standard deviation of the species scores from the CAA calculations to provide an indication of niche breadth for each species (Croft and Chow-Fraser, 2007). T-values ranged from 1 to 3: 1 indicating a broad niche and 3 a narrow niche (Croft and Chow-Fraser, 2007). Plants are an excellent biotic indicator as they are stationary, easily sampled, distributions can be georeferenced, and changes in plant communities can be tracked over time (Croft and Chow-Fraser, 2007).

The WMI has been utilized in other Great Lakes Remedial Action Locations, Cootes Paradise Marsh in the Hamilton Harbour RAP, and Sturgeon Bay in the Severn Sound RAP, to build a community-based monitoring program for before and after RAP initiatives (Croft and Chow-Fraser, 2007). The WMI was proven to be an effective and simple methodology for indicating habitat impairment and ecological status. The management plans of these rehabilitation projects now incorporate the long-term use of the WMI index to ensure habitat integrity and to monitor anthropogenic impact. The WMI is ideal for this study due to its success in previous applications, cost-effectiveness, and ease of repeatability. The index focuses on the presence and overall vegetation coverage within the site, rather than individual abundances, which is time-efficient when assessing multiple habitats. Their methodology involved completing transects parallel to the shoreline within the flooded zone and completing approximately 10-15 quadrants that were .75m x .75m in size. The authors did not estimate percentages, as the focus was to identify submerged, emergent and floating taxa that serve as fish habitat (Croft and Chow-Fraser, 2007). In applying the WMI to this study, it will create a heterogeneous dataset to cross evaluate the differences in local RAP programs and provide invaluable information on plant communities for future studies.

2.1.2 Substrate Composition

The successful colonization of freshwater biotic habitats is dependent on the abiotic components of both consolidated and unconsolidated sediments (Young et al., 2018). Habitats with a diverse substrate composition sustain a higher diversity of plant species and create a more stable environment (Barko et al., 1989). Gerrish and Bristow (1979) demonstrated that there is a positive relationship between the complexities of natural or artificial substrates and how they impact the inhabitation of macrophytes and macroinvertebrates within aquatic environments. Surface complexity, interstitial space, and substrate heterogeneity are key components to a productive littoral zone and are required to sustain a healthy food chain (Schmude et al., 1998). Studies conducted by Schmude et al., (1998) indicated that macroinvertebrates in littoral zones colonized primarily on complex structures rather than simplistic features with little cover. Macrophytes require a finer-grained substrate for nutrients and rooting, with high responsivity to physical, chemical, and biological balances in the substrate (Barko et al., 1989). A higher substrate complexity accommodates a higher density and diversity of aquatic biota, influencing the structuring of fish assemblages. The strong correlation between substrate structure and habitat value makes it an ideal indicator when monitoring rehabilitated habitats.

Texture and granular size can influence the success of root growth and the depth to which macrophyte roots can penetrate (Covich et al., 1999). Coarse textured sediments are nutritionally poor substrates, such as cobble or gravel, that do not support high macrophyte growth rates, if any. However, they do support diverse communities of invertebrates and are an ideal substrate for spawning activities. Habitats with small particle size, such as silt or mud, and low sedimentation characteristically experience active resuspension. This can result in low volumes of macrophyte biomass due to the inhibition of photosynthetic processes. A degree of resuspension can be beneficial for the removal of excessive organic matter that settles atop of macrophyte stands, but the particle size of the substrate must be substantial enough to resettle on the bottom (Wainright and Hopkinson, 1997). There is a fine balance in ecosystem structure and function, where diversity is a major driver successful in littoral ecosystems. The remedial measures implemented within the Thunder Bay AOC recognized this need for increased habitat heterogeneity within the waterfront and have attempted to provide a variety of substrate types to enhance the productive capacity of the benthic communities (RAP, 2004).

Previous RAP stage reports indicate that the primary substrate within the waterfront varies from fine to silty sands within the nearshore areas, gradually changing consistency with depth and distance from the shoreline to a packed silty clay substrate (RAP, 1991). The survey conducted by Anderson (1986) characterized the substrates within the harbor, classifying sand (approximately 50%) at the mouth of the inner harbor, with predominantly silt and clay detected (approximately 50%) in Mission and McKellar river deltas and within the northern inner and outer harbours. Soil compaction can occur from several things, but in the Thunder Bay region it is in part due to the industrial activities and commercial shipping vessels. The level of hardness will vary along the shoreline as it is dependent upon current, wave action, dredging, and propeller action in shipping channels (Anderson, 1986). The higher the exposure to these elements increased the likelihood of soil hardness. Soil compaction is not uniform, however, it can be spatially distinctive. The compactness of the sediment can strongly affect the growth of macrophytes reducing overall habitat complexity. Some macrophytes can adapt with their roots growing longitudinally, but this does not sustain shoot growth and provides poor habitat for fish (Anderson, 1986).

The North shore of Lake Superior is strongly influenced by limnologic conditions which affects the sedimentation resuspension processes, promoting high turbidity, and enhanced nutrient recycling (Madsen et al., 2001). Due to the high energy the shoreline receives, the nearshore habitats are primarily comprised of abiogenic substrates with little biogenic complexity (Kovalenko et al., 2011). The development of coastal shorelines leads to a high volume of hardened surfaces and increased fragmentation. Simplification and homogenization of shorelines reduce the substrate structure and quality of littoral habitat (Madsen et al., 2001). Remediation of hardened shorelines often requires the addition of artificial substrates to mimic the original characteristics of the lakebed shoreline. A common remedy for erosion and habitat alteration is the placement of berm structures to decrease impact along the shoreline (Schmude et al., 1998). Rock rip-rap with a complex 3-dimensional structure theoretically provides more habitat than flat exposed surface area and supports a more taxa-rich environment than retaining walls (Schmude et al., 1998). Simulating various shoreline forms using artificial substrates is a valid solution for restoration initiatives to enhance substrate and abiotic diversity (Schmude et al., 1998). The primary consideration of rehabilitation projects should, therefore, be to encompass the complexity and natural characteristics of the shoreline and avoid replacing them with simple architectures that compromise the quality of habitat and community structure (Schmude et al., 1998; Madsen et al., 2001).

2.1.3 Woody Debris

Large woody debris is integral to habitat complexity as it provides structure, nursing habitat, and aids in sedimentation (Murphy and Koski, 1989). Woody debris has been correlated with higher species density as it contributes to a higher niche breadth. Habitat morphology is influenced by the abundance of woody debris as it contributes to shaping channels, deeper pools, and reduced stream velocity (Murphy and Koski, 1989; Fausch and Northcote, 1992). The removal of woody debris greatly alters the habitat geomorphology, increasing linearity and turbidity. Woody debris influences the retention of fine substrate material, reducing the levels of turbidity contributing to improved light diffusion (Rayner, 2001). Management strategies often include the addition or natural recruitment of large pieces of woody debris to cultivate meso-habitat units and encourage the inhabitation of macrophytes and invertebrates (Rayner, 2001). Not only does woody debris create habitat complexity, but it is also an important feature in the transition of aquatic habitat to the riparian zones along the shoreline or riverbanks (Rayner, 2001; Murphy and Koski, 1989). The addition of large woody debris can provide a productive solution to increasing habitat complexity in aquatic environments that require remediation (Rayner, 2001).

2.1.4 Water Quality

Water quality is a key biological indicator used to monitor the status and trends of aquatic ecosystems, defined by its physical, chemical, and aesthetic characteristics (Environment Canada, 1987; NSW, 2017; Chow-Fraser, 2006). Testing water quality has been utilized in various studies as a habitat indicator and is standard procedure when assessing degraded ecosystems (Roux et al., 1993; Bauer et al., 1999; Chow-Fraser, 2006; NSW, 2017). Chow-Fraser's (2006) studies regarding water quality indices showed a high correlation between habitat condition and land use. Impairment of water quality within coastal wetlands has been attributed to both point and non-point sources of pollution, including municipal or industrial waste, agriculture, and urban runoff (Environment Canada, 1987; Chow-Fraser, 2006). Regardless of the source, degraded water quality and turbid conditions often lead to minimal species richness and abundance in submerged macrophytes, which in turn affects the composition, size, and structure of higher trophic levels (Dennison et al., 1993; Chow-Fraser, 2006). Physical parameters can be tested using in situ probes measuring temperature, pH, conductivity, and dissolved oxygen. Testing water quality is a direct, inexpensive, and accurate solution to monitor the success or substantial changes to restoration projects (Dennison et al., 1993; Chow-Fraser, 2006).

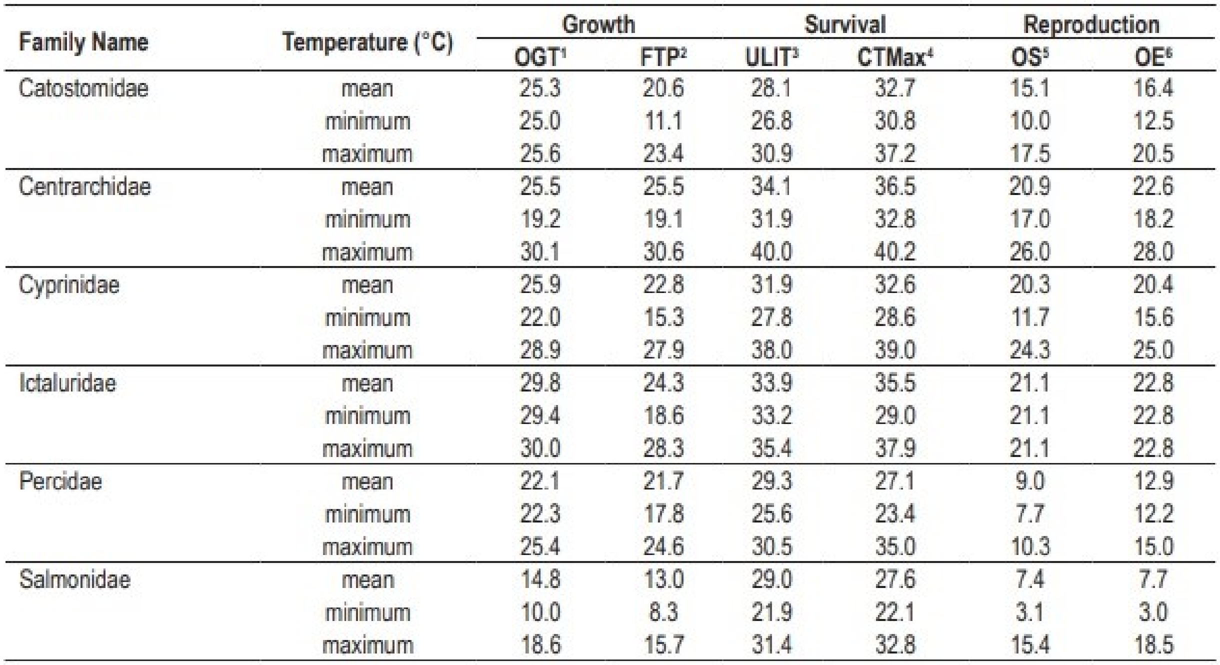
The Canadian Water Quality Guidelines were developed by the Canadian Council of Minister of the Environment (CCME) to provide basic water quality parameters for the protection of aquatic life. The guidelines are not specific to any particular biota, but rather provide numerical limits or statements for specified parameters based on current scientifically defensible toxicological data (CCME, 2003). Aquatic habitats are often resilient, having the inherent capacity to withstand and adapt to ecological stressors (CCME, 2003; Croft and Chow-Fraser, 2007). However, imbalances from natural and anthropogenic disturbance can have adverse effects on habitat. Monitoring water quality is essential for understanding how anthropogenic impacts affect natural and remediated habitats while providing a foundation for developing criteria for future monitoring programs (CCME, 2003; NSW, 2017).

2.1.4.1 Temperature

Thermal variability in the coastal areas of the Great Lakes is greatest during the summer stratified period due to an upwelling of cold hypolimnetic waters and a downwelling of epilimnetic waters (Hlevca et al., 2015). Nearshore coastal habitats within Lake Superior experience high variability in temperature caused by distinct fluctuation in the thermocline. There is a strong correlation between the movement of the thermocline and associated biotic responses influencing mortality, diversity, and distribution of species (Hlevca et al., 2015). Due to frequent cold-water upwelling events on the north shore, fish are highly dependent upon embayments and coastal wetlands to provide thermally suitable habitat (Klumb et al., 2003). In part, the success of these remediated locations is dependent on achieving the correct thermal regime and understanding how the temperature enhances or constrains restoration activities for certain thermal guilds (Klumb et al., 2003; Hlevca et al., 2015).

Temperature is an influential abiotic factor affecting aquatic habitats and their ability to sustain aquatic life (Beitinger et al., 2000; Hasnain et al., 2010). The life cycle of aquatic biota is highly dependent on the external environment with minor thermal changes influencing behavior, respiration rates, reproduction, metabolic processes, and excretion (Brett, 1956; Fry, 1947; Beitinger et al., 2000; Hasnain et al., 2010). Important biological functions achieve optimal performance within comparatively narrow temperature 'windows'. For example, physiological performance (i.e., spawning and egg development) is often maximized within a narrow temperature range, but these optimal ranges vary between species (Kling et al., 2003, Hasnain et al., 2010). If specific thermal conditions are not met, it can decrease the hatching success of some species, but not others, contributing to the rapid transformation of fish species composition. The balance of temperatures also affects oxygen availability, potentially affecting both the mortality of embryos and the physiological activities of fish (Hasnain et al., 2010; Fitchko, 2014). Table 1 depicts the essential temperature ranges for optimum growth temperature (OGT), final temperature preferendum (PFT), upper incipient lethal temperature (UILT), critical thermal maximum (CTMax), optimal spawning temperature (OS) and optimal egg development temperature (OE) determined in the Change Research Report (Hasnain et al., 2010).

Table 1: Growth, survival, and reproduction metrics for freshwater fish taxonomic families. Reproduced from Hasnain et al., 2010. Pg.7.



Family Name	Temperature (°C)	Growth		Survival		Reproduction	
		OGT[1]	FTP[2]	ULIT[3]	CTMax[4]	OS[5]	OE[6]
Catostomidae	mean	25.3	20.6	28.1	32.7	15.1	16.4
	minimum	25.0	11.1	26.8	30.8	10.0	12.5
	maximum	25.6	23.4	30.9	37.2	17.5	20.5
Centrarchidae	mean	25.5	25.5	34.1	36.5	20.9	22.6
	minimum	19.2	19.1	31.9	32.8	17.0	18.2
	maximum	30.1	30.6	40.0	40.2	26.0	28.0
Cyprinidae	mean	25.9	22.8	31.9	32.6	20.3	20.4
	minimum	22.0	15.3	27.8	28.6	11.7	15.6
	maximum	28.9	27.9	38.0	39.0	24.3	25.0
Ictaluridae	mean	29.8	24.3	33.9	35.5	21.1	22.8
	minimum	29.4	18.6	33.2	29.0	21.1	22.8
	maximum	30.0	28.3	35.4	37.9	21.1	22.8
Percidae	mean	22.1	21.7	29.3	27.1	9.0	12.9
	minimum	22.3	17.8	25.6	23.4	7.7	12.2
	maximum	25.4	24.6	30.5	35.0	10.3	15.0
Salmonidae	mean	14.8	13.0	29.0	27.6	7.4	7.7
	minimum	10.0	8.3	21.9	22.1	3.1	3.0
	maximum	18.6	15.7	31.4	32.8	15.4	18.5

2.1.4.2 Dissolved Oxygen

The concentration of dissolved oxygen is an essential factor affecting all aerobic aquatic biota (CCME, 2003). Species abundance, diversity, and interaction within a given area is highly influenced by fluctuations in dissolved oxygen concentrations. The abundance or depletion of dissolved oxygen is governed by several factors. The primary source of dissolved oxygen in freshwater is photosynthesis by plants and atmospheric mixing with certain factors affecting its solubility (CCME, 2003). Concentrations vary temporally depending on light penetration, nutrient availability, oxygen partial pressure, temperature, salinity, water movement, phytoplankton presence, and bio-depletion (MOE, 1997). Dissolved oxygen is highest at the air-water interface and will remain relatively saturated through the water column in shallow water experiencing high velocity (CCME, 2003). In large and deep bodies of water, such as Lake Superior, oxygenation occurs from winds and currents circulating aerated surface water. Climatic conditions, morphometry, productivity, and watershed characteristics influence dissolved oxygen within lakes, with levels ranging from non-detectable to 18.4 mg/L (CCME, 2003). Due to the impact dissolved oxygen has on aquatic biota it's important to monitor levels and trends as it is a basic necessity.

Freshwater at approximately 5ºC and at standard atmospheric pressure has an oxygen concentration of 12.77 mg/L (CCME, 2003). Ideal dissolved oxygen concentrations for aquatic habitats range between 6 to 9mg/L but varies between fish species and activity (CCME, 2003). A minimum of 5mg/L of dissolved oxygen is satisfactory for most stages and lifecycle activities of fish (Alabaster and Lloyd, 1982; CCME, 2003). Upwards of 6mg/L or 7mg/L is required during the spawning season, and greater than 6.5mg/L is required for embryos and early life (MOE, 1997). Environments with concentrations below 3mg/L are considered inhospitable for most aquatic life and are characterized as unsustainable habitat (CCME, 2003). Unacceptably low dissolved oxygen concentrations can result from oxidation processes attributed to biotic respiration, organic matter decay, and direct chemical oxidation (CCME, 2003). Increased mortality or loss of equilibrium due to low oxygen levels occur in habitats with dissolved oxygen levels ranging from 1mg/L to 3mg/L (CCME, 2003). These values were derived from the concept of “slight production impairment” estimates, with a 0.5 mg/L safety margin added to the estimated dissolved oxygen threshold concentrations (CCME, 2003). Elevated temperatures can lead to lower dissolved oxygen levels and solubility in the circulating epilimnion (MOE, 1997). Essentially, more oxygen is required by biota in elevated temperatures as warmer water produces lower dissolved oxygen saturation. Dissolved oxygen is an intricate abiotic component of an aquatic ecosystem and is an essential indicator to be monitored when addressing habitat rehabilitation.

2.1.4.3 Oxidation-reduction potential (ORP)

Ion exchange occurs between oxidizing agents within aquatic habitats to reach stability through the exchange of electrons (Suslow, 2004; Li et al., 2014;). The Oxidation-reduction potential reading provides a rapid-single value that is measured in millivolts (mV) and indicates the degree of oxidation (or the reduction thereof) within an aquatic habitat (Suslow, 2004). ORP sensors rarely establish a fixed point and act as a range of operation bouncing as much as 25 mV in handled units (Suslow, 2004). Readings between 300 and 500 mV are considered sustainable for aquatic habitats, with ranges between 300-320 mV able to reduce the susceptibility of bacterial infection in fish (Horne and Goldman, 1994; Li et al., 2014). Measurements as high as 650 and 700 mV kill off pathogens within 30 seconds, but these high levels have the potential to lead to oxidative damage to fish tissues (Suslow, 2004; Li et al., 2014). Higher levels of ORP can lead to negative influences of feed intake of fish species, ultimately affecting the overall growth rate (Li et al., 2014). Conversely, low ORP readings often indicate low dissolved oxygen and can lead to an increase in contaminants and toxicity of certain metals from excess dead organic material without the oxygen content to effectively decompose (Wetzel, 1983; Suslow, 2004). Lower OPR can be expected in areas with higher exposure to pathogens such as industrial waste facilities or sewage runoff (Suslow, 2004). The "real-time" standardized method of measuring ORP makes it an essential tool for measuring water quality within rehabilitated aquatic habitats.

2.1.4.4 Potential of Hydrogen - pH Scale

One of the most critical aspects of water quality to the survival of macrophytes and aquatic life is the pH (Ohrel and Register, 2006). The pH indicates the acidity or alkalinity of the water. Concentration levels are based on a numerical value determined by the molar concentration of hydrogen ions (H+) ranging from 0.0 (highly acidic) to 14.0 (highly alkaline) (Ohrel and Register, 2006). The preferred pH range for aquatic organisms is between 6.5 and 8.5, with a pH of 7 being neutral. Fluctuations occur in response to increases or decreases in the amount of photosynthesis, respiration, turbulence, aeration, and anthropogenic interference (CCME, 2003). Table 2 indicates the threshold and corresponding physiological reaction for freshwater species based on alkalinity and acidity pH readings (Chapman, 1997; Utang and Akpan, 2012).

Table 2:Water Quality Criteria and Standards for Freshwater Aquaculture. Modified from Chapman, 1997; Utang and Akpan, 2012.

pH Levels	Tolerance Levels and Effects on Aquaculture
<4.0	Acid death point
4.0 – 5.0	No Production
6.5 – 9.0	Desirable range for fish production
9.0 – 11.0	Slow Growth
>11.0	Alkaline Death Point

Aquatic biota is directly affected by pH concentrations outside the natural range. While some species can acclimate, a pH below 6.5 often averts reproduction. As the pH levels exceed 9.0, growth rates and metabolic processes slow and it has been proven to be lethal if exposure is over 10.0 for an extended period of time (Horne and Goldman 1994; Chapman, 1997; Talling, 2010; Utang and Akpan, 2012). The pH can also inhibit macrophyte success as it affects the transformation process of various nutrients, reduces the availability of photosynthetic carbon sources, and prevents longitudinal growth (Talling, 2010). Although tolerance varies among taxa, the acidic threshold for macrophytes is 5.5, where they begin to lose protein content in the leaves with reduced growth rates (CCME 2003; Song et al., 2017). A pH of 8.5 to 9.5 is ideal for plant growth and leads to an increase in protein content in both stems and leaves, indicating that a slightly alkaline environment can promote the synthesis of proteins and plant growth (CCME. 2003; Song et al., 2017). However, as alkaline limits exceed 9.5, reaching a pH of 11 or above, macrophyte growth rates drop (Song et al., 2017). Anthropogenic influences have significantly contributed to fluctuations in pH, which not only affects the aquatic organisms but can affect the solubility of toxic chemicals and heavy metals in the water. Monitoring pH levels provide a long-term database to detect trends in the chemical makeup of freshwater ecosystems and are ideal indicators of industrial pollution or habitat degradation (Ohrel and Register, 2006).

2.1.4.5 Conductivity (SPC µS/cm)

Conductivity is the measure of ionic strength of water and is utilized to provide an infield indication of nutrient enrichment within an aquatic habitat (Briggs et al.,2002). Measured in microSiemens (µS/cm), understanding dissolved ion concentration is essential to freshwater biota survival, growth and reproduction in aquatic habitats (Briggs et al.,2002; Mihir et al., 2015). Higher concentrations of chemical ions or dissolved salts will result in higher conductivity readings (Mihir et al., 2015). Levels over 400 µS/cm can cause excessive levels of algal growth and in turn, affect pH and dissolved oxygen levels influencing aquatic biota health (Briggs et al.,2002). Significant changes in conductivity can be attributed to anthropogenic pollution, agricultural runoff, or sewage causing increased levels of chlorides, phosphates, or nitrate ions within the habitat (Mihir et al., 2015). An increase in hydrogen ions (from acid) can decrease pH to a low of 2, where an increase in nutrients leads or algae blooms lead to a pH of 9.5 (EPP, 2009). Dissolved oxygen is influenced by the excessive build-up of nutrients, leading to lower dissolved oxygen levels, algae production, and the development of stagnant conditions (EPP, 2009). Measuring conductivity is a key indicator in assessing water quality in rehabilitated habitats as it can determine the level of remaining or building pollutants and further provide an understanding of fluctuations in other parameters such as pH and dissolved oxygen.

Table 3:Water Conductivity

Conductivity Reading (µS/cm)	**Rating**	**Description**
Less than 50 µS/cm	Excellent	Very low concentrations of dissolved ions. Nutrient loading is highly unlikely.
50 to 149 µS/cm	Good	Low Concentrations of dissolved ions. Limited nutrient enrichment.
150 to 249 µS/cm	Fair	Slightly enriched nutrients. Thick mats of slime and green filamentous periphyton growth may occur in the summer season.
250 to 399 µS/cm	Poor	Moderately enriched waters. Thick mats of slime and green filamentous periphyton growth are highly likely to occur in the summer season.
400 µS/cm or more.	Very Poor	Enriched waters. Extensive mats of slime and green filamentous periphyton growth are expected.

2.1.4.6 Turbidity

Turbidity is the measure of the water clarity or transparency due to the presence of suspended or dissolved particulate matter within the water column (Wetzel. 1975; CCME, 2003). Turbidity can, directly and indirectly, affect aquatic life by impacting trophic interactions and community structure between primary and secondary levels of productivity (Table 4). Studies have shown that dramatic losses in macrophyte communities have been attributed to changes in light availability (CCME, 2003). The degree of turbidity directly affects photosynthetic processes of macrophytes and periphyton algae, disrupting or completely inhibiting growth and influencing biological production. Once macrophytes become intolerant to the condition, any increased sediment resuspension will place substantial constraints on recovery (CCME, 2003). Furthermore, habitats with higher turbidity absorb a greater amount of solar energy leading to an increase in water temperature. These factors influenced by turbidity can affect benthic production leading to continued degradation and loss of biotic diversity (Table 4). Tracking the level of turbidity and its source is therefore essential when monitoring the success of rehabilitated habitats.

Table 4: Water clarity and effects of turbidity. Modified from Briggs et al.,2002 Stream Monitoring Manual.

Range	Rating	Score	Description
<35cm	Very Poor	1	Extremely turbid water, considered detrimental to the success of aquatic biota.
35 - 54cm	Poor	2	Highly turbid water can be detrimental to biotic life.
55 - 69cm	Fair	3	Moderately turbid water can affect the success of macrophyte stands due to the limiting light penetration and the settling of particulate matter from the water column.
70 - 99cm	Good	4	Slightly turbid, has the potential to inhibit
100cm +	Excellent	5	Crystal clear water with little to no suspended particulate.

Freshwater fish are also susceptible to the damaging effects of high turbidity, directly influencing their behavioral tendencies, physical health and decreasing their resistance to disease and toxins (McLeay et al., 1984; CCME, 2003). Growth and migration of fish can become impaired by high volumes of suspended particulates inhibiting their ability to detect and consume dietary requirements (McLeay et al., 1984). Excess suspended particulates can also cause physical injury to eye and gill membranes by abrasion and clogging of the filtering apparatus of some immature stages of insects and fish (McLeay et al., 1984; CCME, 2003f). The effects of turbidity can not only physically harm fish, but it can decrease populations by reducing the success of spawning activities. Fine particulates blanketing spawning gravels and eggs can hinder embryo development by disrupting gas exchange and metabolic wastes between the eggs and water (CCME, 2003). Due to the significant impact that turbidity can have on habitat and its biota, it serves as an essential indicator when monitoring the success of rehabilitation projects.

2.1.4.6 Hydrodynamic Parameters

The hydrodynamics of aquatic ecosystems is a primary factor that regulates the growth and distribution of submerged macrophytes and sediment dynamics (Madsen et al., 2001; Nikora, 2010). Waves can have both a direct and indirect impact on the successful growth of aquatic plants. Direct impacts from waves occur when waves or currents erode the edges of the habitat, as seen by Robbins and Bell (2000), when wave action altered the heterogeneity of seagrass beds in Tampa Bay (Koch, 2001). Plants can also become uprooted from storm-generated waves or boat-generated waves. Wave heights from 0.1m to 0.3m can increase canopy breakage and prevent the growth of vegetation colonies (Madsen et al., 2001). Plant morphology is also altered due to wave action, as observed by Idestam-Almquist and Kautsky (1995). Plants that experience higher volumes of wave action had shorter shoots than in areas with low wave exposure (Idestam-Almquist and Kautsky, 1995; Koch, 2001).

Sediments that experience high wave action tend to have lower nutrition concentrations and have a coarse texture. Sediment resuspension, change in sediment grain size, mixing of the water column, and epiphytic growth are all indirect impacts that affect the successful growth of submerged aquatic vegetation (Koch, 2001). High wave energy erodes underlying sediment and lowers light availability due to suspended particulate, making it intolerable for vegetation. In the 1970s Chesapeake Bay experienced a major loss of vegetation caused by wave action and a major increase of suspended matter (Koch, 2001). The abundance of submersed aquatic vegetation can be predicted using wave exposure indexes, which are calculated based on fetch and wind intensity (Koch, 2001). Spatial variability and vegetation gaps can emerge from extensive erosion or deposition of sediments causing large decreases in species diversity and abundance.

Water quality and flow regime influence the key habitat characteristics that contribute to the presence of biotic assemblages, as seen in Figure 2. Functional aquatic ecosystems require enough flow for adequate aeration, nutrient cycling, and penetrable light in addition to sustainable water quality parameters for supporting life (Figure 2). Turbulence, meaning temporally or spatially irregular water motion, can benefit macrophyte growth by increasing nutrient cycling and gas exchange or can be detrimental to growth from mechanical stress (Koch, 2001; Madsen et al., 2001). The dispersion of pollen, larvae, seeds, and spores can be affected by the strength and direction of turbulent waters (Madsen et al., 2001). Aquatic vegetation beds often occur in areas where the flow is characterized by the laminar-turbulent transition, however, the optimal level of turbulence is still unknown. Slow velocities, ≤ 0.01 m s^{-1} for freshwater species, generally have a positive relationship between photosynthesis and nutrient uptake (Madsen et al., 2001). Higher levels of turbulence not only increase physical stress, but it impairs macrophyte metabolic uptake processes leading to a decrease in community biomass.

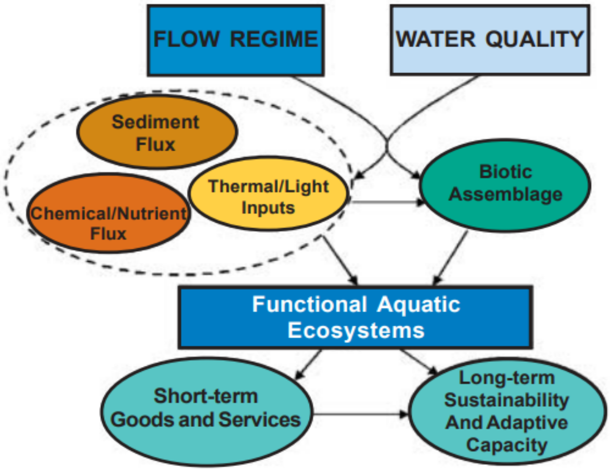


Figure 2: Conceptual model of factors that influence freshwater ecosystems (ESA, 2003).

2.1.5 Habitat Buffer Zone

A buffer zone is an ecotone located between anthropogenic development and wetlands, lakes, or rivers (Maohua, 2016). Buffer zones play a critical role in protecting freshwater habitats from external physical and chemical stressors (EC, 2013; Semlitsch and Brodie, 2003; Lee et al., 2004). These zones are integral to aquatic ecosystem functioning as they influence water clarity, flood control, sedimentation, food-web structure, and the spatial and temporal variation of fish assemblage composition (Pusey and Arthington, 2003). Disturbance or removal of a buffer zone can contribute to erosion, increased surface runoff, degraded water quality, and a decline of aquatic species (Semlitsch and Brodie, 2003; Maohua, 2016). Furthermore, thermal energy can increase from the lack of shade, potentially disrupting reproduction, body morphology, disease resistance, metabolic rates, and even mortality of aquatic biota (Pusey and Arthington 2003; Richardson et al., 2010). The biological importance is undeniable, but regulations to protect them are ambiguous or lacking. Sustainable buffer zones need multidisciplinary planning based on ecological knowledge and socioeconomic considerations to prevent the degradation of wetland habitats (Semlitsch and Brodie, 2003; Maohua, 2016).

The required extent of a buffer zone will vary depending on the aquatic habitat type, landscape context, and hydrological regimes (Pusey and Arthington, 2003; Lee et al., 2004). The intensity of adjacent land uses will influence the ideal range (EC, 2013). There is no one effective buffer width, but buffer zones ranging from 30m to 60m were usually sufficient to support ecological interactions and mitigate the magnitude of potential stressors (Broadmeadow and Nisbet, 2004; EC, 2013). The varying buffer requirements for achieving adequate performance of specified habitat functions can be seen in Figure 3. Linkages between riparian zones and aquatic habitat should be an essential consideration when rehabilitating degraded environments and in preventing further deterioration (Pusey and Arthington, 2003). When planning and executing a remedial action plan, high emphasis should be placed on maintaining biologically meaningful buffers for wetlands and riparian habitats (RAP, 2012).

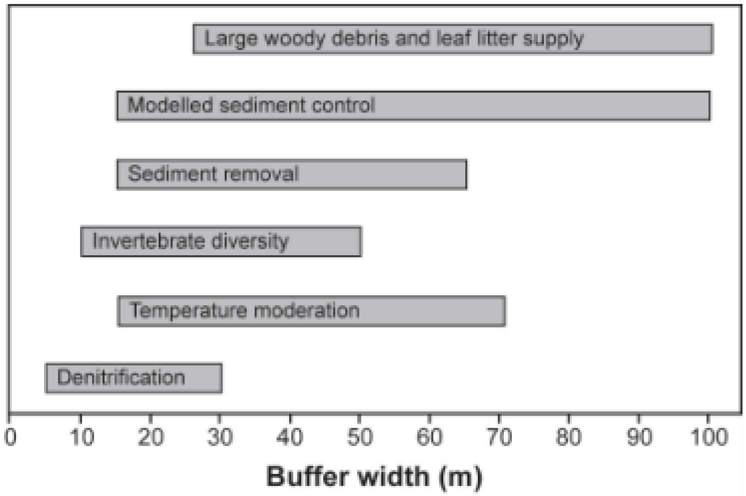


Figure 3: Buffer Width Recommendations (Broadmeadow and Nisbet, 2004).

2.2 Fresh Water Habitat Assessment

A diverse range of methods will be used for subaqueous data collection within the selected waterfront habitats. There are four main components to assessing aquatic habitats: inventorying current habitat conditions, analyzing habitat quality, evaluating potential impairments, and establishing potential habitat improvement activities (Hubert and Bergersen, 1999). Many methodologies have been developed to improve the cost-effectiveness of inventory activities to enable citizen-science approaches to local habitat monitoring while keeping time investments at a minimum.

2.2.1 Habitat Classification Methodologies

Growing societal concerns over habitat health and sustainability are incentivizing efforts to improve methods of delineating and evaluating environmental conditions (Diaz et al., 2004). Refining habitat classification systems is necessary to identify, categorize, and quantify habitat to develop scientifically defensible environmental management strategies (Precision Identification, 2001). Numerous habitat classification approaches have been developed with a particular geographic focus, with the main challenge being the development of “habitat classes” that are appropriate and applicable for a given region (Auster et al., 2009). An ideal habitat classification scheme defines specific indices of the environment to characterize habitats and provide a framework for identifying and mapping features. Documenting the condition of key habitat indicators will allow for the assessment of dynamics and change of rehabilitated habitats over time (Auster et al., 2009).

Habitat maps clarify and expand on the range of options available to decision-makers, the public, and stakeholders when faced with evaluating environmental impacts and trade-offs of proposed or ongoing projects (Auster et al., 2009). In a geospatial context, habitat maps illustrate the characteristics of the environments, as they relate directly or indirectly to the distribution, abundance, and diversity of living aquatic organisms (Scott et al., 1995; Auster et al., 2009). When producing a habitat map, one must choose which environmental indices to represent to better assess ecosystem status, distribution, and change overtime (Auster et al., 2009). In 2007, Auster and associates surveyed local, state, and federal managers to ascertain the range of habitat attributes and resolutions that are considered relevant when conducting habitat assessments. Table 5 indicates the results and the diverse nature of habitat classification requirements for useful map products.

Table 5:Habitat attributes across multiple scales. A modified version from Auster et al., 2009.

Habitat Attribute	**Scale or Approach**	**Example of Descriptor or Modifier**
Geoform Features	Large-Scale Features	Sand dune, bedrock, outcrop, steep slope, ledge, shoal, channel
	Small-Scale Features	Sand waves, depressions, ripples
	Man-made features	Engineered habitat, Docks, Cables
Substrate Features	Linear Classification	Wentworth scale: mud, fine sand, coarse sand, gravel
	Orthogonal Classification	USDA System: Percent of mud, sand, and gravel
	Transition areas	Between sediment types or geomorphic features.
Biological Features	Dominant Species	Biomass or density
	Dominant Species Groups	Invasive vs. non-invasive
	Community Types	Based on species composition
	Key Species	Essential species for freshwater habitat –Based on societal value
Boundaries	Intertidal-subtidal	Threshold depth for subtidal areas.
	Shallow-deep	Max depths of geographical habitat.
Integrative Attributes	Disturbance regime	Current, wave action, anthropogenic interferences.

Habitats serve as proxies for the potential distribution of organisms and can be used to predict the presence of species or community types based on empirical or inferential literature (Auster et al., 2009). An ideal habitat classification scheme encompasses several characteristics that allow data aggregation within and between classification levels (Auster et al., 2009). The classification scheme should link habitats to organisms, aquatic communities, and the physical processes that affect habitat distribution (McKee et al., 1992; Auster et al., 2009). Clearly defined nomenclature and repeatable classification units should be unique and unambiguous to ensure clear derivations of habitat type (Auster et al. 2009). Hierarchical classification is the most common and ideal scheme to allow for geospatial data to be categorized from lower to higher levels of habitat quality (McKee et al., 1992; Auster et al., 2009).

Greene et al. (1999) established a linear classification scheme that incorporated the use of remote sensing and large-scale mapping of the seafloor. They focused on the habitat geology and the use of geophysical techniques for identifying habitat structure and lithology (Figure 4). The relationship between key incises across multiple spatial scales and habitat modifiers identified as significant are illustrated below in Figure 4 (Greene et al. 1999; Auster et al., 2009). Throughout the study, interpretations of geophysical and geological data were ground-truthed and verified using a series of in situ observation techniques (Greene et al. 1999.) This was a critical step for accurate habitat classification. The classification scheme and ground-truthing methodology developed by Greene et al., (1999) has become a standard when classifying aquatic habitat and has been applied by the U.S West Coast Fisheries and Marine Protected Area Management to map and define management areas (Harney et al. 2006; Auster et al., 2009).

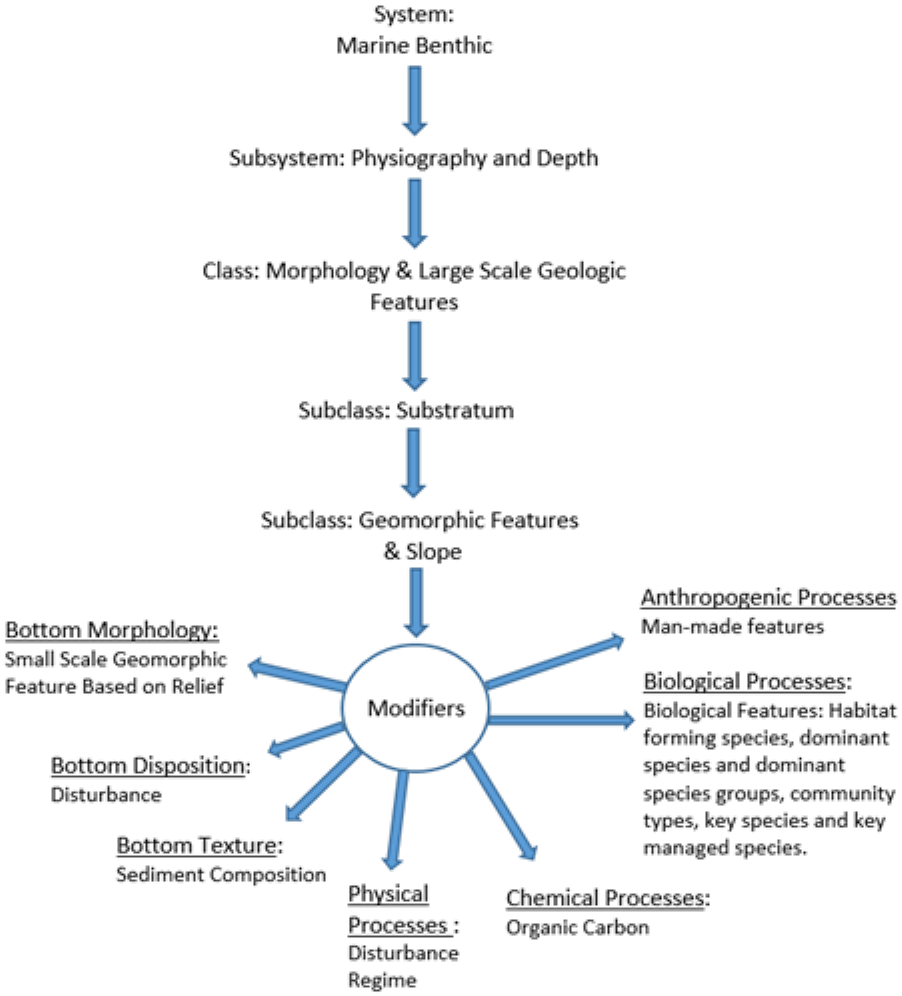


Figure 4: Habitat Classification System Based on Modifiers.

