TECHNICAL REPORT NO. 75

Measuring and Modeling the Effects of Lakeshore Development on Littoral Habitat and Biota in Malletts Bay, Vermont

September 2013

Final Report

Prepared by:
Fitzgerald Environmental Associates, LLC.

For:
The Lake Champlain Basin Program and
New England Interstate Water Pollution Control Commission

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Acronyms

15mX50m	Shoreline development metric combining the effects of development within two distances of buffer rings (15m and 50m)
ANOVA	Analysis of Variance
CB	Converse Bay Validation Study Sites
CCMPO	Chittenden County Metropolitan Planning Organization
COE	Army Corps of Engineers
COTE	Taxa from the macroinvertebrate orders: Coleoptera, Odonata, Trichoptera, and Ephemeroptera
CRF	Colchester Reef Meteorological Station
CVD	Correlation Visualization Diagram
CWD	Coarse Woody Debris
EPA	Environmental Protection Agency
EPT	Taxa from the macroinvertebrate orders: Ephemeroptera, Plecoptera, and Trichoptera
FEA	Fitzgerald Environmental Associates, LLC.
FWD	Fine Woody Debris
GIS	Geographic Information System
KB	Keeler Bay Validation Study Sites
LCBP	Lake Champlain Basin Program
LULC	Land Use Land Cover
LWD	Large woody debris
MMU	Minimum Mapping Unit
MWD	Medium Woody Debris
MSZA	Mandatory Shoreline Zoning Act
NAIP	National Agricultural Imagery Program
NRPC	Northwest Regional Planning Commission
NWI	National Wetlands Inventory
NYDEC	New York Department of Environmental Conservation
OHW	Ordinary High Water
PCA	Principal Components Analysis
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
SB	Shelburne Bay Validation Study Sites
SEM	Structural Equation Modeling
TAC	Technical Advisory Committee
UVM	University of Vermont
VGIS	Vermont Geographical Information System
VMC	Vermont Monitoring Cooperative
VMP	Vermont Mapping Program
VSWI	Vermont Significant Wetlands Inventory
VTANR	Vermont Agency of Natural Resources
VTDEC	Vermont Department of Environmental Conservation
WEP	Wind Erosion Potential
YOY	Young of Year

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Executive Summary

An increasing body of literature from the U.S. and across the globe has linked shoreline development with reduced habitat quality in the littoral zones of lakes and ponds. In the Lake Champlain Basin and throughout the region, there is rising concern over the degradation of lake littoral zones resulting from shoreline development. While other states in the New England have adopted shoreline protection regulations, there are no statewide rules or regulations in Vermont or New York restricting the nature or proximity of shoreline development above mean high water. In response to ongoing littoral zone degradation in the absence of statewide regulations, the Vermont Department of Environmental Conservation (VTDEC) has made substantial efforts to research this topic. Various VTDEC studies on inland lakes in Vermont and Maine highlight the sensitivity of the littoral zone to adjacent development, and the importance of buffer regulations in mitigating impacts.

Prior to this study, limited research had examined the impacts of lakeshore development on littoral habitats of Lake Champlain. Given the larger scale of physical and hydrologic process in Lake Champlain relative to smaller inland lakes, a key question spurring this research was whether the littoral zone response in Lake Champlain would differ from the inland lakes. As a result, the purpose of this study was to research this stressor-response relationship in Lake Champlain to improve the basic scientific understanding of the lake's littoral processes and inform shoreline management strategies.

Lake Champlain is a dynamic and diverse ecosystem shaped by substantial variability in hydrologic, geologic, geomorphologic, and climatic features and processes. The littoral zone of the lake is strongly influenced by seasonal changes in lake hydrology, large tributary inputs of sediment and organic matter, diverse shoreline geology and geomorphic forms, and severe differences in wind and wave exposure dependent on shoreline aspect. Our study was designed to utilize a relatively small set of representative sample points on the lake's shoreline to understand conditions in the greater lake. We chose Malletts Bay in Vermont as our principal study area due to its wide ranging natural characteristics and varying shoreline land cover.

Project Goal and Objectives

The principal goal of the project was to quantify, characterize, and understand the effects of lakeshore development on littoral habitat in Lake Champlain. Specific project objectives included:

- Use high resolution imagery to create detailed maps of shoreline condition and lakeshore land use/land cover;
- Measure littoral habitat conditions and biotic communities across gradients of human development and natural characteristics;
- Model relationships between littoral habitat conditions and riparian and shoreline condition;
- Develop a GIS-based tool to qualitatively predict habitat quality in other areas of the lake;
- Based on the study results, develop recommendations for shoreline protection and best management practices specific to Lake Champlain; and
- Disseminate the study results and recommendations to Lake Champlain Basin stakeholders to improve shoreline management.

Key Scientific Findings

Our intensive study of Malletts Bay covered a total of 90 sites across continuous gradients of natural and anthropogenic characteristics. Key findings from the methods approach, intensive field study, and subsequent data analysis include:

- To address the variability in natural littoral substrate in our study, we stratified sites based on substrate type. We also varied our biota sampling methods based on substrate type. We found this approach was important for addressing the primary research question, as we would expect that large differences in physical habitat across substrate types would override the development effect on littoral habitat.
- Shoreline development has a cascading, and sometimes indirect effect on littoral habitat quality. As shoreline development increases, riparian vegetation decreases, resulting in decreased shading, habitat cover, and inputs of woody debris and organic matter to the littoral zone. The decrease of woody debris and organic matter in littoral habitats reduces substrate available for macroinvertebrates, and changes dynamics of beach erosion, particularly in sandy sites. These results are generally consistent with findings from previous inland lake studies in Vermont.
- We found that variability in wind and wave exposure and littoral slope significantly influenced some characteristics of littoral habitat such as biotic richness and retention of organic matter. These relationships were significant even when their influence relative to shoreline development was considered. However, the relative influence of these natural gradients on littoral habitat was often less than that of shoreline development. These findings expand our understanding of the relative effect of shoreline development on littoral habitat in Lake Champlain and the region.
- In rocky substrates, we found a significant increase in pollution-sensitive macroinvertebrate taxa richness with increasing shoreline development. Although not intuitive, this result is entirely consistent with findings from the VTDEC inland lakes study, and other studies from around the globe. We suspect this response is caused by a combination of increased sunlight and nutrient availability in developed rocky shorelines in our study area. The levels of development typical of rocky shorelines in Malletts Bay do not appear to cause severe increases in runoff or erosion to a degree that would offset the increase in productivity for these pollution-sensitive taxa.
- After observing Malletts Bay's heterogeneity in natural and anthropogenic characteristics in great detail, we now have a greater appreciation for Malletts Bay's littoral zone as an excellent representation of a majority of the Lake Champlain shoreline.

Predicting Littoral Habitat in Lake Champlain

Using the key findings from the Malletts Bay study, we developed a descriptive matrix that accounts for shoreline development, wind and wave energy, and littoral slope in the prediction of littoral habitat. Using this matrix, we developed a GIS-based model to qualitatively predict macrophyte richness, woody debris habitat, and biotic richness in areas outside of Malletts Bay. Our follow-up validation study provides insight into the effect of development on littoral habitat in the larger lake ecosystem beyond Malletts Bay. Our stratified sampling design targeted undeveloped and highly developed sites in each of the three substrate types previously sampled in Malletts Bay and revealed the same general trends in the stressor-response relationships for a subset of the metrics calculated. Key findings from the validation study include:

- With increasing shoreline development, we found a corresponding decrease in tree cover and woody debris in the littoral zone.
- In rocky substrates, macroinvertebrate richness at the "high" and "low" development sites matched the trend of increasing richness with increasing development observed in Malletts Bay and other inland lake studies in Vermont.

Shoreline Protection Recommendations

We identified shoreline priority areas in Malletts Bay based on data from this study, and recommended several general shoreline protection strategies for greater Lake Champlain. In summary, these include:

- To inform local stakeholders and resource managers about significant shorelines in Malletts Bay, we identified ten (10) shoreline priorities across the study area based on an overlay of several spatial datasets depicting habitat and condition information. The shoreline priorities layer is intended to be a short list of areas in Malletts Bay where a confluence of existing data indicates high terrestrial and/or littoral habitat values.
- Our study was not designed to identify or quantify a vegetative buffer width threshold for limiting the impacts of shoreline development on littoral habitat in Lake Champlain; however, based on a review of regional literature, a minimum buffer width of 30m (100 feet) is typically needed to prevent significant impacts on littoral habitat in lakes throughout northern New England. Further research is needed to develop a defensible basis for an appropriate buffer width on Lake Champlain.
- As there is currently no federal or state regulatory mechanism preventing shoreline stabilization above jurisdictional surface water elevations (e.g., mean or OHW) along Lake Champlain, we recommend that shoreline property owners continue to be guided on the alternatives to traditional "hard bank" stabilization techniques.
- We recommend further detailed study of shoreline erosion hazards in Lake Champlain to support the development of erosion hazard mapping and setback guidance for lakeshore municipalities.

Conclusions

The results of our research are generally consistent with findings in other parts of Vermont and support the recommendations put forth by other researchers and managers regarding the protection or naturalization of native vegetation along the shoreline (VTDEC, 2013). Healthy littoral zones provide essential forage and nursery habitat for fish, improve the aesthetic value of the shoreline, and mitigate erosion damage during flooding. While more study of shoreline development is needed across different areas of the lake to better understand the relative influence of natural gradients and human stressors, there is sufficient evidence to support aggressive actions to mitigate development impacts on these critical zones of Lake Champlain.

Our recommendations for mitigation are consistent with those made by others in Vermont and the region, and build upon a body of technical knowledge and management practices specific to Lake Champlain. Other parallel planning efforts related to littoral habitat quality, such as shoreline erosion hazard planning, are equally important in the broader effort to develop holistic planning strategies for Lake Champlain's shorelines. In the future, volatile weather patterns as a result of global climate change will likely lead to increased precipitation and runoff in the Champlain Basin. With this in mind, it is imperative that the protection of natural shorelines be included in strategic resiliency planning at the local, regional, and state levels.

1. Introduction

1.1 Background on Littoral Habitat and Shoreline Development

Lakes are complex and heterogeneous ecosystems composed of a variety of zones. The littoral zone, the nearshore area of a lake, is the most biologically productive part of many lakes (Schmieder, 2004). Littoral zones are characterized by light penetration to the underlying substrate, allowing for the growth of aquatic macrophytes (Brönmark and Hansson, 1998). Native macrophytes—floating, emergent, and submersed aquatic plants—play important roles in aquatic ecosystems, providing nutrients, breeding substrate, and shelter from predation for a variety of fish and macroinvertebrates (Bryan and Scarnecchia, 1992). In addition, littoral zones can receive direct inputs from adjacent terrestrial habitats, notably coarse woody debris (CWD). CWD is a critical terrestrial input to lake ecosystems, providing refugia for fish and macroinvertebrates, and affecting littoral production and nutrient cycling (Christensen *et al.*, 1996).

There is an increasing body of literature examining the effect of lakeshore development on littoral habitat. Development has been linked with changes in littoral habitat structure (Christensen *et al.*, 1996; Radomski and Goeman, 2001; Jennings *et al.*, 2003; Hatzenbeler, 2004), fish communities (Jennings *et al.*, 1999; Schindler *et al.*, 2000; Scheuerell and Schindler, 2004), and aquatic macroinvertebrate communities (Brauns *et al.*, 2007; Butler and deMaynadier, 2007). Human development pressures along lakeshores are increasing nationwide (EPA, 2009). Lakeshore properties are highly valued and sought after, and many lakeside landowners do not understand the negative ecological impacts of development and vegetation clearing along the shoreline. Based on EPA's National Lakes Assessment (EPA, 2009), only 35 percent of lakes nationwide exhibit "good" shoreline conditions characteristic of low levels of human disturbance. The results for Vermont were below average, with only 17 percent of lakes statewide exhibiting "good" shoreline conditions.

In addition to providing myriad benefits to aquatic ecosystems, natural shorelines directly benefit humans by mitigating flood and erosion hazards and filtering stormwater runoff. Natural woody vegetation and associated root mass increase bank resistance to erosion, and provide roughness elements (e.g., fallen logs) on the lower bank that break waves, slow water velocity, and help retain native sediments on beaches (NRC, 2007; Koch *et al.*, 2009). Vegetation and other organic matter found in natural buffers slow runoff from impervious surfaces and reduce conveyance of pollutants to surface waters (Walsh *et al.*, 2005). As climate change increases the frequency and magnitude of severe flooding and stormwater runoff from urban areas, maintenance and/or restoration of natural shoreline vegetation is likely the most cost-effective management practice for improving resilience of aquatic ecosystems and nearby infrastructure (Carpenter, 2012).

1.2 Assessment and Management of Shoreline Development and Littoral Habitat in Vermont

1.2.1 Past Studies and Knowledge Gap

The Vermont Department of Environmental Conservation (VTDEC) and the University of Vermont (UVM) have researched relationships between development and littoral habitat in various "inland" lakes and ponds throughout the state (e.g., Capen *et al.*, 2008; Merrell *et al.*, 2009; and Merrell *et al.*, 2010). Notably, Capen *et al*. (2008) and Merrell *et al*. (2010) demonstrated that developed sites had less woody habitat, leaf litter, and macrophytes, and more sand and embedded sediments than undeveloped sites. Merrell *et al.* (2010) observed structural changes by surveying shoreline and littoral characteristics for 40 lakes within 5 lake classes. They found that removal of native shoreline vegetation simplifies littoral habitat by reducing inputs of terrestrial organic matter in the form of woody detritus and leaf litter, and reductions in autochthonous food/habitat (primary producers within the aquatic system) in the form of aufwuchs (biofilm). This study included sites that were classified as “buffered developed” and found that these intermediate sites were more similar to reference undeveloped sites than unbuffered developed sites. Reduced tree shading was the only structural parameter with a significant impact due to development observed across all habitat types. Rocky littoral sites exhibited the largest response to development with significant changes to shading, medium and fine woody debris, and leaf litter. A biotic response was also evident at these sites with a significant increase in macroinvertebrate density and a decrease in relative abundance of Chironomidae. This study also found thresholds for shoreline development impact based on the width of a native vegetation buffer and the distance of development from the shoreline.

Inland lake macroinvertebrate communities were also assessed by Kamman (2007) to develop the Vermont Lake Condition BioIndex. Community data from 61 Vermont and New Hampshire inland lakes were used to create a scoring system to quantify anthropogenic impacts on macroinvertebrates in different lake classes (well-buffered, low alkalinity, and large) and habitat types (muddy littoral, macrophyte beds, rocky littoral, sublittoral, and profundal). Macroinvertebrate community metrics were analyzed for each combination of lake class and habitat type to highlight statistically significant differences between reference lakes and lakes with known anthropogenic stressors. No single metric responded significantly in all lake classes or habitat types. However, various community metrics and functional feeding groups responded significantly to development for multiple lake class/habitat type combinations (Kamman, 2007). Biotic responses to development were also reported by Merrell *et al.* (2009); they found greater abundance of fish and odonate species at shoreline sites with significantly more riparian tree cover, woody habitat, and macrophytes.

Prior to this study, little research addressed littoral habitat conditions within our region’s largest waterbody, Lake Champlain. In 2010, Lake Champlain Basin Program (LCBP) initiated a project for the purpose of developing and validating a survey method specifically designed for Lake Champlain to quantify shoreline development on Lake Champlain and to assess the effects of development on the natural littoral communities. This report summarizes a research project to address this specific need.

The Lake Champlain ecosystem, including its shorelines and littoral zones, is varied and complex. For this study, resource limitations prevented a study approach that would characterize and account for the lake ecosystem’s full variability, while still meeting the stated needs of the LCBP and other project stakeholders. As a result, the majority of this study was conducted in a representative portion of the lake: Malletts Bay in northwestern Vermont. Malletts Bay represents a large segment of Lake Champlain’s shoreline in Vermont. It includes a wide range in development patterns and extent along its 56 kilometers of shoreline, from undeveloped forested and wetland shores to manmade shorelines with riprap and retaining walls. The littoral zone is equally variable and heterogeneous in terms of substrate (sandy beaches, rocky shores, and silt/macrophyte beds) and exposure (protected coves, shorelines with varying exposure to wind and wave energy), making Malletts Bay an excellent representative subsample of Lake Champlain’s variability. This range of littoral and shoreline characteristics within a sampling area accessible from public boat launches does not exist anywhere else in Lake Champlain.

1.2.2 Lake Champlain Shoreline Regulations

While other states in the Northeastern U.S. have adopted shoreline protection regulations (VTDEC, 2013), there are no statewide rules or regulations in Vermont or New York restricting the nature or proximity of shoreline development above mean water (Vermont) or mean high water (New York) elevation. In New York, the Adirondack Park Agency has jurisdiction over a significant portion of the lake's western shoreline and regulates vegetation clearing and building setbacks along the lake. In Vermont, for larger development projects subject to the Act 250 permitting process (e.g., greater than ten houses), protection of shorelines is considered under Criterion 1(F) (VTNRB, 2010). At the time of the drafting of this report, a bill was under consideration in the Vermont House of Representatives that would establish shoreline protections and a new permitting process statewide. In addition to the aforementioned rules and regulations, shoreline protection near and below mean or high water is provided through the following regulatory processes:

Federal Permitting
Any construction, excavation, or discharging of fill material that encroaches beyond the ordinary high water (OHW) mark of Lake Champlain (98 feet) or the lake's adjacent wetlands and tributaries requires a permit issued by the Army Corps of Engineers (COE). COE does not have jurisdiction over fill or disturbance above OHW, including clearing or development along adjacent shorelines.

State Permitting
In Vermont, any construction, excavation, or discharging of fill material that encroaches beyond the mean water elevation (95.5 feet) requires a Shoreline Encroachment Permit from VTDEC. In New York, excavation or fill below mean high water (98 feet) requires a NYDEC permit under the Protection of Waters Program.

Local Permitting
Vermont municipalities have the authority to enact local shoreline protection zoning; however, according to a summary report completed by VTDEC (2013), fewer than 20 percent of Vermont towns and cities have adopted such regulations. The degree of protection among municipal ordinances varies widely. Most local regulations in Vermont provide minimum buffer widths and building setbacks for new construction, and some provide specifications for tolerable levels of vegetation removal in the buffer zone (Town of Colchester, 2013). No such summary has been completed to date for New York municipalities with shoreline protection regulations.

1.3 Spring 2011 Flooding

Lake Champlain experienced historic flooding during the spring of 2011. This flooding was the result of numerous factors that combined to produce a record breaking flood lasting for weeks. The preceding winter was the third snowiest on record for Burlington, Vermont and spring snowfall depth ranged from four to eight feet in the mountains. The large amount of water stored in the late snowpack was quickly melted during record rainfall events from March through May. Burlington received a record 19.84 inches, and close to 30 inches of rainfall fell in the mountains over this period. The 2011 flood was notable for its magnitude and duration. The previous recorded peak elevation was 101.86 feet (1993) and the highest estimated level was 102.3 feet (1869). The flood elevation peaked at 103.27 feet on May 6, 2011. The record spring rainfall extended the duration of the flooding to 67 continuous days. High winds coupled with flood conditions exacerbated flooding on both north and south facing shorelines (NOAA, 2012).

Spring 2011 flooding caused extensive damage to property and infrastructure along Lake Champlain throughout Vermont, New York, and Canada. In Vermont, more than 800 residences were impacted by the flooding (FEMA, 2011), and more than 2,000 homes along the flooded Richelieu River in Quebec were evacuated for over a month (EC, 2011). The degree and duration of impact from Lake Champlain flooding raised public awareness about the vulnerability of the lake ecosystem, and shoreline residences and infrastructure, in the face of climate change.

The first field season of this study in Malletts Bay was conducted during the period immediately following the spring 2011 lake flooding. Weather during this period was relatively calm and dry, until the influence of Tropical Storm Irene on August 28, 2011 (Figure 1.1)

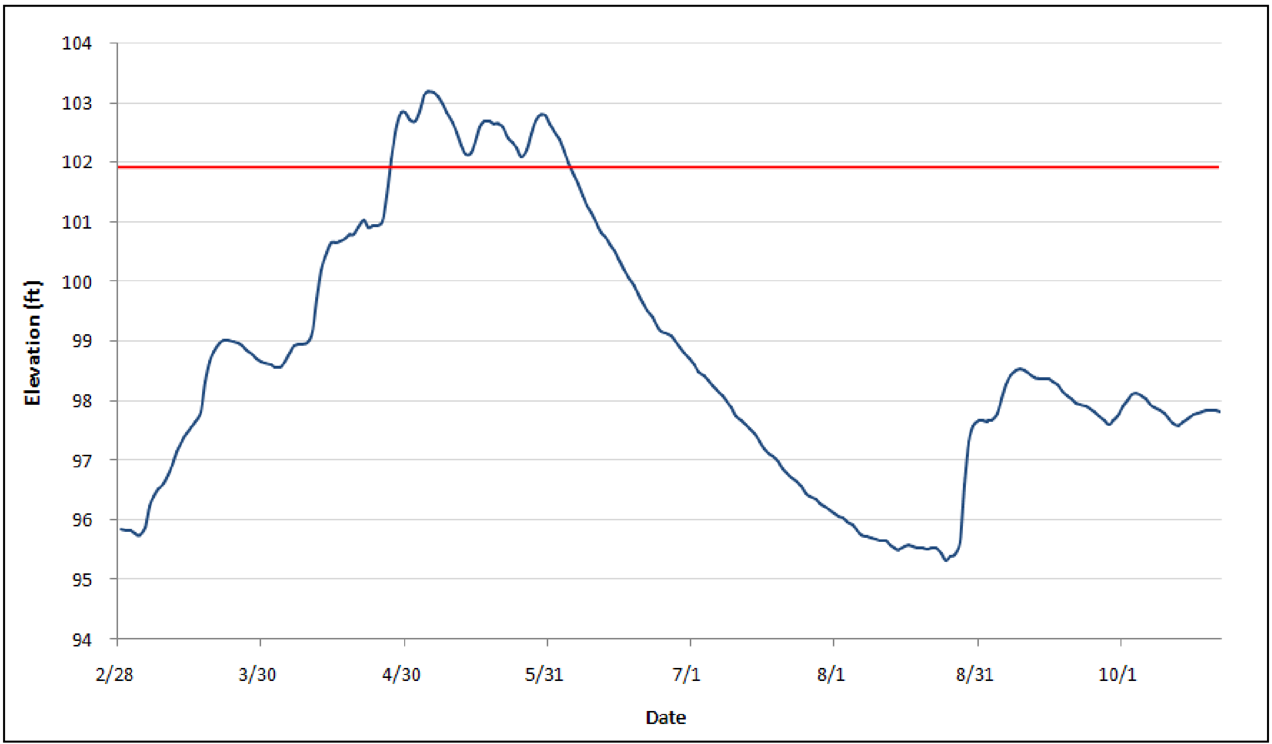


Figure 1.1: Lake Champlain surface water elevation during spring 2011 flooding (USGS, 2012). Red line shows pre-2011 record peak (101.86 feet). National Weather Service Flood Stage is 100 feet.

1.4 Project Goals and Objectives

An increasing body of literature, both in the U.S. and across the globe, has linked shoreline development with reduced habitat quality in the littoral zones of lakes and ponds (Brauns *et al*., 2007; Jennings *et al*., 1999; Merrell *et al*., 2009; Scheuerell and Schindler, 2004; and VTDEC, 2013). To date, little research has examined the impacts of lakeshore development on littoral habitats of Lake Champlain. The principal goal of this project is to quantify, characterize, and understand the effects of lakeshore development on littoral habitats in Lake Champlain.

Specific project objectives include:

- Use high resolution imagery to create detailed maps of shoreline condition and lakeshore land use/land cover;
- Measure littoral habitat conditions and biotic communities across gradients of human development and natural characteristics;
- Model relationships between littoral habitat conditions and riparian and shoreline condition;

- Develop a GIS-based tool to qualitatively predict habitat quality in other areas of the lake;
- Based on the study results, develop recommendations for shoreline protection and best management practices specific to Lake Champlain; and
- Disseminate the study results and recommendations to Lake Champlain Basin stakeholders to improve shoreline management.

Taken together, the results and products of this project have broad implications for the assessment and management of Lake Champlain's littoral habitats and the identification of restoration and protection opportunities. This project addresses several needs identified in LCBP's *Opportunities for Action* (LCBP, 2010). Two specific objectives are addressed by this project. These objectives, supporting the goal to "maintain a resilient and diverse community of fish, wildlife, and plants in the Lake Champlain Basin", include: (1) Restore and maintain a robust fish community and fishery; and (2) Use biological indicators to monitor change in the Lake Champlain ecosystem.

1.5 Project Team

Fitzgerald Environmental Associates, LLC. (FEA) coordinated a Project Team consisting of local scientists and experts from various institutions. Project Team leaders and their roles are summarized below in Table 1.1.

Table 1.1: Project Team leaders and roles

Company/Institution	Project Team Leader	Project Role
Fitzgerald Environmental Associates, LLC.	Evan Fitzgerald	Principal Investigator: structural sampling, data analysis, and reporting
	Joe Bartlett	Field Manager of structural sampling: data analysis, and reporting
Tierra Environmental	Britt Haselton	Co-Principal Investigator: land cover mapping; structural sampling, data analysis, and reporting
University of Vermont	Dr. Ellen Marsden	Co-Principal Investigator: biota sampling, data analysis, and reporting
Saint Michael's College	Dr. Declan McCabe	Co-Principal Investigator: biota sampling, data analysis, and reporting

2. Methods

The methods used in this study are described in detail below, and are generally consistent with the methods outlined in our original LCBP Workplan and Quality Assurance Project Plan (QAPP). Due to the challenges posed by high lake elevation in June, 2011 following the record flooding, minor adjustments to field sampling methods were required. The most significant adjustment was to the fish sampling approach in rocky substrates, and was described in Attachment #1 to the QAPP. This change and other minor changes to the sampling approach are discussed in the following sections. Consistent with the QAPP, steps were taken to evaluate the quality of the data at each step prior to acceptance for use in statistical analysis. These quality assurance measures are discussed separately for each dataset.

2.1 Study Site Selection

Using the site selection approach from our Project Team's approved workplan, which incorporated input from the LCBP Technical Advisory Committee (TAC) in early 2011, some areas of Malletts Bay were excluded from our study (Table 2.1). These areas were excluded for the following reasons: (1) they were assumed to have ecological characteristics or processes that would obscure or confound the lakeshore development effect on littoral habitat, or (2) the littoral slope was unsuitable for sampling.

Table 2.1: Areas excluded from Malletts Bay site selection

Description	Rationale for Exclusion
Tributary confluence	River inputs and deposition of fine sediment and woody debris aro confluence may override development effects. This included a la area near the mouth of the Lamoille River.
Large stormwater outfalls	Inputs of concentrated sediment and nutrients.
Causeways	Non-native rock substrate and absence of shoreline development.
Steep rock faces	Littoral zone too narrow; sampling not practical.
Shallow marshy bays	Littoral zone too wide and shallow with abundant emergent vegetati sampling not practical.

Prior to the initiation of field work, our proposed sample sizes (minimum 90 sites for structural parameters and 30 sites for biota sampling) were evaluated with an *a-priori* power analysis. In many ecological studies, it is challenging to estimate the effect size in an *a-priori* analysis. Based on our literature review of similar studies, we assumed a moderate effect size (0.25) for an ANOVA test. We determined that a sample size of approximately 12 to 15 per substrate group would be adequate to achieve a power level of 0.8 given $\alpha = 0.10$. We were confident that we would achieve this with the structural sampling given our proposed sample sizes. However, we understood that a moderate to large effect size would be needed to detect statistical significance in the biotic communities. As such, we strove to sample greater than the minimum 30 sites for biota as outlined in our proposal and subsequent workplan.

For the 2011 field season in Malletts Bay, littoral sampling sites were initially selected at random among strata of natural and human gradients. Prior to field work, we remotely stratified coarse zones of the Malletts Bay shoreline based on development intensity (strata of 0-33%, 33-67%, and 67-100% impervious surface) and anticipated littoral substrate class (e.g., soft versus hard bottom substrates)

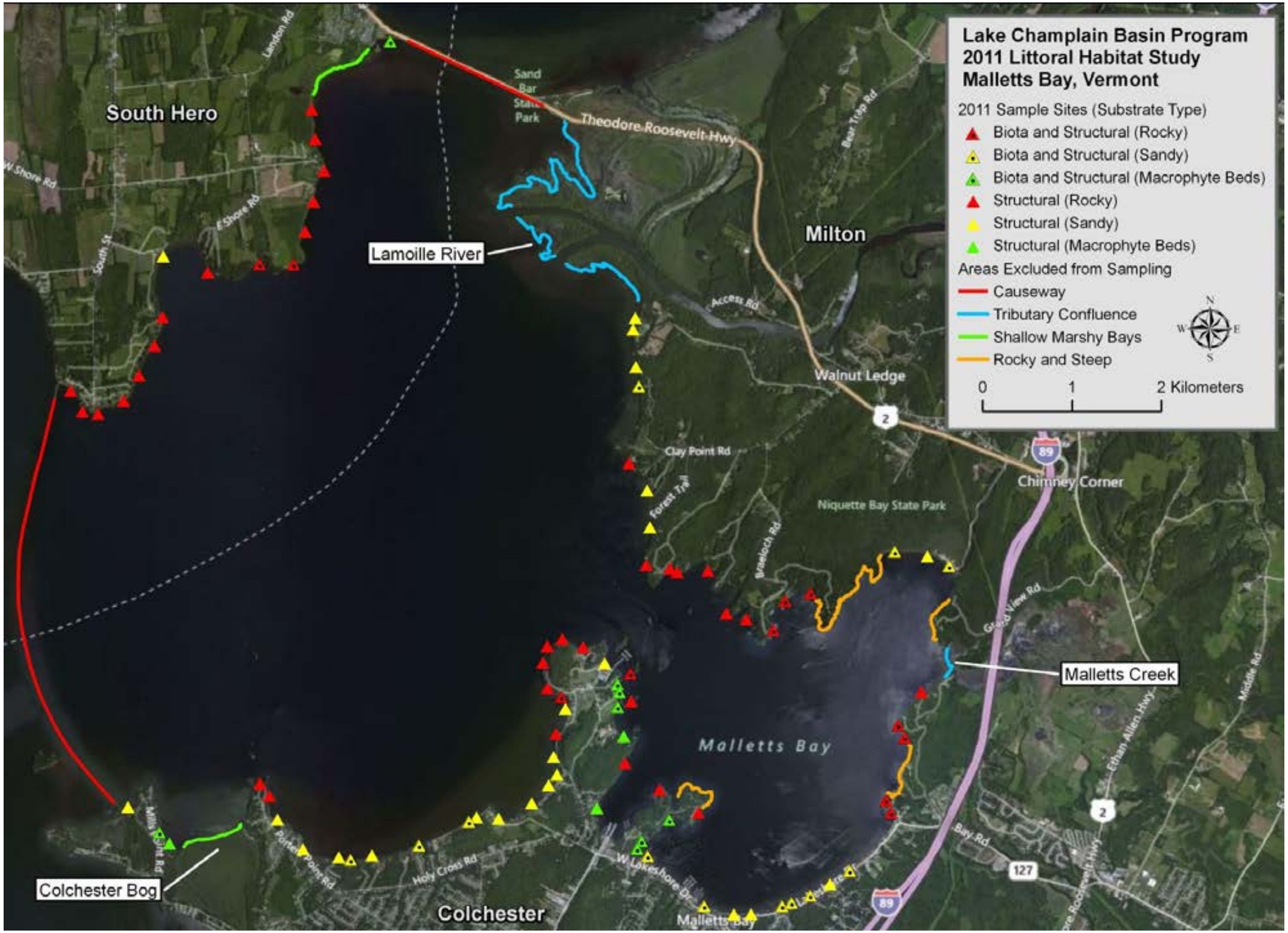


Figure 2.1: 2011 Malletts Bay littoral sample sites and areas of exclusion.

using 2004 and 2009 aerial photography (VCGI, 2005; VCGI, 2009). Following this review, we conducted site visits on June 6, 2011 to review the remote stratification and evaluate sites suitable for biota sampling. Approximately 40 sampling sites were visited during this tour, but the review was challenging due to the flood stage of the lake. The water level that day (102.5 feet) was still near record stage and nearly three feet above the stage at which we started sampling later in June, 2011. Most sites that were deemed to be suitable for biota sampling were indeed sampled. However, some sites were later discarded because littoral characteristics that were not observable at higher stages (e.g., extreme littoral slope) were apparent at lower lake levels. In total, 90 sites were selected for structural sampling, 33 sites for macroinvertebrate sampling, and 35 sites for fish sampling (Figure 2.1).

2.2 Land Cover Mapping

2.2.1 Land Use/Land Cover

Using ArcGIS v.10 software, we developed a land use/land cover (LULC) dataset that depicts riparian areas within 150m of the Malletts Bay shoreline. To build the dataset, we first conducted a detailed, fine-scale mapping of the shoreline. Using the resulting shoreline polyline feature class, we then created a polygon feature class representing a 150m LULC buffer area of the shoreline. Land cover mapping was conducted by “cutting” this LULC buffer area feature class using ArcMap editing tools. Polygons representing land cover features were created based on manual interpretation of various orthophotographic datasets (Table 2.2).

Table 2.2: Orthophotography used for LULC mapping.

Source Dates	Originator	Type	Scale (Resolution)	Format	Primary use
July/August 2009	National Agricultural Imagery Program (NAIP)	True-color, leaf-on	1:40000 (1m)	Compressed JP2	Identify newer urban development
May 2007	Vermont Mapping Program (VMP)	Panchromatic, leaf-off	1:5000 (0.5m)	Uncompressed GeoTIFF	Primary interpretation
May 2004	Chittenden County Metropolitan Planning Organization (CCMPO)	True-color, leaf-on/off	1:1250 (0.5m)	Uncompressed GeoTIFF	Primary interpretation
May 2004	Chittenden County Metropolitan Planning Organization (CCMPO)	Color infrared, leaf-on/off	1:1250 (0.5m)	Compressed JP2	Secondary interpretation
April/May 2004	Chittenden County Metropolitan Planning Organization (CCMPO)	Panchromatic, leaf-on/off	1:1250 (0.5m)	Compressed JP2	Secondary interpretation

Within the Chittenden County portion of Malletts Bay, the primary datasets used for feature interpretation included panchromatic orthophotos collected by VMP in 2007 and true-color orthophotos collected by CCMPO in 2004. The lake level averaged 97.5 feet over the five days of imagery acquisition for the true-color orthophotos. The remaining imagery was collected during similar lake elevations; ranging from 96.5 feet (NAIP) to 98.5 feet (CCMPO). Chittenden County features are accurate to a scale of 1:1250 and current as of July/August 2009. Within the Grand Isle County portion of Malletts Bay, primary interpretation was based on VMP and NAIP orthophotos only. Grand Isle County features are accurate to a scale of 1:5000 and current as of July/August 2009.

In addition to orthophotography, we used a number of ancillary datasets to aid in feature interpretation, including E911 data depicting roads, driveways, and structures (to help identify urban features in wooded areas); the Vermont Significant Wetland Inventory (VSWI); the National Wetlands Inventory (NWI); and various datasets depicting topography.

Features were assigned to one of 18 different LULC classes according to a tailored classification system (Table 2.3) consistent with other inland lake studies in Vermont (Merrell *et al.,* 2010). The classification system was designed to reflect the particularities of mapping the lakeshore areas of Lake Champlain. For example, we incorporated several categories of barren land (e.g., bare rock, beach) and wetlands (e.g., aquatic beds, emergent, scrub-shrub, forested). Three additional classes were not present within the study area (agricultural - orchards, urban - industrial, and barren - other). The classification is fully compatible with existing classification systems developed by the US Geological Survey (Anderson *et al.,* 1976) and the Vermont Geographical Information System (VGIS) partnership (VGIS, 1995).

Table 2.3: LULC classification

Class	VGIS Name	VGIS Code
Agricultural - Crop/Pasture	Cropland and pasture	21
Agricultural - General	Other agricultural land	24
Barren - Bare Rock	Bare/exposed rock	74
Barren - Beach	Beaches and river banks	72
Barren - Quarry/Pit	Strip mine/quarry or gravel pit	75
Brush/Transitional	Brush or transitional between open and forested	3
Forest - Coniferous	Coniferous forest (generally evergreen)	42
Forest - Deciduous	Broadleaf forest (generally deciduous)	41
Forest - Mixed	Mixed coniferous-broadleaf forest	43
Open Water	Water	5
Urban - Commercial	Commercial, services and institutional	12
Urban - Open Space	Outdoor and other urban and built-up land	17
Urban - Residential	Residential	11
Urban - Transportation	Transportation, communication and utilities	14
Wetland - Aquatic Bed	Aquatic bed	621
Wetland - Emergent	Emergent wetland	623
Wetland - Forested	Forested wetland	61
Wetland - Scrub/Shrub	Scrub-shrub wetland	624

All mapping was conducted at a scale no coarser than 1:1250. We employed a minimum polygon size of 0.001 hectares for all features, although non-urban features that occurred as patches were not mapped to this minimum size. For example, a 0.001-ha patch of coniferous forest within a larger matrix of deciduous forest would be included in the deciduous forest polygon (i.e., it would not be mapped as a separate polygon).

QAPP procedures

In accordance with the project QAPP, spatial topology of the LULC dataset was validated to ensure that polygon slivers and gaps were absent. To identify potential digitizing errors, cursory visual reviews of the LULC layer was performed at a scale of 1:5000 by both Britt Haselton and Joe Bartlett to check for accurate classification. Then, following standard LULC QA/QC procedures, a 150m x 150m grid template was developed for the LULC layer extents, and each grid cell was reviewed at a scale of 1:5000. During the review process, 14 areas were identified for discussion, resulting in minor adjustments to the classifications to ensure consistency across the dataset.

2.2.2 Shoreline Condition

In addition to the LULC mapping, we developed a simpler, less rigorous approach to characterizing shoreline condition within Malletts Bay. The intent of this supplemental mapping effort was to produce a rapid characterization of shoreline condition that could be replicated fairly easily in other segments of Lake Champlain (Figure 2.2). Based on orthophotographic interpretation, we divided the detailed shoreline feature class (described in Section 2.2.1) into three different categories: (1) undeveloped; (2) developed without a vegetative buffer; and (3) developed with a vegetative buffer. No prescribed buffer distance was used, and categorization was based entirely on analyst interpretation. We employed a minimum mapping unit (MMU) of 30m.

Figure 2.2: Buffered developed rocky shoreline at site #76.

2.3 Wind and Wave Calculations

As part of this study, we developed a wind erosion potential (WEP) metric to characterize the potential impacts of wind-driven waves on shoreline conditions at the Malletts Bay study sites. Wind-driven waves behave very differently based on water depth. Deep-water waves have no interaction with the lake bottom and wave height is a function of wind speed, duration, and fetch length (Figure 2.3). However, as waves progress into shallower water they begin to “feel bottom” thereby changing wave amplitude and wavelength. Detailed bathymetric mapping and wind/wave models have been used to quantify wind-

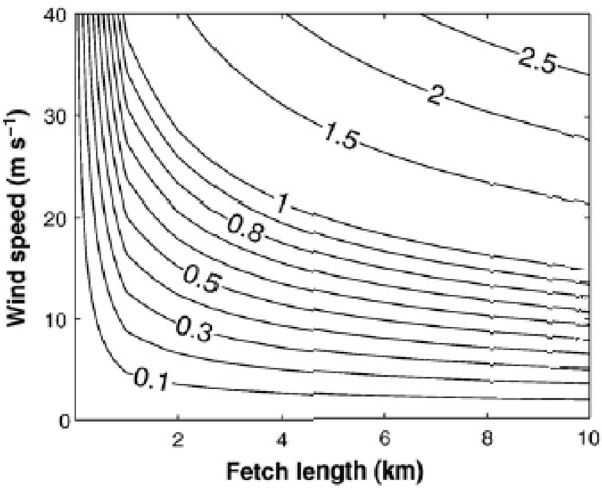


Figure 2.3: Wave height (m) as a function of fetch length (km) and wind speed (m/s); from Vilmundardóttir *et al.* (2010).

driven waves to predict shoreline erosion in a small area of Lake Champlain (Binkerd Environmental, 2009); however, the need for fine-scaled bathymetric data presents a challenge for transferring this depth-dependent approach across large areas of the lake.

A large scale wind/wave model was developed for use in Malletts Bay, but the modeling framework is applicable to the entirety of Lake Champlain. The WEP model was based on 15 minute mean data from continuous wind speed and direction data collected at the Colchester Reef Meteorological station (CRF) operated by the Vermont Monitoring Cooperative (UVM, 2011), and remotely measured fetch distances (bathymetric data for the depth parameter was not included in the model). The CRF station is located approximately 2 km from the southwestern boundary of outer Malletts Bay. The continuous data archive was accessed October 2011, and all available data for monitoring years 2007-2011 were downloaded for analysis. Mean resultant wind speed was converted to 6 categories (0-2 knots, 2-4 knots, 4-6 knots, 6-8 knots, and >10 knots). Wind direction was coded into 32 classes based on compass bearing. Each 11.25^0 wind direction class was centered on the corresponding compass bearing (i.e., N - 360^0 was from 354.375^0 to 5.625^0; see Figure 2.4). The probability of wind speeds over 10 knots was calculated for each of the 32 compass bearing classes.

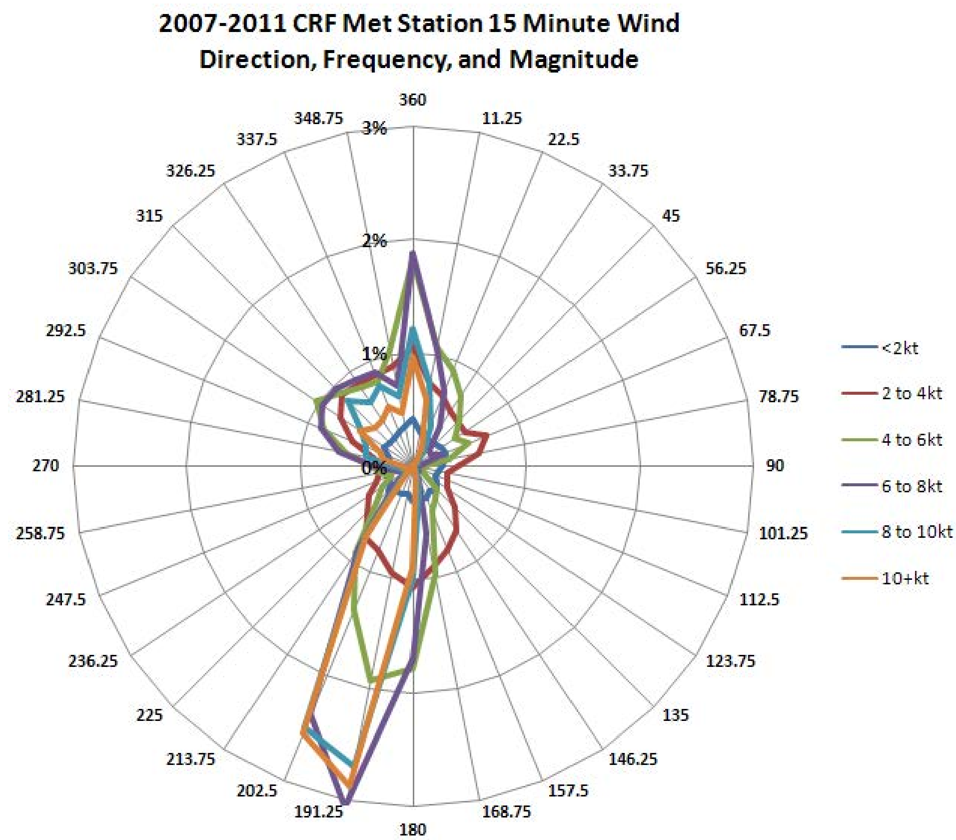


Figure 2.4: Wind rose showing wind direction, magnitude, and frequency (rings) for six wind speed classes from 32 bearings.

Fetch length and shoreline bearing were calculated remotely for each of the 90 study sites in Malletts Bay. The ArcView 3.2 extension Radiating Lines and Points V1.1 tool was used to generate 32 radiating lines spaced at 11.25^0 intervals from each sampling site (Ekebom *et al.*, 2003). The radiating line perpendicular to shore at each site was manually identified and coded. The two lines on either side of perpendicular were also coded to create a wind angle code of 1-5 with 3 being perpendicular and the lines were weighted based on potential wave erosion due to approach angle (0.5, 0.75, 1, 0.75, 0.5 respectively). These five lines represent the 45^0 angle of potential wind impact for each study site (Figure 2.5). The radiating lines were clipped to the extent of Malletts Bay to generate the fetch value (distance in kilometers rounded to the nearest integer). A WEP score was calculated for each site by summing results from the following equation for each of the five radiating lines (Equation 1). The WEP score is effectively non-dimensional, with values ranging from 0 to approximately 60 for the Malletts Bay sites.