A classification system was designed for the Department of Fisheries and Oceans Canada by Precision Identification (2001) to be broad enough in scope, but fine enough in detail to be useful at the national level (Precision Identification, 2001). The system uses a hierarchical classification structure using three different levels, including 1) habitat classification based on biophysical parameters, 2) habitat ranking and management perceptions based on habitat values, and 3) identification and prioritization of restoration opportunities (Precision Identification, 2001). The Habitat Classification System focuses on the attributes that are critical to ecological functioning and best defines aquatic habitat (Table 6) (Precision Identification, 2001). The parameters covered both biotic and abiotic factors, including geomorphology, hydrology, water quality, aquatic vegetation, and overall habitat integrity (Precision Identification, 2001; Trebitz et al., 2011). The system provides sufficient baseline habitat data and contributes to long term management decisions depicted in Table 6.

Table 6: Freshwater Wetland Habitat Classification Template. Modified from Precision Identification, 2001.

Level	**Description**	**Management Prescriptions**
Green Habitat is not considered important to the ecological functioning of the area or in maintaining fishery values.	- Habitat predominantly altered, with little complexity, numerous structures within habitat reach. - Substrates predominantly fine, high organic matter content - Banks are riprap or other altered man-made forms - Epifaunal diversity low - Poor water quality, with insignificant food or nutrient value. - Areas that are unvegetated, sparsely vegetated or dominated by introduced species that provide minimal habitat value	Habitat may be altered but not lost or degraded further.
Yellow Habitat is important to the ecological functioning of the area. In general, direct contributions to fishery values are limited.	- Moderate to poor spawning habitat, limited spawning or rearing opportunities, primarily migratory. - Infrequent gravels or embedded or mixed with fines and silts - Low habitat complexity with little cover - The riparian cover is in poor condition - May serve as important migration or holding habitat - Epifaunal diversity moderate to low. - Moderate water quality values - Occasional unnatural structures.	Habitat may be modified provided that fisheries values are protected and maintained. The development will be permitted subject to satisfactory habitat mitigation and/or compensation
Orange Habitat is highly valuable to the ecological functioning of the area and contributes significantly to fishery values but is not necessarily rare or pristine.	- Frequent clean gravels with some small cobble and boulders - Rearing habitat present with cover and low energy - Moderate habitat complexity with diverse cover. - Continuous but limited areas of natural riparian vegetation (15-30m wide) - Epifaunal diversity moderate - Good water quality values	Locations must be protected from any negative impact. Conservation is preferred, with the maintenance of a 30m riparian buffer zone for aquatic habitats. Habitat should not be altered except under exceptional circumstances when full compensation and mitigation will be required.

Red Habitat is highly valuable to the ecological functioning of the area and contributes significantly to fishery values. Exceptionally high-quality habitats that are pristine or locally rare. Habitats may be critical to the continued viability of fish populations in the area.	- <2% gradient - Clean Gravels with some small cobble and few boulders - Rearing habitat present with complex cover and low energy. - High habitat complexity with ample diverse cover (Aquatic Vegetation, Wood logs) - Extensive intact areas of natural riparian vegetation >30m wide. - Epifaunal diversity moderate to high - No substrate compaction - Excellent water quality values	Locations must be protected from any perturbation that would negatively impact their functioning or flow regime. No development should be permitted unless no alteration or alienation of the habitat will occur. Red coded habitats should be given priority for acquisition and protection. Conservation is recommended by supporting 30m buffer strips.

Freshwater areas that are essential for ecological functioning and contribute to high fishery values were coded Red and Orange (Precision Identification, 2001). The difference between the Red and Orange classifications is that orange habitats are not necessarily rare or pristine, with evidence of previous impacts but unaffected ecologically (Precision Identification, 2001). Environments within these rankings exhibit both biotic and abiotic habitat features necessary for numerous life cycle phases of commercially important fish species (Precision Identification, 2001). Yellow coded habitats are ecologically functioning, widely distributed areas of moderate quality habitat. Habitat complexity is reduced from the red/orange habitats and should be flagged as potential candidates for restoration (Precision Identification, 2001). Lastly, green habitat is not considered ecologically functioning, not appropriate for any key life stages of significant species. They often consist of human-made structures or have been highly modified. As demonstrated, the classification template is designed to define spatial habitat conditions based on a limited but crucial set of parameters for a range of audiences and decision-makers (Precision Identification, 2001).

Oberholster et al. (2014) developed a wetland classification and risk assessment index for non-wetland specialists for the management of natural freshwater wetland ecosystems. The classification system focuses on natural ecological processes in wetland habitats. The creation of their classification index consisted of three phases; obtaining required data, applying the index to selected wetlands to evaluate the applicability of the assessment index, and finally refining the index and enhancing its applicability within different ecological environments and conditions (Table 7) (Oberholster et al., 2014). To validate their findings further, water quality variables were measured and used as indicators of ecosystem integrity (Oberholster et al., 2014). Similar to the classification scheme Precision Identification created, it is hierarchical in structure, and allows for rapid data collection and a broad scale identification of wetland habitat classification. The final classification was derived from using a scoring system (Table 7); the sum of the averages of each variable was transformed into percentages.

Table 7:Habitat Scoring Using a Percentage System (Oberholster et al., 2014).

Ecological Category	Score in Percentage	Description
A	90-100	Unmodified, natural
B	80-90	Largely natural with few modifications. A few small-scale changes in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged.
C	60-80	Moderately modified. Loss and changes in natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	40-60	Largely modified. A large loss of natural habitat, biota, and basic ecosystem function has occurred.
E	20-40	Seriously modified. The loss of natural habitat, biota, and basic ecosystem functions is extensive.
F	0-20	Critically modified. Modifications have reached a critical level, and the system has been modified completely with an almost complete loss of natural habitat and biota

Ultimately the driving goal behind a habitat classification system is the protection of habitat and biodiversity, with attention to economic, environmental, and cultural benefits. Throughout the literature, it becomes apparent that a hierarchical classification structure is a systematic way to describe the diversity, while identifying patterns and processes that influence freshwater habitat at multiple spatial and temporal scales (Precision Identification, 2001; Higgins et al., 2005; Oberholster et al., 2014). A classification framework that takes a 4-level approach within a phytogeographical context including; macrophyte diversity and abundance, substrate, water quality, and buffer zones is ideal when assessing and monitoring aquatic habitat (Higgins et al., 2005). The classification scheme used within this study should incorporate the linear hierarchy of classes outlined by Greene et al., (1999), include habitat attributes identified by Auster et al., (2009), utilize the habitat outline for fisheries value and remediation potential provided by Precision Identification (2001) and create a simple but clear scoring system similar to Oberholster et al., (2014). As spatial data becomes more integrated into environmental management, metrics for summarizing and classifying benthic habitat conditions will become an integral part of continued monitoring and restoration initiatives (Diaz et al., 2004; Brown et al., 2010). The methodology utilized should be intuitive and repeatable, ensuring an effective procedure when monitoring aquatic habitats and their ecological condition.

2.2.2 Side-Scan Sonar

Aquatic habitat assessments provide beneficial information for numerous ecological applications and yield insight into biotic communities and habitat structure (Graham et al., 2017). Locating suitable habitats, understanding patterns of distribution, and abundance of aquatic abiotic communities, aids in estimating the ability of specified taxa to thrive (Graham et al. 2017). When conducting aquatic habitat evaluations, traditional methods were time and labor-intensive and did not provide continuous data (Graham et al., 2017). Acoustic techniques have become a vital tool in habitat assessment, fisheries research, and mapping the extent and distribution of different habitat types (Able et al., 1987). Side Side-scan sonar (SSS) is a low-cost method that not only collects continuous data but is a sophisticated technology for studying aquatic systems (Karser et al., 2013; Graham et al., 2017). Relatively inexpensive techniques have been developed to effectively map and evaluate freshwater habitat, such as the recreational Humminbird unit (< $2,000) or GIS software (Graham et al., 2017). Literature shows that freshwater SSS studies have successfully evaluated and quantified variables including sedimentation, large woody debris, substrate type, fish abundance, and fish spawning habitat (Karser et al., 2013; Christia et al., 2014; Graham et al., 2017). Benthic feature delineation has become a huge priority globally, with SSS imagery providing an initial assessment of geological and geomorphological characteristics of aquatic habitats (Christia et al., 2014).

SONAR is an abbreviation for 'sound and navigation ranging' and can overcome visual limitations such as darkness or high turbidity waters. As documented by Kaeser and Litts (2013), SSS mapping is an ideal technique to describe and quantify a habitat, regardless of depth or clarity. Advances in the processing of acoustic remote sensing data, specifically SSS, have improved the ability to map geophysical characteristics with precision due to increased resolution, scope, and efficiency (Lucieer, 2008). "In side-scan sonar data, acoustic energy reflected from the seafloor (backscatter) is divided into bins representing different beam angles, scaled to an 8-bit dynamic range, and displayed as a greyscale image" (Lucieer, 2008). There are two different systems of SSS, single-beam and multi-beam sonar. Single-beam sends out a single pulse of acoustic sound energy, which can be calibrated to identify habitat features (logs or macrophytes), substrate characteristics, and bathymetry data (Jensen, 2007). Multiple-beam sonar emits multiple sound pulses covering large overlapping swaths to provide two types of data: bathymetric and acoustic backscatter (Jensen, 2007). The acoustic footprint size, sampling interval, sampling speed, and distance between transects determine the output resolution of the data, which can be accurately read by the narrow receivers on the transducer (Jensen, 2007). To achieve the best results, the spacing between sounding and acoustic footprints should be set consistently over the swath to provide a uniform, high detection mapping performance (Jensen, 2007).

Detection and recognition of SSS imagery are key in creating comprehensive and descriptive data. When processing difficult imagery, Kaeser and Litts found it helpful to delineate patches of changing sediment to assist in distinguishing the mosaic of substrates. Substrate types are clearly revealed in sonar imagery, as noted in Figure 5 where boundaries between adjacent substrate types are abrupt and distinct (Kaeser and Litts, 2013). On the far left of Figure 5, you can see characteristics of fine-grained sediment, likely sand due to the rippled appearance, while on the right an outcropping of limestone bedrock gives the appearance of "cauliflower heads" (Kaeser and Litts, 2013). Dependent upon the intensity of echo recorded by the receiver, a variation in brightness will be displayed from the signal. Light or bright displays indicate a strong echo, whereas dark portions represent a weak return (Hook, 2011). A limitation of using SSS to map habitat and distinct features is that raw sonar imagery can appear dimensionally distorted. To create planometrically accurate maps, the imagery must undergo image rectification or transformation. If there are bends (the boat was navigating at a 90-degree bend) within the data or high distortion, imagery must be correctly transformed to properly align with the path taken during the sonar survey to create an accurate map (Kaeser and Litts, 2013). Currently, the most compatible software for transforming SSS data is Reef Master 2 or ArcGIS Maritime Bathymetry. Imagery with an indistinct substrate mosaic or backscatter pattern is verified through "ground-truthing" by either scuba diving or submersible video equipment (Sea-Viewer or ROV). This methodology enables a high degree of accuracy for interpretations as it verifies the lithologies and surface textures of the unknown (McRea, 1999). Visual interpretation of sonar imagery and ground-truthing allows for the development of spatially precise habitat maps.

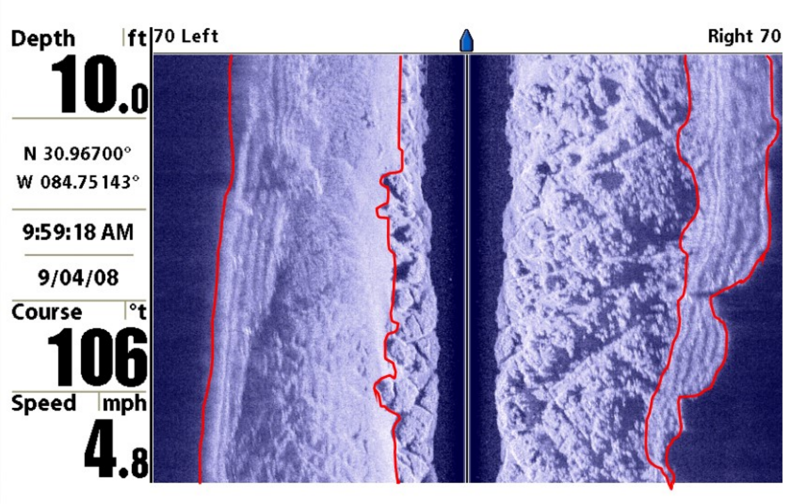


Figure 5:Defined Side Scan Sonar Substrate Mosaic (Kaeser and Litts, 2013)

The bottom composition can be further determined by analyzing the sonar log files. Programs, such as ReefMaster 2, can easily differentiate the hardness variation from sonar returns and depict them onto a map project. Substrate roughness and hardness are recorded by the rate of reflectance of echo returns or "pings" received back by the transmitter (ReefMaster, 2017). Essentially there are three distinct returns (Peak SV, E1, and E2) that give a detailed description of the nature of the lakebed. E1 layer is associated with the roughness or rugosity of the bottom, derived from the sonar returns that immediately follow the initial return (ReefMaster, 2017). The E2 return is more correlated with the bottom hardness. The results are depicted in a range "as the values that ReefMaster calculates for bottom hardness are unit-less and provide only an indication of relative changed in bottom type across mapped areas" (ReefMaster, 2017). Having additional sonar-based imagery of the substrate characteristics aids in delineating structural change, hydrodynamic conditions of deposition, and improves coastal management over time (Smith and McConnaughey, 2016). Synoptic information on the sediment dynamics and characteristics assist in understanding the ecological impacts of development along the waterfront and can increase the success of monitoring and implementing management actions (Van Der Wal et al., 2005).

Several detailed habitat studies have been completed using an SSS-based methodology. Tian (2011) utilized SSS to observe the physical properties of artificial benthic habitats. The study focused on habitat identification and fisheries resource management by creating a data structure providing information on the reef sets, bathymetric contours, textures of bottom sediments, and geomorphological characteristics (Tian, 2011). The research results were promising but required a specified surveying operation and a frequency change to collect adequate survey data. The conclusion illuminated the success of using SSS as a methodology for detecting, assessing, identifying, and monitoring aquatic habitat (Tian, 2011).

A master's student from the University of Georgia quantified and mapped Sturgeon habitat using SSS in the Ogeechee River, which consisted of dark and poor visibility waters. The purpose of Hook's (2008) study was to classify riverine substrate using side-scan multibeam sonar data to identify potentially suitable spawning habitat for Atlantic Sturgeon. Through the use of SSS, Hook was able to identify bottom hardness and areas which have high potential as spawning locations for Atlantic sturgeon. However, the study revealed positional errors in the mapping output, making it difficult to precisely identify transition locations between substrate types. Aside from this issue, the methodology proved to be a highly effective approach for locating substrates of interest (Hook, 2008).

Lastly, Kaeser and Litts (2010) used a Humminbird SSS device and a classification scheme to delineate substrate in the Ichawaynochaway Creek, Georgia. The study's objectives focused on demonstrating a technique that used the Humminbird system to map and classify habitat, evaluating techniques through a comprehensive map accuracy assessment and to compare traditional methodologies to sonar-based ones (Kaeser and Litts, 2010). They concluded that the SSS technique was a rapid, inexpensive, and accurate method of creating high resolution, spatially detailed maps of continuous habitat. The study had an overall classification accuracy of 77%, with most errors stemming from difficulty in differentiating between classes of rocky bottom conditions. The accuracy improved to 86% when coarse substrates were combined into two classes. The study results demonstrated that sonar mapping provides a comparable and effective substitute for traditional habitat assessment methodologies and that it provided high quality geospatially referenced data to fully visualize the underwater habitat (Kaeser and Litts, 2010).

The broad application of side-scan sonar in marine and freshwater habitats has confirmed its success when applied to assessing aquatic habitats and spatial variability (Strayer et al., 2006). These SSS techniques can be used to map shoreline and benthic habitat within both lentic or lotic systems. The data can be integrated into a variety of maps and data layers, allowing an analyst to examine patterns, textures, and anomalies occurring in aquatic landscapes (Kaeser and Litts, 2010). Data quality is dependent upon proper execution, planning, and the conditions during the survey, coupled with experience using GIS software. Literature indicates the need for continued SSS habitat mapping and to apply this remarkable remote sensing technique to further studies in habitat-organism relationships and the identification, prediction, and protection of critical habitat, and the monitoring of habitat change over time (Kaeser and Litts, 2010).

In addition to SSS, down-scan imagery is useful for examining a specific area of structure or objects that may be unclear in the side-scan imagery. The down-sonar beams are thin from front to back but wide from side to side, collecting a strip of data representing all the echoes received by the transducer (Humminbird, 2012). Typically, in shallow waters, a 455 kHz beam gives the best overall image quality and depth, but an 800 kHz beam provides the sharpest image resolution (C.H. Smith Marine, 2017). The data is then compiled and depicted on the display to form a more comprehensible life-like image of what is seen directly below the boat. By interpreting dark and light return displays the observer can determine bottom characteristics, as seen in Table 8 below. Users can control how the returns appear on the display by changing the imaging sensitivity. To reveal weaker returns of interest, particularly in clear or deeper waters, the sensitivity can be increased (Humminbird, 2012). Alternatively, in murky, muddy waters, the imaging sensitivity can be decreased to eliminate clutter from the display (Humminbird, 2012). Down-scan provides highly detailed imagery that enables users to easily decipher unrecognizable features in side-scan imagery.

Table 8:Interpreting the display via Humminbird Down-Scan (Humminbird, 2012).

Display Shade	Return Type	Depiction
Dark Shades	Soft Return	Sand or Mud
Light Shades	Strong Return	Dense terrain: Timber or Rocks.
White	Very Strong Return	Hard bottom/Bed Rock
White Streaks/ Clouds	Quick Strong Return, (often with distinct shadow)	Fish or Bait Ball.
Shadows	Lack of return	Objects on the bottom cause sonar shadow to appear. Longer the shadow, the taller the object.

Down-scan imagery will be used in addition to SSS to illuminate the bottom contour, substrate structure, and aquatic vegetation. Both down imaging and side-scan are sonar technologies; however, they give two completely different perspectives of the water column and aquatic features. Although both systems use high-frequency SONAR waves, from 455 kHz (45°) or 800 kHz (75°), side-scan sonar depicts the imagery extending outward from the sides of the boat within the water column, whereas down-scan shows direct imagery beneath the transducer, as seen in Figure 1 (FFS, 2018). The down-sonar beams are thin from front to back but wide from side to side, collecting a strip of data representing all the echoes received by the transducer (Humminbird, 2012). Using both systems requires three transducers, two side-scan transducers are mounted on adjacent sides of the vessel 15” from the prop, and a narrower down-scan transducer is installed in the middle to view directly below. When the two data sets are combined, it provides the user with a full 180-degree view of the lake bottom (C.H. Smith Marine, 2017).

3.0 Case Study Locations

Thunder Bay's waterfront was identified as one of the forty-three AOCs because of the degradation to the ecosystem and the identification of several beneficial use impairments (BUI) according to the Specific Objectives of the GLWQA (Environment Canada, 1987; RAP, 1991; RAP 2004). Impaired beneficial uses include restrictions on fish consumption (A), degradation of fish and wildlife populations (B), fish tumors and other deformities (C), loss of fish and wildlife habitat (D), degradation of phytoplankton and zooplankton populations (E), degradation of benthos (F), restrictions on dredging (G), beach closings (H) and degradation of aesthetics (I) (RAP 2004). Delisting criteria was linked with remediation projects to address impaired beneficial uses, contributing to the eventual delisting of the AOC itself. This study focuses on some of the delisting criteria for the Loss of Fish and Wildlife Habitat (Target D) (Table 9). The beneficial use will no longer be impaired once evaluation concludes the effectiveness and the associated habitat targets have been achieved (RAP, 2004). Returning the structure and function for a productive biological community is only conceivable once environmental conditions can provide a healthy and hospitable environment (RAP, 2004; ECCC, 2017). The following targets were selected in the Stage 2 RAP Report (2004) for improving the loss of aquatic habitat (Impairments Section D) concerning the selected rehabilitation areas assessed within this study:

Table 9: Delisting Criteria Addressing Loss of Fish and Wildlife Habitat (RAP, 2004)

Target D #	**Delisting Criteria for Impaired Beneficial Use: Loss of Fish and Wildlife Habitat.**
Target D2	Increase diversity and abundance of the fish population in the embayment areas of the Neebing-McIntyre Floodway as compares to unaltered sections of the floodway. ***Monitoring Action FWHM-2: Monitor the Habitat Enhancement on the Neebing-McIntyre Floodway***
Target D3	Protect the mouth and shoreline of McVicar Creek from wave action and foster growth and redevelopment of a historical wetland. ***Monitoring Action FWHM-3: Monitor Effects of Island Creation and Habitat Rehabilitation at Mouth of McVicar Creek***
Target D5	Restore and enhance estuary habitat in the McKellar River to provide critical habitat for resident and migratory fish. ***Monitoring Action FWHM-5: Monitor Effectiveness of Habitat Remediation on McKellar River***
Target D6	Restore access to productive spawning habitat; produce a self-sustaining rainbow trout population in the headwaters of Current River. ***Monitoring Action FWHM-1: Monitoring the Rehabilitation of Walleye Spawning Habitat at Current River Estuary***
Target D8	Standardize aquatic habitat data collection using conventional survey techniques.
Target D11	Revegetate areas in the vicinity of McVicar Creek, Sanctuary Island, and McKellar River, which were disturbed during project construction. Use vegetation indigenous to the AOC and produce a natural plant community. ***Monitoring Action FWHM-11: Monitor Success of Re-vegetation Projects in McVicar Creek and McKellar River.***

Unconfirmed reports, inconclusive assessments, and a lack of long-term monitoring has prompted the need for littoral habitat assessments to assist in addressing the Monitoring Actions outlined in the Stage 2 RAP Report. Although the Northern Woods Alternative Remediation Concept (NOWPARC) was not specified within the Loss of Fish and Wildlife Habitat BUI delisting criteria, the high-profile project was completed as an action item (Action NSP-1) to address the Third Fish and Wildlife Population and Habitat Recommendation (RAP, 2004). NOWPARC has been included in this study to be assessed as it was listed within the monitoring actions (Action NPSM-1(c): Long Term Monitoring of Fish Habitat Improvements Resulting from the NOWPARC project) and is within the scope of this study. Based on the Stage 2 report, the following sites would benefit most from continued monitoring to ensure the success of rehabilitation efforts (RAP 2004).

3.1 McKellar Embayments

Shoreline habitat along the lower Kaministiqua River system was healthy enough to encourage spawning of lake whitefish (RAP, 1991) prior to 1920, whereupon sustained dredging to support commercial shipping created a straight hardened shoreline with an abundance of steel sheet piling and concrete (Kelso and Hartig 1995; RAP, 2012). This contributed to the elimination of littoral habitat, poor water quality, and sediment contaminated by industrial activities, resulting in a decline in biotic capacity (Bray, 1995; Kelso and Hartig, 1995). Surveys of the littoral zone from 1965 to 1986 concluded that the benthos were degraded and that commercial ship traffic significantly impeded habitat productivity and diversity (RAP, 1991, 2012). Currently, the river is closed to commercial traffic, dredging has ceased and is now only used for recreational craft. Coupled with upgrades to effluent regulation and sewage treatment, the water quality within the River has improved (Bray, 1995; Kelso and Hartig, 1995). Restoration initiatives were implemented to increase wetland habitat through natural and artificial generation, with the creation of two shallow embayments to provide an additional three hectares of wetland habitat (Figure 6) (RAP, 2012).

Figure 6:Aerial View of the McKellar Embayments (InfoSuperior, 2018).

The project entailed three primary goals: to restore a productive littoral habitat by increasing diversity of the habitat, apply rehabilitation techniques to the dredged navigation channel and increase recreational opportunities through waterfront access (Bray, 1995; Kelso and Hartig, 1995). Formerly the channel had no dynamic structure and consisted of straight channel walls. The embayments were primarily built to add habitat complexity. The physical dimensions were confined by boundaries of property lines, access, and a nearby underground coal conveyor system (Bray, 1995; Kelso and Hartig, 1995). The design (Figure 7) focused on basin morphometry, attempting to encourage circulation and increasing habitat diversity while eliminating the need for deep excavating adjacent to the coal conveyor (Bray, 1995; Kelso and Hartig, 1995). To improve water quality, wetland pockets (<1m deep) were created to settle out suspended solids from overland runoff with the addition of culverts for water level fluctuations (Bray, 1995; Kelso and Hartig, 1995). Additional features were added to increase detail in the morphology, including bottom grading, gravel shoals, sandpits, and sand bluffs to promote the habitation of many species (RAP, 2012). Although approximately 15ha of land was disturbed as a result of this project, the net gain in habitat productivity should outweigh any losses incurred (Bray, 1995; Kelso and Hartig, 1995).

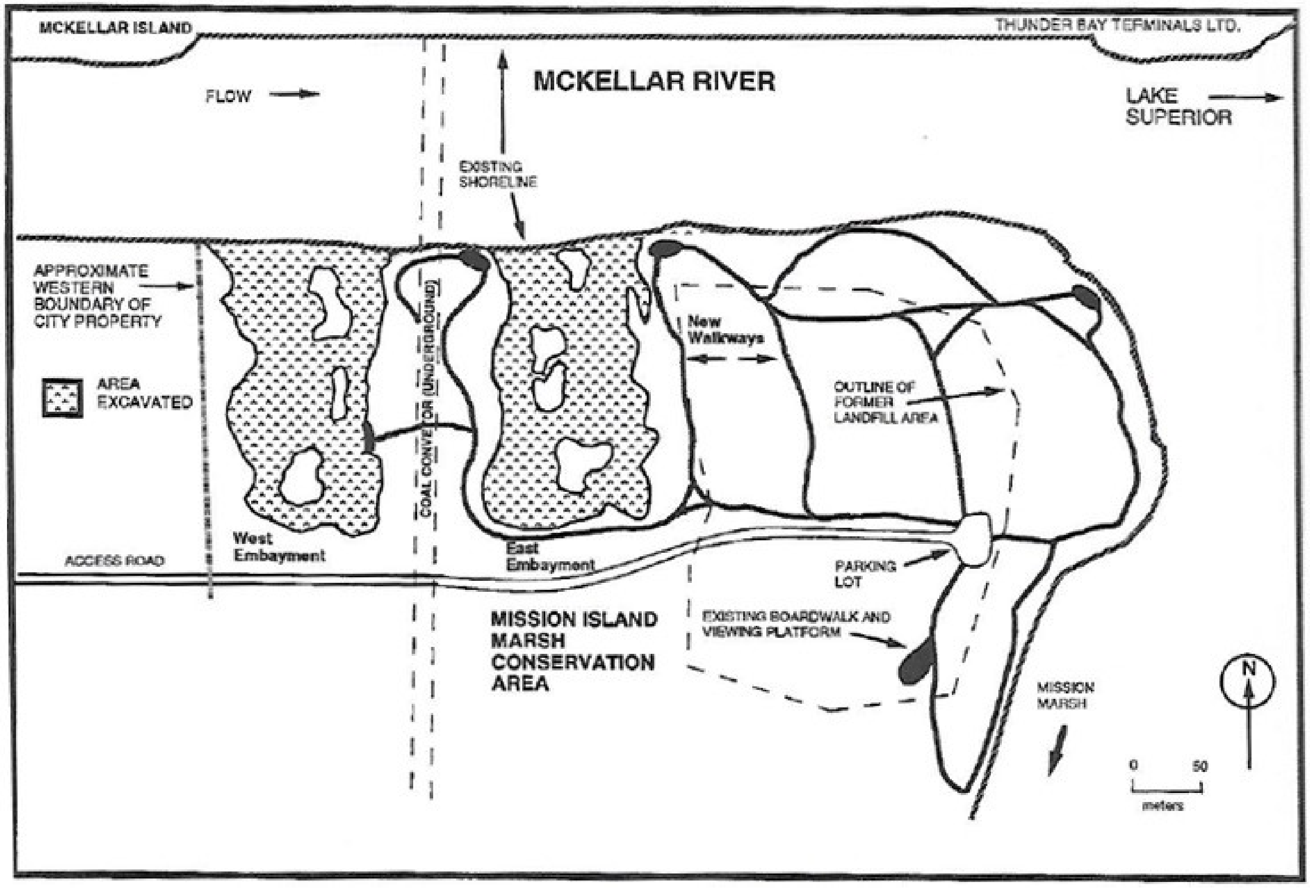


Figure 7: Project Design of McKellar Embayments (Kelso and Hartig, 1995).

A secondary project was completed to enhance the speed and extent of aquatic macrophyte growth (Lee, 1995). Some remedial approaches attempt to colonize species considered desirable for habitat targets, where others focus on natural regeneration (Bray, 1995; Kelso and Hartig, 1995). The project focused on examining natural and artificial colonization of species in two almost identical embayments. Colonization success varies on inter and intraspecific plant composition, limited by depth and substrate type (Lee, P.F. 1995). Embayment one was artificially colonized with aquatic macrophytes with a total of 0.19ha planted (Bray, 1995; Kelso and Hartig, 1995). Macrophytes were native to the Kamininstiqua Valley and were planted within their sustainable parameters. The plants used were either transplanted from the drainage basin or nursery grown at Lakehead University (Bray, 1995; Kelso and Hartig, 1995). Four sites were chosen for transplant. Macrophytes tolerant of wind and wave action were planted within site one, as it was most open to the river channel (Kelso and Hartig, 1995; Lee, 1995). Site two and three were shallower and consisted of species that were attractive to waterfowl and wetland birds (Bray, 1995; Kelso and Hartig, 1995). The last site is an extension from the embayment and consists of taller plant species adding diversity to the habitat. It was noted that difficulty occurred with the colonization of *Vallisneria* and *Sparganium,* as they exhibited a higher mortality rate in transplanting (Bray, 1995; Kelso and Hartig, 1995). A comparison of the two embayments occurred at the end of the first growing season for species present and percentage of cover (Bray, 1995; Kelso and Hartig, 1995). The results from the first year of monitoring (1994), indicated that the transplanted embayment had higher success in plant regeneration than the non-transplanted embayment (Kelso and Hartig, 1995).

Monitoring and assessment objectives were developed to document long term changes in physical structure, chemical composition, and community dynamics (Kelso and Hartig, 1995). Observing change is essential to the evaluation of rehabilitation efforts and its effects on biological productivity and demonstratable technologies (Kelso and Hartig, 1995). Steady monitoring occurred within the first-year testing water quality, benthic invertebrates, and fish populations, with focus placed on documenting condition and use (Bray, 1995: Kelso and Hartig, 1995). Initial studies indicated that the number of fish, waterfowl, and mammals increased within the location, but the submerged habitat itself has yet to be examined (RAP, 2004). Continued monitoring will indicate the long-term success of the project and the progression of the littoral zone for resident and migratory aquatic species.

3.2 Neebing-McIntyre Floodway

Initially (1983), the Neebing and McIntyre rivers were approximately 1km apart along the shoreline of Lake Superior (Cullis, 1995; Kelso and Hartig, 1995). The location was historically used by the Salmonidae family for spawning and smelting, depending upon adjacent aquatic habitats for migration staging areas or for transitional zones of the life cycle (Cullis 1995; Kelso and Hartig, 1995; RAP, 2012). Annual residential flooding led to the creation of a single straight channel with little to no habitat structure (RAP, 2012). The construction of the floodway provides a large degree of flow volume protection and has led to the development of the Intercity Area of Thunder Bay (Cullis, 1995; Kelso and Hartig, 1995; LRCA, 2018). The design has proven to be fully functional in the event of severe precipitation events, reducing major flood damage (Cullis, 1995; LRCA, 2018). However, concern over fish diversity and abundance arose as it became apparent that habitat complexity that is vital to key lifecycle stages was absent (LRCA, 2018).

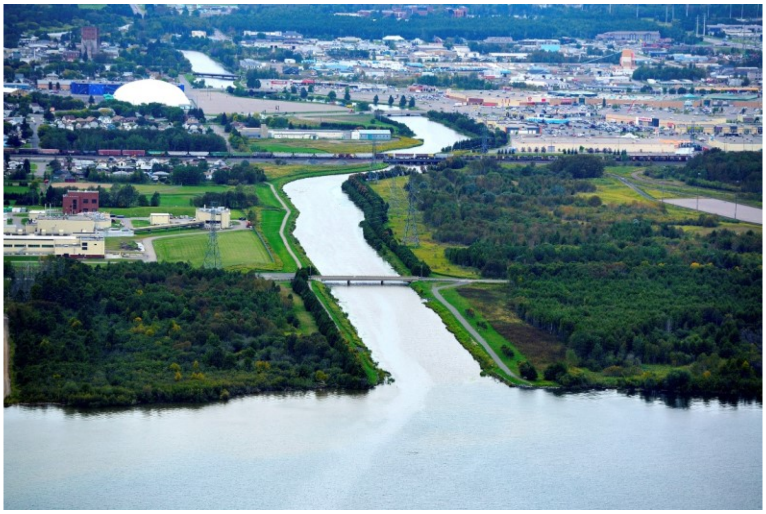


Figure 8: Aerial View of the Neebing-McIntyre Floodway (Lakehead Regional Conservational Authority, 2019).

A remedial action plan was designed to diversify fish habitat within this homogenous floodway. Four embayment structures approximately 30m x 2m were constructed to reduce flow rates, increase littoral structure and emulate natural curvature and complexity of river beds (Figure 9) (Cullis, 1995; Kelso and Hartig, 1995; RAP, 2012). The construction of these structures involved the substrate excavation, the addition of rock fill to increase bank stability, and refugia in the interstices. Various adapted methodologies were applied to increase the stability and success, including Geotextile fabric, Miradrain, subdrain (corrugated drainage tubing), rock dressing, and armour stone (Figure 10) (Cullis, 1995; Kelso and Hartig, 1995). An assemblage of wood pilings, log mats, and boulder piles was added to a 1.25km section of the floodway to increase habitat complexity (Cullis 1995; Kelso and Hartig, 1995; RAP, 2012). The woodpiles were driven into the channel substrate roughly 1m under the surface of the water. Boulder pilings, geotextile, and rockfill were added to specific areas by excavating and filled to a minimum depth of 1m (Cullis, 1995; Kelso and Hartig, 1995). The log mats were constructed with a variety of substrate driven logs and clustered logs fashioned to ensure long term placement, preventing the mats from floating away (Cullis, 1995; Kelso and Hartig, 1995). The objective of the various structures was to prompt aggregation of migrating and resident fish. Greater diversity and abundance were the prime focuses, achieved only by increasing habitat complexity within a homogenous littoral zone (Cullis, 1995).

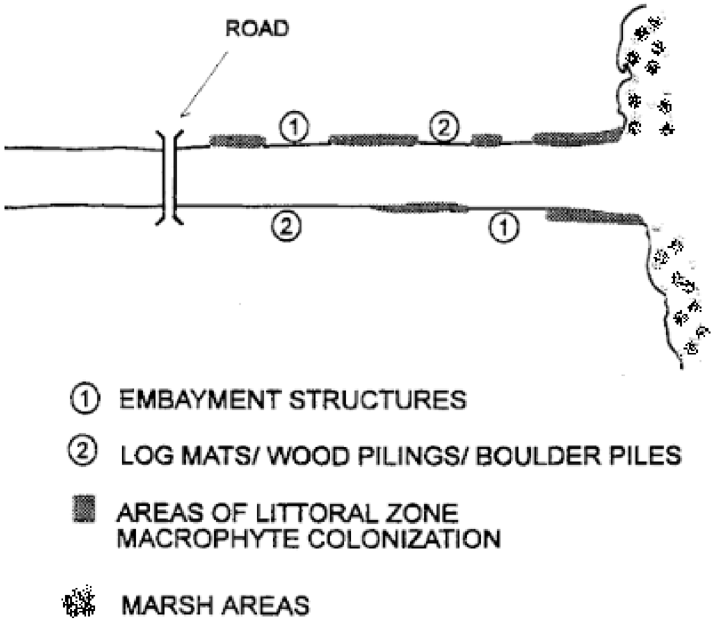


Figure 9: Neebing-McIntyre Embayment Design (Kelso and Hartig, 1995).

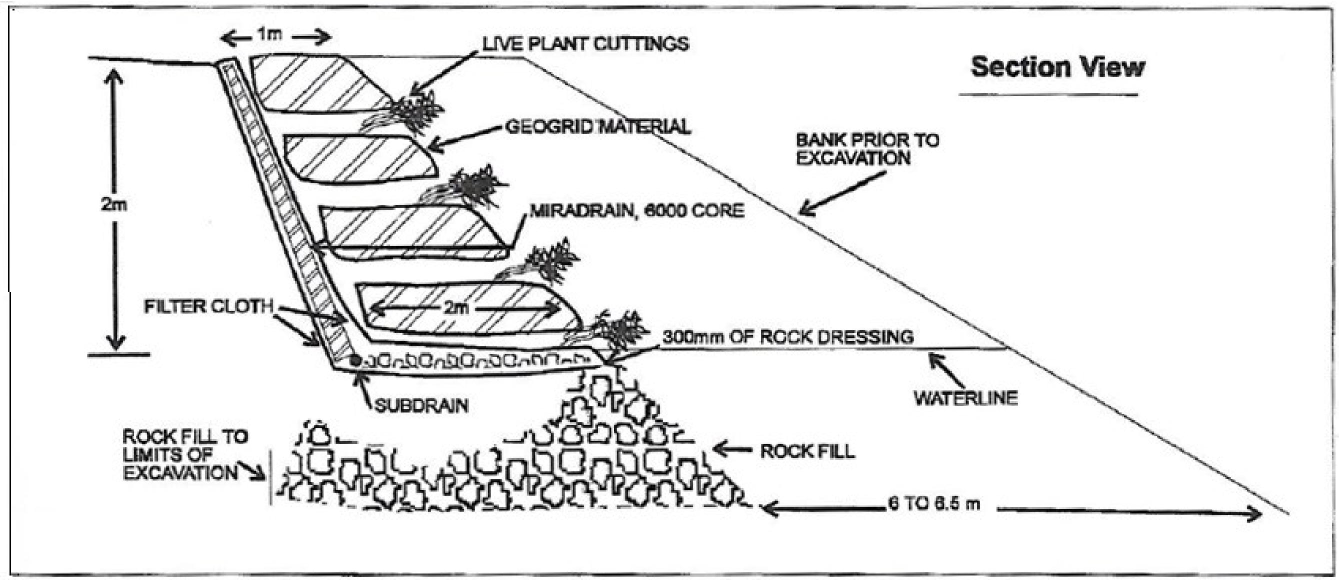


Figure 10: Sectional View of Neebing-McIntyre Embayment Structures (Kelso and Hartig, 1995).

Previous assessments focused on electrofishing, seining, trawling, and benthic sampling with little focus on macrophyte production (Cullis, 1995). It was reported that there was some indication of an increase in fish abundance and diversity in the embayment areas, but there has been no evidence collected through continued monitoring to confirm that the Neebing-McIntyre Floodway has improved habitat using these features (Cullis, 1995; Kelso and Hartig, 1995; RAP, 2012). Studies indicated that the littoral zone on either side of the delta was limited to a narrow strip <1.5m of submerged aquatic vegetation (Kelso and Hartig, 1995; RAP, 2012). Since the completion of the project in 1991, the Stage Two Report indicated no improvements in aquatic habitat (RAP, 2012).

3.3 NOWPARC

The Northern Wood Preservers was a key contaminated site that prompted the designation of the AOC, particularly from the leachates from creosote (polycyclic aromatic hydrocarbons) soaked wood and pulp waste matter (Santiago, 2003; Baker et al., 2008). These pollutants caused an elevation in the levels of toxins in the sediment, impaired water quality, and resulted in severe harm to living species within the habitat (Santiago, 2003). The Northern Wood Preservers Alternative Remediation Concept, the highest-profile remediation project in Thunder Bay to date, was undertaken to reclaim lost wetland through the engineering of habitat enhancements (Santiago, 2003; Baker et al., 2008). Biological testing confirmed three zones (Figure 11) where elevated levels of creosote was causing chronic biological effects and mortality (Santiago, 2003). Zone 1 showed visible contaminants; Zone 2 experienced 50% mortality in test organisms; Zone 3 was considered suitable for natural remediation as contaminant concentrations were low enough to avoid harm to biota (Figure 11) (Santiago, 2003).