Equation 1: WEP = Fetch * Shoreline angle factor * P wind speed >10kt

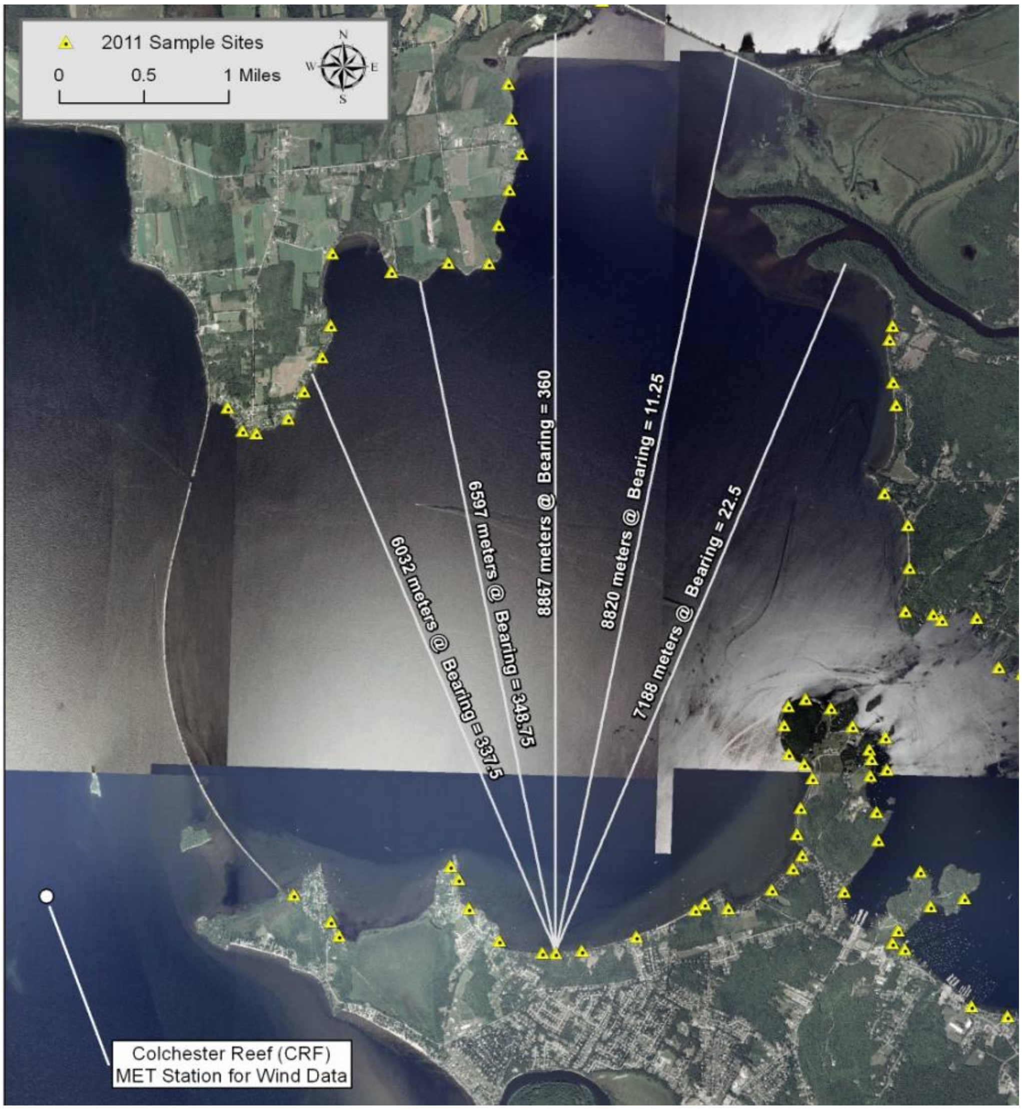


Figure 2.5: Radiating lines and fetch distances for Site #26 in Malletts Bay.

2.4 Field Sampling

2.4.1 Spring 2011 Flooding and Sampling Schedule

Fluctuations in lake level were a major challenge during the 2011 field season. The spring 2011 flood broke all-time records for Lake Champlain and record daily high water continued for 48 days (Figure 2.6). Lake level then dropped to near average for late July and August. The lake level rose rapidly following Tropical Storm Irene and remained at daily record levels for another 36 days. Initial site selection in

Malletts Bay was conducted via boat in early June when the lake level had dropped approximately 0.8 feet from the flood peak; however the lake level during site selection was above the previous recorded all-time high. Structural and biota sampling was conducted from July 20th to September 14th, 2011, with the vast majority (i.e., 85 percent) of our sampling completed during slightly above-average lake elevations. Lake level steadily declined from 97 to 95.4 feet and then quickly rose to 98.5 feet following Tropical Storm Irene.

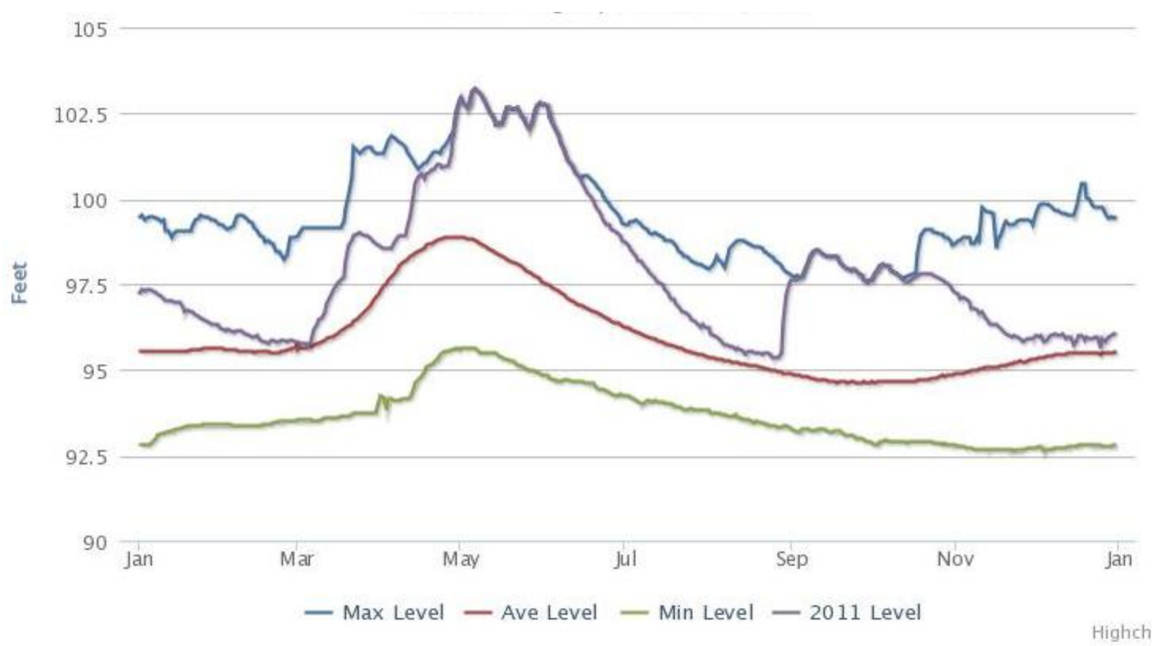


Figure 2.6: Historical lake water levels (maximum, average, and minimum) in relation to 2011 levels (USGS, 2012).

2.4.2 Structural and Vegetative Sampling

Measuring shoreline/riparian condition

Shoreline condition was assessed at each site following an adaptation of the Vermont Agency of Natural Resources' (VTANR) Reach Habitat Assessment protocols (VTANR, 2010) for measuring riparian conditions, shading, cover, slope, vegetation, substrate, beach, and disturbance estimates. Additional development features such as bank armoring, structures, invasive plant cover, and lawns were also recorded (Table 2.4).

Table 2.4: Bank and buffer characteristics collected at each sampling site.

Parameter	Categories and Descriptors				
Bank Slope and Texture	Slope (%)	Texture (%) and Cohesivity (yes or no)			
		Bedrock (%)	boulder/cobble (%)	gravel/sand (%)	silt/clay (%)
Bank Erosion	Percent exposed slope parallel transect				
Bank Canopy	76 – 100%	51 – 75%	26 – 50%	1-25%	0%
Bank and Buffer Vegetation*	Trees (overall % cover)		Invasives (%)	Conifer (%)	Deciduous (%)
	Shrubs/Saplings (overall % cover)		Invasives (%)	WADs† (%)	Saplings (%)
	Herbs (overall % cover)		Invasives (%)	Grasses (%)	Forbs (%)
Buffer Width	>30 m	16 – 30 m	9 – 15 m	4 – 8 m	0 – 3 m

*Separate summaries for banks and buffer; buffer starting point defined by top of slope

† WADs – willows (*Salix, spp.),* alders (*Alnus rugosa*) and dogwoods (*Cornus spp.*)

To describe shoreline and riparian characteristics, observations were made primarily from the immediate shoreline area. In certain areas where the shore was not easily observed from the water (e.g., dense vegetation at the toe of slope) and property permission was not a concern, we further investigated riparian condition by climbing up the bank. Bank slope (percent) was measured using a clinometer. Littoral slope was calculated by measuring the distance from the water's edge to the deep transect at a known depth (i.e., rise over run). The shoreline condition features and littoral habitat characteristics were recorded on a field sheet included in Appendix B. The location of all sampling sites was recorded in the field using a handheld sub-meter GPS (Magellan Mobilemapper CX), and site photos were recorded to show location of transects and shoreline conditions (see Appendix D).

Measuring littoral habitat characteristics

Littoral habitat sampling was conducted following a modified version of the littoral survey methodology used by Capen *et al.* (2008) and Merrell *et al*. (2009). As described by Merrell *et al.* (2009), the methodology of these studies involved establishing three 10-meter floating transect lines at depths of 0.5, 1, and 2 meters at each site. Each transect was divided into two, 5-meter long by 1-meter wide sections, which were then surveyed for coarse woody debris, macrophytes, and substrate distribution estimates (Figure 2.7). Our study reduced the number of transects (to two) and the length (from 10m to 5m). This increased the number of sites that were surveyed during the field season. Transects ran parallel to the shoreline and their locations relative to reference shoreline were constrained by water depth or distance from shoreline as follows: the shallow transect was located at 0.5m depth or 10m from the reference shoreline (whichever was reached first); and the deep transect was located at 1m depth or 20m from the reference shoreline. Based on a review of historical water elevation data and a consideration of natural community colonization of the littoral zone, we designated 96 feet as the baseline mean water elevation for locating our structural transect samples and biota sampling areas.

Figure 2.7: Transect location and area of shoreline and littoral habitat survey.

The field sampling team consisted of one recorder and two observers in the water with snorkeling gear. To maximize consistency in observations over the course of the field season, observations of transect percent cover data were discussed between the sampling team each day. We measured a number of habitat variables and identified all macrophytes species along each transect (Table 2.5). Large woody debris (LWD) was counted for the entire 5m wide area from shoreline to the deep transect. Most macrophyte species were identified in the field using a VTDEC key for common species (VTDEC, 2010). Dr. Sallie Sheldon of Middlebury College joined our sampling team at the beginning of the study to assist with the identification of species. In particular, Dr. Sheldon assisted with the problematic genus of *Najas* to distinguish between native and non-native species. Samples of unidentified macrophytes were collected, labeled, and identified using taxonomic keys (VTDEC, 2010; Crow and Hellquist, 2000). For macrophyte species that were observed as a very small fraction of a transect (e.g., single stem), the presence of the species was noted as 0.1 percent. While these minimal values were effectively negligible for subsequent analyses of relative cover by species, they were counted in macrophyte richness data.

Table 2.5: Littoral habitat variables collected at each sampling site.

Habitat category	Habitat variables	Measurement range
Physical	Sediment type	0-100% cover for various substrate types
	Embeddedness	0-100% embedded
	Large CWD (> 10 cm diameter)	Count
	Medium CWD (4 – 10 cm diameter)	0-100% cover
	Fine CWD (<4 cm diameter)	0-100% cover
	Leaf litter	0-100% cover
Biological	Aufwuchs	0-100% cover
	Macrophytes	0-100% cover for each species present

QAPP Procedures

When all data entry from the 2011 field season was completed in October, 2011, Evan Fitzgerald followed the review procedures outlined in the QAPP to review the data for completeness and representativeness. Completed data sets (in electronic format) were reviewed to ensure completeness of each parameter for each sampled site. No incomplete parameters were found in the review. In addition, a thorough, randomized review of each parameter was conducted for 10 of the 90 sample sites (sites 7, 11, 52, 56, 57, 68, 70, 73, 75, and 85) to ensure a high quality data set. This review resulted in one (1) comment on site 7 regarding the need to follow-up on the identification of a macrophyte species in the shallow transect. This issue was later resolved. No follow-up site visits were needed to verify or adjust the data.

2.4.3 Biota Sampling and Identification

Macroinvertebrate sample collection

Biota sampling sites were selected using a stratified random approach based on the distribution of development intensity (as observed in the field). The 33 macroinvertebrate sampling sites included 10 macrophyte substrate, 12 sandy substrate, and 11 rocky substrate sites. We used a novel sampling protocol for sampling littoral zone macroinvertebrates, combining three sampling methods based on littoral substrate type. The three methods include whole macrophytes sweeps, sampling rocks within quadrats, and kicknet dredging. A minimum of three replicates were collected at each site and all samples were taken 0.5m to 1m below the reference lake elevation (96 feet). Macrophyte beds were sampled by vigorously sweeping a 0.45m wide rectangular net (500um) through the macrophytes along a 10m transect. This procedure yielded a large volume of plant material which was preserved for picking. Rocky substrates were sampled by collecting all rocks and loose substrate to a depth of 4cm into a 500um mesh bag within a randomly placed 0.25m^2 quadrat. Large rocks were washed, scrubbed and sieved in the field to collect all macroinvertebrates. Smaller rocks and gravel were included with the sample. Sandy substrates were sampled by dredging the soft sediments with a 0.45m wide rectangular net (500um) at an approximate depth of 5cm into the substrate for a length of 1m. All samples were labeled and field preserved with 95% ethanol.

Macroinvertebrate picking and identification

All replicates were processed and identified by trained personnel in the Saint Michaels College biology lab under the supervision of Dr. Declan McCabe. Samples were rinsed in a 600um sieve and dispersed on a gridded tray. Squares were randomly selected and picked under magnification until two criteria were met: (1) at least 25% of the sample was picked; and (2) at least 300 individual organisms were picked. The remaining material was retained and preserved. All picked organisms were identified using Merritt, Cummings, and Berg (2008) and other taxon-specific keys. Level of taxonomic identification was genus when possible for organisms of the class Insecta, with Chironomidae identified to Family. Other organisms were identified to Order except for Oligochaeta and Hirudinea.

QAPP Procedures

Completed data sets (in electronic format) were reviewed by Erin Hayes-Pontius or Dr. Declan McCabe to ensure completeness of each parameter for each sampled site. Over the course of the summer in 2011, mock samples consisting of a known number of pre-identified Lake Champlain macroinvertebrates mixed with organic debris and pebbles were introduced into the sample processing lab. These samples were processed through the entire lab procedure from login through final data output to evaluate picking and identification procedures. Results from this process indicated that individual organisms from the Chironomidae family were problematic due to their small size and their tendency to pass through the sieve prior to picking and identification. These results were used to guide additional training needed to ensure completeness and data quality. Using the results of the mock sample identification, we conducted a post-hoc statistical analysis using a paired test with Wilcoxon signed-rank and found that the identified sample populations were not significantly different (p = 0.13) from the known "introduced" sample populations when Chironomidae were excluded.

Fish surveys

Fish were collected at or immediately adjacent to each of the sites selected for macroinvertebrate sampling. At soft-sediment sites, fish were sampled using a 25 m long, 1.3 m high, 6.3 mm mesh bag seine, with two colored floats marking the center 5 m of the net. A 5 m distance was marked along the shoreline, then the seine was pulled perpendicularly offshore, angled parallel to shore at the first colored float, and back to shore at the second float, enclosing a rectangle 10 m long and 5 m wide; then the seine was pulled directly to shore (Figure 2.8). At sites with a sloped contour, the seine was taken offshore no more than 1 m deep.

Figure 2.8: Shoreline seine deployment at a sandy site.

At rocky sites, which were invariably also steeper than soft sediment sites, we deviated from the original sampling plan (per Attachment #1 to QAPP). We had proposed to have divers swim a designated transect, counting and identifying fish within their visual field. Several replicates of this method yielded a maximum count of less than a dozen fish at one site, and at most transects no fish were observed.

Because of depths at these sites, we could not see benthic fishes while swimming near the surface. We therefore used a modified seining method, sampling with a 2.3 m deep seine, 125 m long, with 6.3 mm mesh and a 1.3 m deep bag. The seine was deployed by boat to encompass the largest rectangular area within 2.7 m depth that could be encompassed within the seine. As the seine was pulled to shore, a diver swam around the net and freed the lead-line from snags, while observing possible escapement of fish. Within each of the sampled strata, we took two replicate seine samples to increase sample size and adequately cover the area. Fish species were identified in the field and released. The first 30 individuals of larger species were measured (total length); for smaller species such as logperch (*Percina caprodes*) there was insufficient variability in length to differentiate approximate age (juveniles versus adults). Presence of young-of-year individuals, indicating presence of nursery or spawning habitat nearby, was recorded and numbers were estimated; these small individuals were likely underestimated by the seine due to escapement through the net. Juvenile fishes that were difficult to identify in the field were preserved in ethanol and identified in the lab.

QAPP Procedures

Completed data sets (in electronic format) were reviewed by Dr. Ellen Marsden to ensure completeness of each parameter for each sampled site. Fish identification and measurement was conducted by technicians in the lab who have prior experience with fish research (minimum 2 years at UVM). At least five of each fish species, and any unusual specimens, were checked by Dr. Marsden or Bret Ladago, who have 15 and 5 years of experience, respectively, with identifying Vermont fishes. This review occurred on an ongoing basis to guide additional training needed to correct taxonomic errors and assess data quality. Three questionable specimens (one sculpin and two cyprinid species) were saved and delivered to Rich Langdon, state fish biologist (VTDEC), for identification; however these specimens were lost due to Tropical Storm Irene flood damage in 2011.

2.5 Data Analysis

2.5.1 Shoreline development metrics

Several shoreline development metrics were calculated and explored from the detailed shoreline LULC data. Distance to development from the shoreline and vegetated buffer width were expressed as continuous values quantifying the proximity of development to the shoreline. Composite scoring metrics were also developed to rate the potential impact of shoreline development based on development type and proximity. These metrics assumed that "built" development features such as buildings and driveways had a greater potential impact on overall lakeshore ecosystem health than "outdoor" developed features including landscaping and lawns (Figure 2.9). We explored numerous shoreline development intensity metrics bases on the LULC data developed in this study.

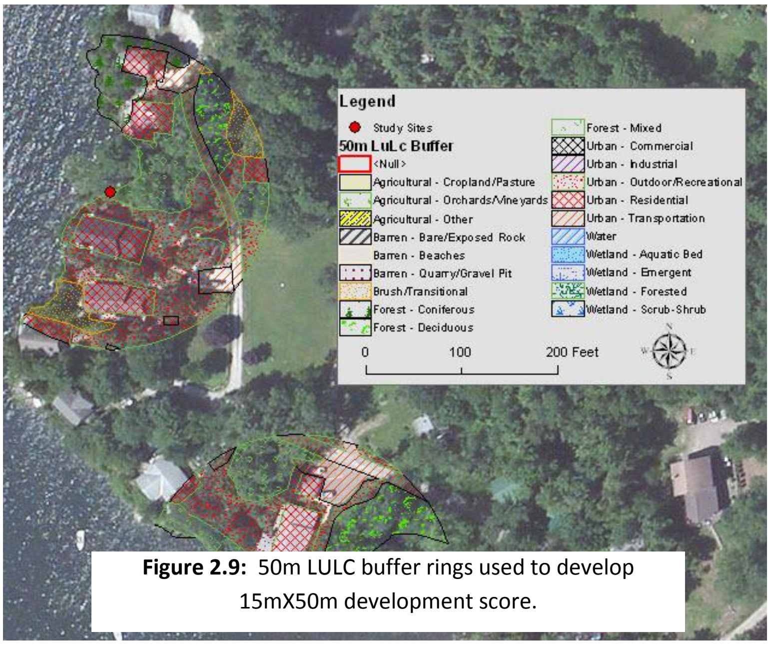


Figure 2.9: 50m LULC buffer rings used to develop 15mX50m development score.

We found that the "15mX50m" shoreline development metric best captured the variability in development intensity and proximity to shoreline across the study area. This metric was calculated by clipping the Malletts Bay LULC buffer area to buffer rings of 15m and 50m from each structural site. The percentage of each buffer ring area designated as "outdoor developed" or "built developed" was calculated. The developed area in the 15m buffer ring was subtracted from the 50m buffer ring to avoid double counting development features. Weighting factors were applied to the developed area percentages to model the range of impacts based on development intensity and proximity to the shoreline. The following equation was used to calculate the 15m X 50m development metric:

Equation 2: 15mx50m score = (%BuiltDeveloped15m*10) + (%OutdoorDeveloped15m*5) + (%BuiltDeveloped50m*6) + (%OutdoorDeveloped50m*3)

The 15mX50m scores ranged from 0 to 10.6 with 0 representing the least developed sites and 10.6 being the most developed. We developed two categorical approaches to scoring development based on the 15mX50m scores described above. The first scheme included three levels of development (High, Medium, and Low) based on even breaks within the sites ranked on development score. The second scheme utilized a natural breakpoint in the development scores that placed sites into high or low development categories. For this second scheme; the Macrophyte and Rocky sites were divided into categories at the same 15mX50m score of 3.5, while the Sandy sites had a lower threshold (1.5) due to the presence of wider beaches at most sites which occupied a large portion of the 15m buffer ring and therefore lowered the 15mX50m score (Table 2.6).

Table 2.6: Numbers of sites of each substrate type in each of the shoreline development categories.

Substrate	Scheme 1 Sample Size (n)			Scheme 2 Sample Size(n)	
	High	Medium	Low	High	Low
Macrophyte	6	5	5	7	9
Rocky	14	14	14	12	30
Sandy	11	12	9	21	11

2.5.2 Structural and Vegetative Metrics

Data from the shallow and deep littoral sampling transect at each site were averaged to develop values for macrophyte and habitat cover (i.e., relative cover for 10 m^2 covered by combined transects) for each site. With the exception of vegetated buffer width and bank canopy metrics, both of which were categorical data, all structural and vegetative survey data were continuous. Continuous datasets were used in appropriate statistical analyses following a normality test of distribution (see Section 2.5.4 for further details). Further metric development and/or adjustments were made to macrophyte data and woody debris data as described below.

Macrophyte Metrics

Using macrophyte data from the combined transects for each site, the following metrics were calculated: richness, invasive cover, dominance, and abundance (Table 2.7).

Table 2.7: Macrophyte metrics.

Metric	Description
Richness	Number of unique taxa present in combined transects
Invasive cover	% of cover represented by invasive macrophyte species
Dominance	% of cover represented by single dominant taxa
Abundance	Total percent cover of macrophytes across both transects (10 m^2)

Large Woody Debris (LWD)

Minor adjustments were made to woody debris density data due to differences in the survey area covered, depending on whether the deep transect location was based on water depth or distance from shoreline (see Section 2.4.2). For example, sites that were distance limited (20m) had a corresponding LWD survey area of $100m^2$, whereas depth limited sites had a smaller area. Therefore, LWD counts for depth limited sites were adjusted to normalize LWD density to an area of $100m^2$.

2.5.3 Biota Metrics

Metrics for macroinvertebrate community characterization

The macroinvertebrate data for each replicate were corrected for the proportion of total sample analyzed, and were combined to create a single mean macroinvertebrate community dataset for each site. We investigated a wide range of available metrics used to characterize macroinvertebrates from general aquatic literature and from studies specific to littoral communities (Kamman, 2007). We excluded species-specific metrics such as functional feeding groups, or Chironomidae richness due to the level of taxonomic identification used for this project. Table 2.8 lists the standard macroinvertebrate and littoral zone specific metrics used in the analysis of macroinvertebrate communities for this study. COTE represents a combination of macroinvertebrate orders that have been identified as important indicators of macroinvertebrate community condition in the littoral zone and is analogous to the more familiar EPT community metric used in streams (Brauns *et al.*, 2007; Butler and deMaynadier, 2006; Kamman, 2007). Macroinvertebrate data from this study are suitable for comparison within each substrate type due to inherent differences in the communities specific to each substrate type and also the differences among sampling approaches and sample area.

Table 2.8: Macroinvertebrate community metrics.

Metric	Description
Abundance	Total number of organisms in sample (adjusted for sub sampling)
Taxa Richness	Number of unique taxa present in sample
Dominance	Proportion of abundance represented by single dominant taxa
Family Richness	Number of unique families present in sample
EPT Richness	Number of unique taxa from Ephemeroptera, Plecoptera, and Trichoptera
COTE Richness	Number of unique taxa from Coleoptera, Odonata, Trichoptera, and Ephemeroptera
% Oligochaeta	% of abundance represented by the order Oligochaeta
%COTE	% of abundance represented by the COTE families
% Chironomidae	% of abundance from the Chironomidae family
Shannon Index	Shannon-Wiener diversity index

Metrics for fish communities

Metrics calculated for each sample site included: species richness, abundance, presence of young of year (YOY; indicating nursery habitat), dominance, biotic integrity, pollution tolerance, and functional feeding group distribution (Table 2.9). Dr. Ellen Marsden supervised the sampling, identification and data processing.

Table 2.9: Fish community metrics.

Metric	Description
Abundance	Total number of adult fish in sample
Species Richness	Number of unique species present in sample
% Dominance	% of abundance represented by single dominant taxa
YOY Richness	Number of unique species of young of year fish present in sample
Shannon Index	Shannon-Wiener diversity index
% tolerant	% of abundance represented by pollution tolerant species
% intermediate	% of abundance represented by species with intermediate pollutant tolerance
% intolerant	% of abundance represented by pollution intolerant species
% top carnivore	% of abundance represented by the top carnivore functional feeding group
% generalist feeder	% of abundance represented by the generalist feeder functional feeding group
% other insectivore	% of abundance represented by the other insectivore functional feeding group
% benthic insectivore	% of abundance represented by the benthic insectivore functional feeding group
% planktivore	% of abundance represented by the planktivore functional feeding group

2.5.4 Statistical Analysis

We explored relationships between the independent (e.g., gradient of development, littoral slope, WEP) and dependent variables (abiotic and biotic metrics) using various statistical methods. Initially, statistical relationships between independent and dependent variables and collinearity between variables was explored with correlation analysis on untransformed data when data were normally distributed (Figure 2.10), or on ranked data using Spearman's ρ values if data were not normally distributed. A significance level of α=0.10 was selected for all analyses, due to the highly variable structural and ecological communities in this study. These correlation diagrams informed more rigorous statistical testing to establish a concise list of structural and biotic variables to best describe the littoral communities (Table 2.10).

Table 2.10: Best predictor parameter for each habitat or community type.

Community Type	Parameter
Structural – Habitat	LWD/100m^2
Structural - Macrophytes	Macrophyte Richness
	Macrophyte Abundance
	Macrophyte Dominance
Macroinvertebrate Community	COTE Richness
	Family Richness
Fish Community	Species Richness
	Abundance
Natural Gradients	WEP10+
	Littoral Slope %

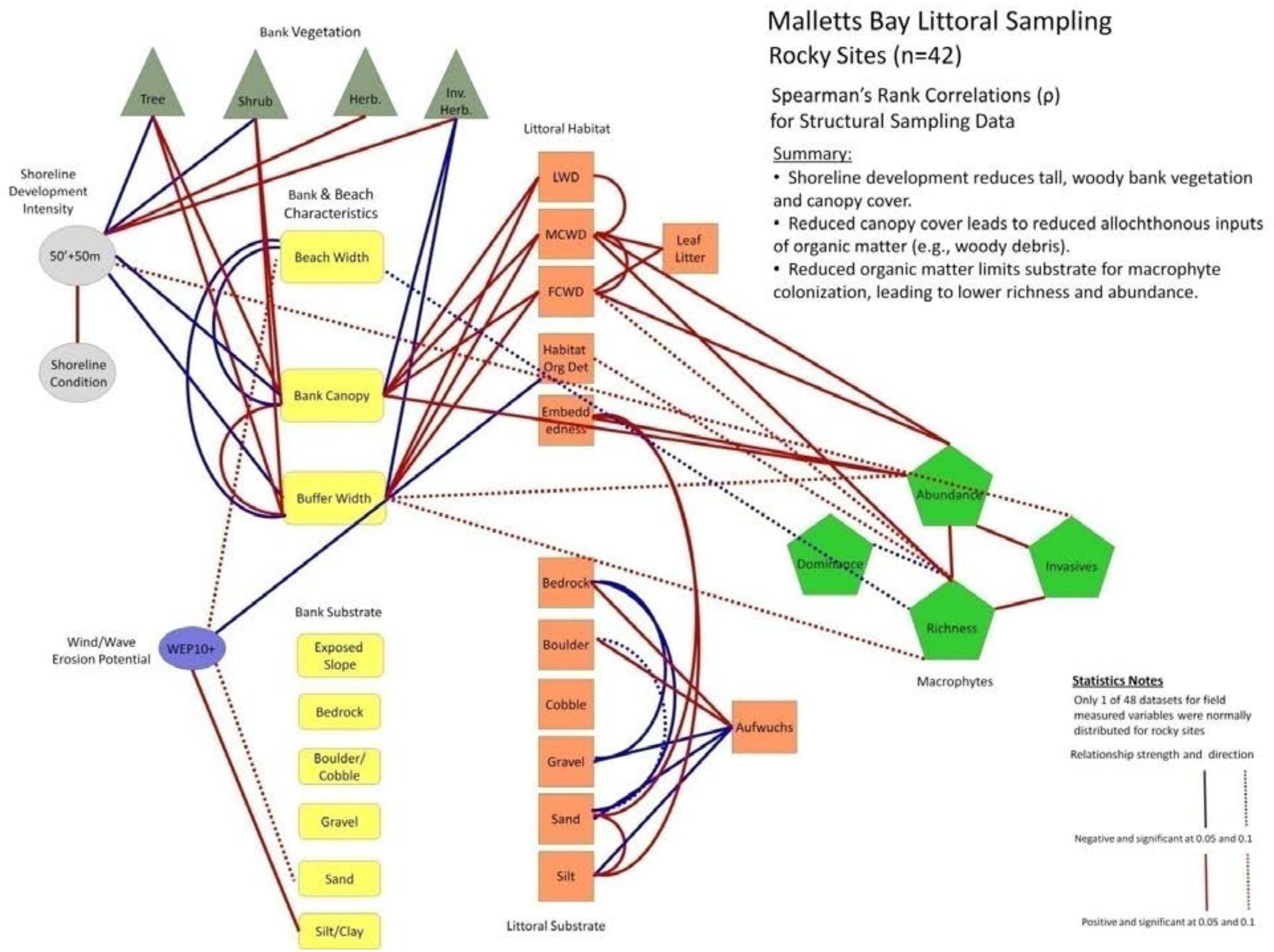


Figure 2.10: Correlation visualization diagram (CVD) for land cover, structural, and vegetative parameters at rocky substrate sites in Malletts Bay.

Testing of Population Means and Medians

ANOVA was used to test for differences between the populations of high and low development sites for structural and biota data. Most populations were not normally distributed. For example, out of a total of 48 measured land cover, structural, and vegetative parameters, only 1, 2, and 5 datasets were normally distributed for the rocky, sandy, and macrophyte substrates, respectively. Many parameters had null values that skewed the distributions. As a result, significance was most often tested using the non-parametric Wilcoxon Rank Sum test.

Principal Components Analysis

Principal Components Analysis (PCA) was used as a descriptive statistical tool for testing covariance within structural variables, and for using orthogonal transformation to develop unique sets of uncorrelated variables (called principal components) for use in multiple regressions. The structural and biota data sets do not represent an ideal homogenous community for PCA, therefore we used the results primarily for descriptive purposes (McCune and Grace, 2002). Numerous sets of structural variables developed from PCA were tested against the most responsive littoral habitat and biota variables. A combined development PCA (15mX50m, distance to development, and vegetated buffer width) and a combined structural PCA (WEP10+, 15mX50m, and littoral slope) were identified as the best PCA models.

Multiple regressions

Multiple regressions were utilized to test multiple predictor variables against structural, vegetative, and biotic response variables. For multiple regressions with biota data, the number of predictor variables was limited to two because of the small sample sizes (i.e., n less than 15). PCA primary and secondary axes were included in the multiple regression analysis to combine additional variables and lessen the risk of overfitting due to limited degrees of freedom.

Structural Equation Modeling (Path analysis)

The correlation visualization diagrams (CVDs; see Figure 2.10) highlighted several logical paths of significance between development and shoreline conditions, littoral habitat, and macrophyte community variables. Structural Equation Modeling (SEM) is an approach that can be used test the statistical significance of more than one causal pathway, often with covarying parameters defined along the path. We selected SEM to analyze several paths between the shoreline development stressor and the response of macrophytes. Path analysis was completed using structural equation modeling with the SAS add-in for JMP 10 (SAS Institute Inc. 2012).

Indicator Species Analysis

Indicator species analysis was performed with the macrophyte species data from the Malletts Bay structural sites. Sites were divided in to three categories based on development as described in Section 2.5.1. PC-ORD v5.18 software was used to calculate indicator values following methods from Dufrene and Legendre (1997). Indicator values were computed based on relative abundance by development group, relative frequency by site, and were tested for significance with 10,000 Monte Carlo simulations (McCune and Grace, 2002).

3. Results and Discussion

3.1 Land Cover Mapping Results

3.1.1 Overall LULC and Shoreline Condition Results

The 150m LULC buffer area dataset includes 3,852 polygons and covers a total area of 672 ha (Figure 3.1). Upland forest, urban, and wetland classes are the dominant land cover types. Of the total LULC buffer area, combined upland forest classes account for 277 ha (41.2%), combined urban classes account for 201 ha (30.0%), and combined wetland classes account for 101 ha (15.0%). See Table 3.1 for a breakdown of LULC class percentages.

Table 3.1: LULC percentages within 150m of the Malletts Bay shoreline.

LULC Class	Area (Ha)	% of Total Area
Urban - Open Space	139	20.7
Forest - Mixed	136	20.2
Forest - Coniferous	76	11.3
Forest - Deciduous	65	9.7
Wetland - Emergent	47	7.0
Brush/Transitional	46	6.8
Urban - Transportation	43	6.4
Wetland - Forested	32	4.8
Wetland - Scrub/Shrub	20	3.0
Urban - Residential	17	2.6
Open Water	17	2.6
Agricultural - Crop/Pasture	16	2.4
Barren - Beach	7	1.1
Barren - Bare Rock	3	0.4
Urban - Commercial	2	0.3
Wetland - Aquatic Bed	2	0.3
Agricultural - General	2	0.2
Barren - Quarry/Pit	1	0.2

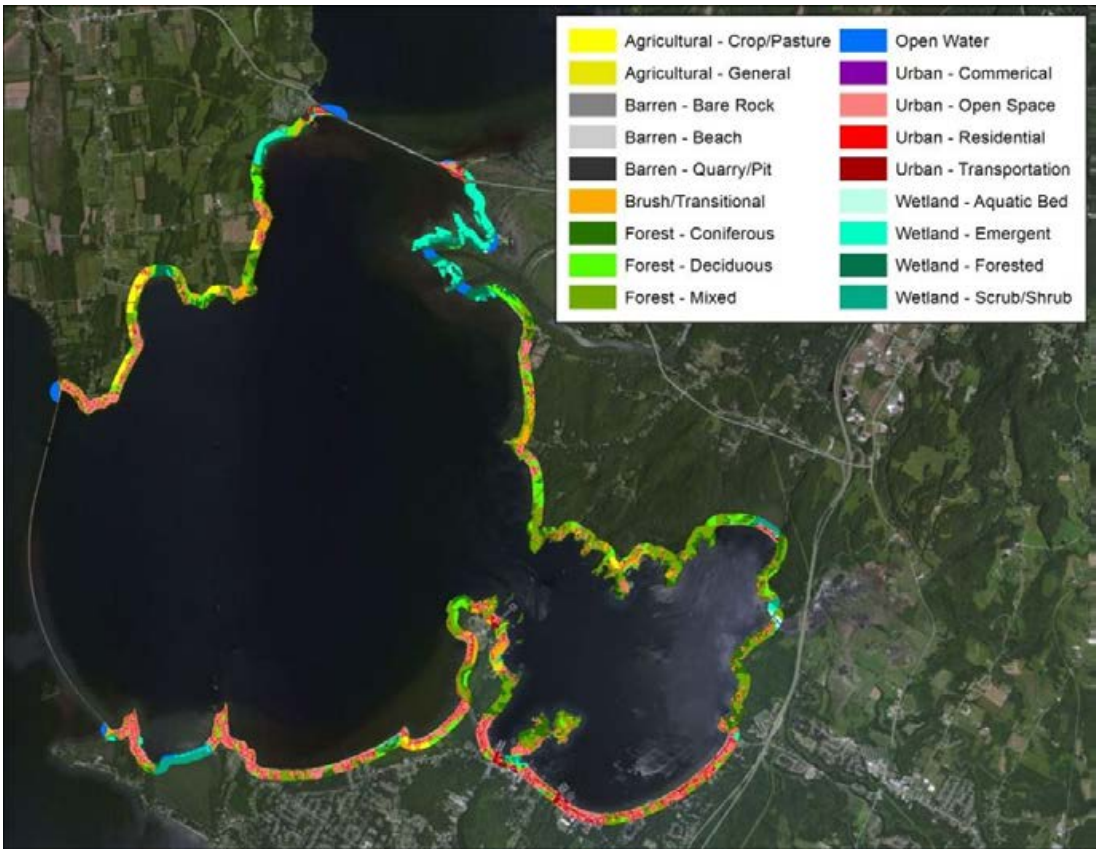


Figure 3.1: Land use/land cover in Malletts Bay.

The shoreline condition dataset (Figure 3.2) includes 191 segments with a total length of 53.8 km. Undeveloped segments total 23.5 km (43.7%), developed segments with a vegetated buffer total 20.6 km (38.4%), and developed segments without a vegetated buffer total 9.6 km (17.9%).

Figure 3.2: Example of shoreline condition mapping in Malletts Bay.

3.1.2 Site-Specific LULC Metrics

The 50m LULC buffer ring dataset for the 90 structural sites covered an area of approximately 35 ha. The complete 50m LULC buffer ring dataset for all Malletts Bay sites is presented in Appendix A. Summary data for high and low development sites for each substrate type are shown in Table 3.2.

Table 3.2: Percent cover of the LULC summary categories for 90 structural sites in Malletts Bay.

Area	Percent Cover – LULC Summary Categories						
	Agriculture	Barren (Rock/Beach)	Brush/ Transitional	Forest	Open Water	Urban	Wetland
50m buffer ring macrophyte "high"	0.0	7.0	5.1	9.4	0.0	76.0	2.6
50m buffer ring macrophyte "low"	3.3	3.1	19.2	27.2	0.3	33.5	13.4
50m buffer ring rocky "high"	0.0	2.5	10.2	24.7	0.0	62.1	0.5
50m buffer ring rocky "low"	0.0	4.0	8.2	68.3	0.0	19.4	0.0
50m buffer ring sandy "high"	1.2	11.1	8.7	18.1	0.0	60.9	0.0
50m buffer ring sandy "low"	0.0	14.1	0.5	60.9	1.0	12.5	11.0

The percent cover of each LULC category for the 50m buffer ring of all 90 structural sites was compared to the 50m LULC buffer area of the entire Malletts Bay shoreline. This comparison shows that our structural sampling sites are representative of the entire shoreline and therefore our results are suitable for interpretation throughout Malletts Bay (Figure 3.3). The entire Malletts Bay shoreline buffer area had a larger percent cover of both wetland and open water, primarily due to the large wetland area near the mouth of the Lamoille River that was excluded from our study as described in Section 2.1.

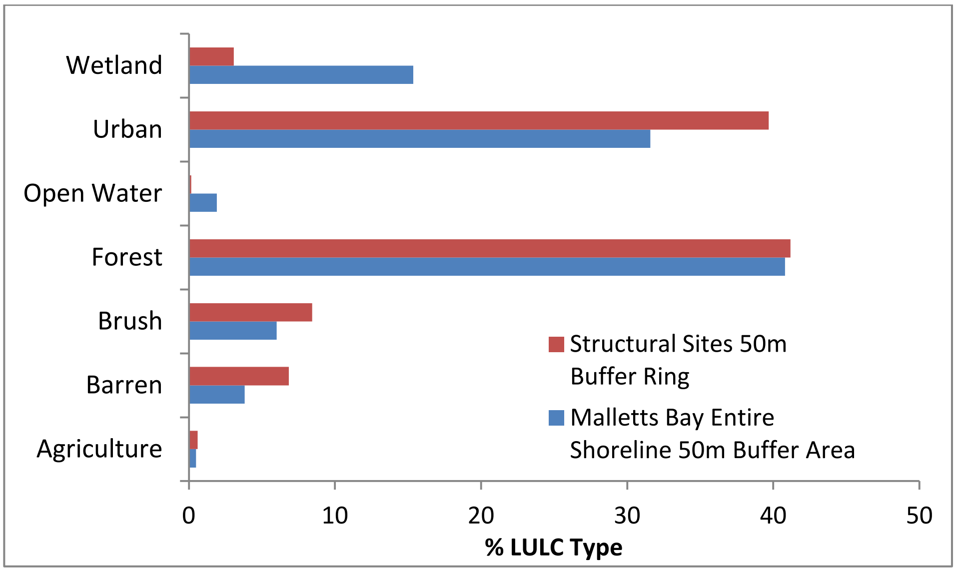


Figure 3.3: Comparison of the 50m LULC buffer rings and buffer area for the entire Malletts Bay shoreline and the 90 sampling sites. The two datasets are not significantly different with Wilcoxon Sign Rank (t-statistic = 4, p = 0.578).

3.2 Structural and Vegetative Results

The following sections summarize key findings of our data analysis to evaluate the effects of shoreline development on littoral habitat and biotic communities in Malletts Bay. Additional results from the statistical analyses and supporting explanations are provided in Appendix C.

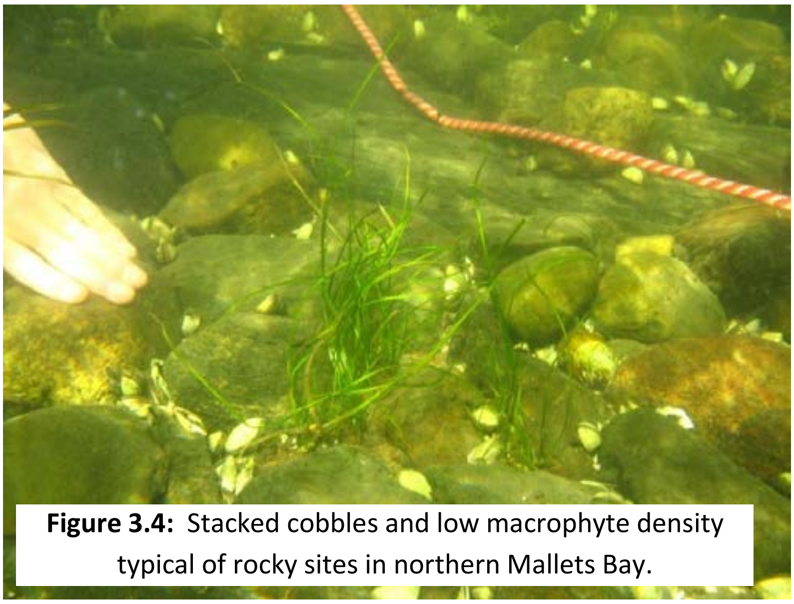


Figure 3.4: Stacked cobbles and low macrophyte density typical of rocky sites in northern Mallets Bay.

The sampling sites spanned the full range of littoral habitat types found in Malletts Bay (see Figure 2.1). Of all substrate types sampled, macrophyte sites were most consistent in terms of bank and littoral structural parameters; sites were typically found in sheltered bays characterized by soft mucky sediment and thick cover of rooted macrophytes. The rocky sites represented the majority of the Malletts Bay shoreline and ranged from narrow bedrock shelves against steep cliffs dropping into deep water, to gently sloping shorelines of stacked cobbles and boulders (Figure 3.4). Sandy sites spanned the range in between macrophyte and rocky, typically with sand dominated substrate and moderate macrophyte abundance. Development intensity range widely within the bay with reference sites located in large conserved areas with wide vegetated buffers to relatively narrow strips of native vegetation located between large houses. The developed shoreline ranged from small camps with modest landscaping and a relatively intact vegetated buffer to shoreline mansions with large sea walls and a complete lack of native bank vegetation.

3.2.1 Shoreline Development Impacts on Banks and Beach

The strongest relationship for all structural parameters was the decrease in shoreline tree cover with development (Figure 3.5). This relationship was highly significant ($p < 0.0001$) across all substrate types (Figure 3.6). The relationship was weaker at the macrophyte sites due to a higher percentage of wetland and brush/transitional shoreline land cover. Percent cover of invasive shrubs and invasive herbaceous plants also increased significantly with development ($p = 0.027$, $p = 0.002$ respectively). Loss of native vegetation and increased invasive plant cover can lead to decreased bank stability and loss of shoreline habitat heterogeneity, affecting wildlife habitat and the supply of terrestrial organic matter to the littoral zone (VTANR, 2009).

Figure 3.5: Bank armoring and intensive shoreline development in Malletts Bay.

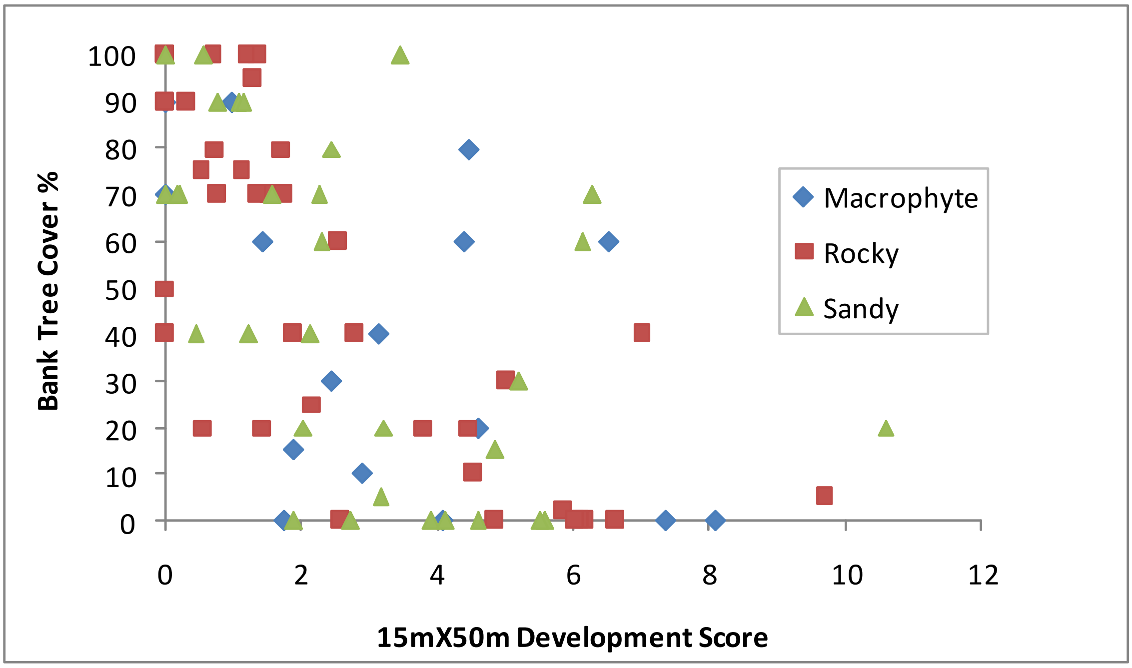


Figure 3.6: Loss of shoreline tree cover with development.