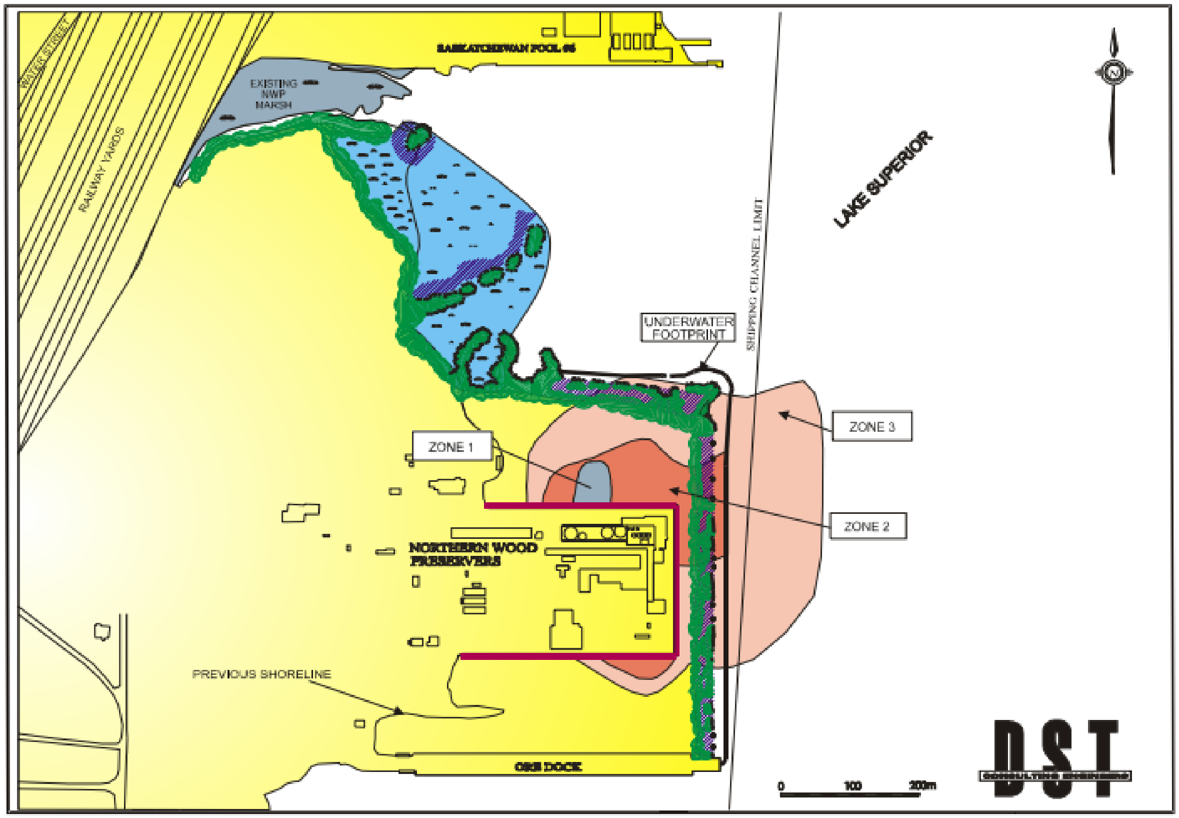


Figure 11: NOWPARC Habitat Blueprints (Santiago, 2003)

NOWPARC was designed to focus on three key objectives: isolate the sources of the contaminants, clean up the contaminated sediment, and enhance the fish habitat (Santiago, 2003; Baker et al., 2008). To accomplish these goals, seven stages were completed including the construction of a rockfill containment berm, environmental dredging, sediment treatment, contaminant isolation structures, stormwater and groundwater control and treatment, fish habitat enhancements, and environmental monitoring (Santiago, 2003). The project resulted in excavation and establishment of 11,000m² of reclaimed land adjacent to the remaining NWP marsh, the development of offshore habitat through the construction of a chain of small landforms, the implementation of various treatments along the containment berm to increase habitat heterogeneity and the creation of a 15-30m habitat buffer zone between the industrial site and the AOC (Figure 11) (Santiago 2003; RAP 2004).

Initial surveys indicated that negative biological effects were considerably reduced or absent in zones immediately outside of the berm (Santiago, 2003). In recent studies, it was concluded that NOWPARC had some recovery since the 2004 remediation process occurred (Willows, 2014). The underwater assessment indicated the natural colonization of submerged macrophytes in varying densities within the constructed berms (Willows, 2014). The study also depicted the variation in the substrate along the wall, showing complexity within the newly constructed 48,000m^2 habitat (Santiago, 2003; Willows, 2014). Further monitoring of the location will provide an indication of how long it takes for a disrupted habitat to recover to its fullest potential and what biotic changes have occurred.

3.4 Sanctuary Island

McVicar Creek was historically important for local fisheries as it was a spring spawning area for rainbow trout (Oncorhynchus mykiss) and smelt (Osmerus mordax) (Geiling, 1995; Kelso and Hartig, 1995; LRCA 2018). However, a decrease in the survival of juvenile fish has been attributed to the recent development of the waterfront park and marina complex due to habitat destruction and alteration (Kelso and Hartig, 1995; LRCA 2018). The Howe Street overpass was constructed in 1985 to increase access to the park and marina complex to the south of McVicar Creek. During the construction, a segment of wetland habitat was filled, disturbing the aquatic habitat and creating a hardened shoreline (Geiling, 1995; Kelso and Hartig, 1995; RAP 2004). Prior to any rehabilitation, the location was described to have barren heterogeneity with banks consisting of sandy silt substrate supporting little macrophyte growth after the construction (Geiling, D. 1995; Kelso and Hartig, 1995; RAP 2004). These conditions lead to a decline in available nursery habitat affecting spawning success rates (Kelso and Hartig, 1995). To compensate, Sanctuary Island: a crescent-shaped island, was built adjacent to McVicar Creek delta to promote the re-establishment of wetland habitat, recreate nearshore nursery habitat, and protect the shoreline from wave action (Kelso and Hartig, 1995; RAP 2004).

The design focused on fostering the natural development of a wetland (RAP, 2004). The project was carried out in 1992 through three phases; Phase I: bank stabilization and substrate enhancement, Phase 2: Island Creation, and Phase 3: site assessment (RAP, 2004). The concept was to create a structure that was shaped, sized, and positioned to trap sediment transported by the longshore current and the creek, while providing enough space to maintain water circulation (Figure 12) (Geiling, 1995; Kelso and Hartig, 1995). The island itself was created from clean, local igneous rock free from silt, shale, and organic matter, with quarry run stone of various sizes ranging from 1-450mm in the middle to 100-450mm on top. A crescent shape was selected to enhance sediment deposition on the lee side of the island from longshore currents and deflection from the creek (Geiling, 1995; Kelso and Hartig, 1995). Eight semicircular and straight rock shoals were constructed to accelerate the natural processes while increasing habitat heterogeneity, provide cover or shelter, and prevent erosion (Figure 12) (Geiling, 1995; Kelso and Hartig, 1995; RAP 2004). Additionally, five subsurface semi-circular trapping structures were also added to the wall to increase sedimentation, as seen in Figure 12 (Kelso and Hartig, 1995). To increase the amount of shade, pockets of protected soil were built above the water level to support the growth of native shrubs and trees (Geiling, 1995; Kelso and Hartig, 1995). Soil pockets of varying depths were added just below the water level to ensure moisture availability to sustain the indigenous vegetation (Geiling, 1995; Kelso and Hartig, 1995).

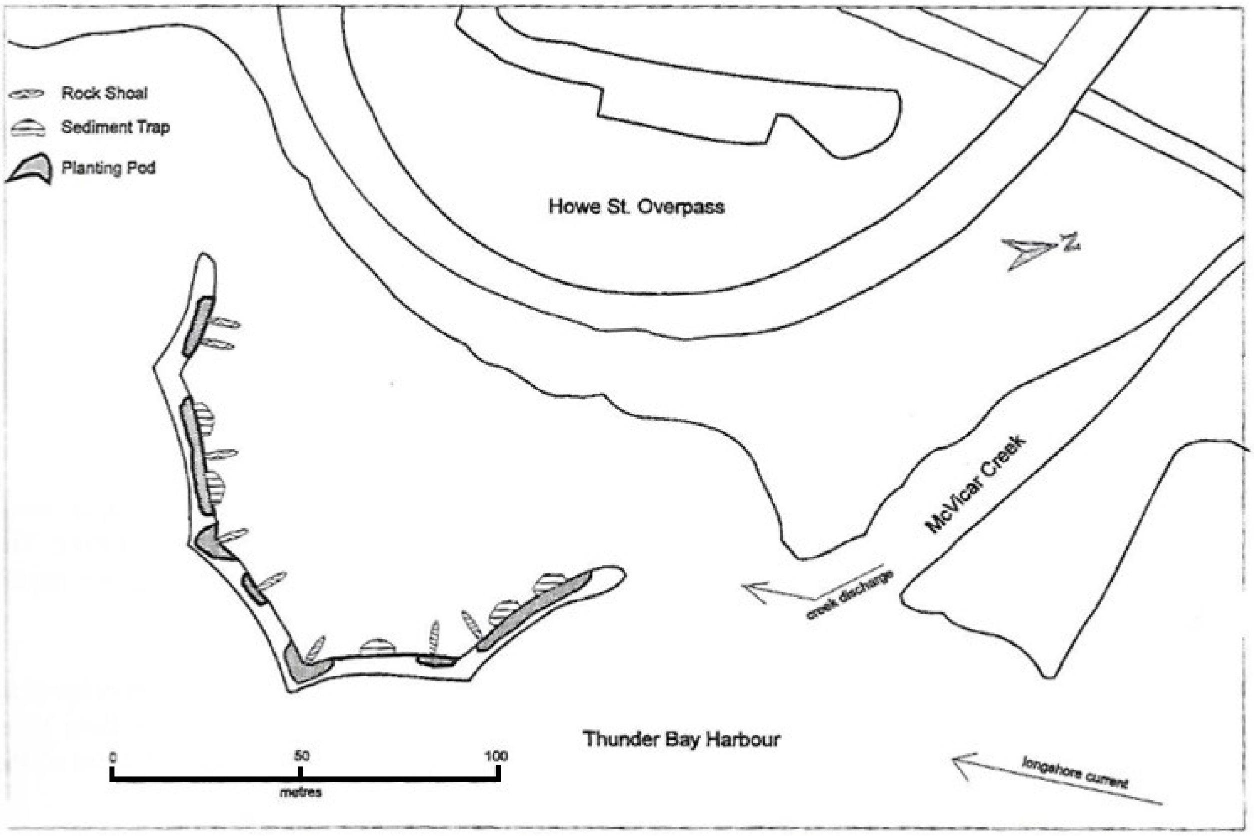


Figure 12: Plan view of Sanctuary Island Rehabilitation Project (Kelso and Hartig, 1995).

It was stated that monitoring efforts should focus on tracking changes in vegetation and fauna within the island (Geiling, 1995; Kelso and Hartig, 1995). Colonization effectiveness was to be monitored through sampling, quantification, and speciation of macrophytes. Seining for fish diversity and abundance was to be conducted in spring, summer, and fall and supplemented with late summer electrofishing (Kelso and Hartig, 1995). Benthic invertebrates were also to be sampled by ponar grab in seven different locations within the lee side of the island and three on the outer berm (Kelso and Hartig, 1995). It is recognized that the maturation of aquatic habitat within the island will be a slow process. Criteria used to indicate success include: evidence of spawning resident fish, presence of juvenile salmonids, the re-establishment of wetlands, an increase in diversity and abundance of macrophyte communities and established nesting by birds (Kelso and Hartig, 1995). The Thunder Bay Remedial Action Plan Stage 2 Report (2004) reports signs of increased macrophyte presence and potential bass nests, but the littoral habitat monitoring efforts have been inconclusive, and remain unconfirmed.

3.5 Current River Delta

The Current River delta has been identified as valuable fish habitat within the Thunder Bay AOC since it provides important spawning and nursery grounds, specifically for Walleye (*Stizostedium vitreum*) (Schram et al. 1991; Kelso and Hartig, 1995; RAP, 2004). Degradation of habitat occurred over the past 130 years from the effects of numerous industrial activities, including Silver Stamp Mill, Saw Mill, road and railway construction, river impoundment for water management, and construction of the boat launch (Kelso and Hartig, 1995; RAP, 2004). The severe results of dredging activities prompted the need for augmentation of the remnant, and creation of new, spawning habitat for walleye. Remnant spawning habitat exists within the three lotic channels exiting into Lake Superior (Figure 13). The river contains favorable spawning features that include gravel/cobble substrate, <2.5m water depth, and current water velocities sufficiently high to prevent high siltation (Kelso and Hartig, 1995; Geiling, 1995).

Figure 13: Aerial view of the Current River delta (Google Earth, 2018).

The enhancement project focused on duplicating previous channel depth, flow, diversity, and substrates to restore access to productive spawning areas (Kelso and Hartig, 1995; RAP, 2012). Three of the locations were positioned within the Current River estuary, with Area 1 (Figure 14) significantly influenced by Lake Superior and was likely historically significant for spawning (Geiling, 1995; Kelso and Hartig, 1995). Areas 2 and 3 were known to be remnant spawning sites within the lotic sections of the estuary (Figure 14) (Geiling, 1995; Kelso and Hartig, 1995). The existing flow pattern was left unmodified, as it had no effect on the successful remnant spawning areas (WEI, 1994). The project included the removal of debris, pool construction, and the addition of clean substrate in the form of gravel, cobble, and boulders (Geiling, 1995; Kelso and Hartig, 1995). Within the lotic sites, placement of the new substrates was completed with attention, using a tracked backhoe to evenly spread the cobble and then tapped down with the backhoe shovel to set the cobble and settle the gravel into the river bed (Geiling, 1995; Kelso and Hartig, 1995). Boulders were then placed randomly to create instream cover and disrupt flow patterns increasing diversity within the stream bed (Geiling, 1995; Kelso and Hartig, 1995). Similar actions were taken in the lacustrine zones, however, after tapping down the cobble substrate a layer of gravel was added atop the coarse substrate assemblage (Geiling, 1995). Wave action was anticipated to settle the loose material amongst the cobble substrate (Geiling, 1995). The project was conducted in December to reduce fish and invertebrate mortality and minimalize sedimentation downstream. The material was placed in low flow when known reproductive activity had ceased (Geiling, 1995; Kelso and Hartig, 1995).

The only monitoring program implemented was to assess the level of Walleye abundance, spawning activity, and frequency of spawning events, with little focus on the success of the habitat itself (RAP, 2012). Trap nets were used for the mark and recapture of Walleye to estimate the population during spawning runs in 1991, 1992, and 1993 (Kelso and Hartig, 1995). A continued evaluation was to be carried out to ensure the recruitment of the populations. To assess egg deposition qualitative diving surveys were conducted, along with seining for juveniles in the peak season (Kelso and Hartig, 1995). Surveys from 1993 concluded that historic and newly created lotic spawning habitat had the presence of viable Walleye eggs (Kelso and Hartig, 1995). The lacustrine site (Area 1) had no eggs present when surveyed (Kelso and Hartig, 1995). Habitat monitoring can provide significant information regarding the success of the enhancement initiatives and if any change has occurred since original construction.

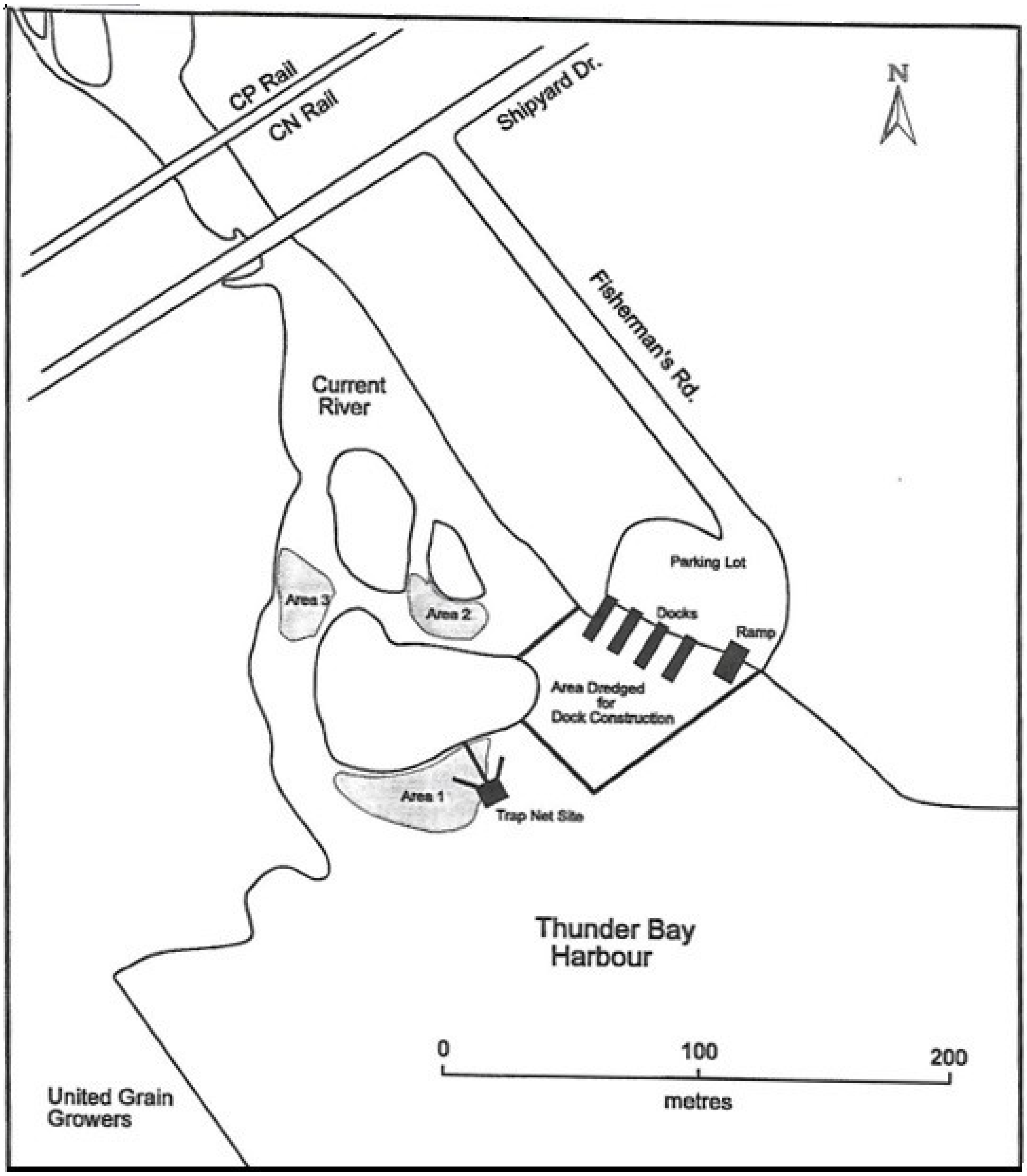


Figure 14: Current River Rehabilitation Blueprints (Kelso and Hartig, 1995).

3.6 North Harbour

The Thunder Bay North Harbour currently remains a local priority within the AOC as there is approximately 350,000 - 400,000 cubic meters, (making up 26 hectares) of mercury-contaminated, enriched organic soil (EOS) located just within the break wall (Figure 15) (RAP, 2004). This material has accumulated since 1920, through the operations of both Abitibi Consolidated (provincial papers) and Cascades Fine Papers Mill since their discharges contained traces of a fungicide treatment with elevated levels of mercury. Operations ceased in 2008 (Saunders, 2014; RAP, 2004). The concentration of mercury ranges from 2 to 11ppm at the surface of the sediment, to 21ppm at depth (RAP, 2004). EOS levels need to be significantly reduced to meet the local industry standard of 0.55 ppm. Since then, Cole Engineering was contracted to provide a Sediment Management Options Report and propose viable remedial options (Saunders, 2014). Ecological and Human Health Risk assessments were also completed by Frans Environmental, which concluded that there could be serious future risks affecting the benthic invertebrates, fish, fish-eating mammals and birds, recreational anglers, and industrial/construction workers (Saunders, 2014; RAP, 2004). A total of 6 remedial action options have been identified including capping, excavation and upland disposal, dredging and upland disposal, dredging and disposal in a new confined disposal facility (CFD), dredging and disposal in a new CFD using the adjacent lagoons, and finally dredging and disposal in the existing Mission Bay CDF (Saunders, 2014).

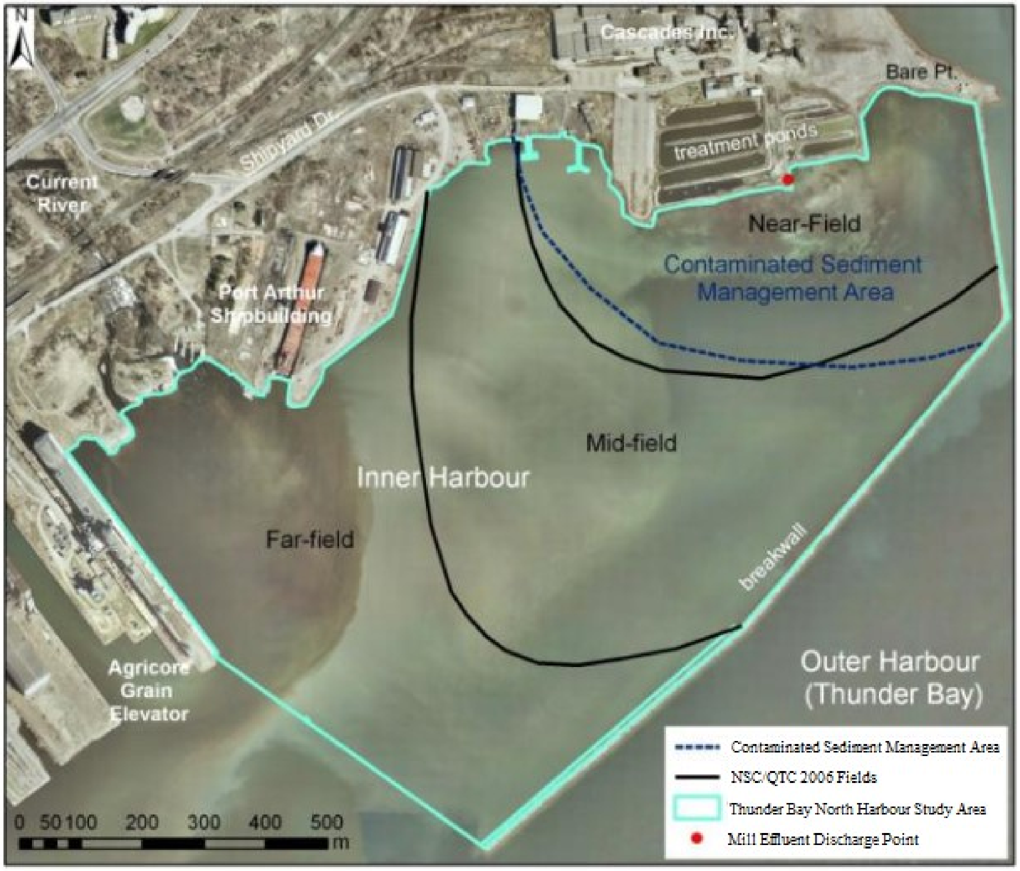


Figure 15: Contaminated Sediment Management Area within the North Harbour (Foster, 2012).

In 2012 North Harbour underwent a habitat synthesis and fish community assessment to assist in selecting an appropriate mitigation strategy for the Contaminated Sediment Management Area (Foster, 2012). Foster (2012) used underwater video and ponar samples as the primary methodology and concluded that the location is primarily composed of soft sediments such as fine sands and silts. Coarser material composed of cobble, rip rap, and gravels existed along the direct shoreline and was lined with pulp fiber to approximately 1m in depth in front of the Cascades Fine Paper Mill (Foster, 2012). Of the 29ha studied, macrophyte abundance ranged from sparse to dense in the midfield area (Figure 14) with no presence directly in front of the mill. It was indicated that due to the availability of nutrients macrophyte colonization was more successful (Foster, 2012).

A Site-Specific Risk Assessment report (SSRA) concluded that the site requires remediation over the extent of the contaminated area (CE, 2014) simply because mercury concentrations must be below 0.55mg/kg to decrease the inherent and long-term risk from contaminants (CE, 2014). To date, no remedial action plan has been implemented, however, further scientific research, habitat data collection, and stakeholder outreach will hopefully result in the execution of one of the suggested remedial plans. North Harbour was examined as part of this study to provide baseline data on the aquatic habitat extent and assist in monitoring the efficacy of eventual remedial actions. Understanding the physical parameters of the North Harbour location, specifically, the extent of the woody debris and logs will be essential for choosing an appropriate remediation approach. This study will allow for better quantification of the habitat features that exist as a result of natural recovery in the area.

4.0 Methodological Approach

The research goals of this study required a multi-method framework to provide a comprehensive understanding of each rehabilitated habitat. The incorporation of various data collection methods increases data validation by combining a range of sources and observations to accurately depict the underwater habitats (Esteves, J., and Pastor, J., 2004). Each step is interrelated and supplemental to the major core initiatives of the research. Habitat complexity, health, and value were established using six essential steps including:

i.) A side-scan sonar survey of each habitat.
ii.) Underwater transects via scuba for ground-truthing.
iii) Vegetation samples were collected and classified into their WMI values.
iv) Water quality was tested testing using Multi-Parameter Handheld Meter and Secchi Disk.
v) Buffer zones were established using GIS Software.
vi) Habitat maps were created using sonar imagery, Reef Master 2, and ArcGIS.

The methodology of this study focuses on being easily repeatable, time-efficient, and cost-effective to encourage more frequent habitat monitoring within Thunder Bay and RAP initiatives across the Great Lakes. The following section expands on the specific procedures and techniques applied.

4.1 Acoustic Side Scan Sonar

Side-scan sonar has proven to be an effective tool for determining habitat distribution, specifically because of its capacity to rapidly map and display data along long shorelines (Able et al., 1987; McEvoy, 2018). Due to the variability of the shoreline, side-scan sonar data will be collected using two separate boats. For deeper water that exceeded 15 ft, a 30ft Bayliner Trophy was used, as it can maintain a track in windy conditions with waves. Its larger size is less affected by the elements and can gather more reliable and informative imagery in open water. A Humminbird 999ci HD SI was mounted to the Trophy allowing the two sets of transducers to scan each side while simultaneously recording and displaying the data on a dual-channel recorder (ReefMaster, 2017). Although the Humminbird 999ci HD SI does not have the down-scan capabilities, it encounters significantly less distortion in the imagery due to increased stability.

A 14ft Lund was used in shallow areas due to its ability to get as close as possible to the inland habitat with minimal disturbance and easy maneuverability. A portable Humminbird Helix 9 G2N Mega Chirp SI was utilized in shallow areas to allow for clearer readings and easy application as it was simply fastened to the side of the boat. Down-scan imagery was used in addition to SSS to illuminate the bottom contour, substrate structure, and aquatic vegetation density. The scanner shows the imagery in significantly greater detail to get a full understanding of the complex vegetation and bottom composition. The unit delivers higher contrast than traditional sonars, improving accuracy and readability of the imagery within Reef Master.

Optimal results require scanning at a maximum speed of 6km/hr, with slower speeds of 3.5km/hr required for high-quality visuals in shallow water (Hook 2008; Kaeser and Litts, 2010; McEvoy, 2018). For the purpose of this study, the high-frequency sonar waves were set to 800kHz to provide the sharpest resolution to increase the readability of the sonar imagery. Capturing fine strands of vegetation, detectible changed in the substrate, and alterations in habitat due to anthropogenic activity is essential to fully understand the remediation success and changes occurring over time.

4.2 Analysis of Bathymetry, Substrate and Aquatic Vegetation Data

ReefMaster2 was used to interpret and analyze the collected SSS data. The creation of the vegetation, bathymetry, and hardness maps required a multi-step approach due to the diverse formatting of the different programs used for side-scan sonar analysis. Initially, the raw side-scan sonar imagery (.DAT files) was imported into ReefMaster's sonar log, with each track positioned in the correct geographic location and the water column removed from the sonar return. Signal noise filtering was undertaken to remove sonar interference and improve the readability of imagery collected from extremely shallow water. The second step prior to imagery analysis requires a depth correction of 1ft to be applied to the sonar files for accurate interpretation. Once the corrections have been made to the sonar imagery, each segment was reviewed, clipped, and edited. Segments with excessive noise or low readability were removed completely or rescanned. The sonar tracks were then combined into a side-scan mosaic to create a blended, highly detailed two-dimensional map of the collected imagery showing underwater habitat features and structure. Based on overlap and appearance, the individual track swaths were edited to produce the clearest depiction possible. Start and end positions could be altered for a neater finish, with the option to adjust port and starboard extent to limit or extend the range of the swath (ReefMaster, 2017). When clear and concise imagery is achieved, the mosaic can be exported in a variety of formats to produce the final maps in ArcMap 10.0.

Detection of submerged aquatic vegetation in the maps required several extra steps due to formatting issues when exporting the mosaics. ReefMaster exports the imagery into a KML Superoverlay, which is not supported by GIS. To digitize the submerged vegetation cover, the mosaic had to be imported into Google Earth, where polygons were created atop the sonar imagery to depict the varying percentage of plant coverage while maintaining spatial accuracy. The shapefiles were saved into a standard KML file and imported and converted into ArcMap by using the "KML Convert" tool. Once the polygons were imported, the symbology could be adjusted and the polygons could be edited to ensure adequate overlap with no slivers in the data. The vegetation transects were added based on Handheld GPS coordinates collected during the underwater assessment. Points were taken at the weighted markers to ensure repetition in the transects between spring and fall. Due to the nature of side-scan sonar imagery, there will be some degree of error in the maps as petite plants may not be picked up on the return. However, underwater (SCUBA) transects and a fish-eyed view (underwater camera) of the location was invaluable in deciphering the sonar data to achieve the highest level of accuracy possible.

4.3 Underwater Transects and Video

Underwater habitat data was collected by conducting linear transects and quadrant surveys to verify the sonar imagery. Transects are a relatively inexpensive in situ visual surveys that cause minimal damage to the aquatic habitat (Croft and Chow-Fraser, 2007). Each location was significantly different in habitat structure and design due to the desired outcome of the remediation project. Underwater transects were chosen based on location size, depth, and habitat complexity, all 25m in length (Titus, 1993). There was limited variation in depth within each habitat eliminating the need for stratified sampling (Titus, 1993). The GPS coordinates of the transects were recorded using a handheld unit within a stationary boat to ensure that the same transects could be replicated in the fall. Transect tracks videotaped using an Action Camera for further in-lab analysis. Where applicable, quadrant surveys were taken every 5m along the transect to estimate the percentage of cover while noting the occurrence of species. Quadrant sampling was accomplished by overlaying a ridged frame that is approximately 1m^2 on the lake bottom; literature indicated that this size has been most successful when differentiating plant assemblages and species diversity over larger areas (Downing and Anderson, 1985; Titus, 1993; Hallacher and Tissot, 1998). Photography was used in conjunction with transects and quadrant sampling for reference to capture a detailed understanding of the habitat complexity and structure. In two locations, Neebing-McIntyre and North Harbour, hazardous conditions prevented the ability to dive and therefore relied on a Sea Viewer "Sea Drop 950" camera with GPS video overlay to conduct the underwater transects.

4.3.1 Vegetation Data

The plant community was surveyed twice during this study, once in early spring (June – early July) and again in the fall (September -October) to ensure adequate species counts (Titus, 1993). Species dynamics change over the season, sampling more than once provides a more representative picture of the submerged aquatic macrophyte community (Ohrel and Register, 2006). The focus of the study was to address the condition of the submerged aquatic habitat, therefore only submergent and floating plant taxa were identified on a presence/absence basis (Croft and Chow-Fraser, 2007). Due to the broad spatial area of the project, emergent species were excluded from the study. Samples were collected to improve the accuracy of the species identification process. As the methodology is geared towards volunteer monitoring programs, it assumes a trained professional may not always be present, therefore, samples allow the species to be identified using a key.

Submerged macrophytes were sampled using varied methodologies depending on the habitat condition. Underwater transects and quadrant sampling was completed in habitats that were deemed safe for diving. Transects were set by divers using weighted markers and samples were collected within the quadrants. However, due to the limited submerged macrophytes within some of the locations, quadrant sampling did not accurately depict the present plant community. Transect sweeps were conducted in addition to quadrants to account for any additional species relevant to the habitat community (Ohrel and Register, 2006). Sampling would cease when no new species were found in three consecutive sweeps of the quadrants and transect. Samples were approximately 2-4 inches in size dependant on the macrophyte to ensure that any identifying features such as leaves, flowers, or fruits were present (Newmaster et al. 1997). Locations with hazardous diving conditions were sampled using a gaff by conducting multiple sweeps of the GPS tracked transect and in field notations of the plant community. Video footage collected using the Sea Drop 950 camera was also used to assess the macrophyte community and densities. Harvested samples were placed within labeled bags indicating location, transect number, and date. Samples were kept in a cooler to preserve them for identification.

The Wetland Macrophyte Index (WMI) (Croft and Chow-Fraser, 2007) was applied when assessing macrophyte species to indicate the niche breadth and tolerance to degradation. The U-value indicated the tolerance of a species to habitat degradation (1 = very tolerant, 5 = very intolerant) and T-value which indicates the niche breadth (1 = broad niche, 3 = narrow niche). The WMI consists of 16 floating species and 52 submergent species. The index identified 15 taxa to genus only for species that were not readily identifiable infield (i.e., Muskgrass (Chara), Stonewort (Nitella), and Quillwork (Isoetes)) and were treated as a single taxon. Taxon such as Pondweed (Potamogeton), Milfoil (Myriophyllum) and Bladderwort (Utricularia) have a wide range of species with assigned U and T-values, however, a conservative value was given to the genus if coarser identification was required when classifying. In cases when there was uncertainty identifying a sample to the species level, the specimen was simply classified to the genus for consistency as recommended by WMI procedures (Croft and Chow-Fraser, 2007).

Macrophyte samples were identified using the Wetland Plants of Ontario Key (Newmaster et al. 1997), Through the Looking Glass: A Field Guide to Aquatic Plants (Borman et al. 1997), iNaturalist (2019), Canadian Museum of Nature Herbarium (CMN, 2019), The Plant List (2013) and World Online Flora (2019). These sources are purposed for a range of users due to their accessibility, educational illustrations, and detailed aquatic plant keys providing the basics of plant ID and more in-depth reference (Newmaster et al. 1997; CMN, 2019).

Macrophyte density was estimated using both video analysis of quadrants and side-sonar imagery. The density classification system used in previous harbour studies was applied to maintain consistency (Willows, 2014). Densities were estimated using a ranged percentage system to indicate approximate cover, seen in Table 10 (Harris et al., 2009 and Willows, 2014). The final percentage range was derived from 1m x 1m quadrant analysis comparing the cover of fauna with the amount of visible substrate (Harris et al., 2009; Willows, 2014). Individual species abundances were not assessed for time efficiency when assessing multiple large habitats. Side-scan sonar and down-scan imagery were used to map vegetation densities over large areas. The high-resolution imagery allows for easy estimation that can then be ground-truthed for high classification accuracy. The texture, edge characteristics, and extent of growth into the water column were key in designating density. Sonar imagery has been utilized in fisheries management and has been proven to be a practical and viable tool for assessing submerged aquatic vegetation stands (Bennett et al., 2019).

Table 10: Vegetation abundance ranges (Willows, 2014)

Submerged Macrophyte Abundances	
Percentage of Abundance	Classification
0%	Absent
1-25%	Sparse
25-50%	Moderate
50-75%	Heavy
75-100%	Very Heavy

4.3.2 Substrate Data

The substrate was classified using infield visual reference, video footage, side scan/down scan imagery, and ReefMasters Bottom Composition module (ReefMaster 2017). Transects provided a clear visual of the substrate and its consistency, with the sonar imagery indicating the spatial extent (Titus, 1993; ReefMaster 2017). Substrate was classified by observing distinct textures and patterns within the sonar imagery (Tian, 2011; Kaeser and Litts, 2013). Colour and hue of the imagery were also indicative of the substrate type and its density (Hook, 2008). The spatial extent of the substrate type was mapped using ReefMasters E2 Bottom Hardness Eco Return function. The hardness return depicts a range rather then a numerical measurement. A light colour in the hardness return indicates a soft substrate that is easily disturbed, and darker colourations is indicative of a harder substrate such as cobble or rock (opposite of sonar imagery returns). Any uncertainty in sonar imagery was ground-truthed using the SeaView 950. As side-scan sonar is being used as the primary methodology for the habitat assessment, no sediment samples were taken for further testing. The sonar imagery and in-field experience provided enough of an indication to adequately classify substrate type (Hook 2008; Tian, 2011; Humminbird, 2012; Kaeser and Litts, 2013)

4.3.3 Water Quality

Water quality is a fundamental aspect of aquatic habitats that sustains ecological processes, including vegetation production and benthic health (Dennison et al., 1993; ESA, 2003; Long et al., 2014). Using a Multi-Parameter Handheld Meter, several variables were tested in-situ including dissolved oxygen, ORP, conductivity, PH level, and temperature. Turbidity was tested using a Secchi disk that was 30 centimeters in diameter (Preisendorfer, 1986; Holmes, 1970). A disk was cut from plastic and weighted, the panels were divided into quarters and painted black and white as per standard testing methods (Preisendorfer, 1986; Holmes, 1970). Measurements were taken twice to ensure precision and consistency. The water quality parameters tested were compared with The Canadian Water Quality Guidelines for sustaining healthy freshwater ecosystems and aquatic biota, as indicated in the literature review (ESA 2003; Dennison et al., 2008).

4.3.4 Riparian and Buffer Zones Measurement

Buffer-zones play a key role in the success of rehabilitation projects (EC 2003; Semlitsch and Brodie 2003; Broadmeadow and Nisbet 2004). Using ArcGIS, the buffer-zone of each aquatic location was calculated and mapped to indicate the minimum 30m buffer extent (Broadmeadow and Nisbet, 2004; EC, 2013). The maps were generated using satellite imagery to show where the zone should extend to and the corresponding land cover currently present. Buffer success can be easily differentiated, indicating which locations require further remediation to reach maximum potential. Achieving and maintaining a biologically meaningful buffer will be essential for achieving restoration goals and continued recovery (RAP, 2004).

4.3.5 Habitat Scoring System

A ranking system was developed from the Department of Fisheries and Oceans Estuarine and Freshwater Habitat Classification template to assess the success of restoration projects based on habitat and fisheries values (Appendix 1) (Precision Identification, 2001). The development of this classification system aids in identifying, categorizing, and quantifying habitat values by using scientifically defensible data collection. The Habitat Classification System needs to be fine enough in detail to address specific indicators, but broad enough for the varying types of habitats along the waterfront. Habitat classification was designated based on the assessment of ecological indicators, improvement of fishery values, and the achievement objectives outlined in each remedial action plan. Historical knowledge and the specific goals set for each restoration project will be used in conjunction with habitat and fisheries values to give a final habitat designation. Designed to be easily applicable and repeatable, the system will help facilitate continued monitoring and the implementation of management strategies to maintain and protect these valuable aquatic habitats.

The habitat classification ranking system ranges from minimal value to the highest value, addressing deficiencies within each aquatic location. Habitats designated as minimal value have been severely altered and do not provide significant ecological functioning to the watershed or estuary (Precision Identification, 2001). The contribution to fisheries' values is limited and habitat mitigation is essential to improve the net value of the habitat. Locations designated as having moderate value assist in ecological functioning but are not known to support key life cycle activities (Precision Identification, 2001). The habitat could benefit from modification but primarily should be protected and maintained. High value habitats are valuable to ecological functioning and are known to support key lifecycle activities (Precision Identification, 2001). They should be protected from any development that would negatively impact habitat functioning. The highest value habitats are considered pristine, providing significant fisheries values and high ecological functioning to the watershed. These habitats must be protected from development as they provide natural fish habitat and are locally rare (Precision Identification, 2001). All habitats, regardless of rank, should follow compensation and mitigation guidelines when any nearby disturbances or developments occur to ensure a No Net Loss of habitat.

Habitats were assessed based on biophysical parameters, habitat complexity and key indices. Habitat indices were given a numerical value dependant on their quality, the sum of these values indicated the categorical class of the habitat (Appendix 1). Features considered to have low habitat value, such as silty clay substrate, 0% vegetation, low U and T-values, little to no buffer zone, and poor water quality with high turbidity, were given a low numerical value of 1. These are common characteristics of habitats that have been degraded or have had a significant degree of anthropogenic influence. Habitats with clean substrates consisting of silty sand with high nutrient content, vegetation levels between 50% to 75% with high diversity, and sustainable water quality parameters with low turbidity were given a higher value of either 3 or 4 depending on the number of categories under the specific criteria. Providing a series of criteria within the ranking system provides a systematic way to categorize, compare, and communicate habitat values. The application of the ranking system to current habitat values provides baseline data to defend management decisions and provide a reference for future restoration projects.

The Habitat Classification System can be used as a tool when conducting infield work but should only be considered as a guideline when assessing aquatic habitats. It is impractical to incorporate all relevant parameters into a single Habitat Classification System due to the numerous possible variables affecting the quality of these rehabilitated habitats. Rather, the classification system focuses on the critical factors that affect the ecological functioning of each rehabilitated habitat, utilizing biotic and abiotic indices that are sensitive to anthropogenic influence. The scoring system attempts to address each location independently, as the six microhabitats under study vary significantly in terms of hydrology, biotic use, and fish habitat. Cross comparing each rehabilitated habitat is difficult as the designs have different desired outcomes and set objectives. However, the classification system is a broad enough scope to designate a habitat class and indicate strengths and weaknesses in each rehabilitation project studied.

5.0 Results

A habitat classification has been designated to each location based on the indices assessed in this study. The following chapter will discuss each location as it relates to the habitat classification table (Table 11) and the justification for each designation based on the field data and analysis performed (Appendix 1). Overall, Table 11 shows that the habitats in the Thunder Bay Harbour are moderate to high value indicating that they are valuable for ecological functioning.

Table 11: Habitat Characteristics and Classification

Submerged Aquatic Habitat Rating of the RAP Locations						
Location	**Submerged Macrophytes**	**Substrate**	**Water Quality**	**Habitat Buffer Zone**	**Total**	**Class**
McKellar Embayments	3	1	5	3	12	**Moderate Value**
Neebing-McIntyre	2	1	5	2	10	**Moderate Value**
NOWPARC	6	3	7	2	18	**High Value**
Sanctuary Island	5	2	6	1	14	**Moderate Value**
Current River	2	3	7	3	15	**High Value**
North Harbour	6	1	7	1	15	**Minimum-High Value**

5.1 McKellar Embayments

The total scanned area amounted to 113,263 m^2, consisting of a small section of the river channel and the embayments themselves. The river delta had an abundance of woody debris, large logs, and abrupt elevation changes which caused a considerable disturbance within the sonar imagery, therefore it was not included on the map. Due to the shallow bathymetric composition and narrow channels of the location, the far edges of the sonar data were slightly distorted due to noise. To ensure reliable substrate data, the extent of the bottom composition relative hardness maps are limited to 1-10ft in-depth within the embayments. Four transects were completed, two on each side of the inner channels of the shallow embayments. Transects 1 and 3 were located near the opening of the embayments, whereas transects 2 and 4 were located near the back of the habitat to ensure full coverage of the location. It was noted throughout data collection that waterfowl, painted turtles, and beavers are currently inhabiting the location. However, the submerged aquatic assessment of the physical parameters and habitat indices indicate that Target D5 (Table 9) have only been partially met.

Submerged Aquatic Vegetation

High turbidity with limited hydraulic activity within the embayment's led to a minimal abundance of submerged macrophytes with only thin strips lining the edges of the banks (Figure 16). Only 8% of the site had macrophytes present, ranging in quantities from 1-25%, covering a total of 8,778 m^2. The majority of the aquatic vegetation was found between the smaller islands, but there was no growth within the middle of the larger channels (Figure 16). A total of 7 species were encountered, which had lower U and T values (Table 12) (Table 1) (Croft and Chow-Fraser, 2007). Central tendency measures of the U-Value indicated that the species present were tolerant of degradation. The T-value was classified as 1 for the location, indicating that the macrophytes have a broad niche and can grow and survive sustainably in several habitats (Croft and Chow-Fraser, 2007). Locations with low overall U and T values are associated with habitats that either have high nutrient loading or suspended solid concentrations (Croft and Chow-Fraser, 2007), which is characteristically correct with what was observed and recorded within the embayments.

Table 12: McKellar Embayment Macrophyte Species for 2018 Season with U and T values.

McKellar Embayments				
Species List				
#	Taxon	Common Name	U-Value	T-Value
1	Potamogeton pusillus	Slender Pondweed	2	1
2	Myriophyllum sp.	Water-milfoil	1	1
3	Vallisneria americana	Tape/Eel Grass	3	1
4	Nymphaea odorata	Fragrant Water Lilly	2	1
5	Sagittaria sp.	Arrowhead species	2	1
6	Callitriche sp.	Water starwort	4	2
7	Potamogeton natans	Broad-leaved pondweed	2	1
MEDIAN			2	1
MODE			2	1

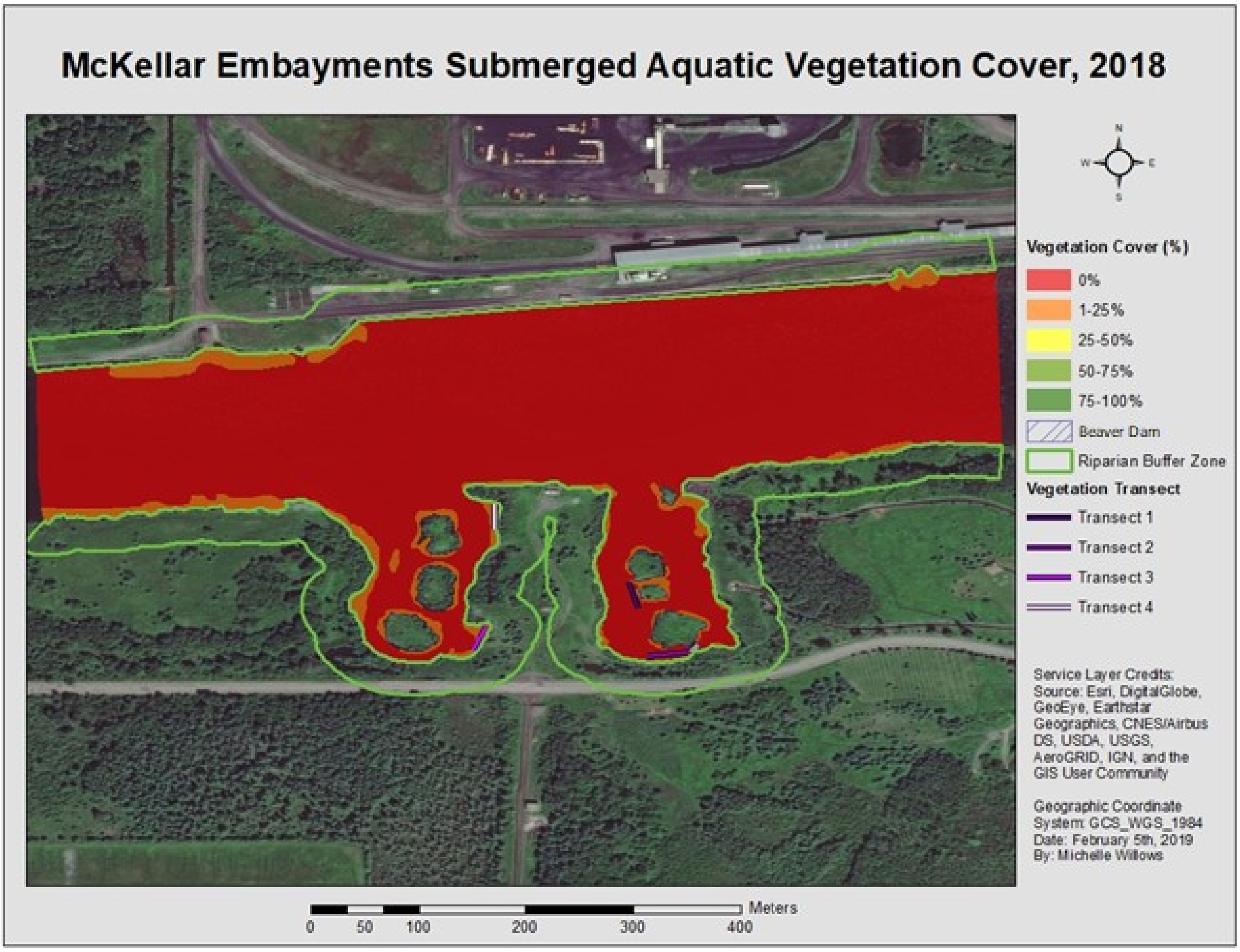


Figure 16:McKellar Embayments Submerged Aquatic Habitat

No macrophytes were present along transect one. However, a green-colored alga (likely a periphyton diatom) was encrusted on the surface of the substrate (Figure 17), which can be indicative of minimal water movement and stagnant conditions. The second transect along the back of the embayments had a large volume of woody debris due to the formation of a beaver dam. Five species of macrophytes were present (Potamogeton pusillu, Vallisneria Americana, Callitriche sp., Myriophyllum sp., and Sagittaria sp.) in low abundances approximately 1m off of the transect along the shoreline with adequate light penetration. The only macrophytes present along transect three consisted of Fragrant Water Lily (Nymphaea odorata) (Figure 18) a known food source of beavers (Allen, 1983), Pondweed (Potamogeton sp.) and Tape Grass (Vallisneria Americana). Transect four received higher volumes of hydraulic energy due to its proximity to the river channel opening and had the highest number of macrophytes present (6 of the 7 species with no Callitriche Sp. present). The predominant species was Fragrant Water Lily (Nymphaea odorata), which typically thrive in still, shallow water bodies where the substrate is primarily composed of silt, as they are known to enhance siltation processes (Else and Riemer, 1984). Fragrant Water Lilly's are a species typically tolerant of relatively degraded conditions and achieved a U-value of 2, and a T-value of 1, based on their ubiquitous distribution.

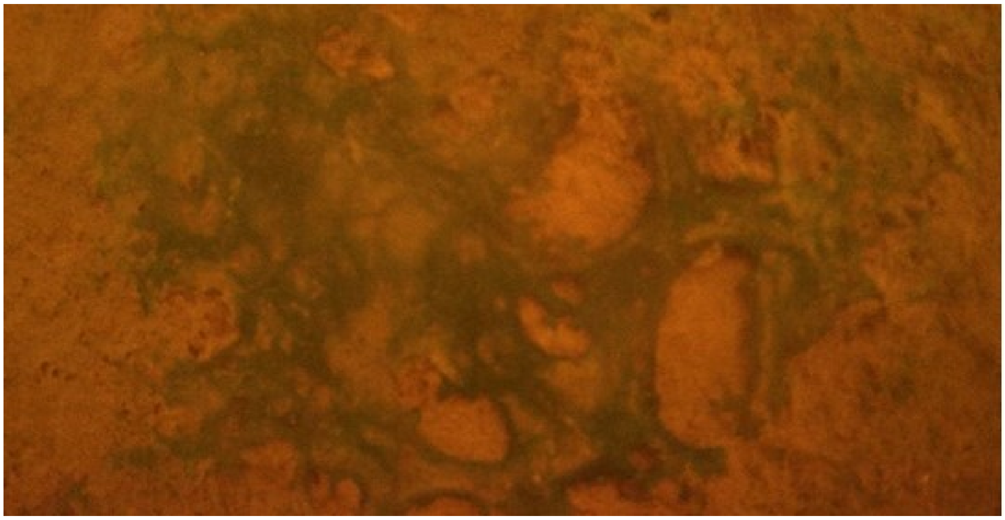


Figure 17: McKellar Embayment Algae.

Figure 18: McKellar Embayment Fragrant Water Lilly (Nymphaea odorata).

The overall rating of the submerged macrophytes within the area was designated as a 2 (Appendix 1). The few species present with primarily low U and T values are indicative of previous habitat degradation and alteration, receiving a 1 for WMI scoring. Macrophyte densities were below 25%, scoring a 1 for abundance. The side-scan sonar imagery and vegetation transects were not indicative of a successful littoral habitat based on quantity, density, and macrophyte U and T values.

Substrates

In the Stage 2 RAP report, the McKellar embayments were described as having a detailed bottom grading with gravel shoals, sand spits, and sand bluffs. However, sides-scan imagery and underwater transects indicated that sedimentation has led to a silty-mud substrate (Figure 19). The side-scan sonar imagery depicts a fine-grained substrate based on its smooth textural appearance and darker hues away from the middle track line, which is common sonar imagery of mud or loosely packed silt (Figure 19). The substrate begins to blend with the banks indicating a gradual transition to terrestrial islands, another characteristic of finer-grained substrates (Figure 19). Underwater transects confirmed the accuracy of the side-scan sonar imagery. The embayment substrate structure was fine-grained and easily resuspended, consistent with the relative hardness echo returns (Figure 20). The substrate structure remained the same for all four transects, despite the change in aquatic macrophyte presence. The nature of the substrate and the suspended fine sediments attenuate light to an extent that submerged macrophytes are only capable of growing in the shallows (Jones et al., 2012). This type of substrate is also known to become stagnant, leading to lower levels of oxygen near the surface layer. The nature of the sediment resulted in a ranking of 1 as it did not promote strong rooting or large abundance of macrophytes to grow within the embayment's, and the substrate was easily resuspended leading to high turbidity impeding photosynthetic processes (Appendix 1).

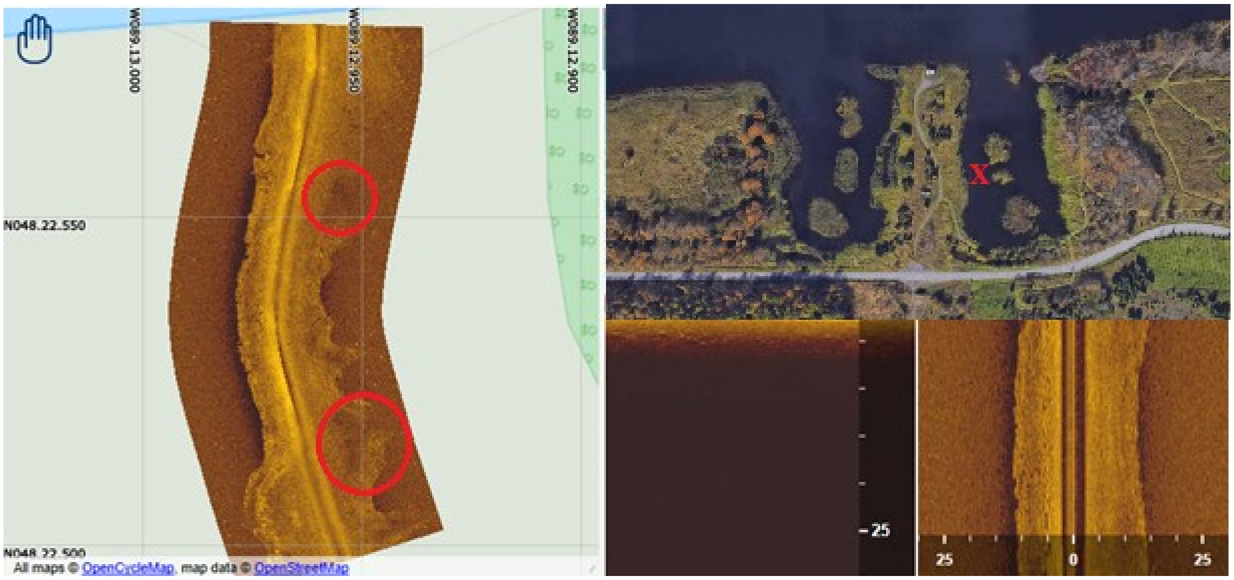


Figure 19: McKellar Embayment Transect One Side-Scan Sonar Imagery.

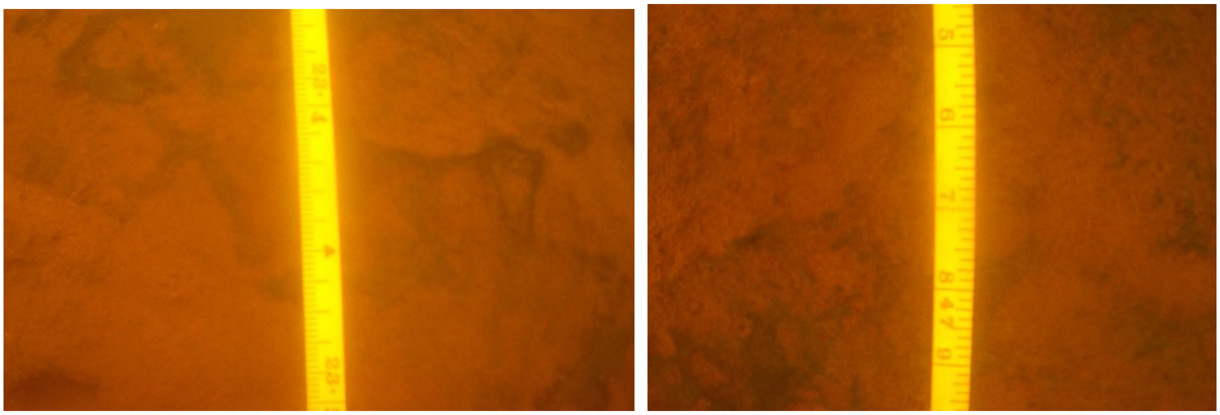


Figure 20: McKellar Substrate Along Transect 1 (Right) and Transect 3 (left).

The McKellar river is comprised of a packed silty-clay substrate throughout the main river channel, as indicated by the dark fine-grained sonar returns (Figure 21). Darker tones indicate an absorptive substrate consisting of small particulate: silt, clay, and mud. The northern wall of the river channel is hardened due to previous industrial infrastructure, consisting of old cement walls and steep vertical slopes. The dredging history in the channel appears in the E2 relative hardness returns and bathymetry, as the hardness levels increase along the cement docking area where the depth reached 20m (i.e., indicated by the meandering contour line in Figure 22).

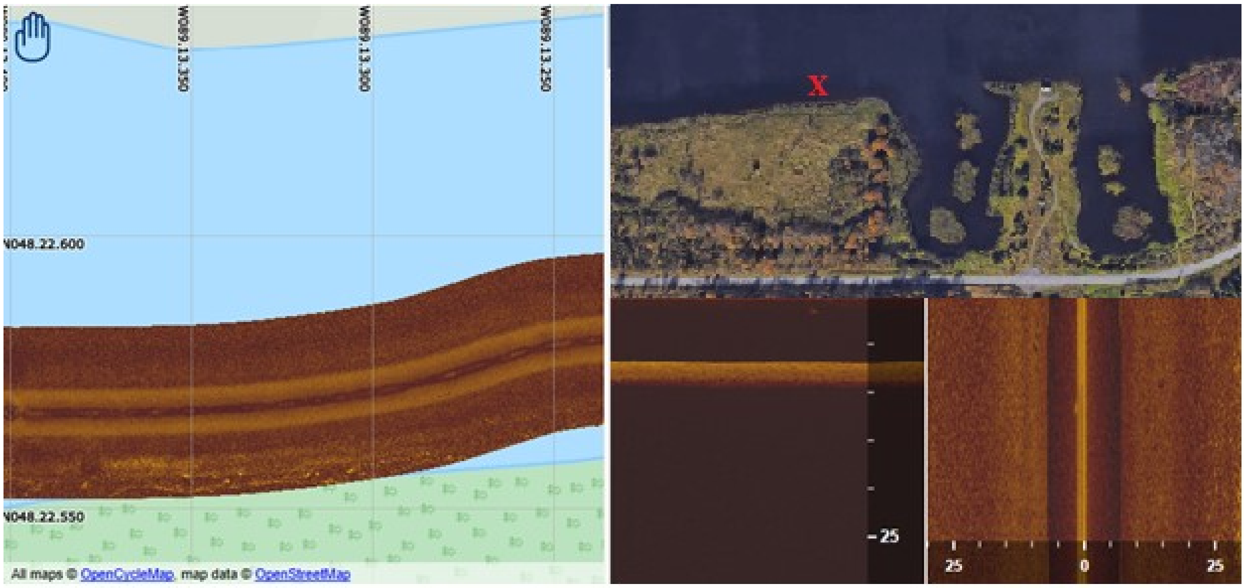


Figure 21:McKellar Embayment Side-Scan Sonar Imagery of Channel Substrate.

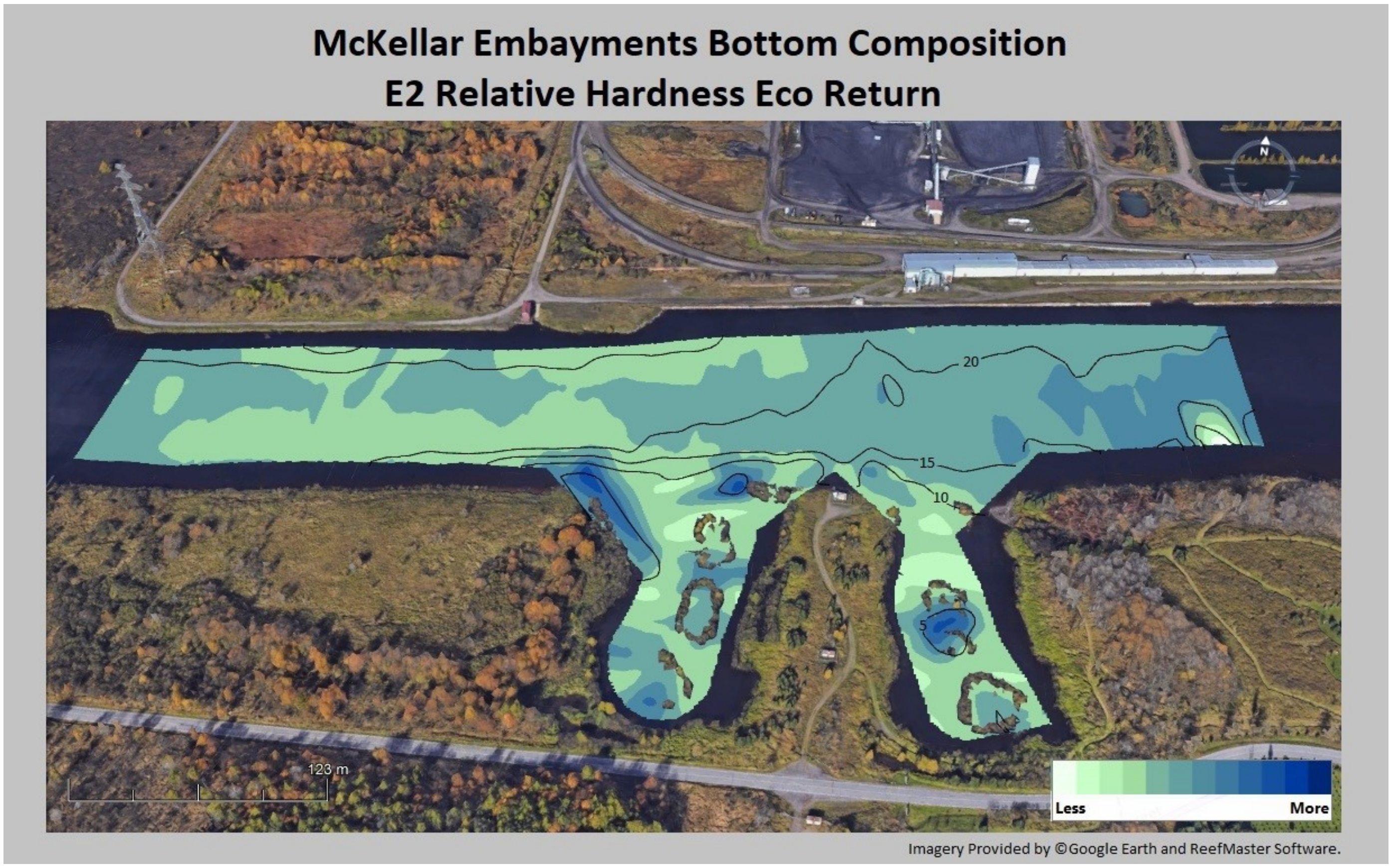


Figure 22: McKellar Embayments Bottom Composition: E2 relative Hardness Eco Return.

<u>Water Quality</u>

Water quality samples were taken mid-water column, approximately 0.5m deep. Temperatures ranged from 14-16°C in the spring, rising to 18-19°C in the fall, nearing the minimum temperature for the majority of fish families (Table 13). The spring temperatures are within the preferendum for Salmonidae, but the fall temperatures exceed the limits of pelagic fish (Table 1). Although the temperature change was not extreme, the increase over the season influenced other parameters of water quality. The McKellar embayments had the highest recorded temperature in the fall of the six locations likely due to the higher turbidity within the location (Table 13). The location's high turbidity levels were considered to be fair but were significant enough to limit photosynthetic potential contributing to a lack in abundance of submerged macrophytes. If an estuary is excessively turbid over long periods, its health and productivity can be greatly diminished.

Table 13: McKellar Embayments Water Quality Results for Fall/Spring 2018

McKellar Embayments Water Quality 2018										
Spring										
Date	Transect #	Temp °C	mmHg	DO %L	DO mg/L	DO ppm	SPC	pH	ORP Mv	Turbidity Bottom (BTM)
08/07/18	T1	14.4	745.2	99.3	10.0	10.0	123.9	7.1	339.3	65cm
08/07/18	T2	14	745	94.6	9.5	9.5	125.8	7.1	332.3	95cm
08/07/18	T3	15	745.2	82	8.0	8.0	148	7.2	115	87cm
08/07/18	T4	16	745	96.5	9.4	9.4	121.6	7.5	204.3	94cm
Fall										
13/09/18	T1	18.2	745.5	96	8.8	8.8	148.7	7.6	322.6	104cm (BTM)
13/09/18	T2	17.8	745.6	91.5	8.6	8.6	147.8	7.4	328.5	98cm (BTM)
13/09/18	T3	19	745.6	88.4	8.8	8.8	149.1	7.8	308.6	119cm (BTM)
13/09/18	T4	18	745.5	88.4	8.2	8.2	147	7.5	329.2	112cm (BTM)

The embayments had neutral pH levels, however, the pH level increased in the fall, trending differently from the other sites but remaining within the acceptable range for aquaculture (Table 1). Dissolved oxygen levels dropped from spring to fall. During the spring sampling, the site experienced dissolved oxygen levels ranging between 8mg/L to 10mg/L. The temperature increased from approximately 2-4 °C along the transects in the fall, which lead to a drop in the dissolved oxygen remaining between 8 to 9 mg/L. A similar pattern was seen in dissolved oxygen %/L, where levels were close to almost 100%/L, and dropped below 96%/L. Conductivity remained within sustainable levels indicating lower dissolved ions and nutrients below 150 µS/cm. Although conductivity increases slightly in the fall, the change was not substantial enough to prompt a severe change in pH or dissolved oxygen levels. These parameters are within acceptable limits for freshwater species (Table 1). Water quality parameters were designated a value of 4 as a result of the consistent temperatures between 15-19.9 ºC, a neutral pH level, and an ideal dissolved oxygen level for biotic survival (Table 1). The turbidity hindered the final ranking, receiving a score of 1 due to the detrimental effect it had on macrophyte colonization (Appendix 1). In combining these totals, the McKellar Embayment's received a score of 5 for water quality.

Riparian Buffer Zone

The shoreline on the opposite side of the embayments is highly hardened due to impervious surfaces from roadways and buildings. It currently lacks complexity, with high gradient walls comprised of steel sheet piling and concrete. The highly impacted shoreline was used for commercial shipping, influencing river bathymetry, substrate hardness, and has little to no littoral habitat. The channel wall itself may not be eligible for rehabilitation, however increasing the number of trees along the wall would be beneficial for providing shade and bank stability. Small improvements remain significant to the river channel as they influence surrounding species and habitat.

The introduction of native terrestrial species within the proximity of the embayments was successful in achieving the minimum 30m buffer zone (Figure 16). The buffer zone consists of several clusters of small trees, shrubs, and apparent grasslands along the riverbanks, seen specifically along the inner strip of land between the embayments (Figure 16). The current vegetation buffer provides limited protection from runoff and solar influences as the species have limited density and height with little depth and complexity in the root systems. Despite the buffer zone reaching the minimum 30m requirement, the location was scored as 3 because the type and quality of vegetation provided limited shade over the embayment's and has a lower filtration capacity (Appendix 1).

Habitat Classification

The location was classified as Moderate Value (Table 14) as it received low scoring within the specific habitat indices (substrate, submerged macrophytes, and water turbidity) assessed within this study. In its current state, the habitat is homogeneously diverse due to uniform silty-mud substrates and exhibits stagnant conditions. The transects and sonar imagery revealed a littoral habitat that requires increased water flow and reduced turbidity levels to encourage the colonization of native macrophytes. Although the embayments increase the diversity of a linear river channel, it provides limited fisheries values (primarily migratory) due to the current lack of submerged habitat complexity. The regeneration of a habitat is a slow process and may take many years or additional interventions to completely recover and reach targets D5 and D11. Should improvement become impeded with no continued benefit over the next 5 years, further action should be considered to elevate the contribution to biological productivity. An indication of success should be represented by the development of diverse and self-sustaining biotic communities with representation from all trophic levels.

Table 14:McKellar Embayments Habitat Characteristics and Classification.

McKellar Embayments Ranking and Classification Based on Habitat Values			
Habitat Characteristics	**Rating**	**Criteria**	**Score**
WMI and Species Count	Moderate	• Neutral U-Values (2-3) and T-Values (2) • Moderate Species Diversity, <10 species.	2
Species Density	Low	• Low density (Sparse = 1-25%) • Sparse patches of vegetation occurring in smaller stands and single strands.	1
Substrate	Low	• Silty-mud and sand substrates poor for vegetation rooting, limiting growth or stability • Easily resuspended and mobile substrates increasing turbidity.	1
Water Quality	Excellent	• Sustainable temperature 15-19.9 ºC for diversification of species. • pH level range 6.5-7.5, ideal for aquatic biota. • High dissolved oxygen levels >7mg/L. • Low levels of conductivity <150 µS/cm.	4
Turbidity	Low	• High turbidity impedes photosynthetic processes of macrophytes. • >1m in the spring and remained considerably turbid in the fall.	1
Habitat Buffer Zone	Moderate	• Meets the required 30m buffer, but otherwise surrounded by impervious surfaces, residential industrial activity.	3
		Total	12
Habitat Ranking and Classification	**Moderate**	Important to the ecological functioning of the watershed or estuary. Direct contributions to fishery values are limited. Not known to support key lifecycle stages but may be important for migration.	

5.2 Neebing-McIntyre Floodway

The sonar survey consisted of the river channel and the delta extending 200m out from the shoreline, reaching a total area of 166,276m^2. The stitched side-scan mosaic displayed the river channel and depth changes with detail, showing the effects of the outflow on the delta. The scanned imagery revealed a high degree of anthropogenic influence, from dredge markings within the channel to an abundance of tires scattered within the location. During data collection, it was noted that there was little boat traffic within the immediate area due to the high degree of fluctuation in depth. Although the waterway is not ideal for public use, the paved walkways and trails had many visitors, indicating an appreciation for the aesthetics and the locations use for recreation.

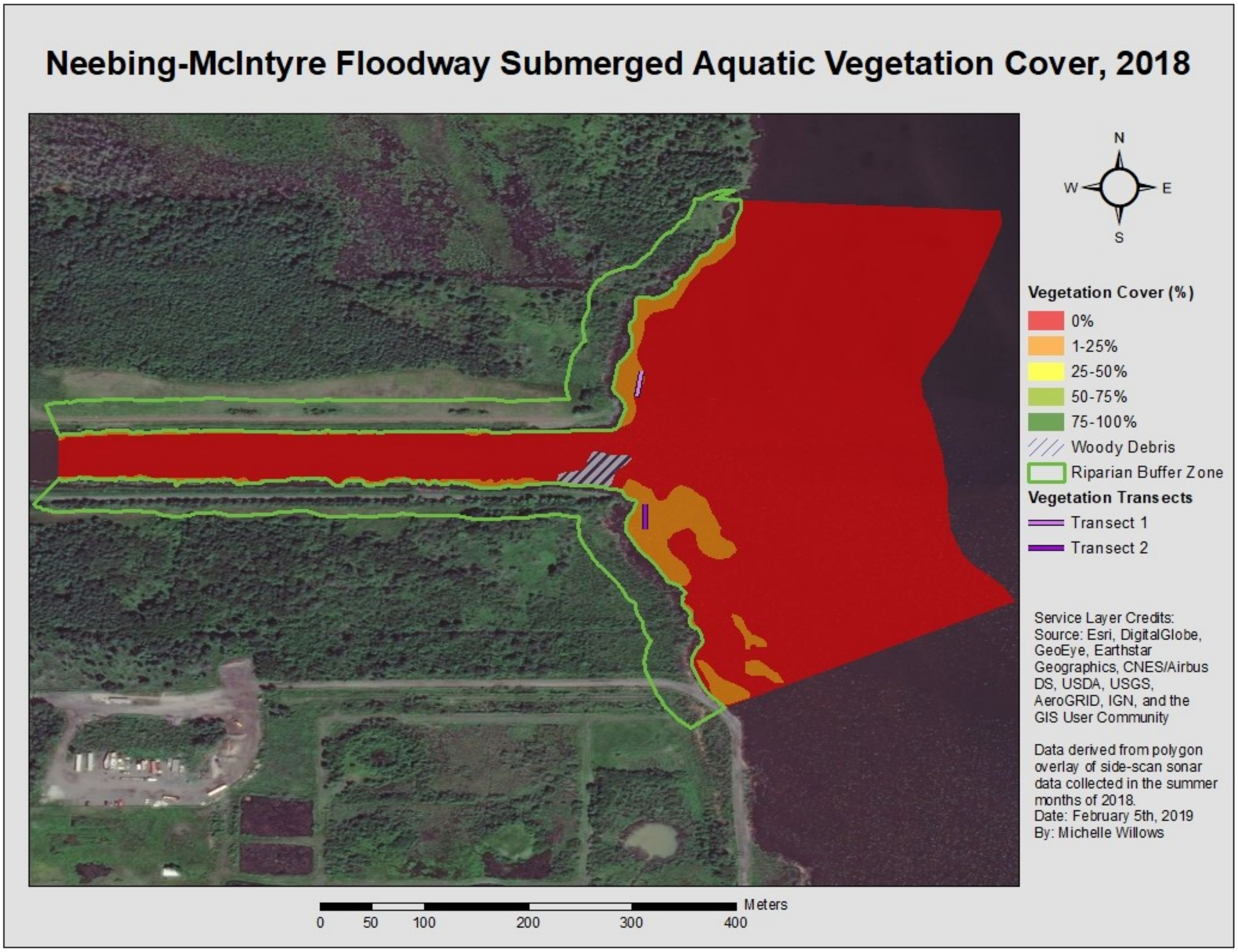
The location experienced high turbidity and a strong current from the river for the duration of the season. Due to the safety concerns of diving in high flowing water with extremely low visibility, transects along each side of the floodway were completed by boat using Sea

Viewer “Sea Drop 950", with GPS video overlay. Two transects were conducted along either side of the floodway shoreline and within areas previously reported to have a thin strip of vegetation (RAP, 2012). The original blueprints and stated goals/objectives of the remediation project indicated that embayment features were developed within the river channel. However, these features were not identified during data collection.

Submerged Aquatic Vegetation

The conditions are unfavorable for macrophyte colonization, affecting the physical ability for macrophytes to successfully grow within the channel and floodway. Of the total scanned location, only 299m^2 had some macrophytic growth (Figure 23). The channel experiences high hydraulic energy which resuspends fine-grained substrates within the floodway. The high turbidity limits light penetration to the rooted submersed aquatic macrophytes (Madsen et al., 2001) restricting abundances to 1-25% along the northern and southern transects (Figure 23). Transect one had four species present throughout the season including: Canadian Waterweed (Elodea canadensis), Richardson’s Pondweed (Potamogeton richardsonii), Tape Grass (Vallisneria Americana) and Pondweed (Potamogeton sp.). The sonar imagery indicated low density with only moderate plant height (Figure 24). Transect two only had two species present, Richardson Pondweed (Potamogeton richardsonii) and pondweed (Potamogeton sp.), sparsely distributed in small patches with sporadic strands extending into the deeper water (Figure 25).

Although there was limited submerged macrophyte colonization, the delta shoreline was lined with large woody debris, old tree stumps, and exposed rooting systems. The woody debris provides a degree of shoreline protection and additional habitat for juveniles and spawning fish. The woody debris should also assist in protecting the shoreline and assist in stabilizing sediments along the waterfront of the delta.


Neebing-McIntyre Floodway Submerged Aquatic Vegetation Cover, 2018

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Data derived from polygon overlay of side-scan sonar data collected in the summer months of 2018.
Date: February 5th, 2019
By: Michelle Willows

Figure 23: Neebing-McIntyre Floodway Submerged Aquatic Habitat Characterization.

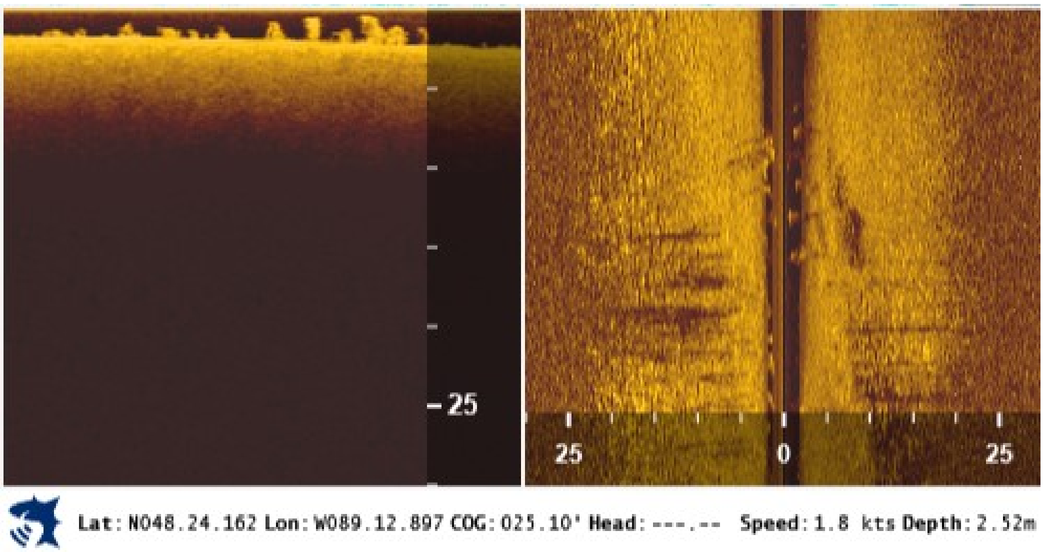


Figure 24: Neebing -McIntyre Sonar Imagery of Sparse Vegetation Cover Along Transect 1.

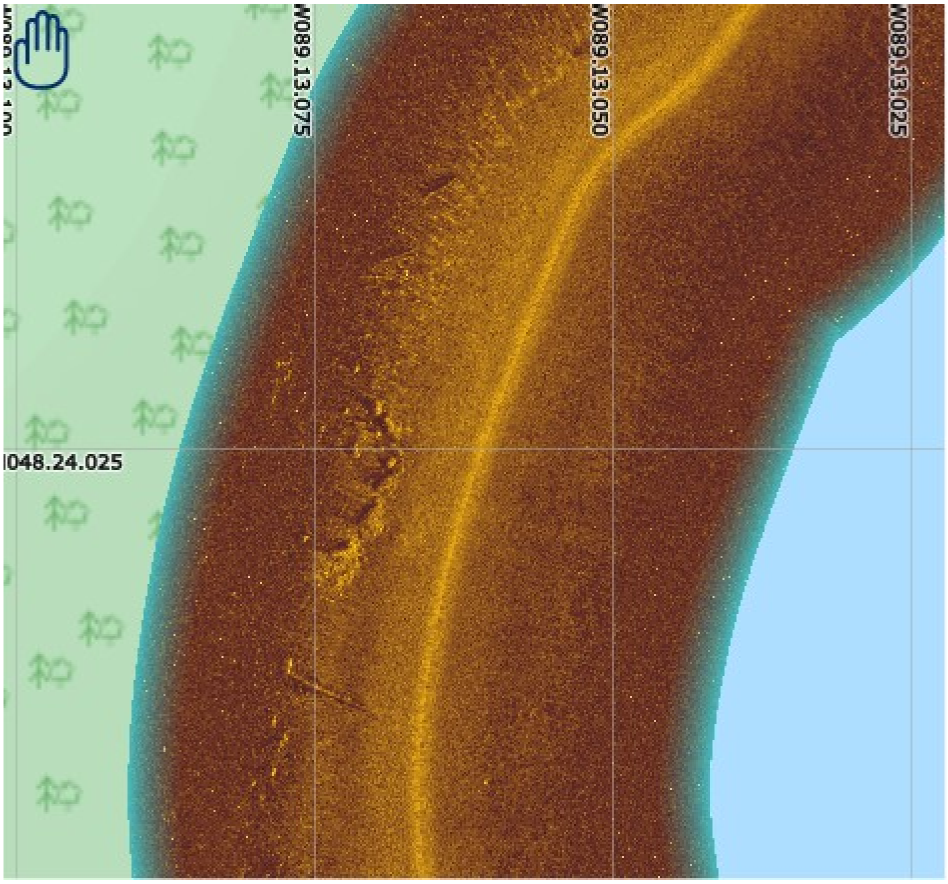


Figure 25: Neebing-McIntyre Sparse Aquatic Vegetation (Transect 1).