Natural sand beaches are widespread in portions of Malletts Bay and are significantly impacted by shoreline development (Figure 3.7). Natural beaches are important and dynamic shoreline features, constantly undergoing erosion and beach building processes. Shoreline development in Malletts Bay appears interrupt these natural processes, especially when bank armoring is installed to stop bank erosion (present at 25% of Malletts Bay sandy sites). Bank armoring and shoreline development interrupt the natural sediment balance and can lead to increased erosion (Figure 3.8) in surrounding areas and instability of substrate in the littoral zone (NRPC, 2004).

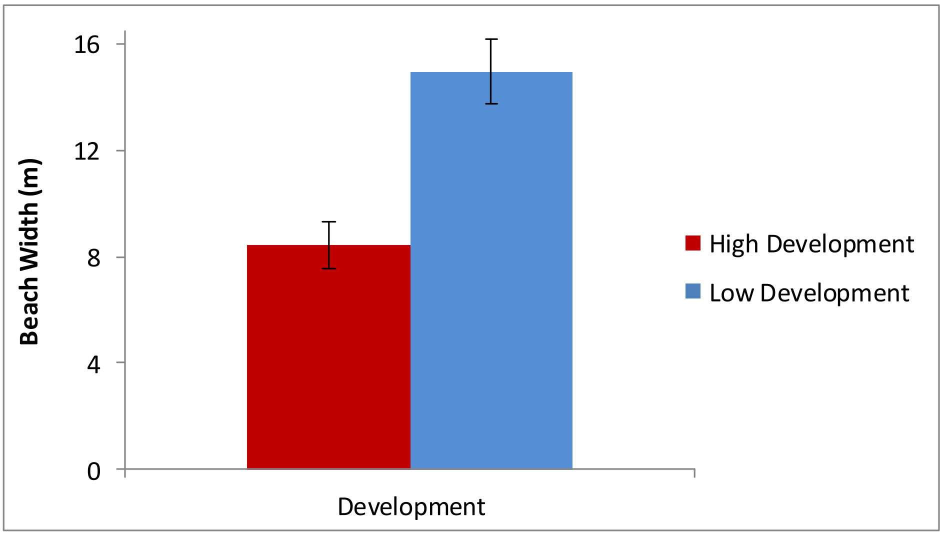


Figure 3.7: At sandy substrate sites, beach widths are lower at more highly developed sites relative to less developed sites (ANOVA; *p* = 0.0002) Error bars represent ±1SE.

Figure 3.8: Northern shore of Porters Point. Extreme erosion along developed shoreline (left); Stable forested banks immediately adjacent to area of extreme erosion (right).

3.2.2 Shoreline Development Impacts on Woody Debris and Habitat

Removal of native vegetation associated with lakeshore development is directly related to a reduction in littoral habitat complexity. Inputs and retention of terrestrial organic matter in the form of woody debris were shown to decrease with development across all structural sites (ρ = -0.184, *p* = 0.0821) with the largest impact found at sandy sites (Figure 3.9). Medium woody debris also decreased with development; however this relationship was not significant. Leaf litter and fine woody debris both increased with development; however both of these parameters had predominantly low values with several influential outliers (sandy sites) and therefore this result is not likely meaningful.

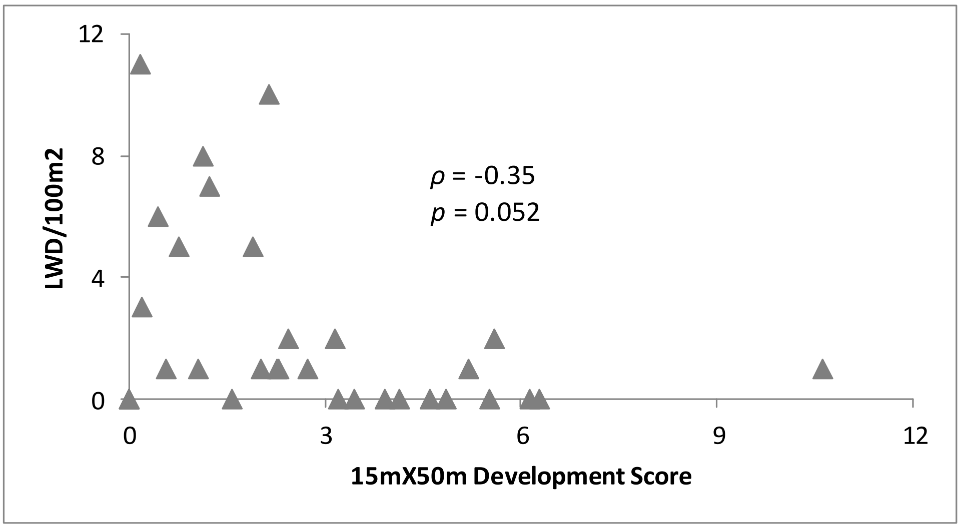


Figure 3.9: Impact of shoreline development on large woody debris at sandy sites.

Bank armoring was also significantly negatively correlated with woody debris density (*p* = 0.033; Figure 3.10). This is likely caused by a combination of shoreline vegetation removal (i.e., reduced recruitment) and increased erosion and mobility of substrate in the littoral zone adjacent to the armoring.

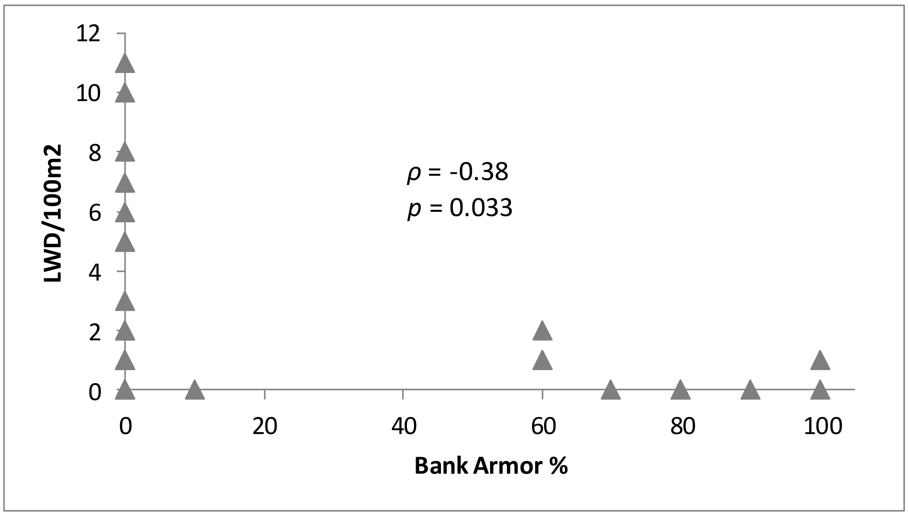


Figure 3.10: Impact of bank armoring on large woody debris at sandy sites.

No significant relationships or trends were identified for the impacts of shoreline development on littoral substrate sizes or distributions (e.g., percent sand) in our study area, in sharp contrast to the primary findings of previous studies of inland lakes in Vermont (Capen *et al.*, 2009; see Section 3.4 for further discussion).

3.2.3 Shoreline Development Impacts on Macrophyte Communities

A total of 39 different macrophyte species were identified across the 90 structural sites in Malletts Bay (see Appendix B for detailed data summaries). The most common and widespread macrophytes were *Vallisneria*, *Zosterella*, *Najas guadalupensis*, and *Najas flexilis* respectively, representing approximately 70% of the total macrophyte cover (Figure 3.11). Two different invasive macrophyte species were identified within Malletts Bay: *Myriophyllum spicatum* and *Potamogeton crispus*. Increased cover of these invasive macrophytes was identified as a possible response to development across all of the structural sites, however this relationship was not significant (p = 0.116). A significant increase in these invasive species was correlated with shoreline development at the rocky sites (p = 0.072). No other direct significant relationships were found between shoreline development and littoral macrophyte communities along a continuous gradient, or when tested against categories of high and low development with ANOVA tests. The CVD for sandy substrates indicated indirect relationships between development and littoral macrophyte communities at the sandy substrate sites. Path analyses exploring the relationship between shoreline development (15mX50m score) and macrophyte abundance and richness were both significantly positive if percent tree cover was inserted between development and the macrophyte community variables as shown in Figure 3.12. This suggests that clearing of shoreline vegetation, which is significantly correlated with development, increases macrophyte abundance and richness due to increased sunlight and potentially higher nutrient availability.

Figure 3.11: Macrophyte identification in Malletts Bay.

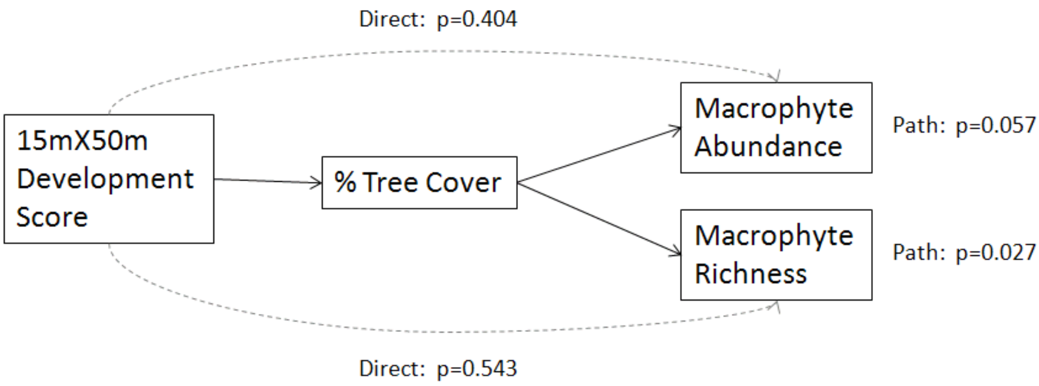


Figure 3.12: Diagram of path analysis for impacts of development on macrophyte abundance and richness at sandy sites.

Indicator Species Analysis

Three species of the genus *Potamogeton* were identified as indicator species for high development at the Macrophyte sites with α = 0.10 (Figure 3.13 and Table 3.3). *Myriophyllum spicatum* was identified as an indicator species for rocky sites (p = 0.046). However, *M. spicatum* was not widespread at the rocky sites and therefore should only be considered a potential indicator species.

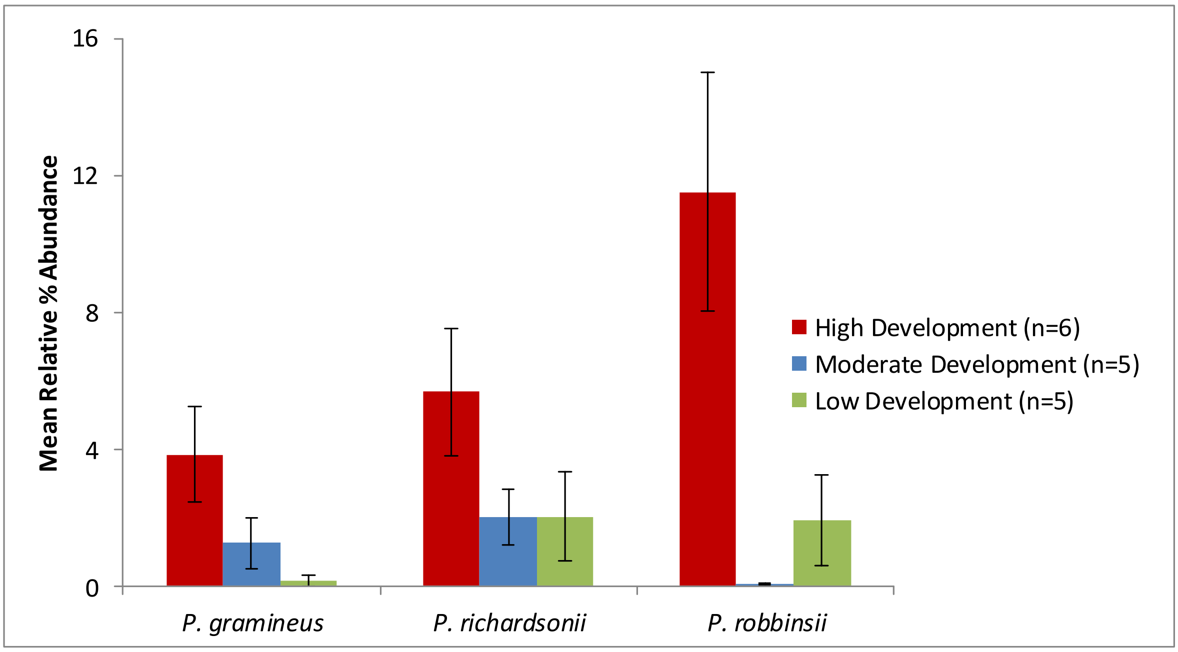


Figure 3.13: Relative abundance of indicator species for development at macrophyte sites with error bars representing ±1SE.

Table 3.3: Indicator species analysis output data for macrophyte sites.

Species	Observed Indicator Value (IV) for High Development	Randomized Groups (IV) for High Development	p-value
P. gramineus	76.2	37.5	0.009
P. richardsonii	58.5	39.2	0.057
P. robbinsii	83.1	41.8	0.003

3.2.4 Structural and Vegetation Response to Natural Gradients

Littoral slope and wind-driven wave erosion potential (WEP) were identified as natural gradients that explain some variation in structural habitat and vegetation within the study area. WEP was found to decrease the percent cover of fine organic matter both in the form of fine woody debris at macrophyte sites and fine organic matter such as senesced algae at rocky sites (p = 0.015 and p = 0.0038 respectively). This would suggest that wave action washes away the finest organic materials while having less of an effect on coarser woody debris. WEP was positively correlated with macrophyte abundance at the macrophyte sites (p = 0.066), suggesting that increased water circulation may benefit plant growth in dense macrophyte beds. Several macrophyte sites were observed to have dense covering of silt on the macrophytes which could increase anaerobic conditions in the underlying substrate, and reduce plant growth and abundance.

Littoral slope was only found to be an important factor for the rocky sites, which is likely due to low variability in littoral slope (<5%) at the sandy and macrophyte sites. Highly sloped rocky sites were typically characterized by a rough and fractured bedrock shelf below the waterline extending from a steep rocky shoreline. Lower sloped rocky sites ranged from smooth bedrock to cobble and boulder piles. All three classes of woody debris were positively correlated with littoral slope at the rocky sites (LWD: p = 0.0875, MWD: p = 0.0003, and FWD: p = 0.031). This would suggest that the steeper littoral slope areas are better suited for retaining woody detritus, perhaps due to the ability of the shelves and steps to capture and "trap" woody debris within the littoral zone.

3.2.5 Interactions Among Development and Natural Gradients

Significant interactions among structural and vegetative response variables, shoreline development, and natural gradient predictors were modeled using multiple regressions. Adjusted model *R*-squared values were low; however, several of these interactions increased the explanation of variance for the structural response variable (Table 3.4).

Table 3.4: Multiple regression outputs for the interactions between development and natural gradients.

Substrate	Response	Predictors	Adjusted Model R^2	Model p-value	Parameter 1 Statistic	p-value	Parameter 2 Statistic	p-value
Rocky	Macrophyte abundance	15mX50m - littoral slope	0.15	0.014	-3.05	0.42	1.52	0.008
Rocky	LWD/100	15mX50m - littoral slope	0.13	0.025	-0.3	0.34	0.11	0.018
Macrophyte	Macrophyte Richness	15mX50m - WEP	0.25	0.061	0.11	0.75	-0.11	0.029

The two models for rocky sites indicate that macrophyte abundance and LWD/100m^2 decrease with shoreline development and increase with littoral slope. This supports the aforementioned findings of reduced terrestrial organic matter supply due to loss of shoreline vegetation and the increased retention of organic matter along steep shorelines, with potentially increased substrate availability for macrophyte colonization. The macrophyte substrate model indicated that macrophyte richness increased with shoreline development, likely due to increased sunlight and nutrient availability (see discussion in Section 3.2.3) and decreased richness with increasing wind exposure. Section 3.2.4 describes the increase in macrophyte abundance with WEP; we infer that a few species are better adapted for taking advantage of the conditions at windier sites, with a resulting increase in abundance and decrease in richness.

3.3 Biota Results

Macroinvertebrate communities in Malletts Bay were distinct based on substrate type. Rocky sites had the highest taxa richness, yet much lower abundance than the soft substrate sites. Sandy and macrophyte macroinvertebrate communities were similar in abundance, and richness; however they differed in composition and dominant taxa. The three habitat types would each be expected to be colonized by distinct faunas. In addition, sampling methods and sampled area differed among the three substrate types so similarity in community composition was not expected. Over 80 percent of the organisms counted at the macrophyte sites were not insects, primarily belonging to Class Gastropoda (snails). Gastropods were abundant in the sandy and rocky sites, however at a much lower proportion of approximately 15 percent. Chironomidae represented approximately 25 percent of the abundance at sandy and rocky sites, and 10 percent of abundance at the macrophyte sites. Amphipods and Bivalves (clams) were common at sandy sites. Rocky sites had the highest abundance and richness of COTE taxa, typically representing approximately half of the richness and one-third of the abundance. A taxa list and the macroinvertebrate metric calculations area provided in Appendix B.

Figure 3.14: Fish seining in Malletts Bay.

Fish communities sampled in Malletts Bay ranged from a richness of 0 to 14 and abundance ranging from 0 to 265 for the combined replicates collected at each site. A total of 28 fish species were counted in Malletts Bay with the most common fish belonging to the Cyprinidae family (minnows and shiners), the Centrarchidae family (bluegill and sunfish), killifish, brook silverside, and yellow perch (Appendix B). These represent approximately 80 percent of the littoral species in Lake Champlain. Species not well represented include larger fish such as pike, walleye, and bowfin; which would be likely to avoid the seine during sample collection (Figure 3.14). Four invasive species were collected in Malletts Bay; alewife, tench, and white perch were rare, while brook silverside were abundant. Young of year (YOY) were found for 19 of the species indicating the importance of the littoral zone for fish reproduction and recruitment. All five functional feeding groups were recorded, with “other insectivore” as the most abundant.

3.3.1 Biotic Response to Shoreline Development

Development

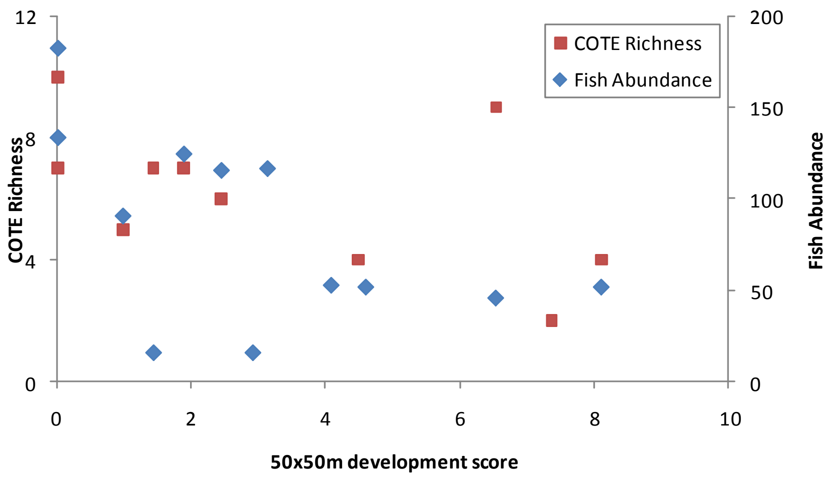


Figure 3.15: Biotic response to shoreline development at macrophyte sites.

Biotic metrics were very responsive to shoreline development intensity. Biotic communities in sandy and macrophyte substrates typically responded with decreasing richness with increasing development, while the rocky sites exhibited the opposite relationship. COTE richness and fish abundance both decreased significantly with shoreline development at macrophyte sites (COTE: ρ = -0.60 *p* = 0.067; fish abundance: ρ = -0.56 *p* = 0.061); Figure 3.15). The impacts of shoreline development on biota at sandy sites was not significant using continuous data; however COTE richness was significantly higher in more developed sites relative to less developed sites (ANOVA comparing high and low development sites; *p* = 0.046; see Figure 3.23)

Shoreline development at the rocky sites was associated with a significant increase in COTE richness (Figure 3.16; ρ = 0.661, *p* = 0.027). Fish richness and abundance were also positively correlated with development scores but were not significant (*p* = 0.136 and *p* = 0.258 respectively). We suspect this is due to increased sunlight and nutrients leading to increased food availability. While not significant, we found increased woody debris, soft sediments, and aufwuchs at the sites with higher development. All of these variables may increase habitat heterogeneity and food availability for macroinvertebrate and fish communities. Increased sediment deposition may provide food to collector-gather invertebrates and may increase area suitable for macrophyte colonization, increasing habitat availability.

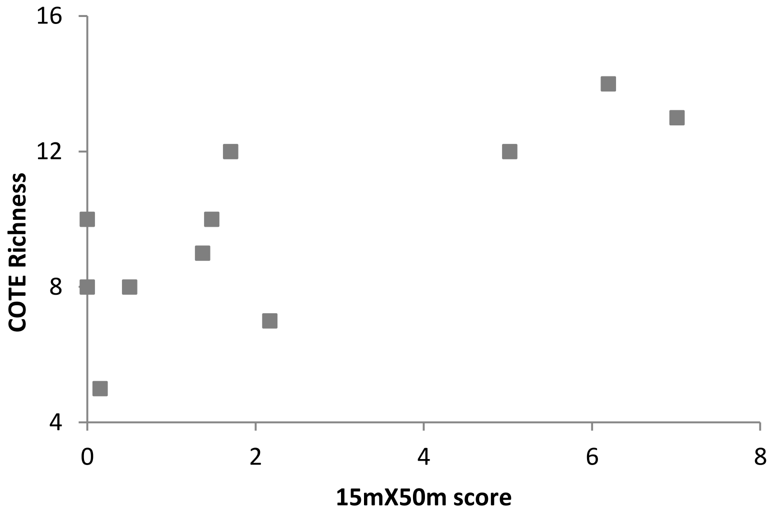


Figure 3.16: Biotic response to shoreline development at rocky sites.

3.3.2 Biotic Response to Natural Gradients

Macroinvertebrate and fish communities were found to significantly respond to natural gradients of WEP and littoral slope. Higher WEP was associated with a greater richness and abundance of typically sensitive taxa at the macrophyte sites. These sites had decreased macroinvertebrate dominance (ρ = -0.552, *p* = 0.098) and increased % COTE (ρ = 0.624, *p* = 0.054); Figure 3.17.