Based on the location's physical conditions, it is not surprising that the species present would exhibit low U and T values. However, due to the substrate present, 5 generalist species were identified and sampled along the two transects (Table 15). These species were either captured on the video imagery or rooted samples were collected by a gaff. The sampled species had features of wear and stress on the macrophytes. The color lacked vibrancy and leaves appeared to be tattered likely due to hydraulic action and suspended particulate. The central tenancy measures for the U-value indicated a mode of 1 and a median score of 2 (Table 15), indicating that the species present have a high tolerance to degraded habitat and water quality. The T-value indicated a score of 1, showing that the species present had a wide niche breadth (Table 15). The WMI score and species count resulted in an initial score of 1. The density of present macrophytes remained within 1-25% throughout the location also receiving a score of 1. The total score for submerged macrophytes based on the two independent categories was 2 for the Neebing-McIntyre Floodway (Appendix 1) (Table 15).

Table 15:Neebing-McIntyre Macrophyte Species for 2018 Season with U and T values.

Neebing-McIntyre				
Species List				
#	Taxon	Common Name	U-Value	T -
1	Potamogeton sp.	Pondweed	1	2
2	Potamogeton richardsonii	Richardson's Pondweed	3	2
3	Vallisneria americana	Tape/Eel Grass	3	1
4	Elodea canadensis	Canadian Waterweed	2	1
5	Myriophyllum sp.	Water-milfoil	1	1
MEDIAN			2	1
MODE			1	1

Substrate

The substrate along the shoreline consisted of coarse sand, as depicted within the side-scan sonar imagery (Figure 26). The brighter contrasts within the ripples indicate a coarser material such as sand or small gravel (Figure 26, right). Both symmetrical and bidirectional ripples could easily be seen, indicating current feedback from the river channel and a shoreline dominated by wave oscillations seen in Figure 26 (Southard et al., 1990). These coarser substrates do not adequately retain nutrient levels to sustain large patches of vegetation. Additionally, the shallow depth leads to high disruption and movement affecting the success of macrophyte rooting.

Depths varied along the delta potentially influencing pockets of sedimentation and contributing to the continuous changes in relative hardness levels (seen in Figure 30). Inadequate sonar depth range may have influenced the full E2 return as the depth was shallower than 5ft at times along transect one and two. Additionally, abrupt moving substrate in the surf or submerged vegetation patches may have interrupted the return causing a lower hardness level. Regardless, the variation in depth and substrate hardness adds complexity to the habitat that is lacking in vegetation. It was also noted that this location had a significant number of tires present along the waterfront, indicating continued anthropogenic impact on the habitat (Figure 27).

The river channel had a maximum depth of 10ft with fairly straight channel walls (Figure 28). The channel had grassy banks with silty-sand sediment (in-field visual reference), transitioning to a fine-grained packed silty-clay substrate in the middle of the channel (Figure 28). Sonar imagery and ground-truthing confirmed a silty-clay composition mid-channel as indicated by the darker sonar returns and texture (Figure 28). Bottom composition profiles (Figure 30) had lighter colored hardness returns, indicative of a softer substrate, with some compaction increasing the hardness level. The low volumes of macrophyte biomass lead to active resuspension of the small particulates, contributing to higher turbidity levels in the river and within the delta. The embayment features, including the bolder pilings, wood pilings, and log mats described within the rehabilitation plans, did not stand out on the surface of the water and were not distinctive on the side-scan sonar imagery as indicated in the original rehabilitation plans (Figure 29).

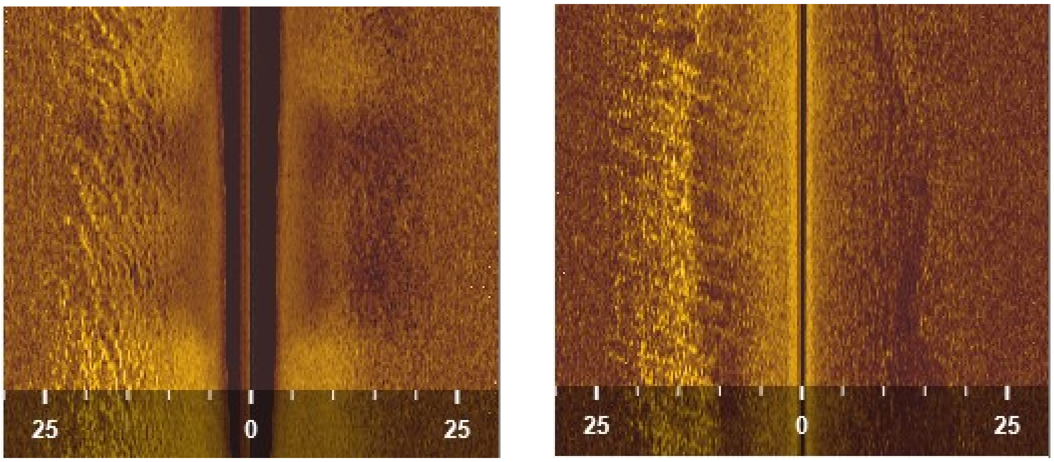


Figure 26: Side Scan sonar Imagery of Bidirectional Sand Ripples (left), with Distinct Symmetrical Ripples (right).

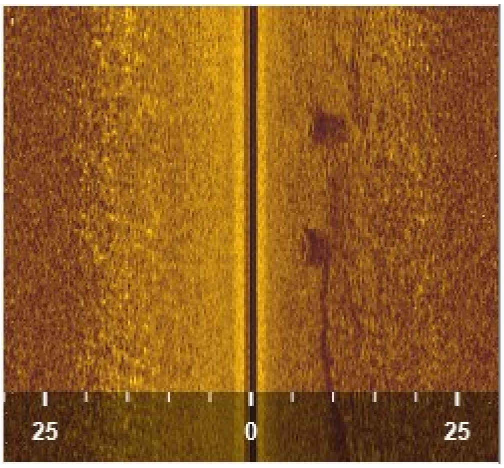


Figure 27:Side Scan Sonar Imagery of Tires.

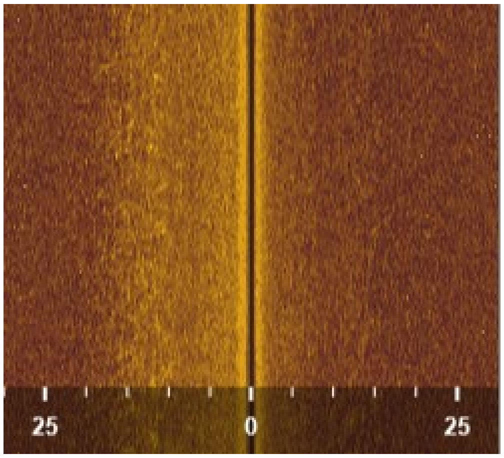


Figure 28:Side Scan Sonar of Fine Substrate.

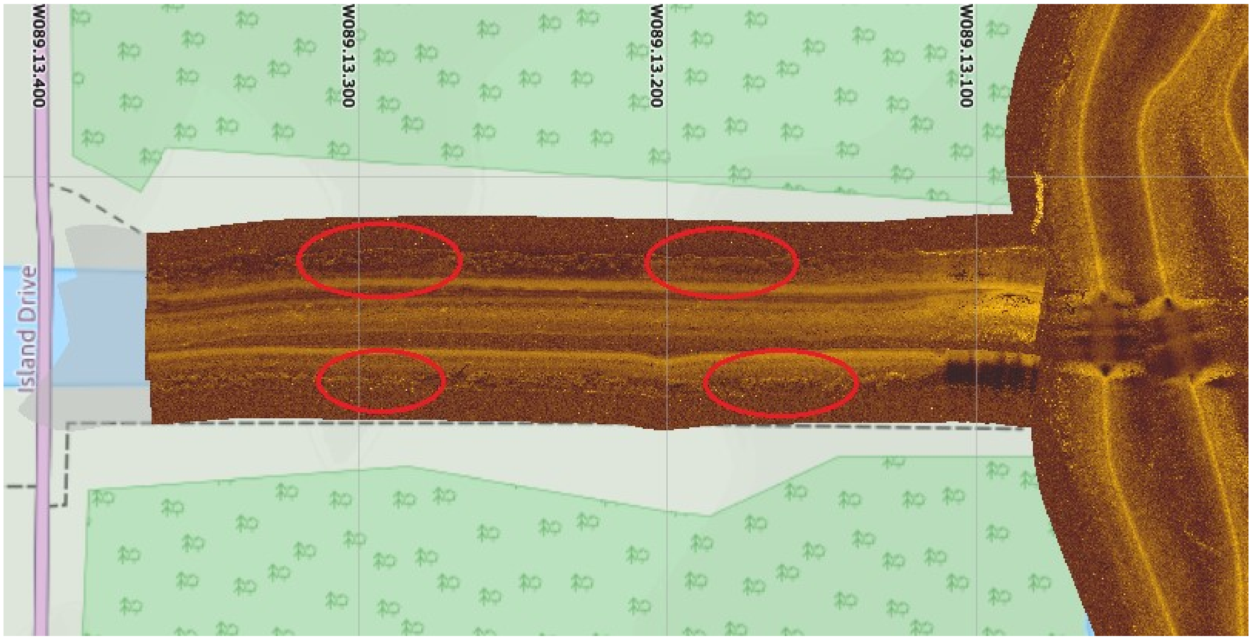


Figure 29: Neebing-McIntyre Side Scan Sonar Imagery of Channel Substrate with Approximate Location of Embayments.

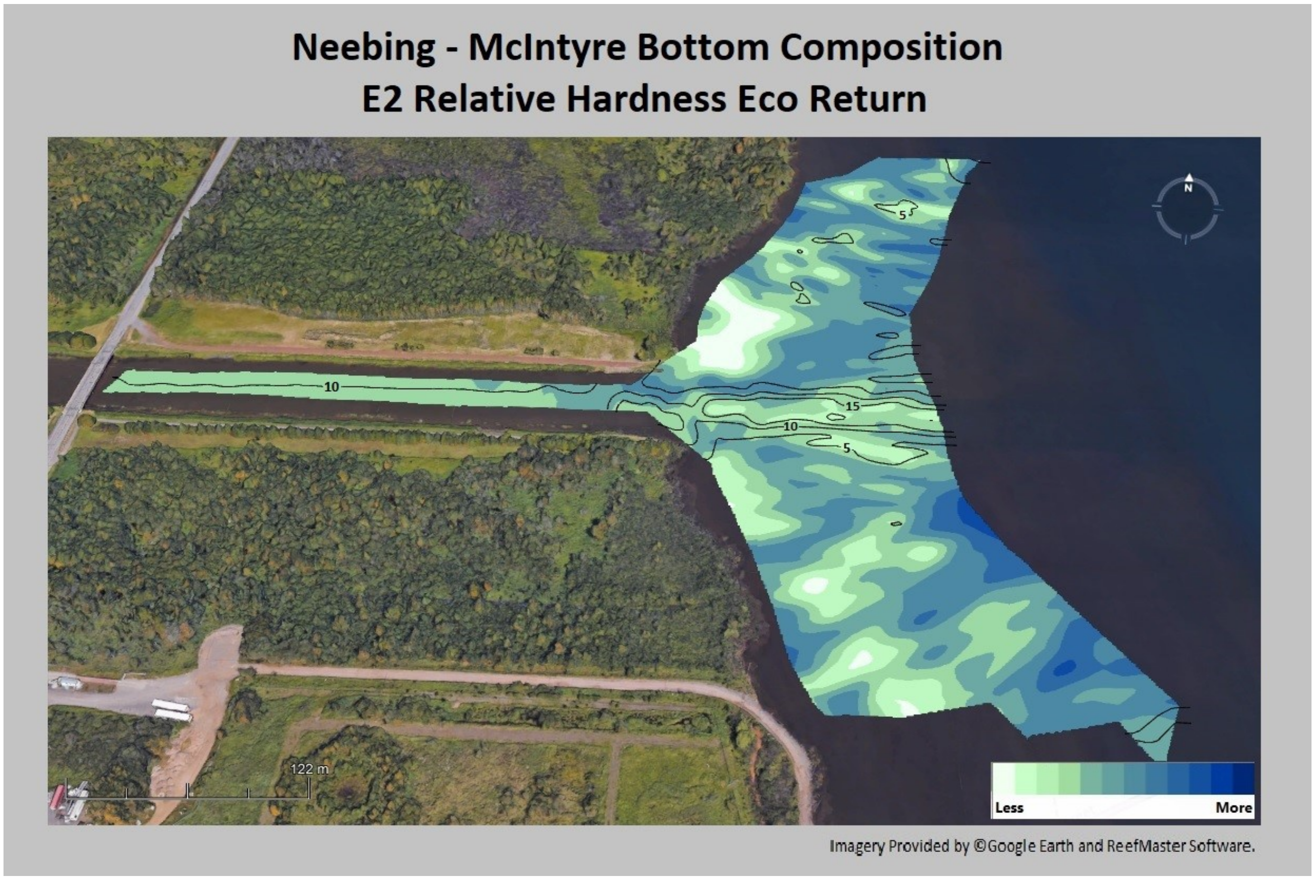


Figure 30: Neebing-McIntyre Bottom Composition Indicating E2 Relative Hardness Eco Returns.

Based on these results, the substrate received a score of 1 due to its homogenous nature. Although there were some variations in the granular size of the substrate, the silty-clay channel and sand-based delta are not ideal for a flourishing species-rich habitat. The substrate was easily resuspended with hydraulic flow affecting the turbidity levels within the channel and floodway and hindered macrophyte success (Kerr, 1995). Furthermore, these substrates are not ideal for spawning, specifically for salmonids that favor coarser material such as rock material or cobble. Additionally, the high turbidity and fine particulates reduce potential spawning activity and prevent the incubation of eggs. These characteristics hindered the final substrate scoring and limit habitat value.

Water Quality

Due to the location of the site and boat availability, water quality readings were taken late spring and late fall. The initial temperature readings were just slightly below 20°C along each transect (Table 16). The elevated temperature is likely linked to the time of the season and the level of turbidity from suspended particles in the floodway absorbing more heat. Fall readings were significantly lower due to the drop in atmospheric temperature and increased precipitation leading to a distinct decrease in water temperature ranging from 5-6°C. The summer temperatures fall within sustainable levels for optimal growth for the majority of freshwater fish families, except for Salmonidae, which requires temperatures below 15°C (Table 1). Fall temperatures are too low for the final temperature preferendum of all families. However, they meet the optimal spawning and egg development temperature for Salmonids, specifically Whitefish (*Coregonus clupeaformis),* which are known to spawn in the fall (Table 1).

Table 16*: Neebing-McIntyre Water Quality Results for Fall/Spring 2018.*

Neebing - McIntyre Water Quality 2018										
Spring										
Date	Transect #	Temp °C	mmHg	DO %L	DO mg/L	DO ppm	SPC	pH	ORP Mv	Turbidity Bottom (BTM)
13/07/18	T1	19.8	744.5	79.7	7.1	7.1	364.7	7.4	349.7	51cm
13/07/18	T2	19.8	744.4	83.6	7.5	7.5	364.7	7.5	346.2	64cm
Fall										
25/10/18	T1	6.1	746.6	108	10.6	10.6	127.3	7.2	303.3	92cm (BTM)
25/10/18	T2	5.4	746.5	103.7	10.3	10.3	168.6	7.3	297.5	94 cm (BTM)

Industrial and residential runoff in the early spring increased the number of dissolved ions and nutrient levels within the river. Levels indicated moderately enriched waters reading 364 µS/cm in the spring. The increased conductivity is likely due to higher water levels and seasonal flooding from meltwater from the urban surface. Levels dropped in the fall to 127 µS/cm to 168 µS/cm which is more sustainable for biotic life and only considered slightly enriched.

Patterns in temperature and conductivity correlate with the dissolved oxygen content of the water. Spring measurements had significantly lower dissolved oxygen concentrations than the fall. The high temperature and turbidity reduced saturation potential in the late spring, producing dissolved oxygen levels that ranged from 7.1 mg/L to 7.5mg/L (Table 16). These readings are significantly lower for a river system but remain within the sustainable range for biotic life. A drop in atmospheric temperature, reduced turbidity, and wave energy increased aeration to the point where fall dissolved oxygen levels exceeded saturation with readings reaching above 100% and recorded concentrations of 10.6 mg/L and 10.3mg/L along the transects in the fall (Table 16). These rates are more characteristic of a river system. Although pH can affect dissolved oxygen levels, readings remained neutral throughout testing and did not exceed 8.0, which is ideal for biota and spawning activity.

Turbidity was significantly high in the spring ranging from 51-64cm due to the silty-clay substrate within the river channel. The depth along the transects was <5ft in some locations, but at no point was the water clear enough to see the bottom in the spring. The high turbidity levels influenced the temperature, dissolved oxygen, and photosynthetic processes of plant life. Turbidity levels this high can be detrimental to stream biota, as the smaller particles can physiologically affect organisms and prevent plant growth. The level of turbidity decreased in the fall, and although there was still a significant amount of particulates in the water column, the Secchi disk could be seen on the bottom. Turbidity decreased further down the shoreline, indicating that the hydrology and substrate composition of the floodway contribute to the lack of water clarity. The water quality parameters tested with the Multi-Parameter Handheld Meter indicated excellent conditions resulting in a score of 4, however, the turbidity influenced the location substantially resulting in a score of 1 (Appendix 1). The final score for the water quality parameters within the Neebing-McIntyre Floodway was a total of 5 (Table 17).

Riparian Buffer Zone

The riparian buffer zone almost meets the 30m requirements along the shoreline within the study area (Figure 23). However, paved walking trails line the channel banks and increase impervious surfaces along the river (Figure 23). These trails prevent the buffer-zone from directly meeting the riverbank, reducing shade, and decreasing the filtration of water entering the river system. Beyond the trails is a grassy terrain followed by a densely forested area on either side of the river delta. Having the >30m forestation will assist in any runoff or degradation that may occur from adjacent industries of the study location.

Although there is a vegetation buffer at the river delta, there is approximately 2km of residential housing and industrial property along the upper portion of the river (Figure 31). The large volume of impervious surfaces has likely led to increased runoff into the river system, potentially influencing conductivity, pH, and dissolved oxygen. Additionally, a degree of habitat fragmentation occurs from the roadway to the south of the river that directly lines the waterfront (Figure 31). Even though there is some buffer at the river mouth, the upstream influence affected the final score, receiving a 2 (Appendix 1). These upstream and surrounding habitat influencers should be considered when designing a remedial action plan.

Figure 31: Neebing - McIntyre River Channel Buffer Impedance. (Google Earth Satellite Imagery)

Habitat Classification

The ecological simplification caused by urban industrial development, river channelization, and the creation of the delta has resulted in a lack of structural and biotic complexity. The habitat was classified as ‘Moderate Value’ because the channel use is primarily migratory, and the river shoreline and delta consisted of limited spawning or rearing habitat (Table 17). Since the aquatic habitat is a river delta, lower volumes of macrophytes can be expected from strenuous conditions. The silty-clay substrate within the river channel contributed to the low score and increased turbidity limiting epifaunal diversity (Table 17). However, the shoreline had additional woody debris and a series of tree roots exposed, which could compensate for the lack of macrophytes by providing shoreline fish habitat. The current buffer zone directly lining the river requires greater habitat variance to contribute to dynamic connections within the main channel. The addition of taller trees with larger rooting systems will increase the amount of shade, stabilize temperatures, and reduce runoff. A more suitable habitat buffer will benefit the aquatic environment and improve fish and wildlife habitat.

Table 17: Neebing-McIntyre Habitat Characteristics and Classification.

Neebing-McIntyre Ranking and Classification Based on Habitat Values			
Habitat Characteristics	**Rating**	**Criteria**	**Score**
WMI and Species Count	Low	• Low U-Values (1) and T-Values (1). • Low species diversity, <5 species.	1
Species Density	Low	• Low density (Sparse = 1-25%) • Sparse patches of vegetation occurring in smaller stands and single strands.	1
Substrate	Low	• Silty-mud or sand substrates poor for vegetation rooting, limiting growth or stability • Easily resuspended and mobile substrates increasing turbidity.	1
Water Quality	Excellent	• Sustainable temperature 15-19.9 ºC for diversification of species. • pH level range 6.5-7.5, ideal for aquatic biota. • High dissolved oxygen levels >7mg/L. • Higher conductivity in the spring 364µS/cm and lowered to 168µS/cm in the fall.	4
Turbidity	Low	• High turbidity impedes photosynthetic processes of macrophytes. • >1m in the spring and remained considerably turbid in the fall.	1
Habitat Buffer Zone	Fair	• Close to achieving 30m minimum buffer, with patch's or gaps of missing vegetation due to brown zones.	2
		Total	10
Habitat Ranking and Classification	**Moderate**	Important to the ecological functioning of the watershed or estuary. Direct contributions to fishery values are limited. Not known to support key lifecycle stages but may be important for migration.	

The overall low habitat complexity and linear shoreline offers little littoral habitat or riverine diversity, limiting the abundance of fish and wildlife populations. It is unlikely that the restoration efforts contributed to the Target D2 (Table 9) within the delisting criteria for Loss of Fish and Wildlife Habitat as the embayment features were not detectable and do not appear to contribute significantly to fish habitat. The habitat may be important to the ecological functioning of the watershed, but it is direct contribution to fisheries values are limited. It is unlikely that the floodway supports key lifecycle stages but may be important for the migration of fish. Continued monitoring should assess the presence of fish within the location. If there are limited populations and diversity, further remediation should be implemented to increase habitat complexity.

5.3 NOWPARC

The total scanned area was approximately 205,785m², requiring a minimum of four transects for an adequate comprehension of the location. Previous studies indicated that there was some vegetation growth, but further detail on the full extent was limited (Willows 2014). The transects were chosen to gain a full understanding of the habitat's complexity and to gauge the degree of revegetation within the manmade berms. Transect one was located in front of the small island and is subjected to high volumes of hydraulic activity from Lake Superior. Transect two was placed within the first embayment area along the shoreline (Figure 40). Transects three and four were set up within the additional berms where sedimentation and vegetation colonization were suspected as they are protected from Lake Superior. The remainder of the location was subject to side-scan sonar imagery analysis.

Submerged Aquatic Vegetation

Submerged aquatic vegetation covered approximately 24% (48,409 m²) of the location, with patches varying in density and diversity. A total of 16 species were collected and identified along the four transects (Table 18). Various patches of woody debris, covering a total of 8,762m^2, assisted in the colonization of macrophytes and added to the complexity of areas without growth. The density and species of submerged aquatic macrophytes varied between each transect as they exhibited different substrates and hydrodynamic parameters. Ideal vegetation abundances covered approximately 6,820m², consisting of patches within the berms and growth along the various depth contours (Figure 40).

Table 18: NOWPARC Macrophyte Species List for the 2018 Season with Assigned U and T values.

NOWPARC				
Species List				
#	Taxon	Common Name	U-Value	T-Value
1	Elodea canadensis	Canadian Waterweed	2	1
2	Myriophyllum sp.	Water-milfoil	1	1
3	Nitella sp.	Stonewort	3	1
4	Potamogeton sp. (1)	Pondweed	1	1
5	Potamogeton Obtusifolius	Bluntleaf Pondweed	2	1
6	Chara sp.	Muskgrass	3	2
7	Potamogeton richardsonii	Richardson's Pondweed	3	1
8	Myriophyllum spicatum	Eurasian water-milfoil	1	1
9	Utricularia vulgaris	Common bladderwort	3	2
10	Myriophyllum sibiricum	Northern (common) water-milfoil	3	2
11	Potamogeton robbinsii	Fern-leaf pondweed	1	2
12	Myriophyllum alterniflorum	Alternate water-milfoil	5	3
13	Potamogeton crispus	Curly-leaf pondweed*	1	1
14	Vallisneria americana	Tape grass, eelgrass	3	1
15	Ranunculus sp.	Crowfoot	2	1
16	Myriophyllum heterophyllum	Two-leaf water-milfoil	3	2
MEDIAN			3	1
MODE			3	1

The first transect had a low volume of vegetation (1-25%) (Figure 32), consisting of only Canadian Waterweed (*Elodea canadensis)*, Pondweed (*Potamogeton sp.*) and Crowfoot (*Ranunculus*). These types of vegetation all have a low U-Value and T-Value, indicating that they have a high tolerance to degradation and have a broad niche in which they can survive. These were likely the only species that could root in the coarser sand substrate, while simultaneously receiving high volumes of fetch from the high exposure to the lake. The abundance and densities remained the same in the fall, with only limited new growth (Figure 33). Due to the hydraulic influence of Lake Superior, substrate composition and shallow depth macrophyte success is limited from regular disturbance and limited nutrient availability.

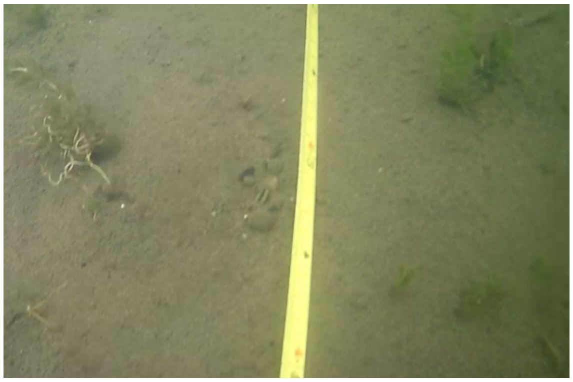


Figure 32: Spring Transect 1 with 1-25% Vegetation Cover.

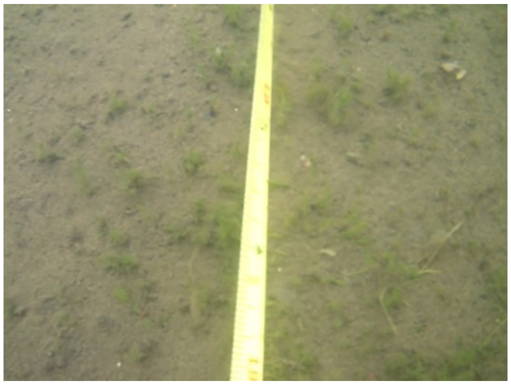


Figure 33: Fall Transect 1 with 1-25% Vegetation Cover.

Transect two, although within the same bay region, was slightly more sheltered by the extending rock-filled berm. Vegetation levels were low ranging from 1-25% coverage in the early spring (Figure 34), increasing to approximately 25-50% coverage at the end of the season (Figure 35). They incorporated the same species as transect one, with the addition of Stonewort (Nitella sp), Northern Milfoil (Myriophyllum sibiricum), Eurasian Milfoil (Myriophyllum spicatum) and Curley-leaf Pondweed (Potamogeton crispus). While these species have a broad niche preference and there is a presence of invasive species, it was noted that Stonewort has a U-value of 3 as they are less tolerant of degraded habitats.

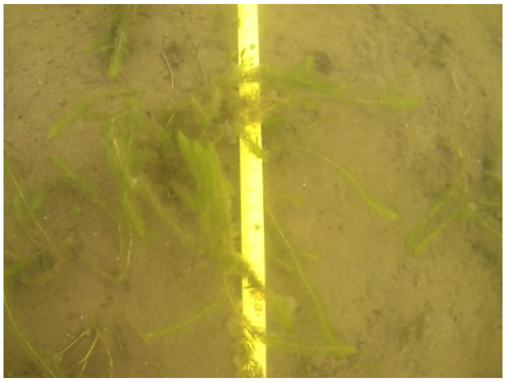


Figure 34: Spring Transect 2 with 1-25% Vegetation Cover.

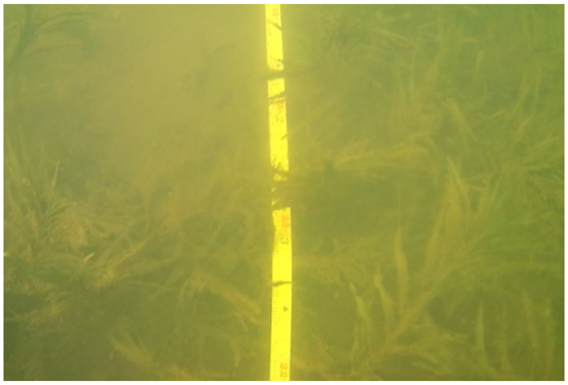


Figure 35:Fall Transect 2 with 25-50% Vegetation Cover.

The third transect was located within the first two man-made rock berms, spanning out across the mid-section, perpendicular to the shoreline (Figure 40). Submerged vegetation cover was extremely high ranging from 75-100% for the entire transect all season (Figure 36 and 37). Species diversity improved over the season with a total of 5 species in the spring, increasing to 9 species identified in the fall. Species such as Alternate Water-milfoil (Myriophyllum alterniflorum) and Richardson's Pondweed (Potamogeton richardsonii) were present, which have a mid-niche breadth and are significantly less tolerant of degraded habitat. The macrophyte growth and diversity indicates that the habitat alterations implemented were successful in increasing habitat value.

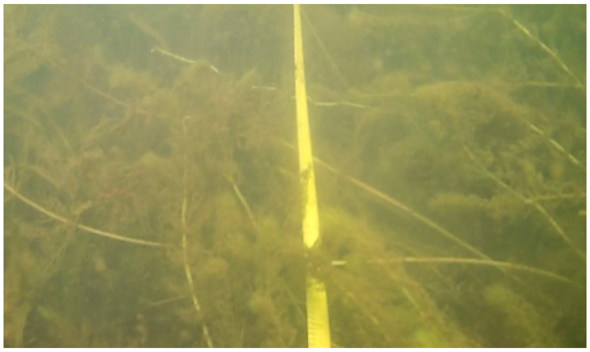


Figure 36:Spring Transect 3 with 75-100% Vegetation Cover.

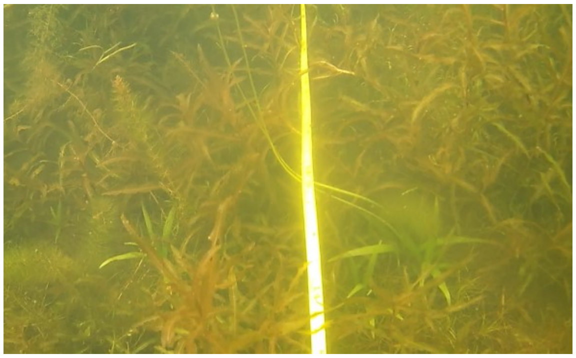


Figure 37: Fall Transect 3 with 75-100% Vegetation Cover.

The final transect was within the next embayment area perpendicular to the shoreline (Figure 40) and had less vegetation coverage in the spring ranging from 50-75% coverage along the transect (Figure 38). Patches of the substrate could be easily seen through the new vegetation growth (Figure 38). Macrophyte coverage increased to 75-100% in the fall as additional growth occurred and existing vegetation grew substantially (Figure 39). The vegetation stand was more homogenous than transect 3, with a top-heavy canopy and lower biomass covering the substrate. The predominant vegetation was Bladderwort (*Utricularia sp*) and Fern-leaf pondweed (Potamogeton robbinsii). The vegetation density transitioned near the middle section of the embayment area, becoming sparser, with patches of the substrate showing along the transect. Sedimentation within the embayment promoted growth and reproduction in the early season.

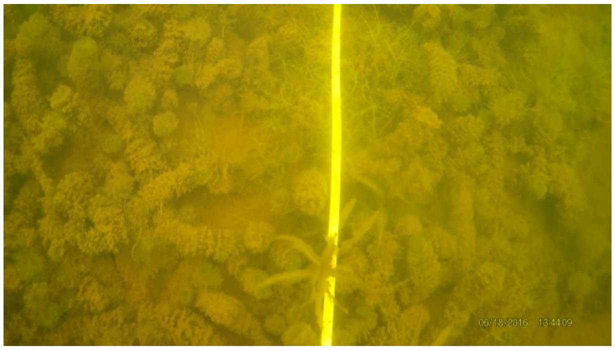


Figure 38: Spring Transect 4 with 50-75% Vegetation Cover.

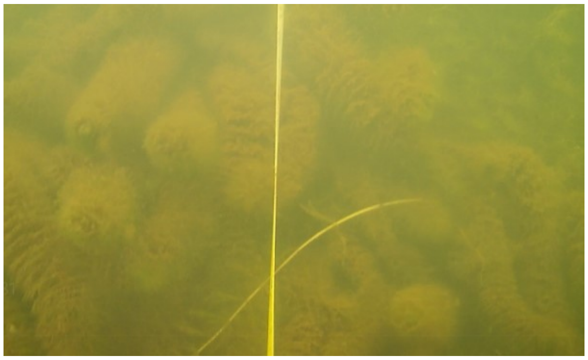


Figure 39: Fall Transect 4 with 75-100% Vegetation Cover.

A significant variety of species was present with a U-value of 3 and T-value of 1, indicating neutrality to habitat degradation and broad niche. The macrophyte growth added complexity and diversity to the location. The WMI and species count was considered high resulting in a score of 3. The submerged macrophytes occurred in patches of varying density throughout the habitat, which is effective for hiding, foraging, and hunting. Macrophyte growth was most successful within the berms, but large patches of substrate throughout the remaining habitat created a degree of fragmentation. Patches of 75-100% occurred only within the extending man-made berms, while the remaining habitat consisted mainly of patches 1%-25% and 25%-50%. The location received a score of 3 as macrophyte cultivation has been successful, but continued growth will further improve the score to an ideal fisheries value. The final score for submerged macrophytes within the Northern Woods location was 6.

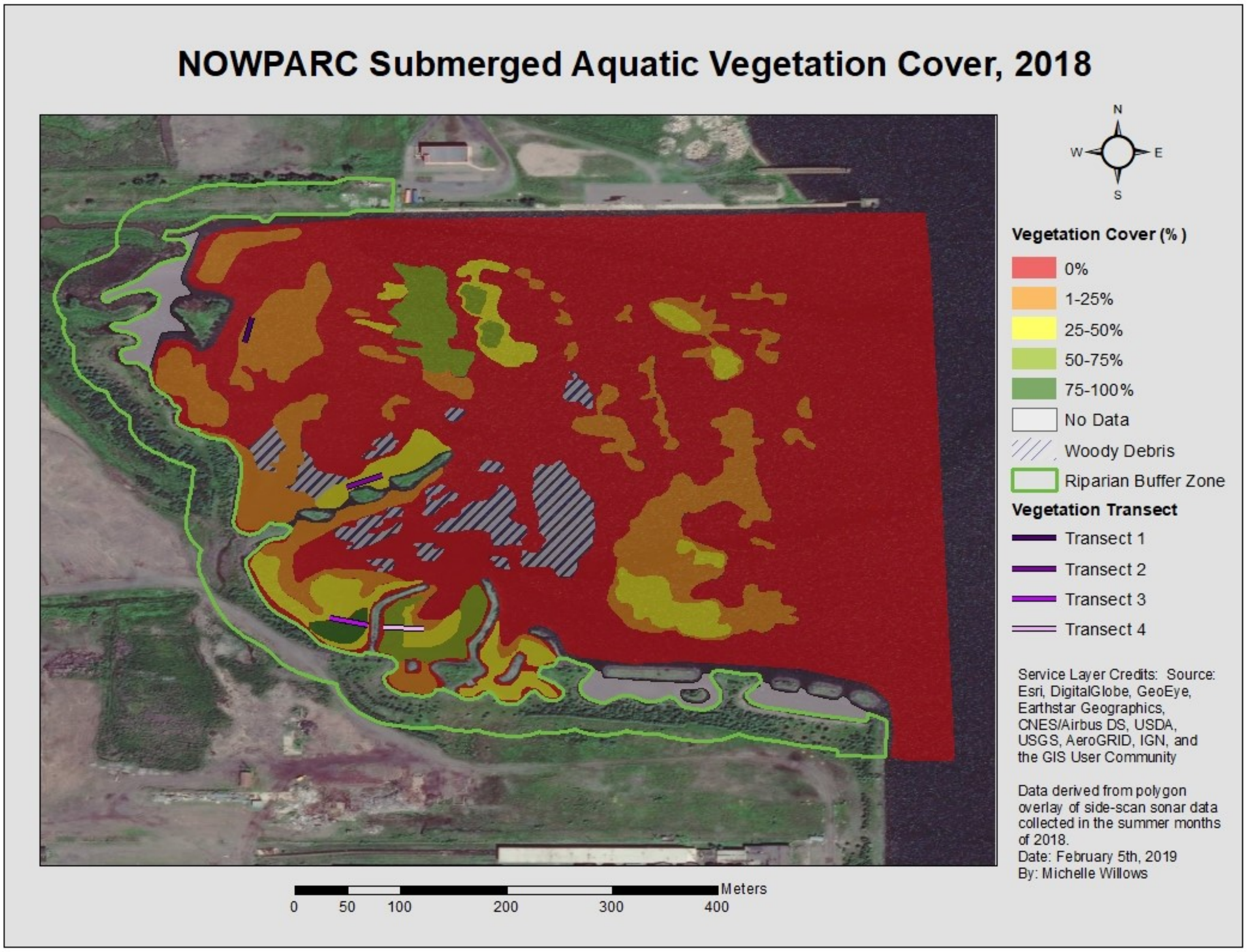


Figure 40:Northern Woods Submerged Aquatic Habitat Characterization.

<u>Substrate</u>

The Northern Woods location has a complex substrate structure varying substantially across the engineered formations. The back shoreline of the habitat was shallow, only reaching to 5ft in depth and is highly susceptible to hydraulic influences of open Lake Superior. The substrate on transect one along the back shoreline was comprised of sand, gravel, and wooden logs (Figure 41). The video footage of the transects and relative hardness returns of the bottom composition reaffirm the extent of these coarser substrates (Figure 44). As the depths increase to 10ft, substrates shift to a silty-sand composition, prompting productive vegetation growth with the development of dense macrophyte stands. A shift to a silty clay bottom composition occurs with depth past 20ft (typical of Lake Superior) and shows a lighter E2 hardness return (Figure 44). The small particle size, reduced pore size, and limited light penetration prevented the successful growth of macrophytes past the 15ft range (Figure 40 and Figure 44).

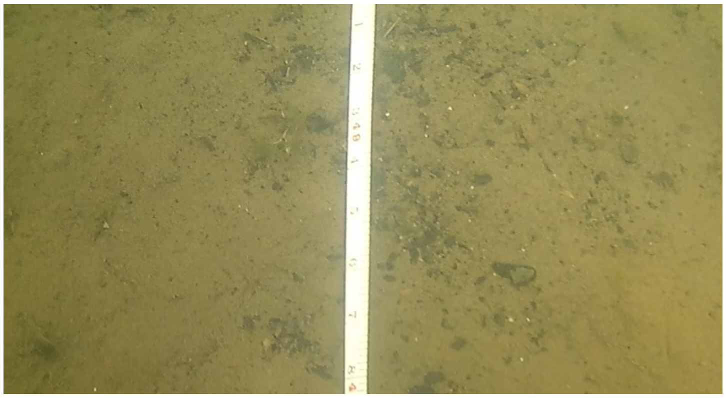
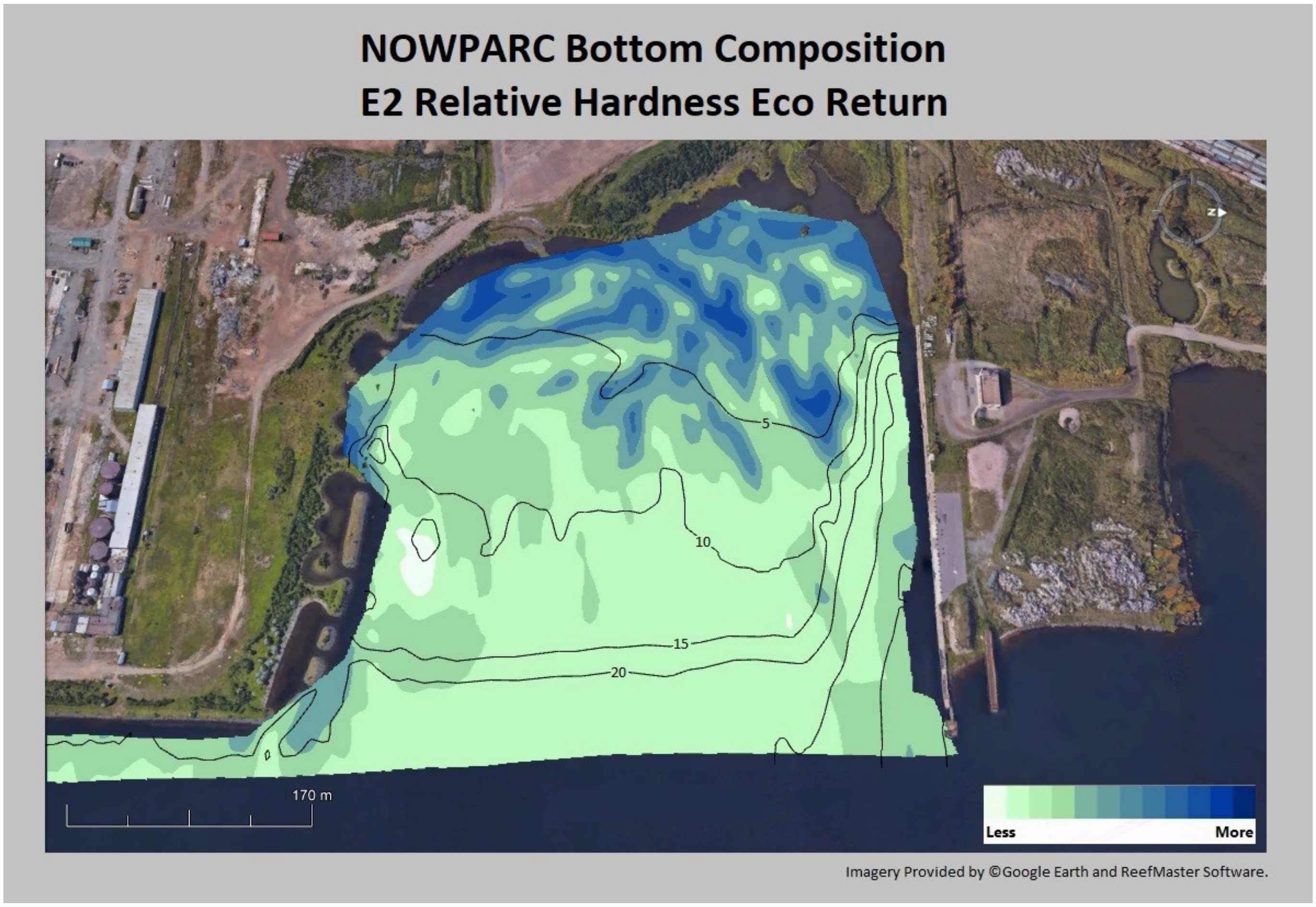


Figure 41: Transect 1: Sand substrate with gravel.

The manmade berms were successful in facilitating sedimentation for productive macrophyte growth. The berms were constructed of large boulders and gravel, creating a steep incline into the macrophyte beds, resulting in abrupt changes in habitat structure. Large mats of vegetation along transect 3 and 4 made the substrate difficult to distinguish through the canopy. Using both the relative hardness returns and transect imagery, it was determined that the primary substrate consisted of a silty-sand within the berms with a layer of small woody debris atop (Figure 42). The large quantities of submerged vegetation within the berms led to a reduction in wave action and increased sedimentation. It was noted in the fall that transects 3 and 4 had a fine layer of sediment and algae settle out atop the vegetation canopy (Figure 43). This can inhibit continued macrophyte growth and prevent photosynthetic processes that limit the productive potential of the vegetation stands.

Figure 42:Transect 3, Silty Sand Substrate with a Layer of Woody Debris.

Figure 43: Transect 4, Sedimentation atop of Macrophyte Canopy.



Imagery Provided by ©Google Earth and ReefMaster Software.

Figure 44: Northern Woods Bottom Composition Indicating E2 Relative Hardness Eco Return.

The final score for substrate in the Northern Woods location was 3, indicating a high value due to its diversity within the berms and along the shoreline (Appendix 1). The location has porous enough substrate to promote successful macrophyte growth within the berms to create an ideal environment for nursery grounds. The berms themselves were made from larger cobble and there was gravel present along the shoreline, both are considered adequate spawning substrate. The varying substrate types, from sand and gravel to silt and clay, increased the habitat complexity throughout the location and provided significant fisheries value along the industrialized shoreline.

<u>Water Quality</u>

The location had lower overall temperatures throughout the season, likely due to its direct proximity to the open waters of Lake Superior. The spring temperatures ranged from 15-17°C decreasing to around 14°C in the fall (Table 19). Due to accessibility, transect 1 was completed later in the season because of boat availability. Either way, the temperature range is optimal for pelagic fish (Table 1) and is also within a suitable range for successful invertebrate cultivation, enabling a sustainable food chain within the location.

Table 19:NOWPARC water quality testing results for Fall/Spring 2018.

NOWPARC Water Quality 2018										
Spring										
Date	Transect #	Temp °C	mmHg	DO %L	DO mg/L	DO ppm	SPC	pH	ORP Mv	Turbidity Bottom (BTM)
04/07/18	T1	17	748.7	107.6	10.3	10.3	128.3	7.5	347	78cm (BTM)
04/07/18	T2	15.2	750.2	104	10.3	10.3	128.8	7.5	356	125cm (BTM)
04/07/18	T3	15	750.4	103.2	10.3	10.3	128.1	7.7	353.6	152cm (BTM)
04/07/18	T4	15.1	750.5	104.3	10.3	10.3	128.5	7.5	336.8	187cm (BTM)
Fall										
19/10/18	T1	6.7	732.8	95.1	9.5	9.5	121	7.2	330	86cm (BTM)
25/09/18	T2	13.9	742.2	92.1	9.3	9.3	133.2	7.3	223.7	137cm (BTM)
25/09/18	T3	13.8	742.1	92	9.3	9.3	122.8	7.2	302.7	149cm (BTM)
25/09/18	T4	14.2	742.3	95	9.5	9.5	142.5	7.2	285.5	197cm (BTM)

The four water quality tests at this location in the spring indicated a pH level of 7.5, just slightly above absolute neutral (Table 19). These levels dropped slightly in the fall, ranging from 7.2 to 7.3, an ideal range for biotic production. The conductivity remained within sustainable limits throughout the season with only slight increases in the fall. The range between 128 μS/cm to 142 μS/cm indicated low concentrations of dissolved ions with minimal impact on biotic life and other water quality parameters. Heavy rain events in the fall may have increased runoff from the adjacent industrial property, increasing the conductivity measurement.

Dissolved oxygen rates varied within the ecosystem due to its complex substrates and habitat features. The locations overall dissolved oxygen content exceeded 100% in the spring and decreased in the Fall. Transect one experienced the highest volumes of dissolved oxygen of the four samples as it is more susceptible to aeration due to a higher volume of wave action and fetch. The samples within the man-made berms had a dissolved oxygen content of 10.4mg/L, with levels dropping to 9.3mg/L in the fall (Table 19). The drop in dissolved oxygen levels could be attributed to microbial decomposition, increased conductivity, and lower volumes of photosynthesis. Regardless of the slight decline, these levels of dissolved oxygen fall within the optimal range for sustaining aquatic biota. The standard testing indicated that the water quality was excellent and received a score of 4.

Overall the location had clear conditions ideal for prompting macrophyte cultivation and allowing for trophic engagement. Low turbidity levels were seen throughout the season as the Secchi disk was visible at all times during testing. Generally, the substrate could be seen through the clear water, but there were times in the spring where large precipitation events increased turbidity levels from runoff carrying particulates along the southwestern edge of the habitat. Dependant upon previous and current weather conditions, suspended solids from runoff could have an adverse effect on the macrophytes, inhibiting plant growth and photosynthetic processes by settling and covering vegetation stands. This phenomenon became apparent, specifically along transect 4, where the bladderwort species had a significant layer of silt that needed to be rinsed off before analysis. Due to this phenomenon, the location received a turbidity score of 3 (Appendix 1). The total score for the water quality was 7, indicating sustainable levels for supporting biotic life and success in rehabilitation initiatives.

Riparian Buffer Zone

The location is close to achieving the ideal 30m buffer but falls short due to compacted roadways and the presence of a gravel pit. This affected the overall habitat classification, receiving a score of 2 for the habitats buffer zone. Along the southern and western shoreline, vegetation meets the requirements with approximately 60m of vegetation on both sides. The buffer falls short along the southwestern curving edge, where it only ranges from 6-10m in thickness (Figure 40). This area experienced lower macrophyte density and diversity with noticeably higher volumes of suspended sediment in the water column. The landscape on the opposing side of the buffer consists of hard-packed roadways and pilings that increase the levels of runoff from the industrial property. Additionally, a small channel from the industrialized property leads into the first embayment area and would benefit from increased filtration that vegetation buffers provide. The location's remediation strategy has succeeded in adding complex habitat and promoting the development of diverse macrophytes. However, improving the buffer zone to meet the >30m recommendation would be highly beneficial for the continued recovery, protection of the habitat and would increase the habitat classification to the highest value.

Habitat Classification

The Northern Wood Preservers Alternative Remediation Concept was successful in achieving substantial habitat complexity, resulting in a high classification value (Table 20). The field data indicated a positive transformation exhibiting complex habitat features, substrates, dynamic macrophyte growth, varying depths, and a moderate amount of woody debris. (Table 20). The diverse macrophyte assemblages demonstrated the productive capacity of the engineered berms and the ability to increase habitat complexity and restore historic wetland areas. The berms create enough protection from fetch to promote adequate sedimentation and sustain growth, with water quality measurements that are ideal for the majority of fish families. The habitat is valuable to the Thunder Bay harbour as it does provide ecological function while breaking up the heavily industrialized shoreline. While the habitat is not necessarily rare or pristine, it likely contributes significantly to fisheries' values by providing adequate rearing and feeding habitat due to high dissolved oxygen levels and the various forms of cover from the open lake. Overall the project achieved its goal of creating a sustainable littoral zone.

Table 20: NORPARC Habitat Characteristics and Classification.

NOWPARC Ranking and Classification Based on Habitat Values			
Habitat Characteristics	**Rating**	**Criteria**	**Score**
WMI and Species Count	High	• High U-Values (3-4) and T-Values (2) • High species diversity <15 species.	3
Species Density	High	• Medium-sized patches of various densities from 25%-100%. • Varied macrophyte densities increase habitat complexity.	3
Substrate	High	• Complex substrate structure. • Consists of a clean cobble substrate, gravels, and silty sand with high nutrient content. • Porous enough to promote strong rooting.	3
Water Quality	Excellent	• Sustainable temperature 15-19.9 ºC for diversification of species. • pH level range 6.5-7.5, ideal for aquatic biota. • High dissolved oxygen levels >7mg/L • Low levels of conductivity <150 µS/cm	4
Turbidity	Moderate	• Low levels of turbidity, the substrate could be seen along each transect. • Some fluctuation in turbidity after large precipitation events.	3
Habitat Buffer Zone	Moderate	• Close to achieving 30m minimum buffer, with patch's or gaps of missing vegetation due to brown zones.	2
		Total	18
Habitat Ranking and Classification	**High**	Valuable to ecological functioning and contributes significantly to fishery values but is not necessarily rare or pristine. Typical of habitat compensation primarily successful but requires further adaption to fully offset habitat impacts. The area assists in key life cycle activities for species that contribute to fisheries.	

5.4 Sanctuary Island

Sanctuary Island has an extending berm to compensate for habitat destruction when the Howe Street overpass was built (Figure 45). The primary focus of this area was to determine if the rehabilitation efforts were successful in protecting the shoreline from wave action enough to cultivate the growth of macrophytes and redevelopment of a historic wetland. The sonar survey covered 94,287m^2 of the location, including the inner and exterior berm area and the area directly in front of the McVicar Creek. Two transects were completed: one parallel along the inner berm wall and the second along the opening that leads into the inner berm habitat. These two locations were selected based on the different amounts of hydraulic activity that they receive to compare if species and patch densities differed based on hydrologic influence.

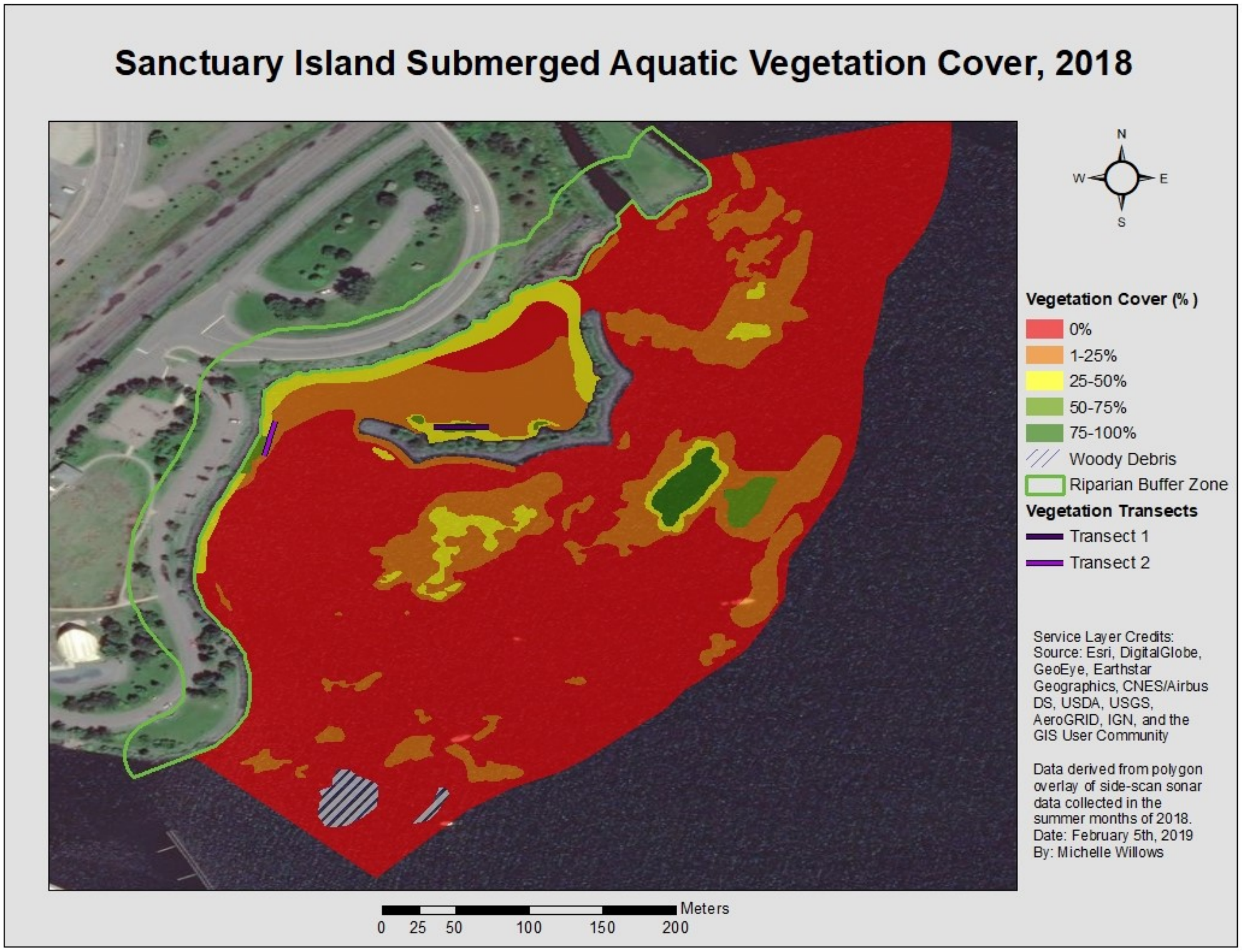
Figure 45: Sanctuary Island and Howe Street Overpass.

Submerged Aquatic Vegetation

The site had a high diversity in species lining the western shoreline walls, with patches varying in size and density throughout the location. The imagery indicated the successful growth of macrophytes covering approximately 26% of the area. A total of 12 species were collected and identified along the two transects (Table 21). Original expectations were that an abundance of vegetation would develop within the inner berm wall, decreasing in density within the channel entrance of the crescent. Side-scan sonar imagery and underwater transects painted a different picture, with lower densities within the inner berm and distinct patches with high density within the berm opening. Sonar imagery also revealed a large patch of macrophytes with successful longitudinal growth covering roughly 796m^2 of the outer berm wall along the 10ft depth contour (Figure 46).

Table 21: Northern Woods Macrophyte Species List for 2018 Season with U and T values.

Sanctuary Island				
Species List				
#	Taxon	Common Name	U-Value	T-Value
1	Elodea canadensis	Canadian Waterweed	2	1
2	Potamogeton amplifolius	Curly-leaf pondweed	1	1
3	Potamogeton sp.	Pondweed	1	2
4	Myriophyllum sp.	Water-milfoil	1	1
5	Potamogeton robbinsii	Fern-leaf pondweed	4	2
6	Myriophyllum verticillatum	Whorled water-milfoil	4	1
7	Vallisneria americana	Tape grass, eelgrass	3	1
8	Ranunculus sp.	Crowfoot	2	1
9	Potamogeton richardsonii	Richardson's Pondweed	3	2
10	Myriophyllum sibiricum	Northern (common) water-milfoil	3	2
11	Potamogeton zosteriformis	Flat-stemmed pondweed	3	1
12	Callitriche sp.	Water starwort	4	2
MEDIAN			3	1
MODE			3	1



Sanctuary Island Submerged Aquatic Vegetation Cover, 2018

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Data derived from polygon overlay of side-scan sonar data collected in the summer months of 2018. Date: February 5th, 2019 By: Michelle Willows

Figure 46: Sanctuary Island Submerged Aquatic Habitat Characterization.

Transect one exhibited lower diversity and density than transect two. Macrophytic density ranged from 1-25% as the substrate was easily visible and indicated thin stands. Only 4 species were prominent along transect one. Of the four species, two are considered invasive, Curly-leaf pondweed (*Potamogeton amplifolius*) and Eurasian water-milfoil (*Myriophyllum spicatum*). The U and T-value scored low for all of the sampled macrophytes, indicating that they have a high tolerance to degradation of water quality and a broad niche preference (Table 21). The fall transect showed an increase in density and height of macrophyte stands ranging 25-50% vegetation cover, with the addition of two species along transect 1. Crowfoot (Ranunculus sp.) and Northern Milfoil (*Myriophyllum sibiricum*) were identified in the fall samples, resulting in a higher U-value than the species in the spring transect (Table 21). The location experienced some similarities to that of the McKellar Embayments, where macrophyte colonization was impacted by minimal water movement through the inner berm habitat and higher levels of turbidity (Figure 47). Limited hydrologic flow resulted in the growth of algae and sponges encrusting the sediments and plant stems in some locations along transect one (Figure 48). The higher turbidity throughout the sampling season may have impacted the productive growth of macrophytes over the season, limiting densities established within the inner berm.

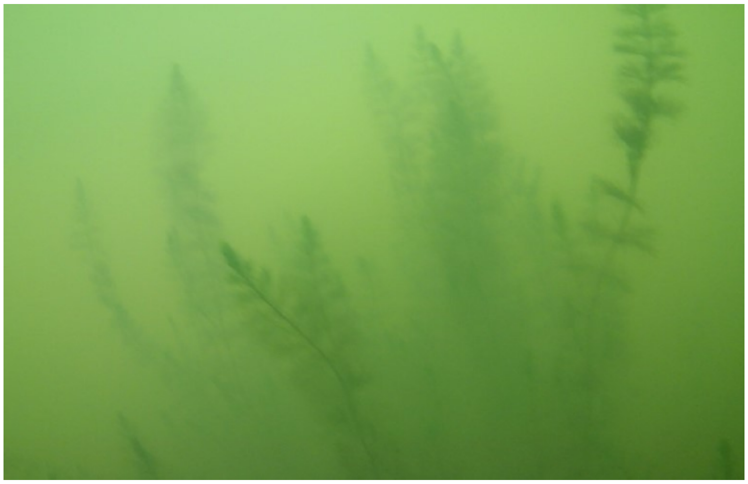


Figure 47: Macrophyte stand of 25-50% Along Transect 1 Experiencing Higher Levels of Turbidity.

Figure 48: Aquatic Sponge along Transect 1.

The extending berm provides a degree of protection within the open channel allowing suitable aeration, stimulating vegetation growth, abundance, and diversity. Transect two had developed submerged macrophyte beds, with twice the amount of species during spring sampling than that of Transect 1. Submerged vegetation increased significantly, with patches ranging from 50-75% coverage in the opening of the berm and along the cobble walls (Figure 49). The species present scored much higher in T-Values, specifically Fern-leaf pondweed (*Potamogeton robbinsii*) and Northern Water Milfoil (*Myriophyllum sibiricum*), indicating their intolerance to degraded habitat and water quality. The majority of the species had a U-value of 3, indicating niche neutrality. As the channel opens to Lake Superior, vegetation drops as the substrate switches to a silty-clay, limiting vegetation growth to patchy sections.

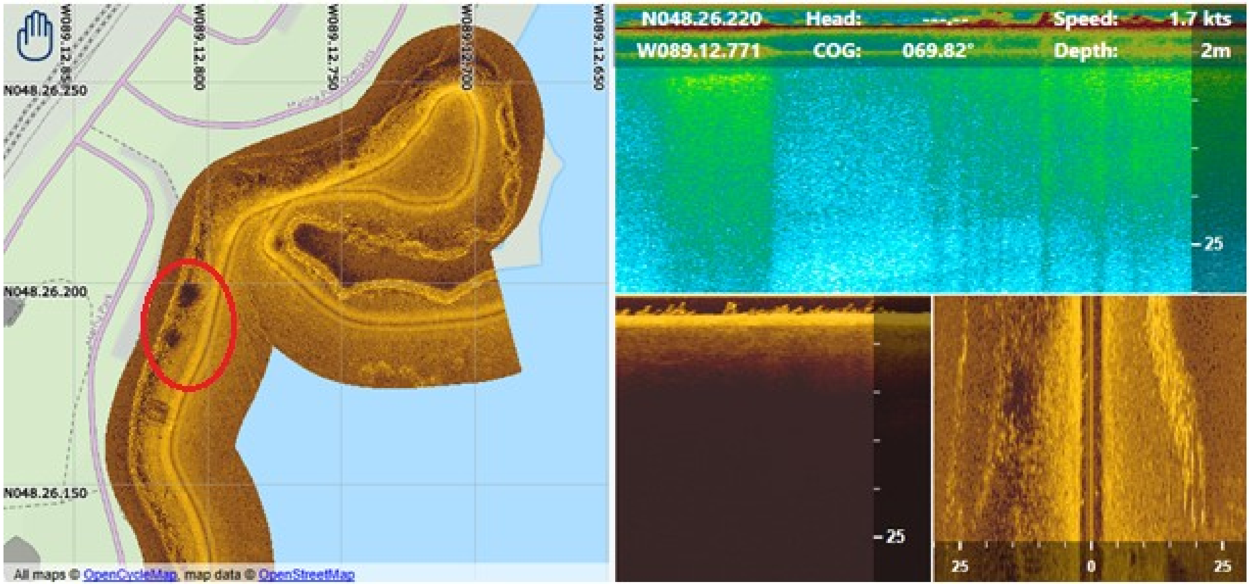
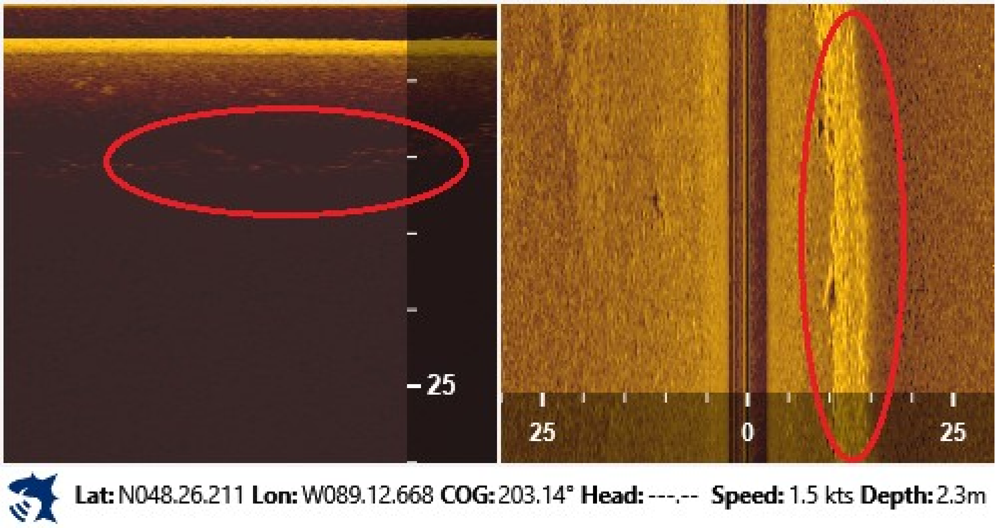


Figure 49: Sanctuary Island Side-Scan Sonar Imagery Depicting Macrophytes along the Cobble Shoal.

The location received a score of 3 (Table 23) for the WMI and species count as there were more than 10 species present with over half of the species having higher U-Values of 3 or 4 and with numerous species having a T-Value of 2. Species density was moderate, scoring a 2 as a large portion of the location had vegetation densities ranging from 1-25% and 25-50%. This is a significant improvement to what was previously described as a barren shoreline.

Substrate

An objective of the project was to stabilize the banks from erosion, thus the berm and shoreline are lined with large cobble. The transition from the cobble walls to the bottom substrate is abrupt. The sonar imagery depicts this change well as it appears bumpy with shadows and quickly transitions to fine-grained sand that appears smooth with some ripples from wave action (Figure 49 and 50). The substrate directly within the berm wall consisted of fine-grained silty-loam and was easily disturbed and loosely packed. The relative hardness E2 echo return further indicated a soft substrate due to its light coloration on the map (Figure 52). Substrate composition was confirmed to be accurate by the underwater transects and video footage (Figure 51). The lower densities of vegetation contributed to sediment resuspension and slight turbidity.



Lat: N048.26.211 **Lon:** W089.12.668 **COG:** 203.14° **Head:** ---.-- **Speed:** 1.5 kts **Depth:** 2.3m

Figure 50: Sanctuary Island Distinct Change in Substrate from Cobble to Sand Substrate.

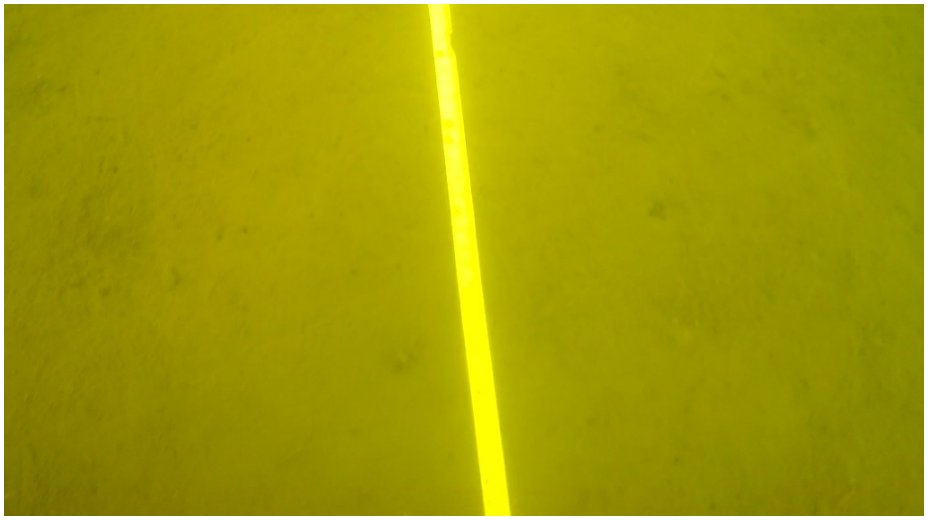


Figure 51: Sanctuary Island Transect 1 Depicting Fine Grained Silty-Loam Substrate.

Sediments within the channel opening along transect two and in front of the berm consisted of a coarser silt-sand combination. These sediment dynamics directly affected the successful growth and abundance of submersed macrophytes within the location. The substrate enabled successful growth of rooting systems, that in turn, increased the stability of the substrate and prevented resuspension leading to higher water clarity. This shift in sediment composure is indicated within the E2 hardness return as the coloration slightly darkens (Figure 52). Approximately halfway across the outer berm wall the substrate shifts again to primarily sand based with some silt composition, likely attributed to depth and sedimentation of particulates from the McVicar Creek system. The highest volume of dense vegetation was found in this location (Figure 46). The substrates directly in front of the river within the delta are primarily hard-packed sand, gravel, and cobble due to continuous erosion from flowing water. This can be seen in the E2 return (Figure 52) as the return appears dark in color.

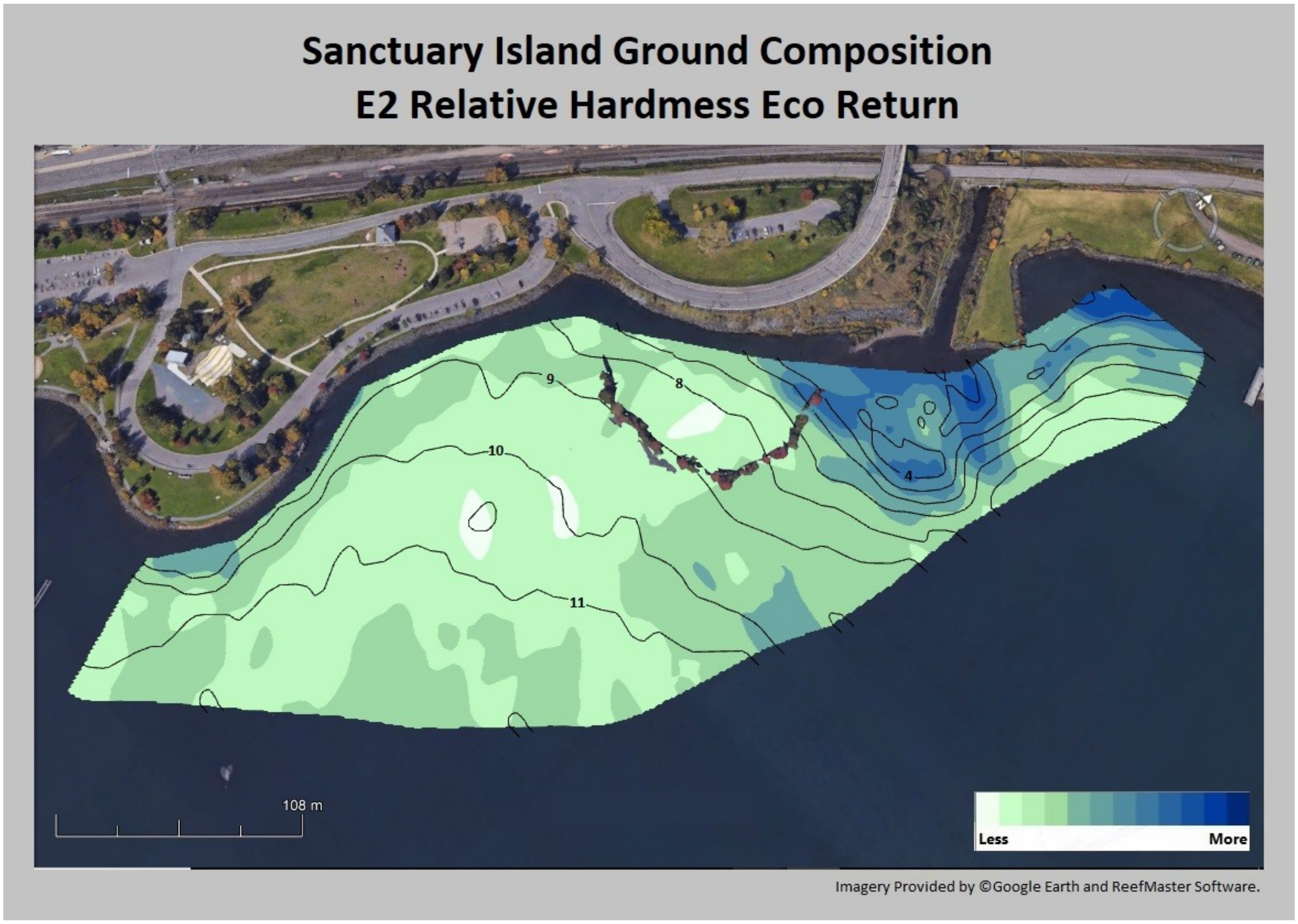


Figure 52: Sanctuary Island Bottom Composition Indicating E2 Relative Hardness Eco Return.

The substrate within the location received a score of 2 as there is minimal variation within the study area and it appears to have a fairly homogenous bottom (Appendix 1). The area within the man-made berm was the focus of the study and primarily consisted of silt-based substrates. Higher substrate complexity would increase the overall score of the habitat and encourage increased colonization of macrophytes and other biota.

Water Quality

Sanctuary Island experienced the highest pH recording of the 6 locations, having a pH level of 8.0 and 8.2 in the spring (Table 22). Although it is still within the recommended range, higher values would cause the site to exhibit slow growth and would not be recommended for fish production (Table 1). However, the pH levels dropped within the fall to neutral levels of 7.08 and 7.14, which is well within the acceptable range for a successful habitat (Table 22). The alteration in pH level is likely a result of stormwater runoff from the roadways in the early spring and the various chemical additives it transfers due to the impervious surfaces surrounding the location. Residential storm-water runoff filtering into the McVicar Creek will also influence the water quality as it drains directly adjacent and into the remediated habitat. The buffer along the McVicar Creek is not substantial enough to adequately filter toxic loadings from non-point sources, which could contribute to the fluctuations in water quality readings and alter habitat conditions.

Table 22:Sanctuary Island Water Quality Testing Results for Fall/Spring 2018.

Sanctuary Island Water Quality 2018										
Spring										
Date	Transect #	Temp °C	mmHg	DO %L	DO mg/L	DO ppm	SPC	pH	ORP Mv	Turbidity BTM=Bottom
28/06/18	T1	19	740.4	115	10.3	10.3	138.3	8	335.9	135cm
28/06/18	T2	18.5	740.5	113	10.3	10.3	135.5	8.2	330.4	265cm (BTM)
Fall										
19/10/18	T1	6.6	733.1	96.7	9.5	9.5	126	7.1	344.7	150cm
19/10/18	T2	6.7	733.2	93.2	9.4	9.4	133.1	7.1	340.9	258cm (BTM)

Spring temperatures were slightly above the optimal growth preferendum for Salmonidae but remained low for other families of fish (Table 1). The fall temperatures were fitting for spawning of Salmonidae. The habitat is exposed to the open waters of Lake Superior and this influences lower overall temperatures year-round. Conductivity exhibited very low concentrations of dissolved ions and nutrients ranging from 126 µS/cm to a maximum of 138.3 uS/cm. The temperature and conductivity readings indicated ideal levels and should not affect the other water quality parameters. Dissolved oxygen was above 100% in the spring, likely attributed to the adjacent river system, wind and wave aeration, the rapid aeration of the water from passing vessels, and a higher volume of photosynthesis due to increased plant volumes along the transects. The saturation dropped below the spring levels ranging from 93% to 96% dissolved oxygen in the fall. Microbial decomposition of the aquatic vegetation may have had an impact on dissolved oxygen within the location during the fall as temperatures were significantly lower. The overall high levels of dissolved oxygen are suitable for spawning and egg development, indicating that the inner berm habitat could be beneficial for fish migration and as a nursery for juveniles. The water quality testing resulted in a score of 4 (Appendix 1), with clean conditions acceptable for aquatic life.

Transect one had higher turbidity all season with lower overall water clarity and visibility, whereas transect two had clear water with sunlight penetrating well into the water column. The spring transects showed higher turbidity likely due to the high volumes of runoff that the location receives from the urbanized shoreline and McVicar Creek. The fall turbidity levels lowered to >100m along transect two, however, transect one developed the presence of a white haze within the water column. The same phenomena were noted directly within the harbor adjacent to Pier 3 and Pier 1. Testing for the chemical properties of the substance was not within the scope of this study but should be addressed in future monitoring of the waterfront. The turbidity also appeared to influence macrophyte growth as plants had begun to die off and decompose earlier in the fall. The location received a score of 2 for turbidity as the water was not substantially clear and there were some visibility issues during transects (Appendix 1).

Riparian Buffer Zone

Although there are a few independent trees and shrubs growing atop the constructed crescent, there is no real vegetation buffer between the habitat and the roadways along the waterfront. Due to the parking lots, piers, and paved overpass, there is an abundance of impervious surfaces that would directly drain into the habitat and adjacent harbor after any heavy precipitation event (Figure 47). A score of 1 was attributed primarily due to the waterfront infrastructure, large cobble substrate, and steep banks (Appendix 1). However, 1700 mixed shrubs, deciduous, and conifer trees were planted for bank stabilization and aesthetic enhancement along the McVicker Creek delta in 1993 (Kelso and Hartig, 1995). These initiatives were ideal for the habitat recovery of the creek and should be continued along the habitat shoreline and on either side of the river delta to compensate for the lack of buffer directly lining the inner berm habitat.

Habitat Classification

The location is visited frequently by the boating community due to its proximity to marina park and because of the convenient mooring balls available for safe harboring. The boardwalk around the location was used by many for aesthetic and recreational value and various fish species were noted during the research. A species of Catostomidae (Suckerfish) was present along transect one in the spring, but due to the low visibility, it could not be fully identified other than its obvious physical features. Benthic invertebrates were in abundance within the berm opening, specifically Nematomorpha tangled within the vegetation samples. Additionally, a large number of Larus argentatus (Herring Gull) reside on the adjacent marina break wall and several other species of waterfowl utilize the area. The aquatic biota has evidently increased since restoration initiatives took place.

The habitat was classified as moderate value as it is important to the ecological functioning of the watershed, but its direct contributions to the fisheries are limited in its current state. The location is likely used for predator/prey interactions and may influence migration up the McVicar Creek. Continued macrophyte colonization within the berm will provide increased habitat connectivity by providing nursery habitat for juveniles. While there is still room for improvement, the rehabilitation project was successful in its targets D3 and D11 of sheltering the shoreline from wave action leading to the growth of submerged macrophytes within the vicinity of McVicar Creek. A location that was once described as barren now has a moderate diversity and abundance of macrophytes with the presence of benthic invertebrates. The only hindrance impeding the habitat from reaching a higher class is the lack of buffer zone and slight turbidity which lowered the locations' overall score (Table 23).

Table 23: Sanctuary Island Habitat Characteristics and Classification.

Sanctuary Island Ranking and Classification Based on Habitat Values			
Habitat Characteristics	**Rating**	**Criteria**	**Score**
WMI and Species Count	High	• High U-Values (3-4) and T-Values (2) • High species diversity <15 species.	3
Species Density	Moderate	• Moderate Density (Moderate = 25-50%) • Patches of macrophyte growth occur sporadically throughout the habitat.	2
Substrate	Moderate	• Some habitat complexity with the presence of two or more substrate types. • Consists mostly of silty loam with adequate pore space for some vegetation.	2
Water Quality	Excellent	• Sustainable temperature 15-19.9 ºC for diversification of species. • pH level is 7.0-8.5, sustainable for aquatic biota. • High dissolved oxygen levels >7mg/L. • Low levels of conductivity <150 µS/cm.	4
Turbidity	Fair	• Fair turbidity levels, <1.5m within the and >2m within the channel. • Significant turbidity after precipitation events.	2
Habitat Buffer Zone	Low	• Little to no buffer. • Large amounts of impervious surfaces increasing runoff	1
		Total	14
Habitat Ranking and Classification	**Moderate**	Important to the ecological functioning of the watershed or estuary. Direct contributions to fishery values are limited. Not known to support key lifecycle stages but may be important for migration.	