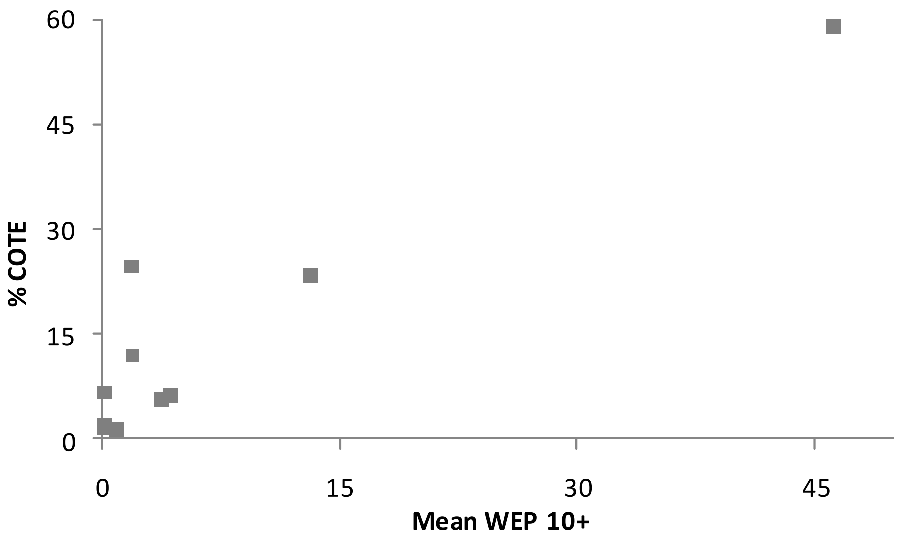


Figure 3.17: Response of Coleoptera, Odonata, Trichoptera, and Ephemeroptera richness to wind driven wave exposure at macrophyte sites.

Wave action may increase macrophyte productivity by removing fine sediment and increasing water circulation, improving food availability and habitat quality for certain COTE taxa. LWD was also significantly positive with WEP for the subset of macrophyte sites included in the biota sampling (ρ = 0.484, *p* = 0.079), suggesting that greater wind and wave action may transport woody debris into the littoral zone, thereby increasing food and habitat availability. Fish richness at macrophyte sites was not significantly related to WEP (ρ = 0.134, *p* = 0.677).

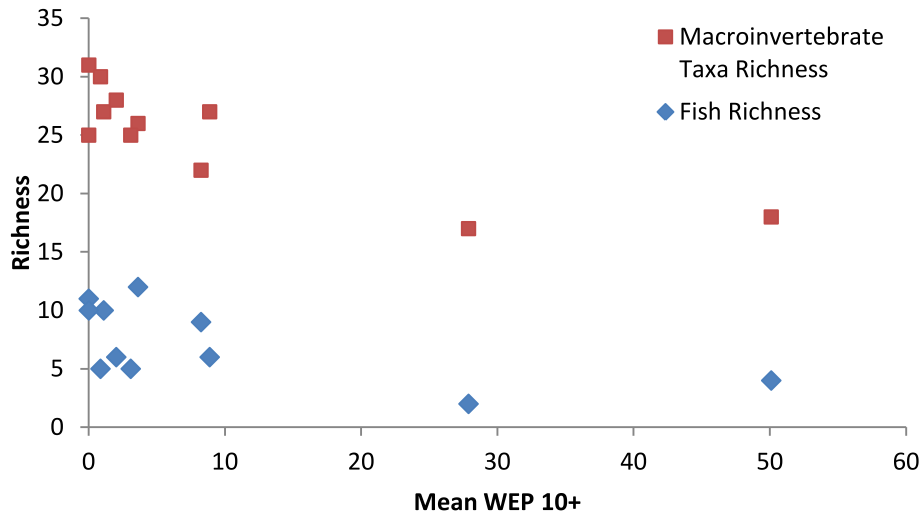


Figure 3.18: Biotic response to WEP at rocky sites.

Macroinvertebrate taxa richness and fish richness were both negatively correlated with WEP at rocky sites (ρ = -0.66, *p* = 0.028, and ρ = -0.56, *p* = 0.025, respectively; Figure 3.18). Both relationships indicate that the littoral biotic community may be tolerable of wind and wave exposure up to a certain degree (i.e., WEP score of 20 shown in Figure 3.18). Biotic richness is likely reduced in shoreline areas exposed to frequent wave action due to scour and the lack of stable soft substrates. COTE richness was not significantly responsive to WEP, however the relationship did show a negative trend (ρ = -0.389, *p* = 0.237). More research is needed to better understand the mechanisms by which littoral biotic communities in Lake Champlain are adversely affected by wind and wave exposure.

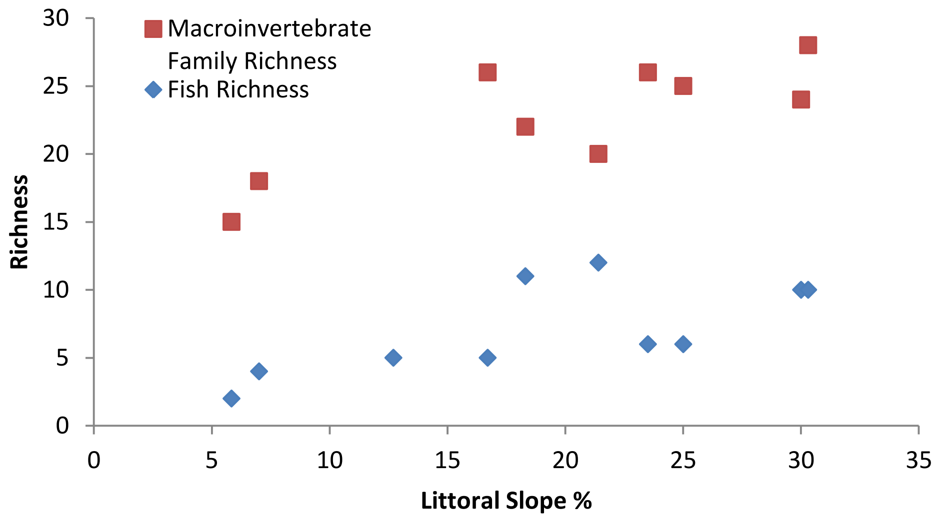


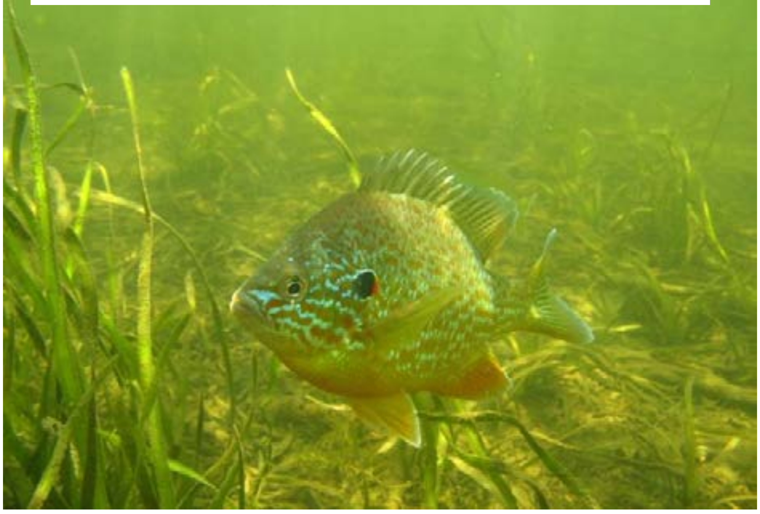
Figure 3.19: Biotic response to littoral slope at rocky sites

Macroinvertebrate family richness and fish richness were associated with increasing littoral slope at rocky sites (ρ = 0.68, p = 0.029, and ρ = 0.64, p = 0.025, respectively; Figure 3.19). COTE richness and %COTE were not significantly correlated with littoral slope, however both trended positively with slope (ρ = 0.508, p = 0.134 and ρ = 0.103, p = 0.777 respectively). Variations in bedrock observed at the steeper, rocky sites in Malletts Bay, including ledges and shelves, may provide greater habitat complexity and cover for biota in the littoral zone. In addition, the increase in retention of woody debris observed at steeper rocky sites (Section 3.2.4) may also provide greater substrate, cover, and food sources for macroinvertebrates than in lower sloped sites. Littoral slope was consistently low at the macrophyte and sandy substrate sites and therefore not analyzed for correlation with biotic communities.

Fish richness and macroinvertebrate richness are positively correlated (ρ = 0.53, p = 0.094); therefore, we suspect that the same natural gradient factors affect both populations. Fish richness is also likely linked to macroinvertebrate richness as a simple factor of food availability.

Biotic responses were also observed with structural and vegetative variables at all sites. COTE richness (ρ = 0.643, p = 0.045) and fish abundance (ρ = 0.726, p = 0.017) increased with medium woody debris at rocky sites, supporting the importance of littoral habitat heterogeneity for food availability and cover (Brauns *et al.*, 2007). Macrophyte percent dominance was significantly negatively correlated with fish richness (ρ = -0.529, p = 0.077) at macrophyte sites, and with macroinvertebrate taxa richness (ρ = -0.556, p = 0.082) at sandy sites. This also supports the importance of littoral habitat variability to diverse biotic communities.

Figure 3.20: Pumpkinseed sunfish in Malletts Bay.



3.3.3 Interactions Among Development and Natural Gradients

Significant interactions between biotic response variables, shoreline development, and natural gradient predictors were modeled using multiple regressions and PCA (Table 3.5). The multiple regression models combining development with WEP or littoral slope explained more of the variance within the biotic metrics than the direct, single-predictor relationships. That these relationships were statistically significant even when their influence relative to shoreline development was considered suggests that shoreline development and natural gradients both influence biotic communities in the littoral zone.

Fish richness and COTE richness were both significantly responsive to littoral slope and shoreline development. The parameter estimates for each model suggest that the two biotic communities are not equally affected by the predictors; fish are more sensitive to littoral slope, and macroinvertebrates are more sensitive to shoreline development. The combined predictors of WEP and development explained additional variation in COTE richness at rocky sites with each parameter increasing significance compared to the direct, single-predictor relationships.

Table 3.5: Multiple regression outputs for the interactions between development, natural gradients and biota.

Substrate	Response	Predictors	Adjusted Model R^2	Model p-value	Parameter 1 Statistic	p-value	Parameter 2 Statistic	p-value
Macrophyte	Fish Abundance	WEP – 15mX50m	0.39	0.046	1.17	0.097	-9.11	0.108
Sandy	Macroinvertebrate abundance	WEP – 15mX50m	0.30	0.082	27.73	0.116	-176.3	0.176
Rocky	Fish Richness	Littoral slope – 15mX50m	0.47	0.043	0.24	0.041	0.43	0.23
Rocky	COTE Richness	WEP – 15mX50m	0.66	0.005	-0.064	0.083	0.79	0.004
Rocky	COTE Richness	Littoral slope – 15mX50m	0.64	0.011	0.096	0.13	0.63	0.011
Rocky	COTE Richness	PCA1-1 - PCA1-2*	0.39	0.074	-0.79	0.082	0.82	0.12
Rocky	COTE Richness	PCA2-1 - PCA2-2$^{\pm}$	0.73	0.004	1.235	0.004	1.256	0.02

*PCA1-1 - PCA1-2 = First two components based on PCA containing15mX50m, WEP, littoral slope, distance to development, and vegetated buffer width

$^{\pm}$PCA2-1 - PCA2-2 = First two components based on PCA containing 15mX50m, WEP, and littoral slope

Two different PCA axes were developed to incorporate more predictor variables without violating sample size limitations (see Appendix C for supporting data). Both PCAs were significant for COTE richness at rocky sites; however, the increased complexity of the model only resulted in a marginal increase in the proportion of variance explained by the model. These results suggest that the primary factors affecting biotic richness in Malletts Bay are shoreline development intensity, littoral slope, and wind and wave exposure.

3.4 Comparison to Vermont Inland Lakes Study

3.4.1 Structural and Vegetative

Our results from structural, vegetative, and biotic assessments of Malletts Bay supported many of the key findings of the Vermont Inland Lakes study. Figure 3.21 presents the relative percent difference for all structural sites divided into high or low development categories with significant *p*-values reported in Table 3.6. Relative percent difference is calculated as the percent difference between the mean values for low versus high developed sites ((high value - low value)/high value). Additional significant relationships are displayed for sandy substrates.

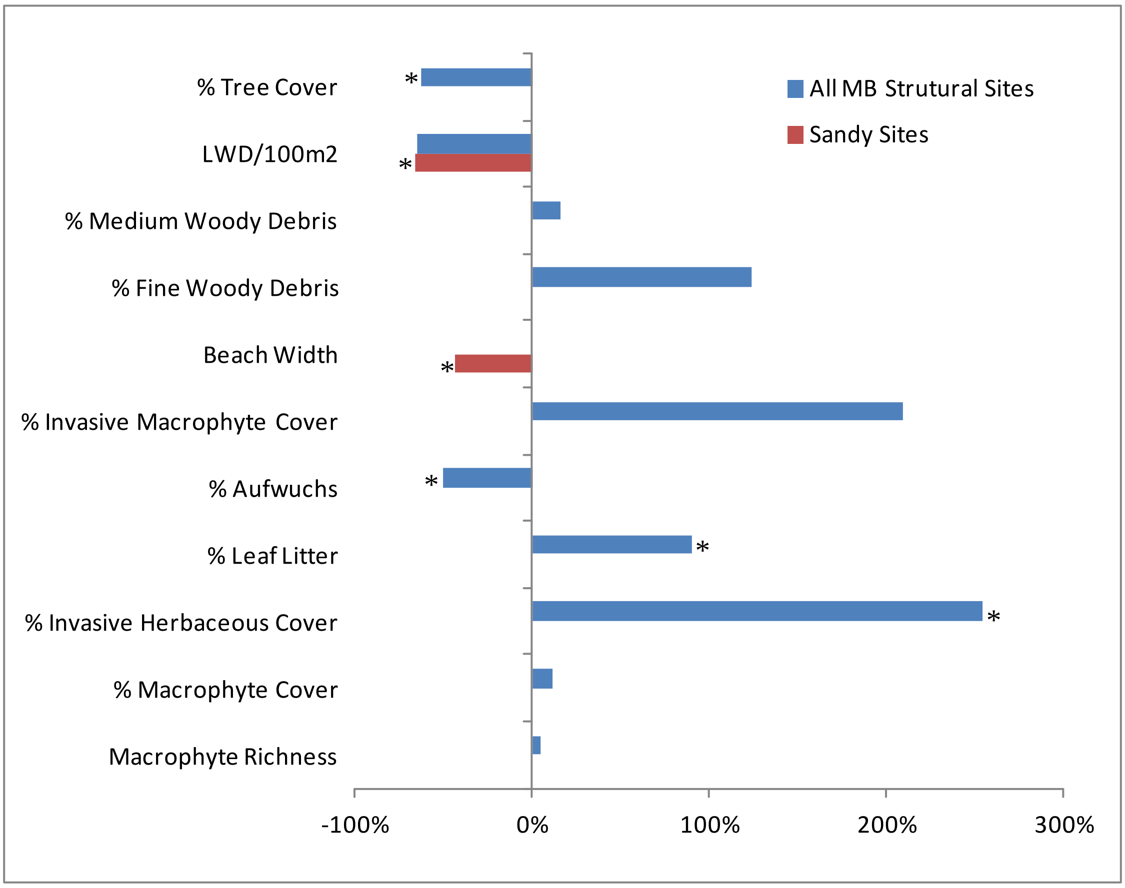


Figure 3.21: Mean relative percent change in structural and vegetative parameters between sites classified as high and low development. *denotes significance for Wilcoxon rank sum test.

Table 3.6: Supporting *p*-values for Figure 3.21.

Substrate	Parameter	Wilcoxon Z-stat	*p*-value
Sandy	LWD/100m^2	-1.84	0.065
Sandy	Beach Width	-3.44	0.0006
All	% Tree Cover	-5.52	<0.0001
All	% Aufwuchs	-2.51	0.012
All	% Leaf Litter	1.75	0.081
All	% Invasive Herb	2.98	0.003

The loss of native shoreline vegetation was the primary driver of most of the reported structural findings for both the inland lakes study and our study in Malletts Bay. The inland lakes study also found reduced cover of all allochthonous organic matter: large, medium, and fine woody structure, and leaf litter, resulting in an overall simplification of littoral habitat (Merrell *et al.* 2009; Merrell *et al.* 2010). We found reduced large woody structure, and increased fine and medium woody structure with development. This discrepancy is likely due to the increased circulation of water and the effect of waves in Malletts Bay, which may reduce the importance of immediate shoreline condition on some littoral habitat components. Macrophyte community response was variable in the inland lakes, however large lakes were shown to have reduced macrophyte abundance with increasing development. The impacts of shoreline development were shown to be reduced with the presence of a native vegetation buffer; whereby developed shorelines on inland lakes were shown to be more similar to reference shorelines.

The impacts of development were lowest if buffers met certain width criteria (5-9m) and if structures were set back approximately 20m from the shoreline (Merrell *et al.* 2010). This supports the weighting we selected for our 15mX50m development metric (Equation 2) to describe the development effect in Malletts Bay.

3.4.2 Biotic Communities

Macroinvertebrate samples collected from eight large oligotrophic inland lakes are consistent with some of our key biotic findings (Figure 3.22). VTDEC found no significant change in the macroinvertebrate communities at sandy sites, and found increased density and reduced Chironomidae abundance at rocky sites with unbuffered development (Merrell *et al.* 2010). These findings suggest a reduction in pollution tolerant taxa and increased overall density with increased shoreline development, despite the reductions in shading and inputs of terrestrial organic matter. The high development rocky shoreline sites in Malletts Bay had increased Chironomidae populations, but the increases in COTE richness also suggest a community with higher richness of invertebrates typically sensitive to pollution. We also found fish abundance and richness to increase with development at these sites.

An increase in richness in biotic communities in response to development along rocky shorelines was also described by Brauns *et al.* (2007) and De Sousa *et al*. (2008). De Sousa *et al*. describe a "bottom up" control on invertebrate response in rocky substrates, whereby an increase in epilithon biomass supports greater abundance and richness in the community. In Malletts Bay, the observed increase in biotic richness this response is likely caused by increased sunlight and nutrient availability in developed rocky shorelines. These factors tend to increase food availability for many taxa within the macroinvertebrate communities we found most responsive to development (i.e., COTE). The degree of development we observed along most rocky shorelines in Malletts Bay may not cause increases in runoff or erosion to a degree that would impact these pollution-sensitive taxa.

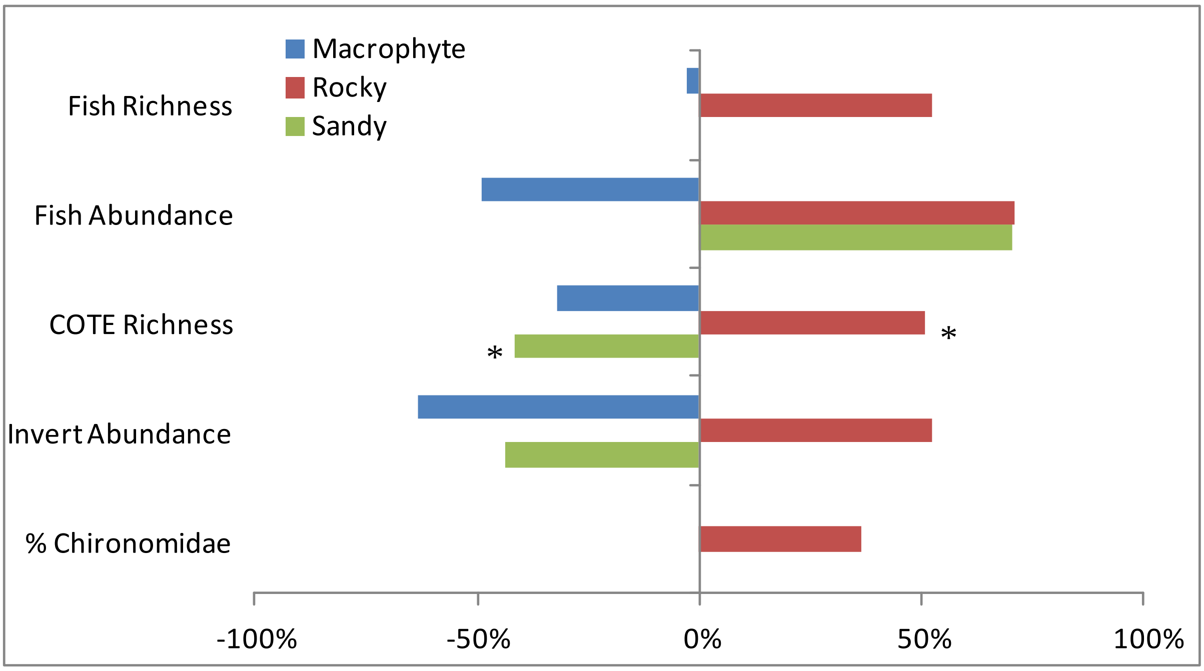


Figure 3.22: Relative percent change in biotic parameters between sites classified as high and low development. *denotes significance from Wilcoxon rank sum test.

3.5 Summary of Statistical Power

We conducted a post-hoc power analysis using our Malletts Bay dataset (Table 3.7). Our level of significance for all tests was $\alpha = 0.10$. For several key study findings, statistical power was well above levels considered adequate (i.e., 0.80) for inferences across a wider area. For the structural habitat responses that we found most significant, only woody debris density had a level of power below 0.80. For the biotic responses in rocky sites, statistical power was very high for the macroinvertebrate metric that best represented the overall trend (COTE), while it was lower for fish richness.

Table 3.7: Summary of statistical power for key structural and biota study results.

Littoral Indicator Type	Predictor Variable(s)	Response	Statistical Test	Littoral Substrate	Sample Size	Statistical Power
Structural	Development	Tree Cover	ANOVA	All	90	1.00
		LWD/100m^2	ANOVA	All	90	0.64
		Beach Width	ANOVA	Sandy	32	0.99
Biota	Development	COTE Richness	ANOVA	Rocky	11	0.92
		Fish Richness	ANOVA	Rocky	11	0.44
	Development, WEP	COTE Richness	MR†	Rocky	11	0.98
		Fish Richness	MR†	Rocky	11	0.49
	Development, Littoral Slope	COTE Richness	MR†	Rocky	11	0.97
		Fish Richness	MR†	Rocky	11	0.72

† Multiple Regression

Based on this review, we recommend that future studies of this kind in Lake Champlain representing a continuous gradient of development and natural features include a comparable sample size (i.e., 100 sites) for the structural and vegetative habitat parameters. However, we recommend that the sample sizes be increased to a minimum of 25 for biota.

Alternatively, future studies in Lake Champlain could include a design similar to the VTDEC study of inland lakes, whereby only high and low development sites were sampled rather than a continuous gradient of development. Using this type of study design, sample size requirements could be relaxed while still achieving comparable levels of statistical power. This would save effort and costs.

4. GIS-based Predictive Model

4.1 Littoral Habitat Matrix

Using results from modeling of Malletts Bay sites, we developed a framework for qualitatively predicting littoral characteristics in greater Lake Champlain in terms of macrophyte richness, woody debris habitat, and biotic richness. We recognized the challenge in classifying substrate type, lakeshore development, and influential natural gradients using remotely sensed data. As such, we chose to make predictions of different responses across substrates using a simplified grouping of soft bottom substrate (sandy and macrophyte substrates) and hard bottom (rocky) substrate. We felt there were sufficient similarities in the modeling results between sandy and macrophyte substrates to justify this grouping, and we were limited in our ability to predict differences between sandy and macrophyte substrates using a bathymetric model of slope in GIS.