Currently, the berm extends out and away from the river. It appears that sedimentation may have closed the small opening connecting the inner habitat to the river. Increasing the depth of the small channel and lining it with a cobble substrate may allow a higher volume of water to flow through from the river while adding to substrate complexity within the inner habitat. Improved circulation within the extended manmade berm would likely decrease turbidity, increasing light penetration, and result in improved vegetation abundances. Additionally, there is no riparian zone, and runoff within the area accumulates within the habitat from a lack of filtration through the site. Increased flow would help dilute the concentrations of any pollutants and prevent settling of any harmful chemicals on top of the substrate. The habitat would also benefit from improved storm-water management along the McVicar Creek to increase the quality of water entering the site as the buffer along the river system and the habitat is encroached by residential housing. Several different practices can be applied to help minimize the strain that storm-water has on the habitat quality and benefit the connectivity between the two ecosystems.

5.5 Current River

The prospect of spawning and nursery grounds within the Current River heightened the need for restoring the key habitat. The total area scanned was 184,448m^2, extending out past both commercial docks. Through the duration of data collection, there was a high volume of precipitation. Only two transects were conducted due to the size of the location, boat traffic and hydraulic flow from the river. Transect one was conducted in front of the island where the flow was reduced and where suspected macrophytes may be growing. The second transect was located within the river channel itself to confirm the type of substrate delineated within the restoration plans. Due to the flow of water, high traffic of fishing boats, and the proximity of the shipping dock, transects were not completed in the deeper water. It was noted that when the original vegetation transects were laid on June 6th, 2018, transect two had a high volume of fish sightings including Bass, Suckers, Walleye, and Lake Trout. The diversity in fish sightings could be an indication that the habitat enhancement and channel reconfiguration prompted success in fish migration.

Submerged Aquatic Vegetation

The habitat conditions were not favorable for the growth of submerged aquatic macrophytes due to the high flow velocity, substrate structure, and increased turbidity due to tannins from Boulevard Lake. Transect one, along the front of the island, had little vegetation present with only sporadic rooted strands occurring in single-sand patches amongst gravel and large cobble substrates (Figure 53). Sparse vegetation on the lower end of the 1-25% scale, covered 10% (18,202 m^2) of the location. This resulted in a score of 1 for species density (Figure 54). Only three species were present in the location throughout the duration of sampling including; Water-milfoil, Canadian Waterweed, and Pondweed (Table 24). The U and T values scored low for all species, indicating a high niche breadth and tolerance to degradation, and received a score of 1 WMI for species count. Transect two, located within the inner river channel, had 0% vegetation due to the large cobble substrate and consistent flow (Figure 56). The development of dense vegetation stands is unlikely due to the high hydrologic flow, boat traffic, a nearby shipping channel, and substrate structure impeding root development and growth. The total submerged macrophyte ranking was a 2 because the parameters do not prompt growth and because there were few species present in very low densities.

Table 24: Current River Macrophyte Species for 2018 with U and T values.

Current River				
Species List				
#	Taxon	Common Name	U-Value	T-Value
1	Potamogeton sp.	Pondweed	1	2
2	Elodea canadensis	Canadian Waterweed	2	1
3	Myriophyllum sp.	Water-milfoil	1	1
MEDIAN			1	1
MODE			1	1

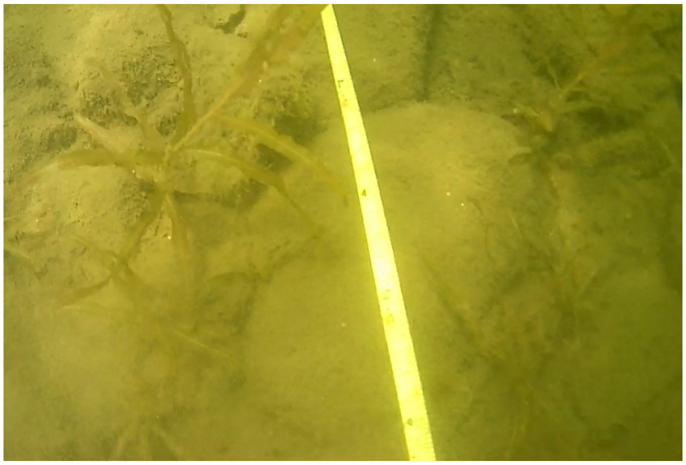
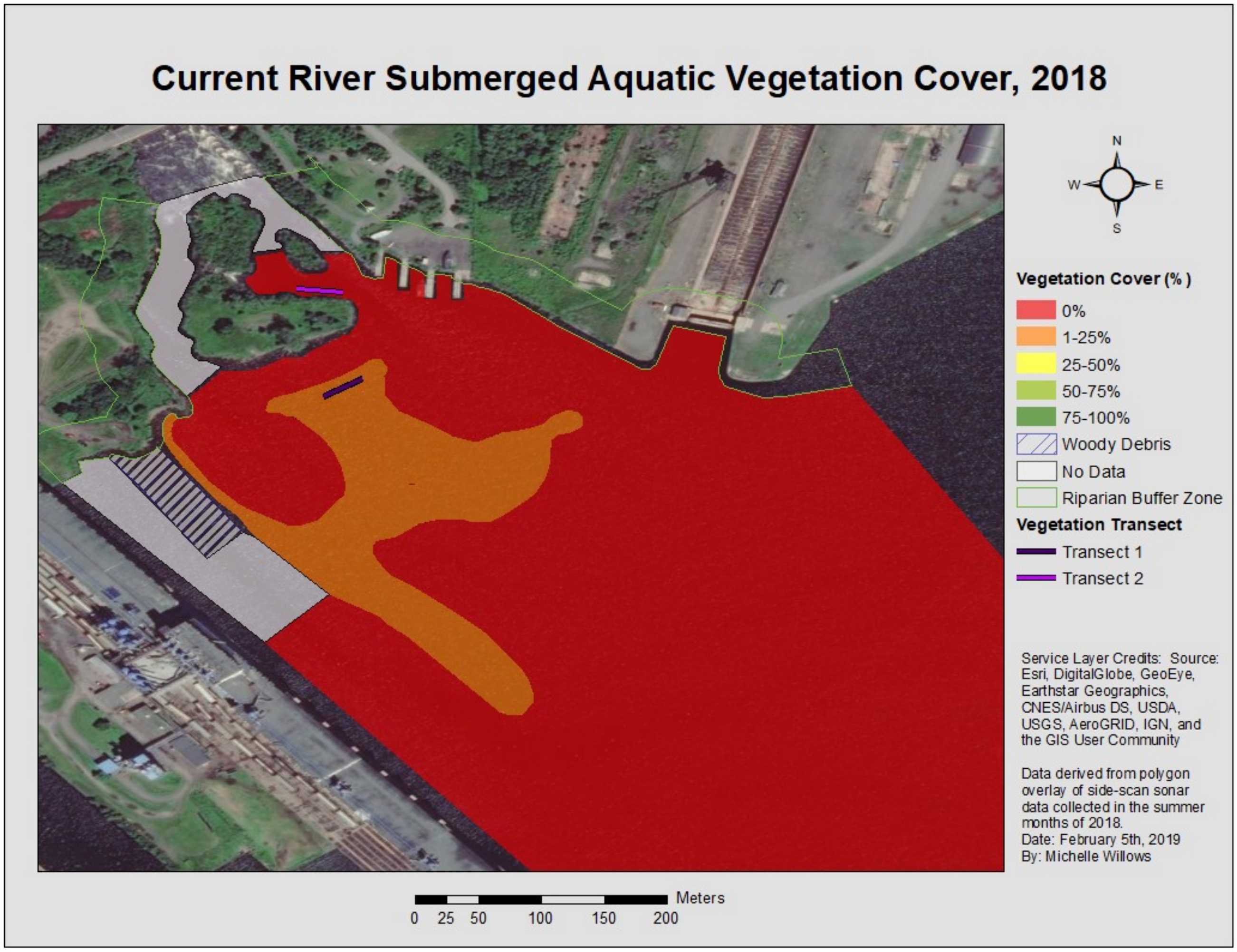


Figure 53: Current River Transect 1: Sparse vegetation growing amongst a cobble-based substrate.



Current River Submerged Aquatic Vegetation Cover, 2018

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Data derived from polygon overlay of side-scan sonar data collected in the summer months of 2018.
Date: February 5th, 2019
By: Michelle Willows

Figure 54:Current River Submersed Aquatic Habitat Characterization.

Substrate

Coarse substrates within the location are characteristic of strong flowing waters. Transect 1 was mainly comprised of smaller cobble and gravel, remaining consistent along the front of the small land formation extending across to the old dock cribbing (Figure 55). The dark blue hues within the E2 hardness return provide a visual reference of the extent of the harder substrate within the habitat (Figure 57). The bottom composition within the river channel along transect 2 consisted of larger cobble with a sand substrate beneath (Figure 56). Although this type of substrate is not ideal for vegetation growth, it does provide ideal habitat for benthic invertebrates, which is key for spawning rivers. The cobble within the river channel remained clean and stabilized the banks, reducing erosion of the island. As depth increases, the substrate begins to change at a 20ft contour line to a silty-clay substrate (Figure 57). The change is indicated by the E2 hardness returns as it alters from a dark coloration to a lighter softer substrate (Figure 57).

The substrate directly within the river channel and zone of remediation received a score of 3 as it is ideal for stream beds and provides various suitable spawning substrates (Appendix 1). The substrate appears to be characteristic of what was delineated within the project outline and is stable with large crevices for invertebrates and small fish to thrive and hide. The gaps between the cobble were not filled in with silt or sand, remaining clean and ideal habitat for spawning and egg development.

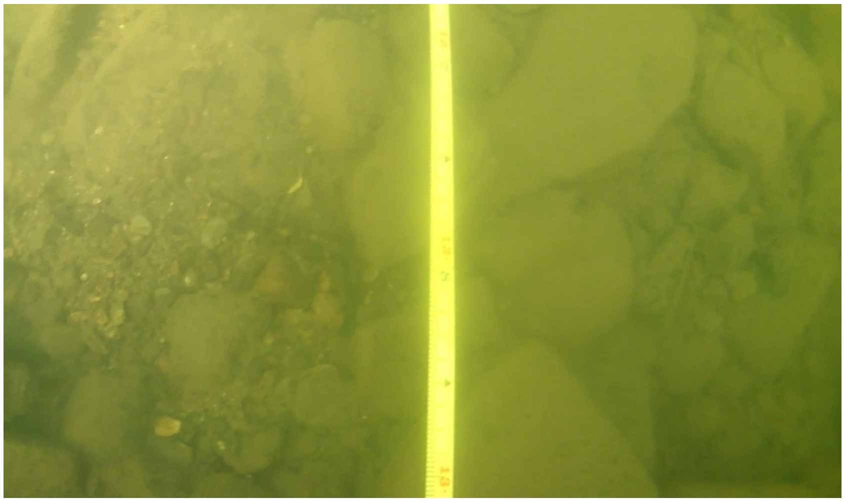


Figure 55:Current River Transect 1 with smaller cobble and gravel substrate.

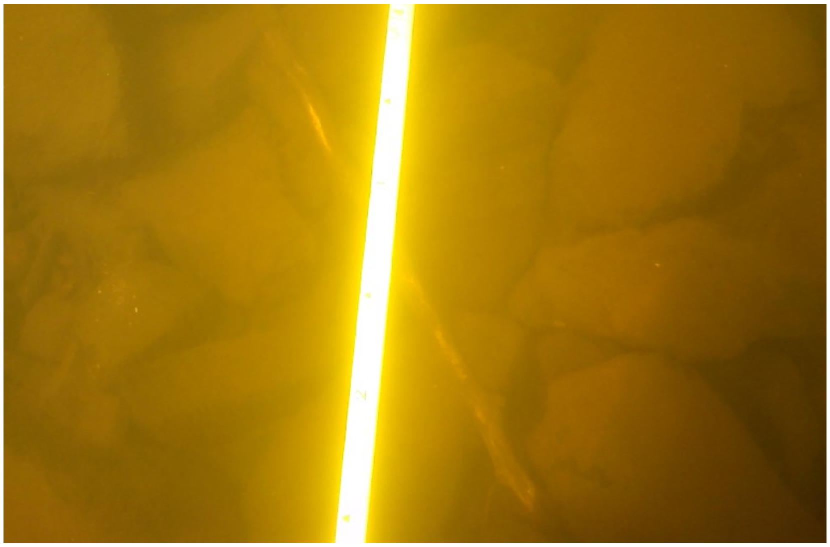
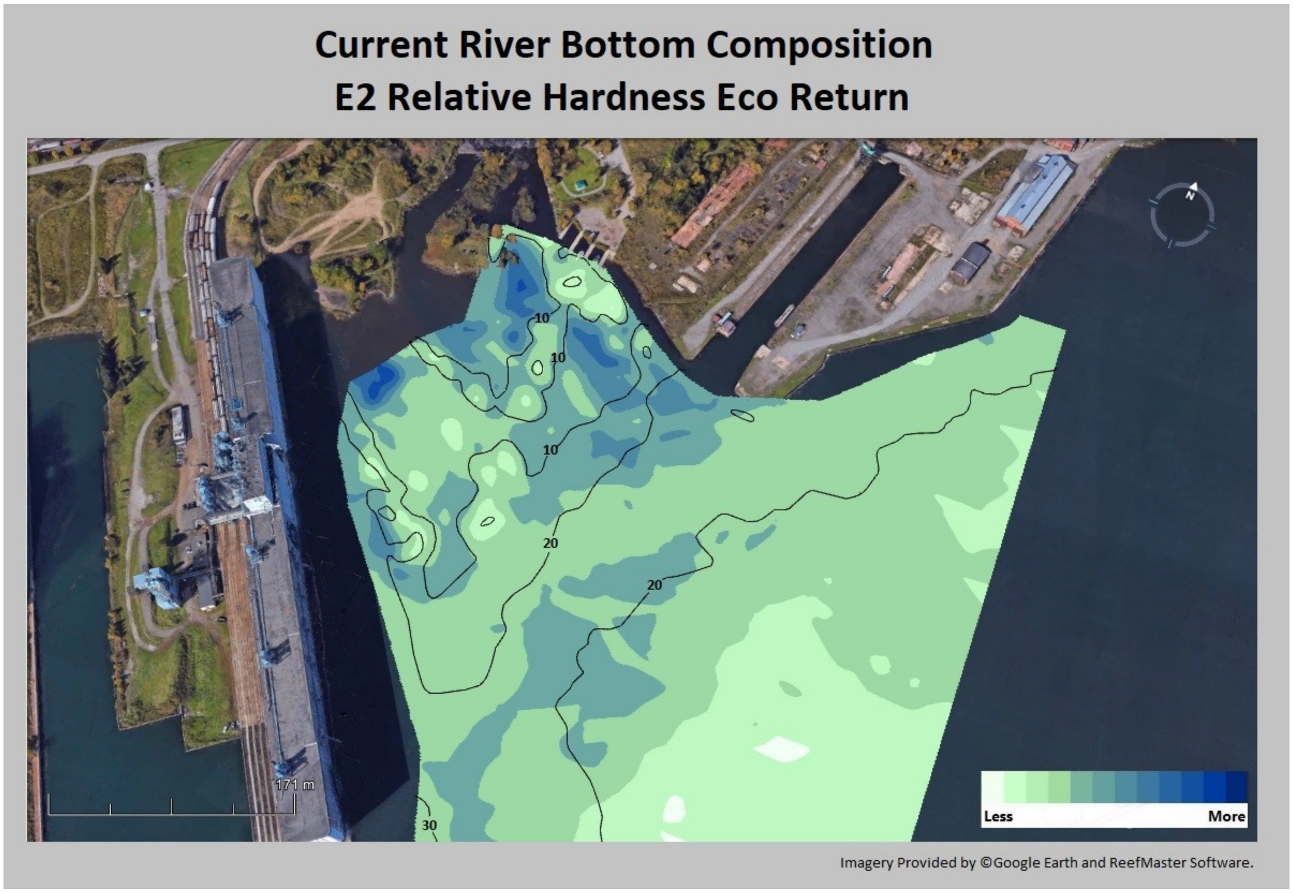


Figure 56:Current River Transect 2 Depicting Larger Cobble Substrate with Darker Water Colour from Tannins Upstream.



Imagery Provided by ©Google Earth and ReefMaster Software.

Figure 57: Current River Bottom Composition Indicating E2 Relative Hardness Eco Return.

The bottom of the delta channel and interior of the dock slips showed packed silty-sand substrate. High hydraulic activity has led to compaction, leaving little porous space for rooting or plant growth (Figure 57). There are many clear anchor drag-marks within the substrate (Figure 58), probably caused by commercial fishing vessels and docking at the boat launch near Fisherman's Park. Dredging has occurred on either side of the river floodway, as seen on the sonar imagery from a sharp decline in depth and shadows from sediment mounds (Figure 59). It is clear that the location and its substrate have been highly modified due to both commercial and recreational anthropogenic activity.

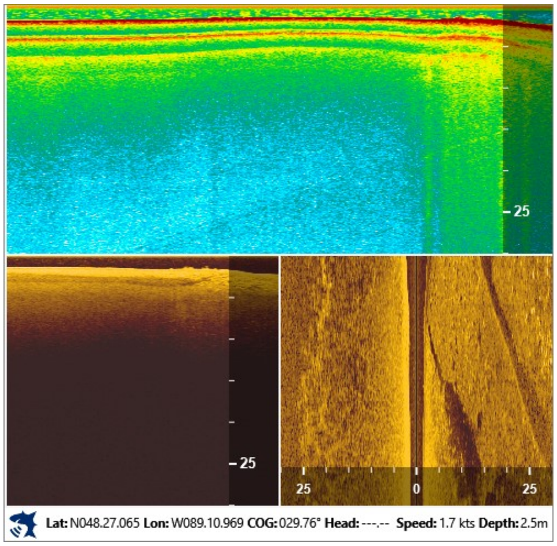


Figure 58: Current River Sonar Imagery of an Anchor Drag Mark.

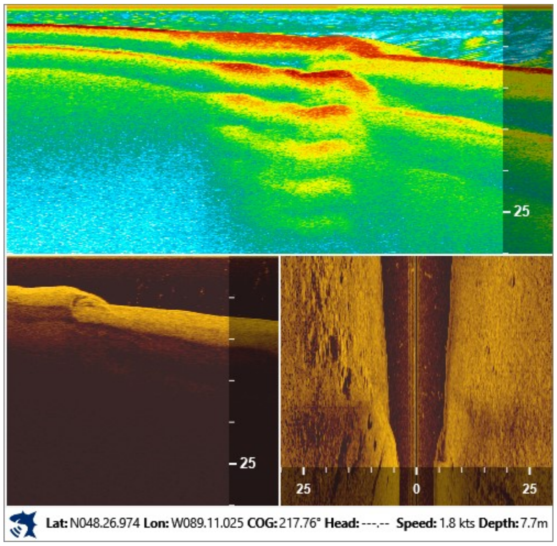


Figure 59: Current River Sonar Imagery of Dredging Along Shipping Dock.

Water Quality

Initial temperature readings in the spring ranged from 17.3 to 20.8, which falls within the optimal growth and preferred range for the majority of freshwater fish families, except for Salmonidae (Table 1). These readings could be attributed to Boulevard Lake, as the lake is fairly shallow with moderate turbidity leading to warmer water flowing directly into the study area. Temperatures remained high in the fall reading 18°C and reaching the maximum for Salmonidae spawning but still suitable for other families (Table 25). The spring water quality readings indicated that both transects within the location had a pH reading of 7.6 and remained neutral during the fall (Table 25). As indicated by Lawson 1995, Tarazona, and Munoz 1995, the site falls within the recommended pH level for fish production.

Table 25: Current River Water Quality Results for Spring/Fall 2018.

Current River Water Quality 2018										
Spring										
Date	Transect #	Temp °C	mmHg	DO %L	DO mg/L	DO ppm	SPC	pH	ORP Mv	Turbidity BTM=Bottom
26/06/18	T1	17.3	745.8	108.5	10.6	10.6	114.6	7.6	331.1	110cm
26/06/18	T2	20.8	745.9	94.5	8.3	8.3	114	7.6	322.5	155cm (BTM)
Fall										
13/09/18	T1	18.4	748.1	95.9	8.8	8.8	134.8	7.7	316.2	206cm (BTM)
13/09/18	T2	18.7	748	92.3	8.4	8.4	150.8	7.4	308.6	174cm (BTM)

Conductivity was very low in the spring with concentrations of 114 μS/cm. The low levels are likely derived from the fresh meltwater from the lake upriver. The level of dissolved ions increased in the fall and remained within sustainable limits but was approaching slightly enriched conditions. The increase in conductivity and dissolved ions may have influenced the drop in dissolved oxygen seen in the fall. The dissolved oxygen is directly affected by the flow of the river, as there is little vegetation within the area contributing to oxygen levels. Dissolved oxygen levels along transect one exceeded saturation, with transect two just slightly below 100%. The spring experienced dissolved oxygen levels around 10.6mg/L and 8.3mg/L and decreased to approximately 8.8mg/L to 8.4mg/L in the fall (Table 21). As previously mentioned, dissolved oxygen levels should not fall below 7mg/L, therefore the location falls within dissolved oxygen requirements for spawning and biotic activity. The water quality readings from the Multi-Parameter Handheld Meter indicated excellent conditions receiving a score of 4 (Appendix 1).

Turbidity levels were moderate along both transects exceeding 100cm. During the spring data collection, transect two had a red tinge in color attributed to the organic tannins from the decomposing vegetation upstream in the shallow lakes and ponds which decreased visibility and increased turbidity. Although the Secchi disk could be seen, the water was not crystal clear and had particulates suspended in the water column all year round. The level of water clarity improved over the summer, reaching >100cm during fall testing. The tannins influenced the water clarity for this location and resulted in a score of 3, indicating moderate turbidity (Appendix 1).

Riparian Buffer Zone

The riparian buffer zone just meets the recommended 30m buffer minimum within the river system. The buffer could be improved as the adjacent brown zone to the south of the river channels consisted of a seemingly obsolete gravel roadway preventing the expansion of green space (Figure 54). The location received a score of 3 for its buffer zone (Appendix 1). The river would likely benefit from increased shade and filtration that a denser buffer would provide. However, the river delta and waterfront habitat are surrounded by hardened shorelines due to the adjacent parking lots, fishing docks to the northeast and the major shipping/loading dock to the southwest. Focus should be placed on improving the local brown zones and increasing the number of trees anywhere possible to reduce the impact of anthropogenic activities.

Habitat Classification

The Current River remediation project was successful in meeting the criteria for spawning habitat and received a high habitat value within the river system itself (Table 26). The habitat contributes to fisheries values, migration, and predator/prey interactions assisting in key lifecycle stages for commercially valued species. Numerous fish species were encountered throughout the duration of the study, indicating the frequent use of the habitat. The substrates are ideal for spawning, consisting of frequent clean gravels with cobble and boulders with idyllic water quality readings. The enhancements to the river and spawning habitat appear to be achieving targets D1 and D6 (Table 9) based on the delineated objectives. The only hindrance to the habitat was the limited macrophyte growth, which will unlikely change due to the nature of the site and continued interference. To completely delist the location from its beneficial use impairments continued studies should focus specifically on egg deposition and fry production of Walleye.

Table 26:Current River Habitat Characteristics and Classification.

Current River Ranking and Classification Based on Habitat Values			
Habitat Characteristics	**Rating**	**Criteria**	**Score**
WMI and Species Count	Low	• Low U-Values (1) and T-Values (1). • Low species diversity, <5 species.	1
Species Density	Low	• Low density (Sparse = 1-25%) • Sparse patches of vegetation occurring in smaller stands and single strands.	1
Substrate	High	• Several sizes of the substrate to encourage spawning, migration, and invertebrates • Clean cobble substrate, gravel, and silty-clay.	3
Water Quality	Excellent	• Sustainable temperature 15-19.9 ºC for diversification of species. • pH level range 6.5-7.5, ideal for aquatic biota. • High dissolved oxygen levels >7mg/L • Low levels of conductivity <150 µS/cm	4
Turbidity	Moderate	• Low levels of turbidity, the substrate could be easily seen along each transect. • Some fluctuation in turbidity after large precipitation events.	3
Habitat Buffer Zone	Moderate	• Meets the required 30m buffer, but otherwise surrounded by impervious surfaces, residential industrial activity	3
		Total	15
Habitat Ranking and Classification	**High**	Valuable to ecological functioning and contributes significantly to fishery values but is not necessarily rare or pristine. The area assists in key life cycle activities for species that contribute to fisheries.	

5.6 North Harbour

Due to known Mercury contamination, no underwater transects were completed by SCUBA in this location. Instead, a Sea Viewer “Sea Drop 950", with GPS video overlay, was utilized to collect color video to gather data on substrate type and submerged aquatic vegetation. The total area scanned was 702,328m^2, extending from the edge of the break wall and past the Wilderness North docks. A total of 3 transects were videoed at this location, as the site itself is 26 hectares in size. The transect locations were chosen based on the ability to get grab samples of vegetation and assess the variability of the shoreline. The spring samples were collected before the completion of the side-scan sonar imagery, which influenced the transect location. The information within the video imagery provides enough detail to gain further understanding of the habitat without the inherent risk.

Submerged Aquatic Vegetation

A total of 11 species were encountered with the underwater transect footage and macrophyte samples. The calculated mode and median for the U-Value equated to 2 (Table 27), indicating tolerance of various aquatic conditions and degraded habitat. The central tendency regarding the niche breadth resulted in a value of 1 (Table 27), signifying that the majority of the species are able to inhibit a wide range of habitat and have broad niche requirements. Species that were common and growing in high density were Canadian waterweed (Elodea canadensis) and Coontail (Ceratophyllum demersum), both having low U-Values and known for their dominance in polluted wetlands. Specifically, Coontail is known for absorbing required nutrients directly from the water column, eliminating the requirement of porous nutrient-rich sediment for growth. Canadian Waterweed is a great competitor of invasive macrophyte species, such as Eurasian Milfoil, as it is tolerant to shade stress. Its adaption to low light levels increases its ability to form dense mats, outcompeting other species for resources. Although the densities of macrophytes were high, the species composition reflected signs of a degraded habitat.

A noted phenomenon captured in the side-scan sonar imagery was the presence of clouds within the water column. It is speculated, based on in-the-field observation, that the nature of the clouds is pluming green algae (Figure 60). The algae clouds were vibrant and thick which is why it likely provided a pulse return strong enough for the sonar to pick it up on the imagery.

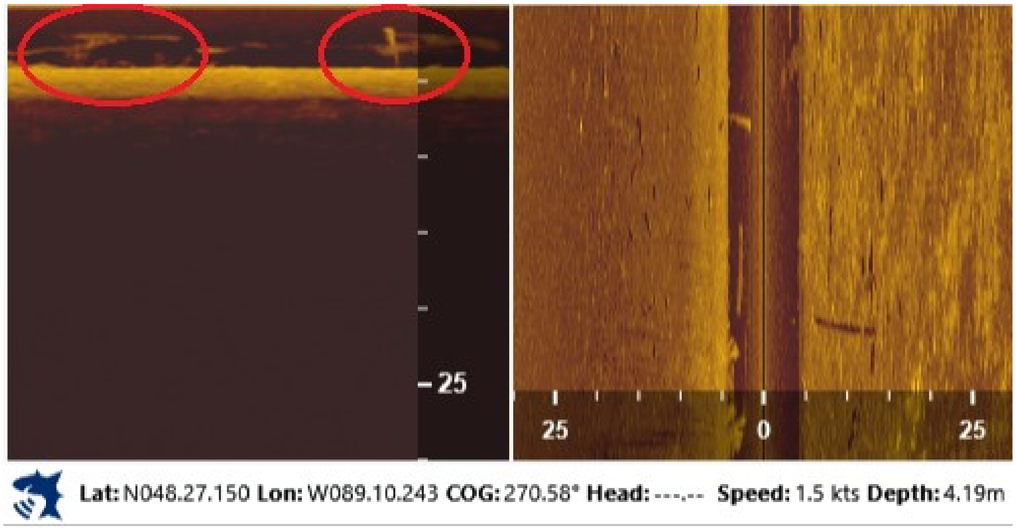


Figure 60: North Harbour Sonar Imagery of Algae Plume.

Table 27: North Harbour Macrophyte Species for 2018 Season with U and T values.

North Harbour				
Species List				
#	Taxon	Common Name	U-Value	T-Value
1	Myriophyllum sp.	Water-milfoil	1	1
2	Potamogeton sp.	Pondweed	1	2
3	Elodea canadensis	Canadian waterweed	2	1
4	Ceratophyllum demersum	Coontail	1	1
5	Vallisneria americana	Tape grass, eelgrass	3	1
6	Utricularia sp.	Bladderwort	3	2
7	Myriophyllum spicatum	Eurasian water-milfoil	1	1
8	Ranunculus sp.	Crowfoot	2	1
9	Potamogeton richardsonii	Richardsons pondweed	3	2
10	Callitriche sp.	Water starwort	4	2
11	Potamogeton robbinsii	Fern-leaf pondweed	4	2
MEDIAN			2	1
MODE			1	1

The imagery depicts a large abundance of submerged macrophytes along the inner breakwall at North Harbour. Macrophyte abundance remained between 50-75% for all three transects, covering approximately 53606 m^2 within the north-eastern corner (Figure 64). As the sonar tracks progressed along the shoreline to the north-west, vegetation volumes dropped to 25-50% with a distinct increase in woody debris and logs. The sonar imagery revealed a large, dense patch of macrophytes successfully growing within the 15-foot contour line (Figure 61). In agreement with Foster's (2012) studies, the patch of vegetation had a density of 75-100% covering 25,801 m^2 growing atop the approximate location of the <1m deep pulp substrate (Figure 64). Large woody debris and sizeable logs lined the outer limits of the vegetation patch ranging approximately 8-9ft in length (Figure 62) and covering approximately 163,858 m^2 of the scanned location (Figure 64). The larger logs influenced the vegetation zone by preventing the uprooting of macrophytes from hydraulic processes. The break wall also provided shelter from the open fetch of Lake Superior, creating an ideal setting for macrophyte success. Based on the imagery and the linear extent of the vegetation growth into the water column the vegetation would likely consist of Milfoil, Coontail, or a species of Pondweed.

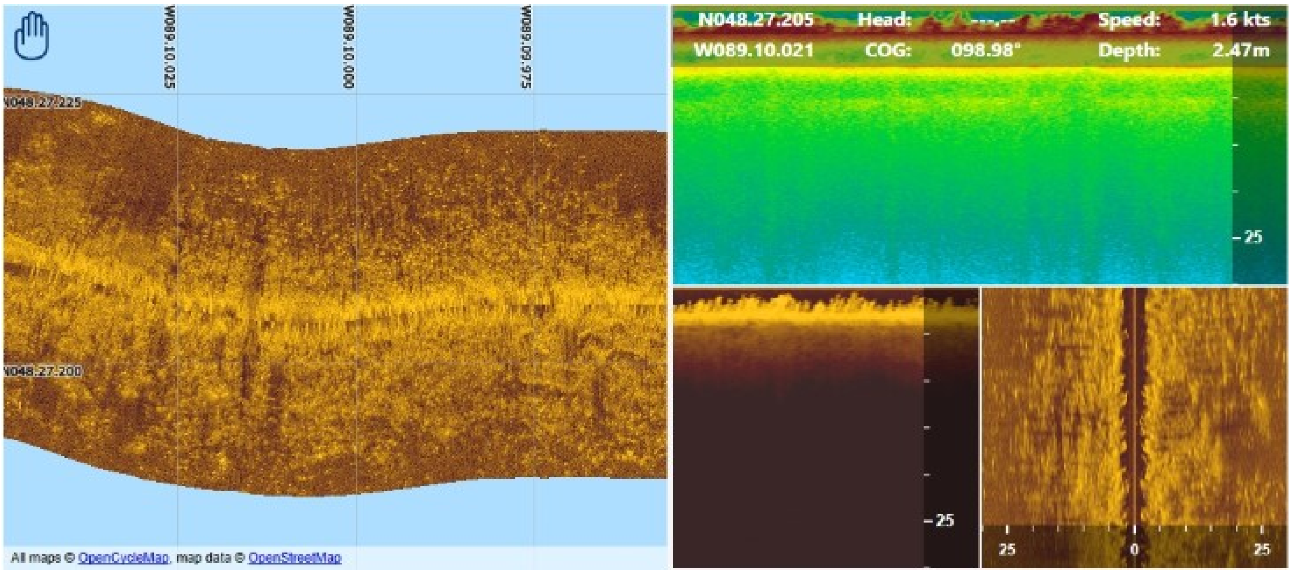


Figure 61: 45North Harbour Dense Vegetation of 75-100%.

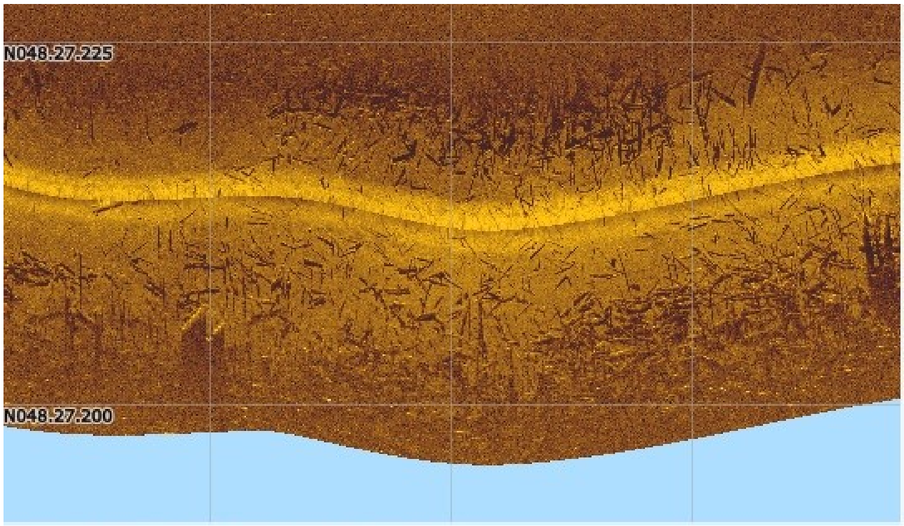
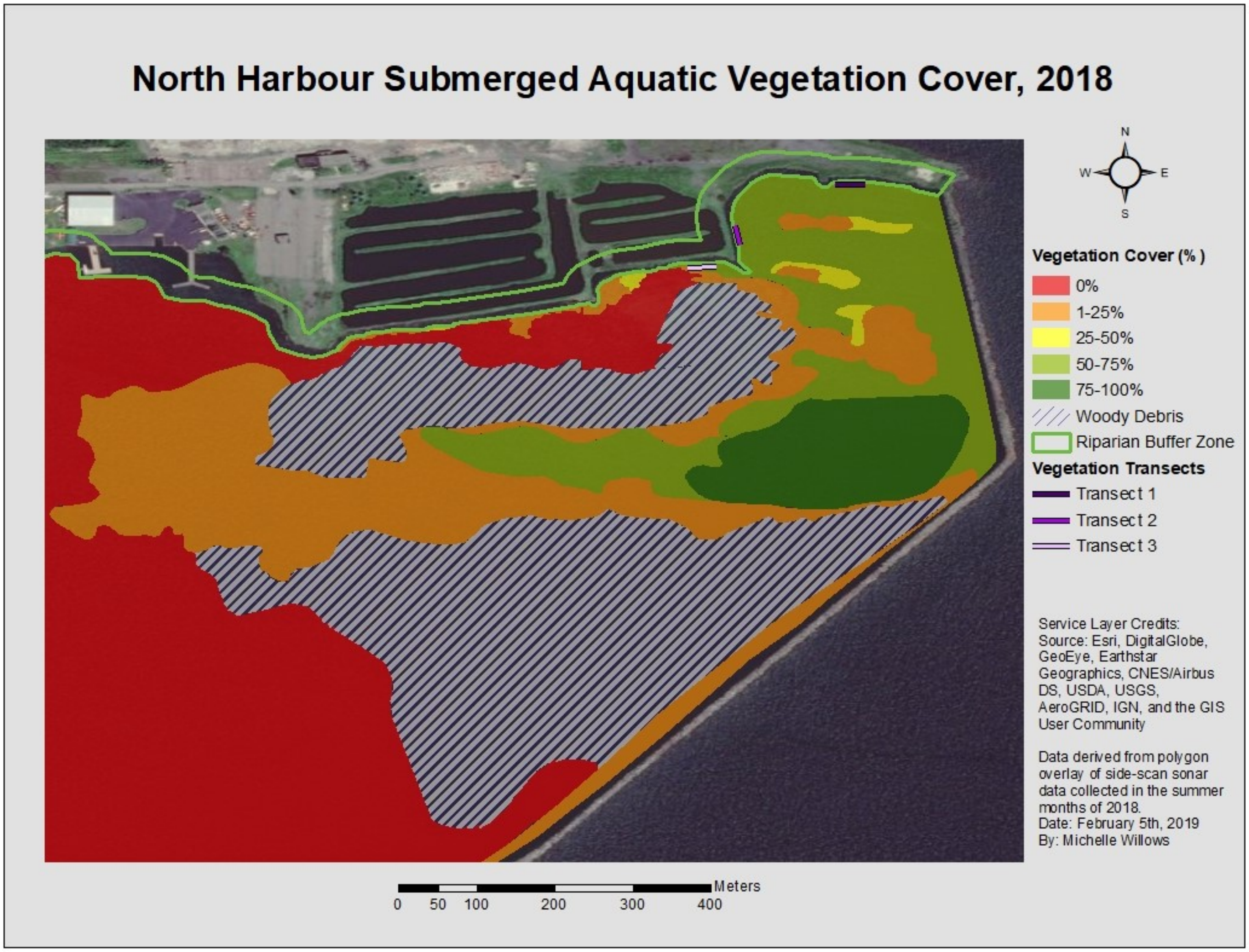


Figure 62: North Harbour Dense Woody Debris.

It was noted during the vegetation transects that an increase in small woody debris had a negative effect on macrophyte success, decreasing growth and abundance (Figure 63). The area directly in front of the man-made lagoons had high volumes of small woody debris atop the substrate resulting in 0% vegetation growth (Figure 63). The western portion of the habitat also has 0% vegetation growth, as seen in Figure 65 with minimal complexity. The depth remains consistent at 15ft with a shift to a packed silty-clay substrate that is not ideal for rooting. This section of the habitat experienced a high volume of anthropogenic disturbance due to its close proximity to the shipping channel, docking area, and previously dredged area. Even though this section has low habitat complexity, it can contribute to edge effect and biodiversity.

Figure 63: North Harbour Small Woody Debris Outside of the Lagoons.

The vegetation was scored as moderate within the Wetland Macrophyte Index and species count as the location had more than 10 species present, with neutral U-values and low T-values, resulting in a score of 2 (Appendix 1). The species density had a score of 4 as the variation in macrophyte stands provides a setting for high biodiversity. A significant portion of the habitat was within the ideal range of 50-75% with patches of higher and lower densities creating enough variation for hunting or foraging and a nursery. In combining the WMI and species density scores, the final submerged macrophyte score was a total of 7.