We found a significant relationship between soft and hard bottom groupings with respect to littoral slope in Malletts Bay, with a slope breakpoint of 6.5 percent ($p < 0.001$; see Appendix C for supporting results). Using this breakpoint, we were able to correctly classify 90 percent of our sites into hard and soft bottom groups. We attempted to improve on this prediction using available soil parent material data (NRCS, 2008). Macrophyte beds tend to be associated with fine-grained lacustrine parent material in the adjacent uplands, while rocky sites are associated with glacial till in the adjacent uplands (Figure 4.1). Although the parent material associations were intuitive and informative, they did not significantly improve our ability to distinguish between the substrate groups.

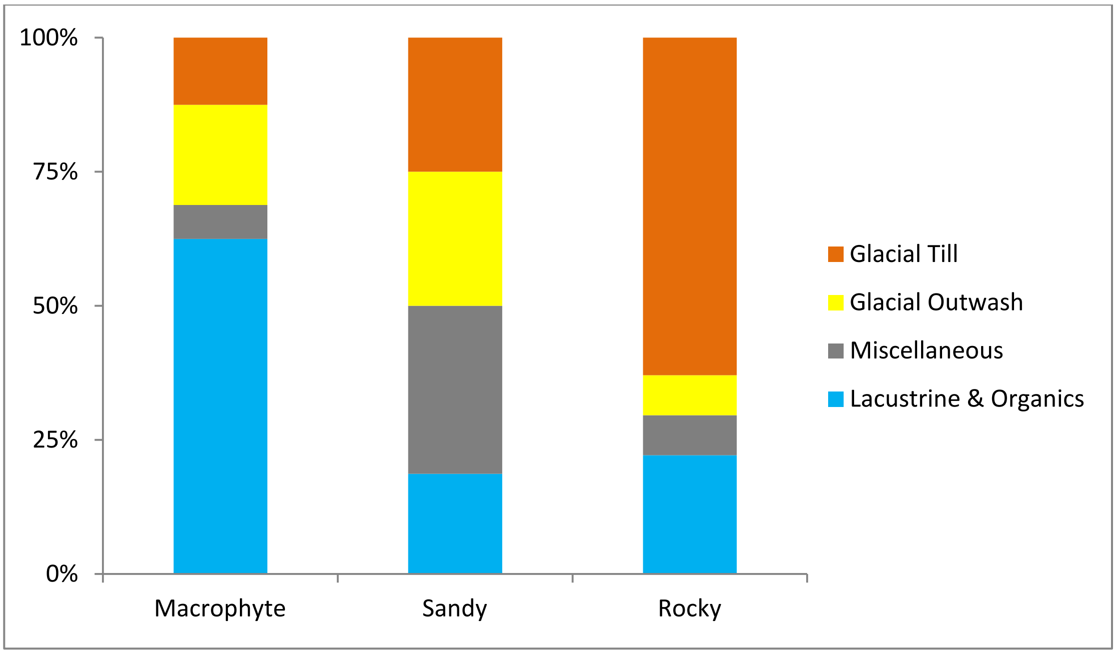


Figure 4.1: Average distribution of lakeshore soil parent material within a 50m radius adjacent to littoral sampling locations in Malletts Bay, organized by substrate type.

To refine our model input variables using remotely sensed data, we explored statistically significant breakpoints in the Malletts Bay data for categorizing "high" and "low" influence of WEP and littoral slope on littoral habitat (see Appendix C for supporting statistical results). We determined a significant breakpoint at a WEP value of 20 in the response of biotic richness in both substrate groups, and in macrophyte richness in the soft bottom sites. For hard bottom sites (classified as littoral slope >6.5%), a secondary littoral slope breakpoint of 18 percent classified high and low slope rocky sites and was significant for predicting differences between macrophyte richness and biotic richness, whereby increased slope resulted in increased richness in both cases (see Appendix C for supporting results).

We developed two matrices for the substrate groups to qualitatively summarize the influence of lakeshore development, wind/wave energy, and littoral slope on three littoral habitat metrics (Table 4.1 and Table 4.2). We recognized there would be the additional error in GIS-based predictions of WEP and littoral slope, and chose to predict relative littoral habitat quality within each substrate group. Section 4.2 provides further discussion of how lakeshore development, WEP, and littoral slope variables were measured remotely and incorporated into the model.

Table 4.1: Model matrix for soft bottom sites including sandy and macrophyte substrates with littoral slopes less than 6.5%. Malletts Bay values are shown in parentheses.

Littoral Habitat Metric	High Development		Low Development	
	High WEP (>20)	**Low WEP (<20)**	**High WEP (>20)**	**Low WEP (<20)**
Macrophyte Richness	Moderate (2)* †	Highest (13) †	Lowest (5) †	Moderate (11) †
Woody Debris Habitat	Lower (1.1)		Higher (2.9)	
Biotic Richness	Lowest (3) †	Mod-Low (4) †	Mod-High (6) †	Highest (7) †

† Median values used due to low sample sizes within some classification groups; all other values are means.
*n=2 for matrix bin; overall trend indicates macrophyte richness is more responsive to development than WEP.

Table 4.2: Model matrix for hard bottom (rocky) sites with littoral slopes greater than 6.5%. Malletts Bay values are shown in parentheses.

Littoral Habitat Metric	High Development		Low Development		High Development		Low Development	
	High WEP (>20)	**Low WEP (<20)**	**High WEP (>20)**	**Low WEP (<20)**	**High Littoral Slope (>18%)**	**Low Littoral Slope (6.5 - 18%)**	**High Littoral Slope (>18%)**	**Low Littoral Slope (6.5 - 18%)**
Macrophyte Richness	Lower (4)		Higher (4.8)		Mod (5.5) †	Lowest (2.5) †	Highest (5) †	Mod (4.5) †
Woody Debris Habitat	Lower (0.3)		Higher (2.4)		Lower (0.3)		Higher (2.4)	
Biotic Richness	Mod (n/a)	Highest (13) †	Lowest (7.5) †	Mod (9.5) †	Highest (13) †	Mod (2)* †	Mod (10) †	Lowest (8) †

† Median values used due to low sample sizes within some classification groups; all other values are means.
* n=1 for matrix bin; multiple regressions indicate biotic richness is more responsive (positive direction) to development than littoral slope (see Table 3.5 for Malletts Bay results).

4.2 Model Development

Using ArcGIS ModelBuilder v. 10.1, we developed a custom tool to predict littoral habitat quality based on the relationships summarized in the habitat matrix. ModelBuilder allows for the creation of complex models that efficiently utilize the entire suite of geospatial analysis tools by linking many tools together into one step. The Littoral Habitat Model has the principal function of placing particular shoreline points of interest into various categories summarized in the habitat matrix—high/low development, soft/hard littoral substrate, and high/low WEP—and then using these categories to qualitatively predict biotic richness, woody debris abundance, and macrophyte richness.

The model has three input parameters: (1) littoral slope, an automated calculation (based on Lake Champlain bathymetry data) used to predict substrate type; (2) development intensity, a user-defined selection based on guided interpretation of aerial imagery; and (3) WEP, an automated calculation based on shoreline aspect, fetch, and generalized wind speeds. To run the model for a point of interest on the Lake Champlain shoreline, a user first edits an existing polyline feature class to represent fetch length and direction from the point of interest, and then selects a development intensity of "high" or "low” from a dropdown menu. The model is then executed. The output is a table containing predicted quantitative values for littoral slope and WEP intensity; predicted substrate type (soft or hard bottom); and predicted qualitative categories (low or high) for WEP intensity, biotic richness, woody debris abundance, and macrophyte richness.

To classify substrate type as soft or hard—a critical branching point in the habitat matrix—the model relies on a predetermined breakpoint for littoral slope. As discussed above, an analysis of field measurements indicated that a littoral slope of 6.5% accurately classified approximately 90% of our sites into hard or soft bottom groups. Because of the relative coarseness of the bathymetry data compared to the finer-scale slope measurements made in the field, modeled slope values for our field sites were substantially different from our field values; generally, the modeled values underestimated slope. We calibrated the modeled slope breakpoint accordingly: a comparison of the two datasets with simple bivariate plots indicated that a modeled slope value of 1.9% corresponds with the field value breakpoint of 6.5%. Within the hard bottom sites, a modeled slope value of 3% corresponds with the field value breakpoint of 18% for predicting macrophyte and biotic richness. Both of these breakpoints were determined by the modeled slope breakpoint which best captured the "high" and "low" values from the field slopes.

To enable automated WEP calculation, we used a simplified procedure to determine WEP within the model. Similar to the modeled slope values, the modeled WEP values were scaled differently than the original WEP values used in the habitat matrices. Using bivariate plots of the two parameters, we determined that a modeled WEP value of 10 corresponds with the original WEP breakpoint of 20 used in the habitat matrices.

The Littoral Habitat Model has two primary limitations. First, the model relies entirely on the relationships in the littoral habitat matrix to predict habitat values; where those relationships do not hold true, the model will be incorrect. Second, because of its reliance on modeled slope values instead of field measurements, the model is limited in its ability to accurately predict substrate type, particularly hard-bottomed (rocky) substrates. This is due to two primary factors: (1) in some bedrock areas, the topography is characterized by small ledges and other nearshore microtopographical features that are not captured in the bathymetry data; and (2) there are similarities in littoral slope between rocky and sandy beaches. Nevertheless, comparisons to 2011 and 2012 field sites demonstrate that the model accurately predicts substrate type approximately 75% of the time.

See Section 5.3.3 for a discussion of model results for the validation study. User documentation for the model, including a more thorough description of its components, is included in Appendix E.

4.3 Model Demonstration Workshop

FEA and Tierra Environmental hosted a model demonstration workshop on July 31, 2013, for staff from LCBP, VTANR, Lake George - Lake Champlain Regional Planning Board, Lake George Association, The Nature Conservancy Adirondack Chapter, and Stone Environmental. The design, features, and operation of the littoral habitat model were discussed and demonstrated. Several recommendations for model improvements were discussed and added to the model user guidance appendix (Appendix E), including additional aerial imagery examples of shoreline development classifications to assist users in selecting "high" or "low" development level. Potential future improvements to the model were discussed and included operability with multiple versions of ArcGIS, enhancement of littoral substrate predictions based on soil parent material, refinement of littoral slope and WEP thresholds, and refinement of development level classification.

5. Validation Study

5.1 Site Selection

A validation study was conducted in the summer of 2012 to test and validate the littoral sampling methodology and the GIS model predictions outside of Malletts Bay. Potential sampling areas were identified with input from the LCBP TAC. Initially four areas were identified for consideration: Keeler Bay, Appletree Bay, Shelburne Bay, and Converse Bay. A site tour of Appletree Bay indicated that no macrophytes beds were present and that the area lacked a comparable development gradient to Malletts Bay. Keeler Bay (KB), Shelburne Bay (SB), and Converse Bay (CB) were selected as the study areas for the project validation (Figure 5.1). A total of eighteen sites were selected for structural analysis, and six (6) sites for biota sampling (Table 5.1). Development intensity was estimated for the study areas prior to site selection. Paired sites for each substrate were then selected to contain a high and low development site. Paired sites were also selected to minimize variation in WEP between the sites. Validation structural and biota sampling was conducted from July 31 to August 14, 2012.

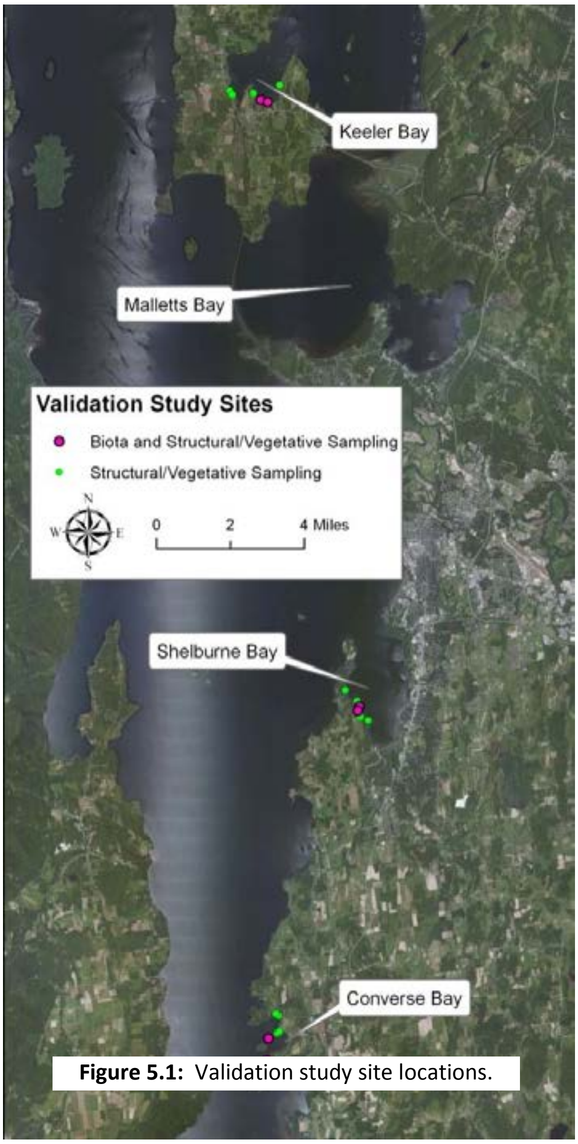


Figure 5.1: Validation study site locations.

Table 5.1: Validation study areas and sites by substrate.

Study Area	Substrate		
	Macrophyte	Rocky	Sandy
Keeler Bay	2 structural	2 structural	2 structural/biota
Shelburne Bay	2 structural/biota	2 structural	2 structural
Converse Bay	2 structural	2 structural/biota	2 structural

5.2 Changes in Sampling Methods

Lake Champlain water levels were relatively low in 2012 and were well below the reference water elevation (96 feet) used in 2011. Lake elevation dropped from 94.7 feet to 94.5 feet during the validation study. Site selection was particularly challenging for macrophytes beds in Keeler and Converse Bays. The combination of low water and low littoral slope resulted in large areas of macrophytes areas with insufficient depth for sampling. The reference lake level for the validation study was reduced to 94.5 feet to account for the low lake level and yield macrophytes sites with sufficient water depth for sampling.

Figure 5.2: Dense zebra mussel colonies in Shelburne Bay.

Zebra mussel (*Dreissena polymorpha*) populations are relatively low in Malletts Bay and were only found in small concentrations along the southern shore of Grand Isle during the 2011 field sampling. In contrast, the validation sites were located in areas of the lake with high concentrations of zebra mussels. This presented a challenge for both structural and biota sampling of rocky substrates. Zebra mussels covered all substrates and had to be partially removed to estimate substrate and habitat cover. Fish sampling required additional assistance to maneuver the seine over zebra mussels. Macroinvertebrate sampling required removing all zebra mussels from substrate to be counted and scrubbed to collect invertebrates clinging to the mussels (Figure 5.2). All other structural and biota methods were unchanged from the 2011 methodology.

5.3 Results and Discussion

5.3.1 Structural and Vegetative Results

The low sample size for the validation study limited the types of statistical analyses available to interpret structural and vegetative results. Many of the general trends identified in Malletts Bay were also observed at validation study sites; however the reduction in tree cover was the only relationship we identified that was significant (ρ = -0.828, *p* <0.0001) for all substrate types with shoreline development (Figure 5.3).

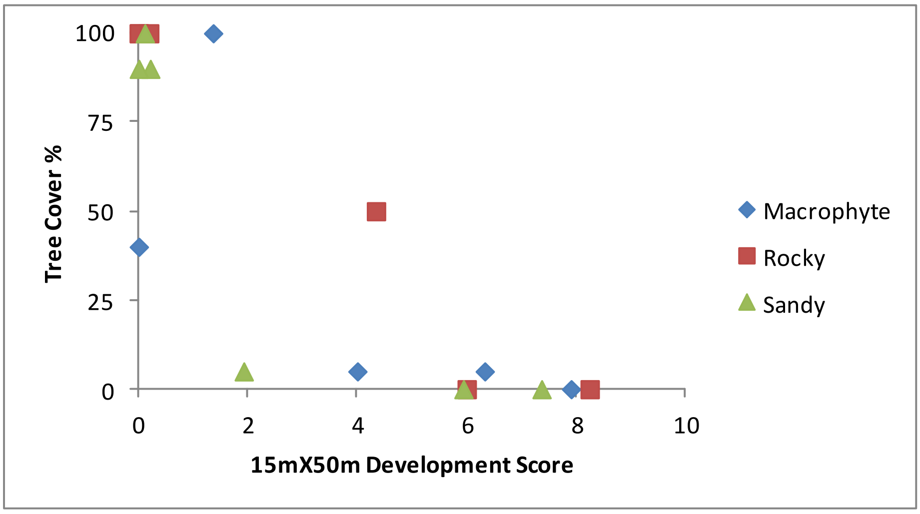


Figure 5.3: Loss of shoreline tree cover with development.

Large woody debris decreased with shoreline development at the validation sites. The relationship was not significant (ρ = -0.348, *p* = 0.158); however the data closely follows the significant relationship found in Malletts Bay (Figure 5.4).

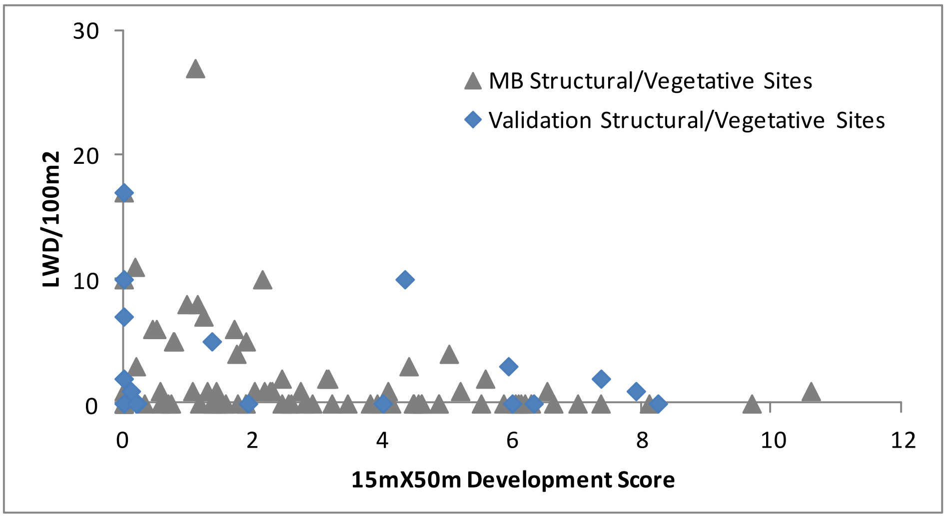


Figure 5.4: Loss of LWD with development at Malletts Bay and Validation sites.

5.3.2 Biota Results

Due to the large differences in the physical habitat, the associated organisms, and necessarily different sampling approaches, biological comparisons within a single substrate type are most appropriate. We expected that the very large effects of physical habitat observed in Malletts Bay would swamp any effects of land use in comparisons that involved two or more substrate types. During the validation study we collected biota samples from a pair of representative sites (high development and low development) for each substrate type. We then determined how the biological response variables at the validation sites ranked within the datasets measured from Malletts Bay in 2011 (Figure 5.5).

The macroinvertebrate community composition at the macrophyte sites was very similar between Shelburne Bay and Malletts Bay. Both areas had a high proportion of Gastropoda (snails) and similar abundance and richness of COTE species. Macroinvertebrate samples collected from rocky sites in Converse Bay had very similar richness and abundance of COTE taxa to Malletts Bay, which was unexpected given the extreme densities of zebra mussels in the main lake sites. These samples contained densities of over 2000 zebra mussels per square meter, drastically altering the substrate surface and creating a very complex benthic habitat. Gastropoda and Amphipoda populations were much higher, possibly in response to the nutrients in the waste from zebra mussel colonies. The sandy sites sampled in Keeler Bay indicated a much higher richness and abundance of COTE taxa. Both the richness and abundance were distributed over a range of taxa suggesting a general improvement in habitat quality for COTE taxa. The bivalve family Sphaeriidae represented 25-40% of the abundance at the sandy sites both in Malletts Bay and Keeler Bay, but were not found in large abundance at any other sites.

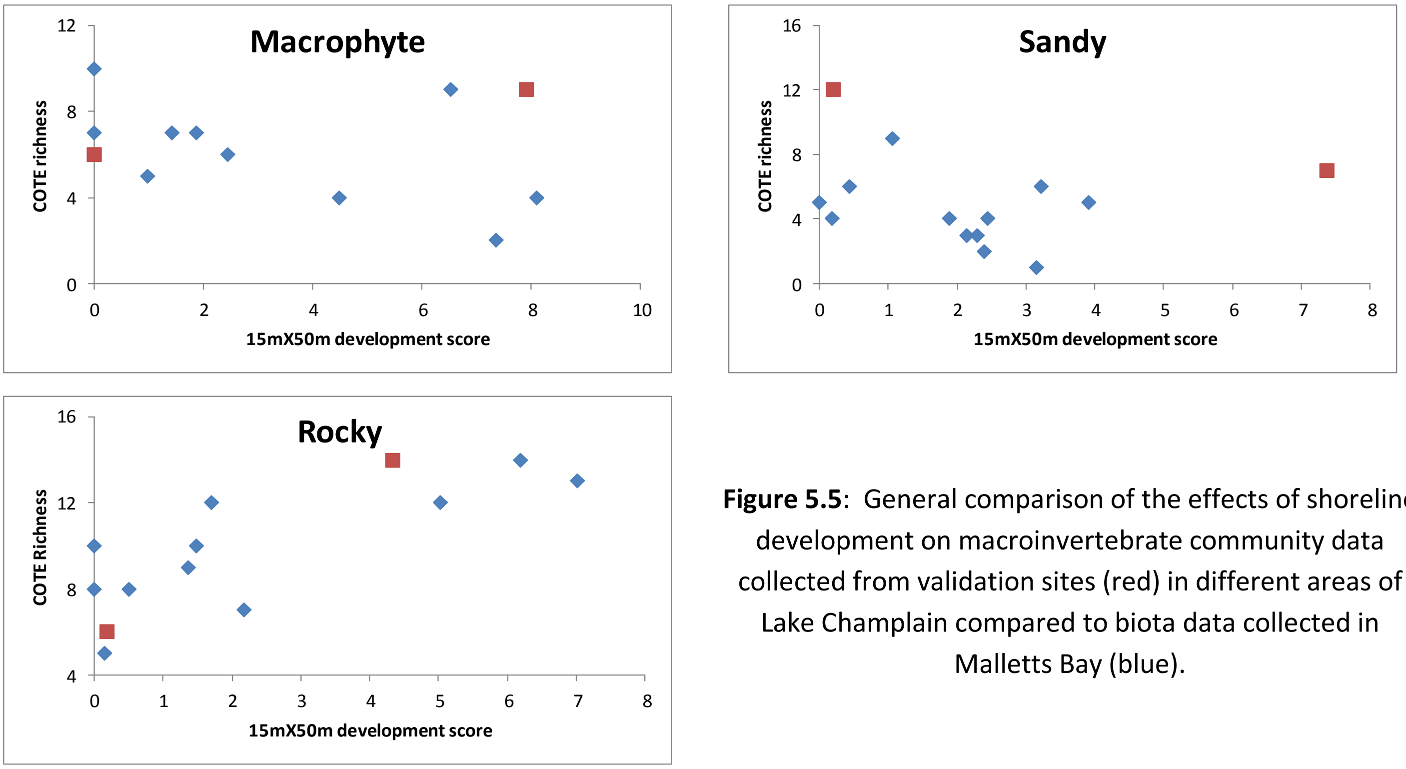


Figure 5.5: General comparison of the effects of shoreline development on macroinvertebrate community data collected from validation sites (red) in different areas of Lake Champlain compared to biota data collected in Malletts Bay (blue).