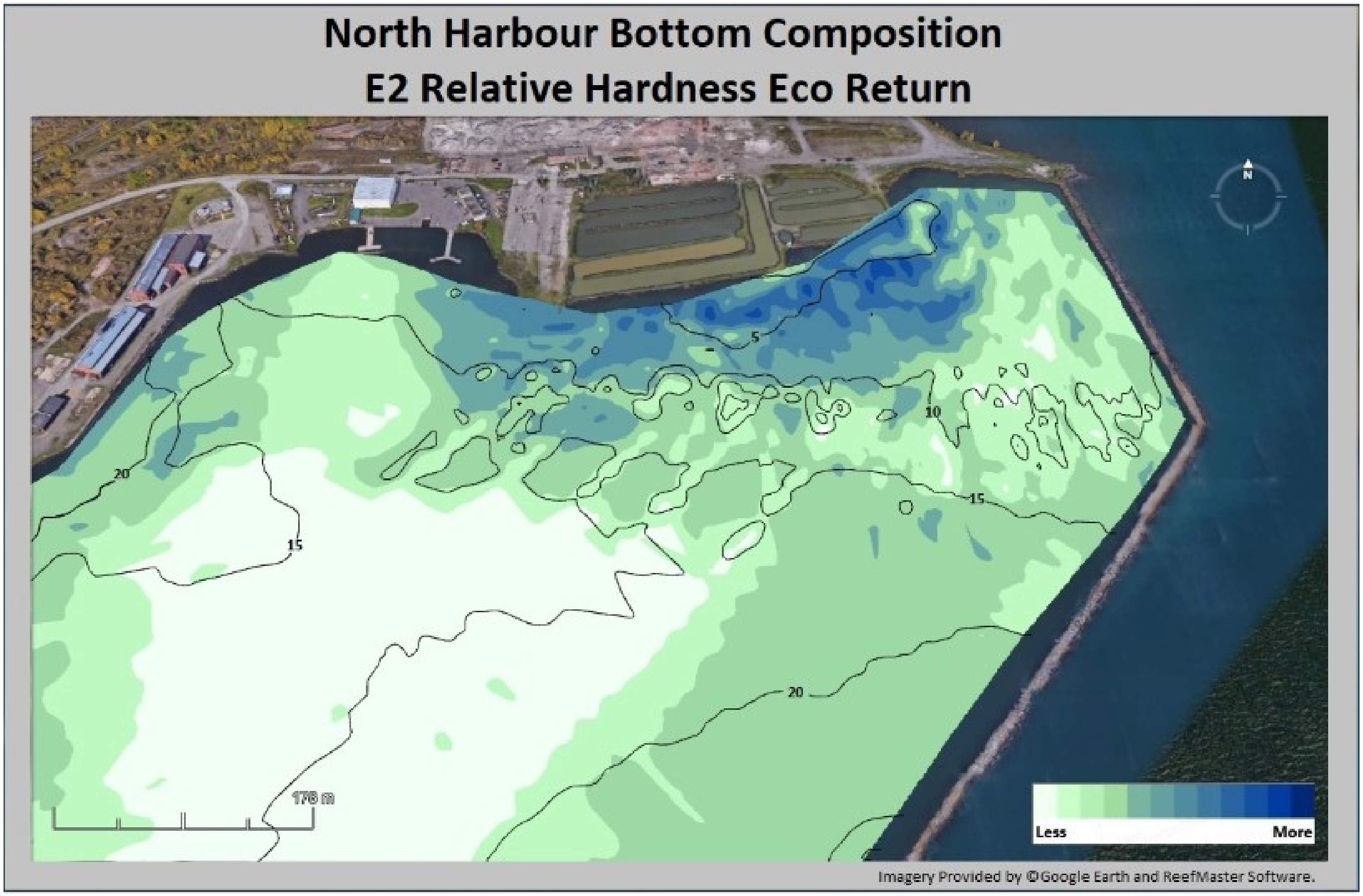
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Data derived from polygon overlay of side-scan sonar data collected in the summer months of 2018.
Date: February 5th, 2019
By: Michelle Willows

Figure 64: North Harbour Submerged Aquatic Habitat Characterization

Substrate

The substrate structure shows three major shifts based on the E2 echo return depicting bottom composition in relation to hardness levels. The substrate directly in front of the manmade lagoon consisted primarily of packed silt and woodchips which created darker hues in the E2 return (Figure 65) and in-field observation. The packed substrate is likely attributed to the construction material chosen for the lagoon project. Due to the nature of this substrate, no vegetation growth occurred in front of the lagoon as it does not likely retain nutrients or promote root stabilization. Past records of substrate composition show the presence of flocculent, which may account for the patchy appearance in the hardness imagery in front of the lagoons (Figure 65) (Foster, 2012). The E2 echo return indicates a change in substrate and hardness approximately 100m in front of the lagoons to a fine-grained silty-clay. The abundance and density of the macrophytes there may be interfering with the acoustic return and backscatter received by the transmitter, indicating a softer substrate. Regardless, based on the imagery and previous studies conducted by Foster, R. (2012), it can be assumed that the substrate consists of fine silt underneath the vegetation and woody debris. This finer substrate stays consistent along the inner brake wall in the northeastern corner but increases in grain size and texture size along the inner shoreline adjacent to the lagoons. The slightly coarser substrate, in addition to the protection of the break wall from the open fetch of Lake Superior, provides an ideal density of vegetation (50-75%) with species diversity improving the complexity of the habitat. The location, however, received a score of 1 for the substrate structure affected by the pulp/mercury contamination and extensive flocculent and high silt composition (Appendix 1).

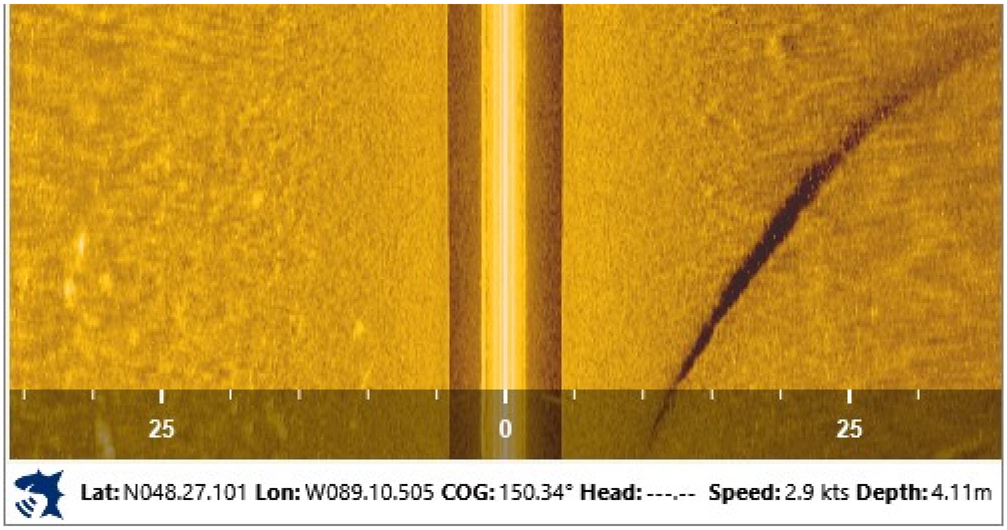


Imagery Provided by ©Google Earth and ReefMaster Software.

Figure 65: North Harbour Bottom Composition Indicating E2 Relative Hardness Eco Returns.

The substrate in the western portion of the location just past the Wilderness North docks changes to a silty-sand based composition. Sloping ridges and distinct layering are portrayed within the substrates caused by the adjacent highly active shipping port, dredging, and nearby harbor. Large anchor spar marks can be seen in the sand (Figure 66) that appear as a long dark streak in the imagery with no elevation change, indicating continued destructive anthropogenic activity. Small craters are visible in the imagery near the shipping slip and to the west of the tilling ponds. These features are easily seen as there is no vegetation within that region of the site. This crater phenomenon is caused by the processing of organic compounds and gas by-product from decomposition (Sand-Jensen et al., 1982). The gas eventually builds to a point where it can break the surface of the substrate, leaving a small crater where it previously existed

(Sand-Jensen et al., 1982). These craters are typically seen in locations that previously grew aquatic vegetation. The side-scan sonar imagery proved to be successful for verifying anthropogenic and biotic influences on the habitat, assisting in understanding the bottom composition of the contaminated site.



Lat: N048.27.101 **Lon:** W089.10.505 **COG:** 150.34° **Head:** ---.-- **Speed:** 2.9 kts **Depth:** 4.11m

Figure 66: Large anchor mark along the hardened shoreline in the proximity of docking location.

Water Quality

Despite known contamination, standard water quality testing showed adequate results in regards to the standards set by the Canadian Water Quality Guidelines for the Protection of Aquatic Life. The temperature within the nearshore location ranged from 17-18°C in the spring and remained consistent at 17°C in the fall (Table 28). Following the parameters set in the Climate Change Research report, these temperatures are ideal preferendum for the family Salmonidae, Percidae, and Ictaluridae (Table 1). However, these temperatures are not ideal for the reproduction of economically valued species as they exceed the optimal spawning and egg development temperature. The site's thermal parameters are characteristically ideal for nursery grounds and provide ideal settings for habitat productivity.

Table 28: North Harbour Water Quality Results for Fall/Spring 2018.

North Harbour Water Quality 2018										
Spring										
Date	Transect #	Temp °C	mmHg	DO %L	DO mg/L	DO ppm	SPC	pH	ORP Mv	Turbidity BTM=Bottom
17/07/18	T1	17.1	749.2	87.8	8.5	8.5	115.9	7.2	336.4	169cm (BTM)
17/07/18	T2	17.6	749.1	76.2	7.2	7.2	117.2	7.3	331.6	160cm (BTM)
17/07/18	T3	18.3	749	82	7.6	7.6	120.5	6.9	348.4	171cm (BTM)
Fall										
13/09/18	T1	17.3	748.2	90.3	8.7	8.7	116.6	7.6	297.4	171cm (BTM)
13/09/18	T2	17.6	748.2	92.3	8.7	8.7	116.8	7.3	201.2	166cm (BTM)
13/09/18	T3	16.9	748.3	87.6	8.2	8.2	116.4	7.1	319.7	167cm (BTM)

Tracking the dynamics of pH and dissolved oxygen together is vital for understanding and preventing eutrophication. The pH levels of three transects within North Harbour remained around 7, indicating a neutral pH level, which is the desirable range for aquaculture. There was a slight increase in pH reading in the fall that did not exceed a pH of 8.0 (Table 28). Dissolved oxygen levels were lower in the spring ranging from 7.2mg/L to 8.5mg/L and remained around 8.2mg/L to 8.6mg/L in the fall (Table 28). These readings lie within the ideal concentrations for aquatic habitats and are high enough to potentially support critical life stages of fry. The percentage of dissolved oxygen was below 100% ranging from 76% - 86% in the fall and increasing to 87% - 92% (Table 28). The location experienced lower levels of saturation due to the break wall preventing aeration from waves and fetch along the shoreline. An additional contributor may be from the volume of microbial decomposition of the wooden debris in warmer temperatures. Additionally, conductivity remained within sustainable limits indicating low concentrations of dissolved ions and limited nutrient enrichment. The presence of algae blooms seen on the sonar imagery may be attributed to nutrients leaching from the lagoons or specific wastewater discharges. Overall, the parameters indicated high water quality and received a score of 3 because these parameters are within a suitable range for aquatic life.

The habitat substrate and aquatic vegetation were clearly visible from the boat, indicating high water clarity. The Secchi disk reading indicated >1m with the level of clarity remaining consistent for all three transects (Table 28). Turbidity has the potential to be significantly dynamic within the location due to the ease of which the substrates are disturbed. Some suspended particulate matter was present due to anthropogenic activity on the waterway producing waves within the break wall. The unconsolidated structure of the sediment allows it to be easily re-suspended into the water column, making water clarity highly variable based on surrounding activity. Regardless, the low levels of turbidity have enabled successful growth in macrophytes even in the deeper water of 15-20ft. The final ranking for the turbidity was excellent, receiving a score of 4 (Appendix 1). The total score of North Harbour was 7 based on the two independent water quality determinants. Although the location is contaminated, the standard in situ water quality tests (not testing for mercury, nutrients, or contaminants in general) was indicative of a sustainable environment.

Riparian Buffer Zone

The highly industrial shoreline lacks any presence of natural habitat. The majority of the surface cover is impervious due to packed roadways, paved parking lots with several buildings in close proximity to the water. The only vegetation providing protection from runoff is a small strip of grass between the gravel road and the shoreline (Figure 64). The terrestrial vegetation present had a buffer of approximately 10m, which does not meet the 30m requirement harbor and set by HMHIE. Due to the high amounts of impervious surfaces, industrial activity, and a limited vegetative strip, the buffer zone received a score of 1 (Appendix 1). The 30m buffer is a crucial aspect for the filtration of any runoff carrying contaminants into the water source and should be enhanced with remedial efforts.

Habitat Classification

The North Harbour side-scan imagery indicated three major variations of habitat within the study location. The most Western section, closest to the shipping dock, had no vegetation present consisting of a silty-sand bottom with little changes in depth. Progressing to the middle of the site parallel to the tilling ponds, a high volume of woody debris is apparent atop the substrate. Historical industrial activity within the region is the primary cause of this abrupt habitat alteration. The logs appeared to be embedded in fine-grained loose sediment with little to no vegetation between logs. Continuing easterly, there is a shift in vegetation growth and abundance based on collected imagery. It appears that the woody debris encouraged the stabilization of macrophyte growth as it lines the outer edges of the dense vegetation beds. The innermost area within the break wall experienced a high degree of habitat complexity due to the volumes of submerged macrophytes and woody debris. The sonar imagery indicated the impact of anthropogenic activities, including; dredging, logging, and the installation of a break wall, which has all led to such dynamic variations within one location.

Designating a class for the North Harbour was problematic as it is a contaminated site with mercury and other organic chemicals, yet otherwise exhibits the ideal habitat characteristics of a nearshore aquatic habitat. Therefore, it falls into a unique range as it is currently hazardous to aquatic biota due to contaminants but has high fishery values based on indices used to assess habitat value.

Table 29: North Harbour Habitat Characteristics and Classification.

North Harbour Ranking and Classification Based on Habitat Values			
Habitat Characteristics	**Rating**	**Criteria**	**Score**
WMI and Species Count	Moderate	• High U-Values (3-4) and T-Values (2) • High species diversity <15 species. • High presence of non-native species.	3
Species Density	Moderate	• Many high density 50-75% areas. • Medium-sized patches of various densities from 25%-100%.	3
Substrate	Low	• Silty-mud, sand or gravel, substrates • Substrate composition shows the presence of flocculent. • Easily resuspended and mobile substrates increasing turbidity.	1
Water Quality	Excellent	• Sustainable temperature 15-19.9 ºC for diversification of species. • pH level range 6.5-7.5, ideal for aquatic biota. • High dissolved oxygen levels >7mg/L • Low levels of conductivity <150 µS/cm	4
Turbidity	Moderate	• Low turbidity 70-99cm • Some fluctuation in turbidity after large precipitation events.	3
Habitat Buffer Zone	Low	• Little to no buffer. • Large amounts of impervious surfaces increasing runoff	1
		Total	15
Habitat Ranking and Classification	**Minimum to High**	Valuable to ecological functioning and contributes significantly to fishery values but is not necessarily rare or pristine. Typical of habitat compensation primarily successful but requires further adaption to fully offset habitat impacts. The area assists in key life cycle activities for species that contribute to fisheries.	

Despite the known mercury-contaminated organic sediment in the North Harbour site, the habitat shows signs of significant potential and importance to fisheries (Table 29). The habitat's proximity to a major spawning river and its overall complexity would enable the ecosystem to support spawning, rearing, and various stages of fish lifecycles. The high score is a result of high-water quality values (absent of contaminant data), a large diversity in macrophyte species and stand densities, with high complexity due to wooden logs and riprap along the northeastern shoreline (Table 29). Since the Current River lacks a nursing habitat and a buffer zone within its delta, the North Harbour habitat could be complementary to the fisheries services it provides.

6.0 Discussion

While seeking the 'Highest Value' classification as an outcome from remediation, the habitats within this study do not meet the criteria since they are still recovering from the previous degradation. Highest value habitats are considered pristine or locally rare with minimal outstanding urban impact, complex structure, and a natural presence. Due to the high volume of shoreline modification and the surrounding urban influences, additional remedial action may be required to reach a higher score. However, it's important to recognize that the habitats assessed were considered minimal value prior to rehabilitation efforts, with limited contributions to a functioning ecosystem. Now after rehabilitation and recovery time, these locations are showing progress towards their designated habitat goals outlined in the Loss of Fish and Wildlife Habitat delisting criteria.

The results indicated variation in habitat rehabilitation success, with final scores ranging from moderate to high value (Table 11). The remedial action efforts at NOWPARC and Current River were effective in improving fisheries' value by enhancing key habitat features that contributed to a more productive environment. Although these locations differ substantially in design and purpose, both were designated as high value habitats. Each were found to be valuable to ecological functioning and assist in key life cycle activities of species that contribute to the fisheries. NOWPARC was successful in creating a complex fish habitat that could support predator and prey interactions. The colonization of diverse macrophytes and a variation in substrate type across the habitat was key for a higher score. Having larger cobbles and gravels for spawning in addition to areas porous and nutritious enough to sustain the growth of macrophytes increased the habitat value significantly (Environment Canada, 2013; Valley et al., 2004). The substrate also played a role in the successful remediation of Current River, as the addition of clean cobble encouraged the presence of fish and promotes spawning activities both at the river mouth and upstream. The variation in size of the substrate, ranging from gravel to boulder, provided significant habitat complexity contributing to an overall higher score.

Three of the locations assessed received a classification of moderate value (McKellar Embayments, Neebing-McIntyre, and Sanctuary Island), indicating that these locations are important to the ecological functioning of the waterfront, but still do not support key life cycles. Several common factors appeared to limit the success of these rehabilitation projects despite the broad range of techniques and designs applied. The habitat indicators that reduced the final score were: the density and diversity of macrophytes, substrate composition, and buffer zone. Macrophyte growth was limited in diversity and abundance lowering the overall level of physical complexity. The species within these locations had low U and T values indicating that they are tolerant of degraded environments (Croft and Chow-Fraser, 2007; Thomaz and Cunha, 2010; Kovalenko et al., 2011). The lack of complexity of both the substrate and the vegetation provided a homogenous habitat that does not sustain abundant biological communities (Maddock, 1999; Meynecke et al., 2008). Lastly, the buffer zone of each habitat was below the recommended 30m or lacking the diversity required to protect the habitat from municipal and industrial runoff. The inadequacies in these characteristics lowered the site complexity and offer limited rearing and spawning opportunities for key fisheries species such as the Salmonidae family. These habitats would benefit from continued remedial action to assist in achieving their restoration goals.

Remedial designs that were successful in achieving set goals and increasing the habitat value contribute to a more effective framework for habitat rehabilitation. Restoration initiatives that did not meet the design objective and received a moderate habitat value provide essential experience and knowledge for future applications in habitat management. The following chapter discusses the trends and patterns exhibited within the rehabilitation projects and how they impacted fundamental indicators and overall habitat condition

6.1 Submerged Macrophytes

The creation of extending berms to protect shoreline habitat from wave action and fetch was found to be an effective remedial strategy for fostering macrophyte growth and the redevelopment of historic wetlands. This was demonstrated by NOWPARC and Sanctuary Island as locations were previously described as barren before the creation of the new habitat features and now support patches of dense and diverse macrophytes. These berms not only provided protection for habitat development but increased complexity along an otherwise linear shoreline. The wetland habitats are in the early stages of re-establishment, but already show encouraging signs of biotic recovery in macrophyte diversity and density. Although Sanctuary Island received a moderate value classification, the progress from its prior state indicates the rehabilitation efforts have improved macrophyte growth and habitat quality. These locations experienced positive results in littoral habitat recovery, providing a powerful justification for habitat restoration and investment in areas dominated by human-infrastructure.

The Neebing-McIntyre and McKellar projects attempted to increase habitat diversity through the creation of the embayments but experienced limited recovery of the littoral zone. The results correlated with the findings by Roni et al. (2008), who indicated that the success of embayment structures was confounded by a lack of consideration of geology, channel type, climate, exotic species, site preparation, size of or exclusion of buffer zone or upstream processes. The Neebing-McIntyre's small and shallow embayments adjacent to fast-flowing waters resulted in a high level of erosion making it difficult to distinguish mats or pilings apart from the riverbank itself. The embayments did not appear on the side-scan sonar, nor were they detectable during in site assessment, indicating limited contributions to diversifying habitat. The larger deep embayments on the McKellar river produced stagnant conditions that would benefit from improved circulation to foster macrophyte growth. Turbidity levels were high as the macrophyte densities are not substantial enough to stabilize sediments. Different or additional habitat alterations may be necessary when rehabilitating fast-flowing homogenous habitats, requiring training structures to alter hydrodynamic conditions to increase habitat complexity.

River training structures are a cost-effective and ecologically beneficial alternative to creating embayments when rehabilitating rivers (Radspinner et al., 2010). The focus of these structures is to encourage a higher level of biological activity by recreating a sinuous water flow, thereby increasing the diversity of substrate, depths, and velocities (Radspinner et al., 2010). The application of training structures such as Wing Dam Notching, Alternating Dikes or Stepped Up Dikes would be a productive alternative to river restoration design as they increase habitat dynamics and can keep rivers navigable by reducing the need for dredging (Peipoch et al., 2015). These options would further slow the current and allow for macrophyte rooting and habitat complexity. Maintaining navigation channels while supporting a diverse habitat would be an ideal solution for Neebing-McIntyre specifically. The McKellar Embayments would also benefit from the design of river training structures to alter stream hydraulics and assist in directional flow. The addition of berms extending from the downstream entrance of each embayment would encourage a higher volume of flow and would be ideal for improving stagnant conditions (Radspinner et al., 2010; Peipoch et al., 2015). The simplification of the flow regime within these rivers has resulted in the loss of historical habitat niches. Continued modifications to improve the diversity of these aquatic habitats could eventually achieve Target D2 and D5 (Table 9) to increase littoral productivity. Future projects addressing linear river habitats with similar characteristics to the Neebing-McIntyre or McKellar river should consider alternative methods of training structures as there are several designs with a specified focus for achieving the ideal outcomes.

6.2 Substrate

Remediated habitats with significant sub-surface complexity and substrate heterogeneity scored higher than those with a homogenous bottom. The NOWPARC site exhibited various substrate sizes and trends across the habitat which contribute to a more stable environment (Barko et al., 1989). The substrate conditions provided the physical balance required for the inhabitation macrophytes and invertebrates, with enough diversity to encourage spawning activity (Schmude et al., 1998). The variation in texture and granular size resulted in the colonization of macrophytes in various densities, providing pivotal habitat for predator and prey interactions. A variety of substrate types within a habitat increases niche breadth and supports diverse populations of biota, ultimately improving the overall habitat value.

Current River also received a high score due to the size variation of the substrates. The remedial efforts to improve remnant and create new habitat involved the addition of clean gravel, cobble, and medium-sized boulders. The substrates were chosen to restore access to productive spawning areas while maintaining some diversity for the species that utilize the river system. While coarse substrates are beneficial for spawning, they did not support high macrophyte growth rates with minimal diversity in species. An increase in macrophyte abundance and diversity would benefit the habitat greatly by providing rearing habitat and increasing connectivity between the river system and the lake. However, macrophyte growth was not a priority for the spawning of commercially valued fish species. Therefore, the substrates at this location were ideal for the set goals and objectives of the project.

The lack of substrate structure and complexity at McKellar Embayments and Neebing-McIntyre River resulted in low substrate scores. Each habitat had a homogenous bottom comprised of silty-clay, mud, or sand. These substrates do not promote the growth or strong rooting of macrophytes. The fine-grained silty substrates increased the locations' turbidity and limited photosynthetic processes of macrophytes. Plants were only eligible to grow near the surface in low densities. Sanctuary Island experienced similar issues as the silty-loam substrate within the berm was easily resuspended which influenced turbidity levels, reduced the potential growth of macrophytes, and prevented strong rooting. Little complexity of the bottom substrate existed except the large cobble and boulders used to form the bank walls. Improved substrate complexity would benefit these sites and increase the inhabitation of various biota essential for fish habitat.

Remedial projects should ensure a large enough variety of substrates to support a taxa-rich environment (Schmude et al., 1998). Remedial projects should confirm there is enough sedimentation to promote macrophyte growth and complex 3-dimensional substrates to encourage the inhabitation of invertebrates. Using artificial substrates to increase habitat complexity in degraded habitats is an ideal solution to enhance the quality of habitat and support a diverse microhabitat (Anderson, 1986; Schmude et al., 1998; RAP, 2004). Future remedial projects should focus on enhancing the simplified shoreline and substrate complexity to increase the productive capacity of the littoral community.

6.3 Water Quality

The standard water quality testing with the handheld multiprobe indicated the desired parameters for fresh-water biota. In accordance with The Canadian Water Quality Guidelines, the aquatic habitats assessed exhibited sustainable temperatures, maintained a neutral Ph, low conductivity, and high dissolved oxygen content (CCME, 2003). These results are key as water quality is highly interrelated to other habitat indices (CCME, 2003). The only limiting factor of water quality observed was the high turbidity levels of the river habitats. Due to the substrate type (silty-clay) and continuous flow of the river systems, it will be challenging to significantly reduce turbidity to encourage a higher volume of macrophyte growth. The addition of river training structures and coarser substrates could improve the quality over time. Future initiatives should prioritize clarifying the water to encourage the colonization of macrophytes, therefore adding complexity to the habitat. Additionally, continued testing should include heavy metals and chemical compounds within the water column to contribute to the current baseline data set.

Water quality within the Great Lakes Areas of Concern requires monitoring and treatment of municipal wastewater and urban runoff. (Detenbeck, 1999; Kok et al. 2000; Kok, 2004). While Thunder Bay is considered a low-medium concern for these urban drainage components, it is important to optimize and maximize the efficiency of existing management systems (Kok et al. 2000). Sewage discharge, sewer overflows, and stormwater runoff can highly degrade the water quality of aquatic habitats (Detenbeck, 1999; Kok et al. 2000). The Neebing-McIntyre Floodway is a prime example of where high volumes of urban runoff due to the proximity of residential housing influenced the conductivity and dissolved oxygen content of the water in the spring. To ensure continued sustainable water quality, any urban development within the proximity of these rehabilitated habitats should adopt stormwater management programs. The construction of stormwater ponds, retrofitting old stormwater systems, and the implementation of at-source controls is essential for protecting the long-term water quality of Thunder Bays waterfront (Detenbeck, 1999; Kok et al. 2000).

6.4 Buffer Zone

The rehabilitation projects lacked a dense and diverse shoreline buffer zone. A minimum of 30m is known to maintain water quality and aquatic habitat functions with some variability based on the location and its proximity to industrial infrastructure (Environment Canada, 2013).

Locations such as Sanctuary Island and North Harbour had little to no buffer zone, potentially impacting the success of the aquatic habitats due to limited protection from surrounding stressors. The NOWPARC site almost meets the 30m requirement but has sections where the buffer falls short. Improving the buffer zone would increase the overall habitat score enough to reclassify the habitat to the highest value. While locations such as Current River and McKellar Embayments met the minimum extent, the buffer zones lacked density and high diversity hindering the speed of recovery due to runoff and increased turbidity. Their buffer zones consisted of a few key tree species with a primarily shrub and grass composition with little substantial rooting systems to filter runoff or prevent bank erosion.

Penczak (1995) conducted an evaluation on the effect of rehabilitated buffer zones on fish diversity in the Warta River, Poland. The results indicated that buffer zone rehabilitation exceeding 30m increased fish diversity from 11 to 16 species (Penczak, 1995; Roni et al., 2008). Studies conducted in New Zealand by Parkyn et al. (2003) also demonstrated that water quality and bank stability was improved with rehabilitated buffer zones. However, larger buffers exceeding 30m were required to sustain water quality parameters and enhance macroinvertebrate communities. A higher species variation encompassing both grassy regions for waterfowl nesting and larger trees for shoreline shade with substantial rooting would highly benefit each habitat and assist in achieving Target D11 (Table 9). Future efforts should calculate and account for an adequate buffer zone to encourage natural growth and recovery. Larger buffer zones will also minimize negative impacts from surrounding stressors and providing physical separation from anthropogenic influences. Further enhancement to buffer zones would increase the amount of wildlife habitat along the waterfront, contributing to the delisting of BUI Loss of Fish and Wildlife Habitat within the Thunder Bay Harbour.

6.5 Spatial Overlap and Connectivity

The results also indicated the importance of spatial overlap and connectivity, illustrated by North Harbour and Sanctuary Island. These habitats directly influence migratory fish and biotic life cycles by providing essential habitat and nursery grounds to adjacent river systems. The North Harbour would benefit from rehabilitation and detoxification as it provides essential estuary habitat that is absent within Current River. It has the potential to be a successful nursery based on its multifaceted features, dense aquatic vegetation development, complexity decoupling trophic interactions, and apparent ecosystem stability. Sanctuary Island has improved previous conditions by increasing the macrophyte community, providing some habitat for migratory fish, and reducing the industrialized edge effect that waterfront development created. Although the habitat is not yet considered high value, the slow recovery of the historic wetland will be beneficial for inhabitation of biota, development of juvenile fish, and encouraging spawning in the McVicar Creek. The concept of connectivity between ecosystems is essential for habitat selection of fish and increases the fisheries value of the spawning rivers (Kritzer et al., 2016).

7.0 Limitations and Bias

The Wetland Macrophyte Index was applied within this study to build on a community-based monitoring program that uses aquatic plants as a proxy indicator of habitat quality. Its purpose is to be easy to use and versatile to ensure continued monitoring for Remedial Action Projects across the Great Lakes and in additional freshwater ecosystems. Unfortunately, the presence of a botanist or an herbarium may be limited requiring those who are often volunteers to ID plant species to the best of their ability without misrepresentation. The WMI accounted for the fluctuating knowledge and experience by providing a coarser classification option to the genus to reduce misclassification as not all species are readily distinguishable. The coarser the identification, the lower the WMI Score. The WMI is a reasonable and easily repeatable methodology as long as there is consistency in the application (Croft and Chow-Fraser, 2007). Knowledge of species and characteristics were cumulatively developed with experience throughout the duration of this study using a number of viable resources. To prevent incorrect classification or inflated U and T values, plant identification was performed at genus values for a more conservative estimate. Therefore, U and T values could inherently have lower values. Some locations which had a larger volume and increased spatial complexity also required a higher number of transects. This has the potential to affect species sampling and counts associated with a greater surface area. However, the inherent risks of boat traffic within locations such as Sanctuary Island and Current River proved the selected transects appropriate.

Further limitations and biases affecting the research occur from the susceptibility of some test locations to Lake Superior wave action and currents at stream outlets. A high degree of sonar imagery distortion occurs both at the Neebing-McIntyre Floodway and the Current River, where sonar imagery is negatively affected by ‘noise’ or signal disruption due to river currents. To confirm the remotely sensed sonar interpretations, ground-truthing was required to confirm substrate characterization. Additionally, Humminbird Sonar devices are limited to line surveys at a constant speed for optimal imagery. Scanned locations with tight spaces and sharp turns, such as the NOWPARC habitat berms, were severely distorted and did not adequately portray the high volumes of submerged macrophytes that were present along the transects. Lastly, sonar shadowing of both woody debris and vegetation can influence perceived abundance levels, as seen in the North Harbour imagery. Many of the functions in ReefMaster can filter out the noise while adding depth corrections, but these issues need to be considered when identifying and classifying habitat complexity.

8.0 Conclusion

Globally, aquatic ecosystems have been significantly altered, depleted, eroded, or contaminated beyond natural repair, thereby requiring restoration and redevelopment (Hartig and Vallentyne, 1989). Initiatives of the Great Lakes Water Quality Agreement focused on two concepts involving an ecosystem approach while implementing remedial action plans (Hartig and Vallentyne, 1989). Dozens of methods have been developed to rehabilitate freshwater habitats, with only a few utilized within the Thunder Bay Waterfront (Roni et al., 2008). Remedial action plans are reactive to known problems, addressing beneficial use impairments to prevent the loss of essential fish and wildlife habitat and decline in biodiversity (Hartig and Vallentyne, 1989). Designs vary from natural enhancements to creating immediate changes in physical habitat, with the objective of rapidly increasing target species (Roni et al., 2008). Projects that focused on the large changes in physical habitat and mimic natural processes were found to be the most successful across Canada, the United States and in Thunder Bay (Hartig and Vallentyne, 1989; NRC, 1992; Roni et al., 2008). From project development and goal setting to monitoring and evaluation, a multidisciplinary, holistic approach improves the likelihood of success (NRC, 1992).

The efforts put forth to remediate and increase littoral productivity along the Thunder Bay waterfront should be recognized as an achievement. The study produced encouraging results, illustrating that the remedial action plans increased habitat quality from minimal value to moderate value and above. Adverse results are underrepresented and are equally valuable for current and future remediation projects (Geist et al., 2016). Restoration initiatives that did not meet the design objective, Neebing-McIntyre embayments, provide essential experience and knowledge for future applications in habitat rehabilitation. These projects play an important role in advancing the state of practice, with lessons arising from applied research to launch credible coastal engineering programs to aid habitat degradation (NRC, 1992). Although they may not be pristine, these projects have the potential to provide ecosystem services, contribute to aesthetics along an industrialized landscape, and benefit the economy through local fisheries and improve recreation experiences (Allan et al., 2015). Intervention on the most basic level (i.e., improving the buffer zone), would increase the final scoring of these habitats to a level high enough to only require monitoring. In a city dependant on its industrial infrastructure for economic development, even brief habitats are imperative and shouldn't be discredited.

The Habitat Classification System is a useful tool for comparing the strengths and weaknesses of the various techniques and rehabilitation designs applied to each location within this study. The key habitat indicators used within the classification system were efficient in gauging the level of recovery and ecological responses to restorative efforts. Assessing the condition of macrophytes, classifying substrate structure, testing water quality, and defining buffer zones proved to be essential when determining the condition of the littoral zone. Utilizing side-scan sonar imagery was effective for visualizing the spatial extent of physical indicators to gauge overall habitat complexity and understanding the progress of each rehabilitation project. Ground truthing the sonar imagery by conducting underwater transects and collecting species samples eliminated knowledge gaps within the data and enabled the application of the WMI. The methodologies applied within the study were successful in emphasizing the change in habitat value derived from completed restoration projects (NRC et al., 2002). It is evident that remedial action plan projects have enhanced habitat value and contribute to improving the Loss of Fish and Wildlife beneficial use impairment (NRC et al., 2002).

Successfully addressing the North Harbour is an essential step in the delisting of Thunder Bay as an Area of Concern. Current mercury levels exceed the Provincial Sediment Quality Guidelines and remedial actions are required (RAP, 2004). Selecting and applying a sediment management option remains an outstanding initiative of the Thunder Bay RAP team and the

Public Advisory Committee (RAP, 2004). Any contributing data to achieve this long-term goal is valuable. Maps of existing habitat conditions provide updated information and needed guidance for the decision-making process. The results of this study will assist in defining what habitat loss is to be expected from the construction of onsite containment facilities and what compensation measures should be taken. Accounting for habitat compensation, while accommodating social and economic interests of the respective communities, can result in flexible institutional arrangements to implement locally designed ecosystem approaches (Hartig and Vallentyne, 1989).

Increasing annual investment in research and evaluating rehabilitation efforts will reduce the disconnect between conservation initiatives and long-term management plans (EC, 2013). An evident change in the biota community and fish inhabitancy may take years or decades for some restoration projects (Kelso and Hartig, 1995). Long-term annual monitoring can better detect the gradual change, track trends, allow for adaptive management techniques to continuously modify programs based on new results, increase accountability, and prevent the precluding loss of habitat. Addressing complications or shortcomings with current projects allows for continued habitat development and further assists in the delisting of Thunder Bay's AOC (Geist et al., 2016). Ensuring accountability through continued monitoring keeps funding partners informed, justifies the cost and time expenditures (NOWPARC), enhances communication between the community and scientists, and increases overall public awareness and support for restoration initiatives (Hall et al., 2006). Remedial action plan projects, such as the Hamilton Harbour, depend on extensive regular reporting to define problems and provide solutions (Hall et al., 2006). Tracking habitat trends will assist in predicting future behaviors of indicators, such as water quality or macrophyte growth, allowing for more accuracy in management policies (Hall et al., 2006).

Remedial action plans are a notable change in a management mentality from one that was once fixated on pollution control efforts, to full consideration of overlapping responsibilities of habitat destruction and contamination. Once the rehabilitation efforts have shown substantial success to delist Thunder Bay as an area of concern, it is important to maintain focus on managing human uses and abuses of the natural resources and encourage a "No Net Loss" of rehabilitated habitats (Allan et al., 2015). Adaptive management is essential to the remedial action plan process as it continually improves policy and practices by learning from the outcomes of operational programs (Hall et al., 2006). Ensuring targets and restoration goals are completed supports lake-wide management initiatives set by the Great Lakes Water Quality Agreement. The Thunder Bay remedial action plan projects have been exemplary for the development of international initiatives to actively rehabilitate anthropogenically degraded environments and resolve specific environmental objectives (Hartig and Vallentyne, 1989).

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Appendix 1: Habitat value ranking and classification chart. Categories submerged macrophytes and water quality are broken into two sections as a high degree of variation can occur between the attributes. In doing so, a precise and clear classification numeral can be distinguished.

Ranking and Classification Based on Habitat Values			
Parameter	**Score**	**Rating**	**Criteria**
Submerged Macrophytes			**WMI and Species Count**
	1	Low	• Low U-Values (1) and T-Values (1). • Low species diversity, <5 species.
	2	Moderate	• Neutral U-Values (2-3) and T-Values (2) • Moderate Species Diversity, <10 species.
	3	High	• High U-Values (3-4) and T-Values (2) • High species diversity <15 species.
	4	Excellent	• Highest U-Values (4) and T-Values (3) • Highly diverse >20
			Species Density
	1	Low	• Low density (Sparse = 1-25%) • Sparse patches of vegetation occurring in smaller stands and single strands.
	2	Moderate	• Moderate Density (Moderate = 25-50%) • Small patches of macrophyte growth occurring sporadically throughout the habitat.
	3	High	• High Density 50-75% • Medium-sized patches of various densities from 25%-100%. • Larger patches of substrate still showing through creating showing recovery or continued growth within the location. • Gentle sloping shoreline with some marsh features with a high presence of non-native species.
	4	Excellent	• Large patches of a varying range of densities from 50-75% and 75-100% creating a habitat with high complexity. • Vegetation is blended over the environment creating an extensive habitat over a larger space. • Dense marsh vegetation composed of local species.
Substrate	1	Low	• Silty-mud, sand or gravel, substrates poor for vegetation rooting, limiting growth or stability. • Easily resuspended and mobile substrates increasing turbidity.
	2	Moderate	• Small cobbles in river systems or silty loam with adequate pore space for some vegetation.
	3	High	• Clean cobble substrate for river systems OR silty sand with high nutrient content. • Porous enough to promote strong rooting. • High nutrient content.
Water Quality	1	Low	• Extreme temperature <25 ºC • pH exceeds the neutral limits, reaching extreme acidification or alkalinity (<5 or >9.5). • Very low dissolved oxygen levels <3mg/L • High Conductivity >300
	2	Moderate	• Moderately high 20 ºC -25 ºC • pH exceeds the neutral limits (<6 or >9).

			• Moderate dissolved oxygen levels 5mg/L • Moderate Conductivity >250
	3	High	• Sustainable temperatures 10-14.9 ºC, ideal for pelagic fish, specifically the family Salmonidae. • pH levels between 8-9, signifies intense photosynthetic activity. • Good dissolved oxygen levels 6g/L -7mg/L • Low conductivity <200
	4	Excellent	• Sustainable temperature 15-19.9 ºC for diversification of species. • pH level range 6.5-8.5, ideal for aquatic biota. • High dissolved oxygen levels >7mg/L • Low Conductivity <150 µS/cm
	Turbidity		
	1	Low	• High turbidity ranging from 35-54cm, detrimental to most aquatic biota.
	2	Fair	• Fair turbidity levels, 55-69cm
	3	Moderate	• Low Turbidity 70-99cm
	4	Excellent	• Clear Water >100cm
Riparian Buffer Zone	1	Low	• Little to no buffer. • Large amounts of impervious surfaces increasing runoff
	2	Fair	• Close to achieving 30m minimum buffer, with patch's or gaps of missing vegetation due to brown zones.
	3	Moderate	• Meets the required 30m buffer, but otherwise surrounded by impervious surfaces, residential industrial activity
	4	Excellent	• Exceeds required 30m buffer • Ideal for filtration, shade and increased diversity to larger critical function zone.
Class	**Range**	**Total**	
Minimal Value	6-9	Habitat not considered important to the ecological functioning of the watershed or in maintaining fishery values. Limited contributions exist but are not sensitive to development. The location is not known to support key lifecycles but may contribute to migration. Low overall habitat productivity. Habitat consists of anthropogenically altered areas, with poor quality buffer zones, unstable substrate and highly surrounded with infrastructure.	
Moderate Value	10 -14	Important to the ecological functioning of the watershed or estuary. Direct contributions to fishery values are limited. Not known to support key lifecycle stages but may be important for migration. Usually pertains to areas that are adjacent to agriculture, industry or influenced by residential use with minimal riparian or backshore areas.	
High Value	15-19	Valuable to ecological functioning and contributes significantly to fishery values, but is not necessarily rare or pristine. Typical of habitat compensation primarily successful but requires further adaption to fully offset habitat impacts. The area assists in key life cycle activities for species that contribute to fisheries.	
Highest Value	20-23	Highly valuable to ecological functioning contributing significantly to fishery values. Considered pristine or locally rare. The location is known to support key lifecycles for rare or endangered species. It provides a natural fish habitat with any habitat compensation areas successfully developed. The habitat is considered complex with high macrophyte diversity and densities, high substrate heterogeneity and sustainable water quality for biotic life. No development should be permitted within these areas.	