Fish communities at the validation sites were also similar to those in Malletts Bay. The macrophyte sites had the highest fish richness and abundance (Figure 5.6). No fish were captured in either seine replicate at the low development sandy site; however, a school of approximately 400 emerald shiners was counted at the sandy high development site. Richness at the high development sandy site was similar to Malletts Bay sites. The rocky sites had reduced richness compared to Malletts Bay, but this result should be interpreted with caution because of the likelihood of fish escapement during sampling (due to the net's tendency to snag on zebra mussel colonies).

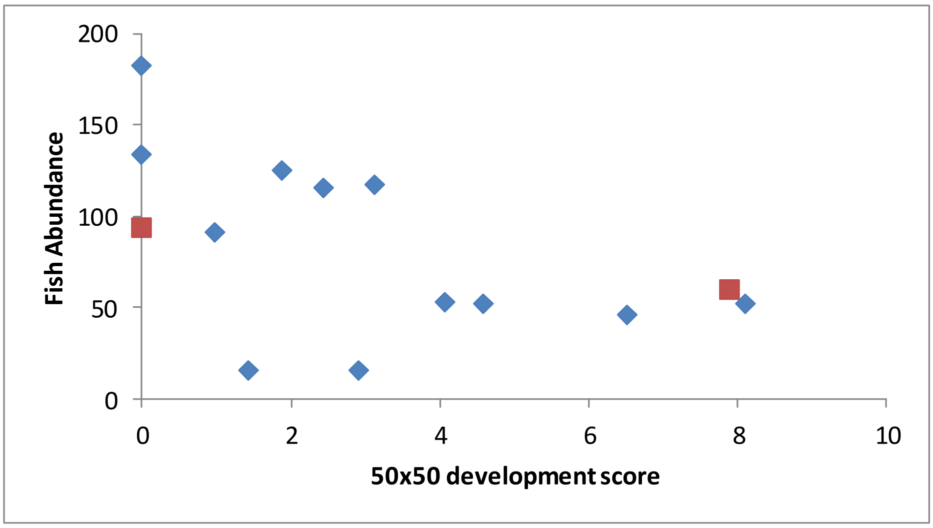


Figure 5.6: Effect of shoreline development on fish abundance at macrophyte sites for validation sites (red) compared to Malletts Bay sites (blue).

5.3.3 Field Results Versus Model Predictions

We ran the Littoral Habitat Model on the 18 validation sites to test model predictions against our field sampling data from sites outside of Malletts Bay (Table 5.2). The validation sites were intentionally selected to represent distinct high and low development levels and were controlled to limit the influence of large variability in WEP and littoral slope. The predictor model outputs are based on the development, WEP, and littoral slope thresholds described in section 4.1.

Table 5.2: Comparison of field results and Littoral Habitat Model predictions for the validation sites.

Site	Location	Substrate	Development Class	Predicted Macrophyte Richness	Macrophyte Richness	Predicted Woody Habitat	Woody Debris	Predicted Biotic Richness	COTE Richness	Fish Richness
116	CB	Macro	H	Highest	7	Lower	0	Moderately low		
118	CB	Macro	L	Higher	6	Higher	5	Moderate		
109	SB	Macro	H	Higher	9	Higher	1	Moderate	9	6
108	SB	Macro	L	Lower	9	Higher	7	Lowest	6	10
102	KB	Macro	H	Highest	12	Lower	0	Moderately low		
101	KB	Macro	L	Moderate	12	Higher	2	Highest		
114	CB	Rocky	H	Higher	5	Lower	10	Highest	14	2
113	CB	Rocky	L	Higher	3	Higher	0	Moderate	6	3
112	SB	Rocky	H	Higher	6	Lower	0	Moderate		
111	SB	Rocky	L	Higher	8	Higher	10	Moderate		
103	KB	Rocky	H	Higher	6	Lower	0	Moderate		
106	KB	Rocky	L	Higher	5	Higher	0	Moderate		
115	CB	Sandy	H	Higher	7	Lower	0	Highest		
117	CB	Sandy	L	Lowest	4	Higher	1	Moderately high		
107	SB	Sandy	H	Higher	6	Lower	3	Highest		
110	SB	Sandy	L	Higher	8	Higher	17	Moderate		
105	KB	Sandy	H	Highest	7	Lower	2	Moderately low	7	4
104	KB	Sandy	L	Lowest	9	Higher	0	Moderately high	12	0

The overall model prediction success rate was moderate and we believe that these results were influenced by inherent natural variability in the structural, vegetative, and biota data and low sample sizes. Comparisons are improved when grouped by the individual sampling area (i.e., Converse Bay), suggesting that large scale factors such as geology and hydrology may be important considerations for quantifying littoral habitat over an area as large and diverse as Lake Champlain. Relative COTE Richness was successfully predicted for all three substrates and closely followed trends identified in Malletts Bay (Section 5.3.2). Woody debris was more responsive to development level than the other natural gradients included in the modeling, which highlights the larger effect size present in the validation sites for development level and lower effect of natural gradients. Macrophyte richness was relatively consistent between development level within each bay but indicated potential differences in macrophyte communities between the bays.

We recommend a larger and more diverse sample size for future use of this model. We feel it would be valuable to test the model for variability within other localized areas of Lake Champlain in addition to sites distributed throughout the Lake Champlain shoreline. The soft substrate model groups represent four potential combinations of development and WEP and the rocky model groups represent eight potential combinations of development, WEP, and littoral slope. Therefore a sufficient sample size would be needed within each of these categories to fully test the model.

6. Shoreline Protection Recommendations

6.1 Shoreline Priorities in Malletts Bay

To inform local stakeholders and resource managers about significant shorelines in Malletts Bay, we identified ten shoreline priorities across the study area (Figure 6.1 and Table 6.1). To delineate shoreline priorities, we created an overlay of several spatial datasets depicting habitat and condition information: (1) Element Occurrences of rare, threatened, and endangered species and significant communities from the Nongame and Natural Heritage Program; (2) undeveloped shorelines greater than 1,000 feet (304.8 m) in length (extracted from our shoreline condition dataset); and (3) structural sampling sites that placed in the upper quartile for macrophyte richness. We made a preliminary selection of shoreline segments that intersected any of these layers (in the case of the sampling sites, we selected shoreline segments within 50 m). We then reduced the number of potential priorities by eliminating short stretches (less than 1,000 feet in length). Based on a visual review of the resulting preliminary priorities, we modified and consolidated shoreline segments to create the final priority layer.

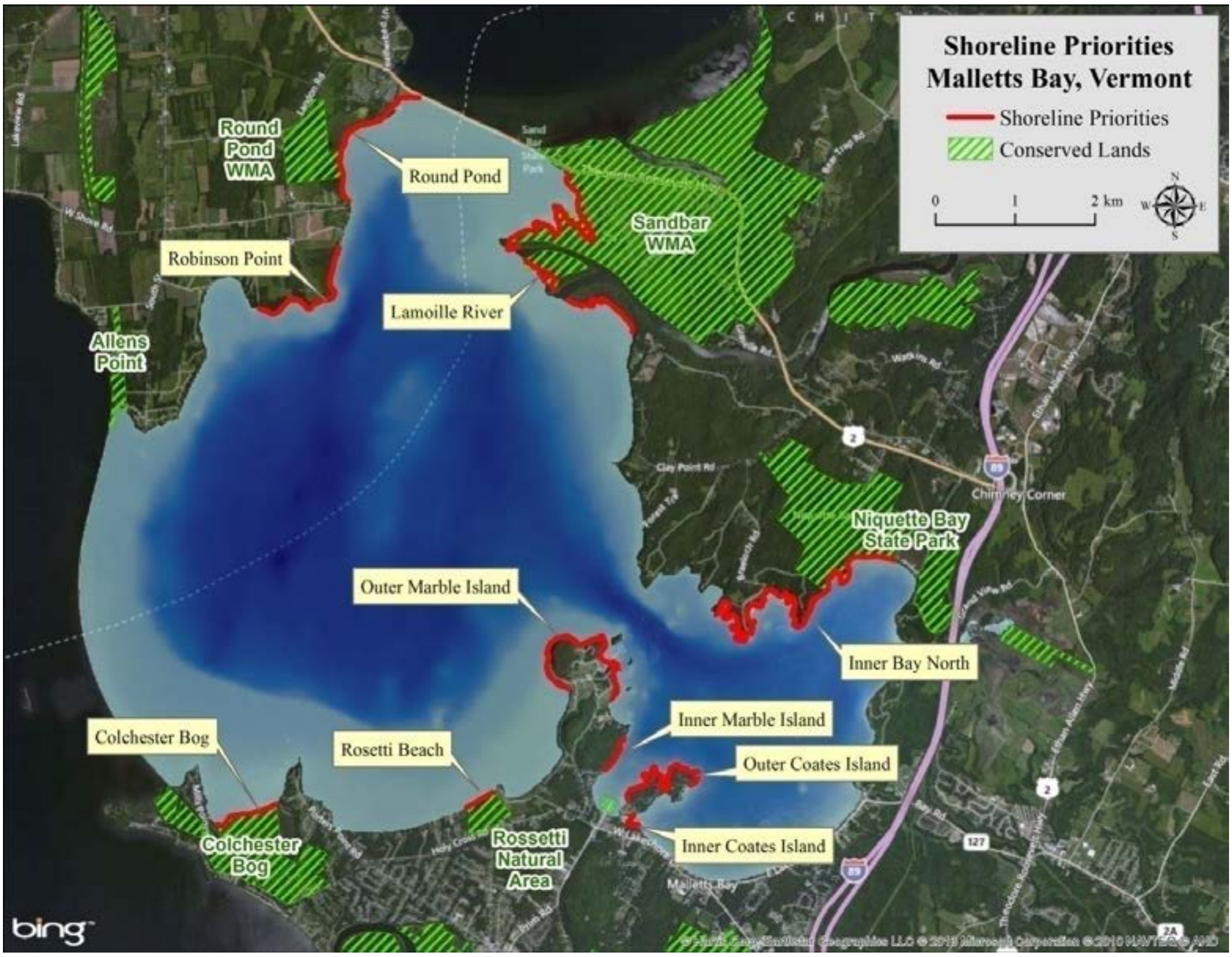


Figure 6.1: Shoreline priorities in Malletts Bay, Vermont. The following areas have some degree of shoreline development: Outer Marble Island (moderate), Inner Marble Island (low), Outer Coates Island (low), and Inner Bay North (low). Improving vegetated shoreline buffers in these areas would support the restoration of the natural and resilient littoral communities.

Table 6.1: Attributes and Justification for Shoreline Priorities.

Name	Element Occurrence(s)	Undeveloped Shoreline > 304.8 m	High Macrophyte Richness	Overall Length (km)	Conserved length (km)
Colchester Bog	X	X	Not sampled	0.8	0.8
Inner Bay North	X	X	X	6.2	1.4
Inner Coates Island		X	X	0.3	0.0
Outer Coates Island	X	X		2.2	0.0
Inner Marble Island	X	X		0.5	0.0
Outer Marble Island	X	X	X	2.8	0.0
Lamoille River	X	X	Not sampled	5.3	4.0
Robinson Point	X	X		1.9	0.0
Rosetti Beach	X	X	X	0.4	0.4
Round Pond	X	X	X	2.1	0.4

The shoreline priorities layer is intended to be a short list of areas in Malletts Bay where a confluence of existing data indicates high terrestrial and/or littoral habitat values. The priorities represent only a small portion of Malletts Bay shorelines with significant habitat. Our research indicates that healthy shoreline and littoral habitat conditions occur across a range of physical and land use gradients in Malletts Bay, and it is necessary to preserve (or improve) these conditions wherever possible. In addition, the priorities do not necessarily indicate sensitive or high-quality littoral habitat. While some areas of priority shoreline are strongly associated with such habitat, others—particularly Inner Bay North's cliffs and ledges—are not. While these steep, rocky shorelines may not contain significant littoral habitat, they are typically associated with significant terrestrial natural communities—notably Limestone Bluff Cedar-Pine Forests—and so are included as shoreline priorities.

Finally, this prioritization was not solely intended to identify areas suitable for land protection; indeed, a substantial amount of priority shoreline is either already conserved, already developed, or consists of small parcels not conducive to fee or easement protection. Rather, the shoreline priorities depict areas where a suite of conservation and management tools may have utility for protecting terrestrial and littoral habitat values.

6.2 Shoreline Protection Recommendations

Natural shoreline vegetation provides invaluable ecosystem services, including habitat for species found in the riparian and littoral zones, protection against erosion hazards and direct sedimentation, mitigation of upslope water quality impacts (e.g., stormwater runoff), and aesthetics for viewsheds from water and land (Figure 6.2). Numerous studies across the nation and Vermont have demonstrated the benefits of robust, natural shoreline vegetation for the protection of water quality and littoral habitat. The results of our research in Lake Champlain are generally consistent with findings in other parts of Vermont (e.g., Capen *et al.* 2008, Merrell *et al.* 2009, and Merrell *et al*. 2010) and

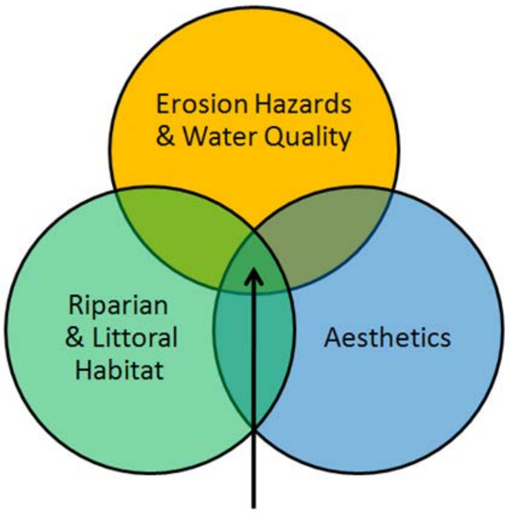


Figure 6.2: Shoreline Protection: Intersection of Functions and Values

support the recommendations put forth by other researchers and managers regarding the protection and/or naturalization of native vegetation along the shoreline (VTDEC, 2013). In the future, volatile weather patterns resulting from global climate change will likely lead to increased precipitation and runoff in the Champlain Basin (Stager and Thill, 2010). As such, it is imperative that the protection of natural shorelines be included in strategic resiliency planning at the local, regional, and state levels. Maintaining and improving riparian vegetation is likely the most cost-effective approach to improving resiliency to climate change in lake ecosystems (Carpenter, 2012).

The following sections provide recommendations for mitigating the effects of development on littoral habitat in Lake Champlain. The recommendations are supported by findings in this study and others in the region, as summarized in Section 3 of this report.

6.2.1 Vegetative Buffers

Our study results, and those from the VTDEC inland lakes studies (Merrell *et al.*, 2010), show a consistent pattern in shoreline development impacts on littoral habitat. As shoreline development increases, the subsequent loss in riparian vegetation results in decreased shading, habitat cover, and inputs of woody debris and organic matter to the littoral zone. There is overwhelming evidence supporting this cause and effect, but how this science has been translated into land use regulation in Vermont, New York, and other states in New England has been variable (VTDEC, 2013).

Merrell *et al.* (2010) further analyzed data from the inland lakes study and determined that minimum riparian buffer and structure setback distances mitigated the impact of shoreline development on numerous littoral characteristics. For sites with a minimum buffer width of 7m and a structural setback of at least 17m, there was no difference between developed and undeveloped sites for the following littoral zone characteristics: shoreline shading, large woody debris, leaf litter, sand substrate, and substrate embeddedness. This suggests that the impacts to aquatic habitat can be prevented through proper site design and vegetation retention at shoreline properties.

A similar study of developed and undeveloped sites was recently completed on lake shorelines in Maine by the VTDEC and the Maine Department of Environmental Protection (VTDEC and MDEP, 2013). The state of Maine has a Mandatory Shoreline Zoning Act (MSZA) that prevents structures and limits vegetation clearing within a 100 foot buffer zone. A paired sampling approach, following the VTDEC approach on the inland lakes, was carried out in 5 lakes in Maine. The results of this study indicated that shoreline tree cover, shading, littoral woody debris, and sediment embeddedness did not differ significantly between the two types of sites. As with the Vermont study, this suggests that shoreline zoning standards can prevent development impacts on the littoral zone.

Using data from our Malletts Bay study, we reviewed the influence of a 7m and 10m vegetated buffer width on the littoral habitat data. While we found a significant relationship between buffer width and tree cover for the 7m and 10m buffer width ($p < 0.0001$), fewer littoral habitat characteristics were responsive to these buffer thresholds in Malletts Bay. Large woody debris density, which was an indicator for all inputs of terrestrial organic matter in our study, was correlated with the 7m buffer ($p = 0.042$) and 10m buffer ($p = 0.023$) in sandy substrates, but not in rocky ($p = 0.158$ for 10m width) or macrophyte ($p = 0.126$ for 10m width) substrates. No other structural, vegetative, or biotic richness indices from the littoral zone were correlated with the 7m and 10m buffer threshold in our study.

It is difficult to conclude whether these results suggest that a 10m buffer width is inadequate for protecting littoral habitat in Lake Champlain. We have learned that other natural gradients (e.g., wind exposure and slope) have a strong influence on littoral habitat, even when considered relative to shoreline development. These natural gradients may drown out some of the shoreline development effect, especially in the case of sites exposed to wind and wave energy where organic matter is mobilized and transported more readily. While further study is needed in Lake Champlain to determine appropriate buffer guidance, we believe a 10m buffer width is inadequate, especially for those areas prone to seasonal flooding and erosion. We recommend further research of the lake's shorelines to develop a defensible basis for an adequate buffer width along Lake Champlain.

6.2.2 Bank Protection and Stabilization

Human development within the shoreland area should be guided so as to occur in a manner with minimal impact on littoral habitat and water quality. However, as evidenced by the flood of 2011, owners of existing shoreline property are willing to make significant investments to stabilize banks and protect their land and buildings from future flooding and erosion. Shoreline erosion conflicts are likely to increase in the future as a result of climate change and increased frequency of flooding in the Champlain Basin (Stager and Thill, 2010). While there is currently no federal or state regulatory mechanism preventing shoreline stabilization above jurisdictional lake elevations (e.g., mean or OHW), we recommend that shoreline property owners continue to be guided on the alternatives to traditional "hard bank" stabilization techniques.

The Shoreline Stabilization Handbook prepared by the Northwest Regional Planning Commission ("NRPC Handbook"; NRPC, 2004) presents a summary of shoreline protection methods using vegetation and bioengineering techniques tailored to conditions along Lake Champlain. The techniques are intended to mitigate the impact of shoreline stabilization on aquatic ecosystems primarily by maximizing the use of vegetation. In the wake of spring 2011 flooding, NRPC secured funding from the VTANR Ecosystem Restoration Program to identify shoreline landowners with eroding property in Franklin and Grand Isle Counties and provide technical assistance for stabilization designs following the NRPC Handbook. This outreach program was successful in disseminating information about these alternatives approaches and in providing examples of how the techniques can be implemented in different shoreline settings. Based on the experiences gained from this model outreach program and the wider body of literature on this topic, below is a summary of key considerations for shoreline stabilization in different settings in Lake Champlain.

High Risk Sites

Some shoreline settings are inherently more prone to flooding and erosion. Properties with limited relief from the lake's elevation are prone to flooding and damage from wind-driven wave run-up. Properties with higher exposure to wind and wave energy, especially those found on highly erodible soils, are prone to erosion and bank failure. In these cases, traditional structural armoring may be the only realistic option. The NRPC Handbook provides a summary of various traditional techniques for hard bank armoring depending on the setting. In addition, not all hard bank techniques are equal from a littoral habitat standpoint. At sites where the shoreline persists along the hard bank surface throughout much of the year, research has shown that irregularly surfaced armoring (e.g., rip-rap) has similar macroinvertebrate richness to natural rock shorelines (Brauns *et al.*, 2007). This suggests that some of the impacts of hard bank armoring on biotic communities can be mitigated by considering available habitat on the hard armor surface.

Moderate Risk Sites

In shoreline settings with intermediate risk to flooding and erosion, “hard” techniques can be integrated with bioengineering approaches to maximize vegetation along the bank. The NRPC Handbook presents several options for incorporating the use of natural fabrics and woody vegetation tolerant to the harsh conditions along shorelines. Where wind and wave exposure or soil types warrant an intermediate approach, vegetation can be installed within and behind engineered rock walls (Figure 6.3) to increase shading, habitat cover, and inputs of woody debris in the littoral zone.

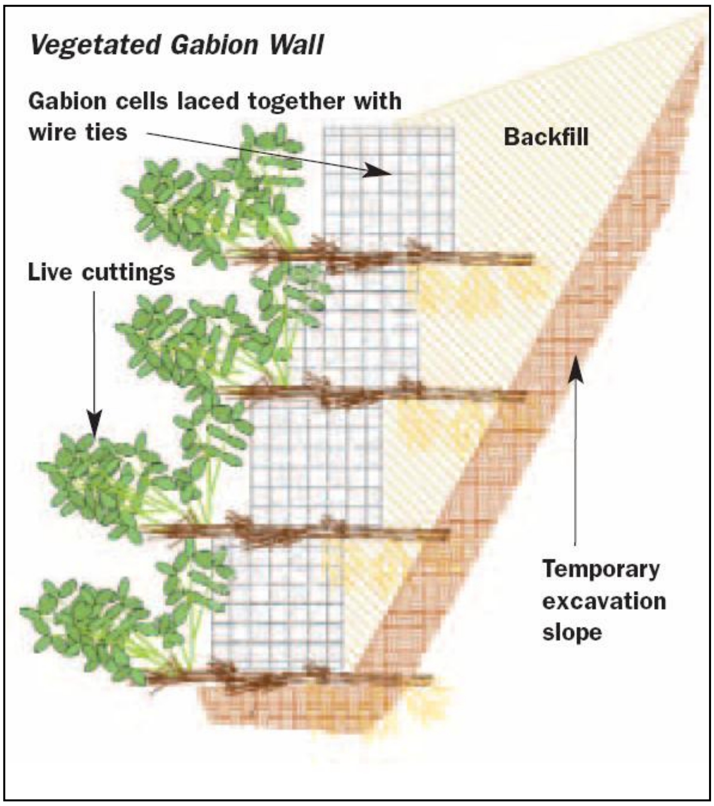


Figure 6.3: Example of integrating vegetation into a traditional bank armor approach to mitigate impacts on the littoral zone (NRPC, 2004).

Low Risk Sites

For shoreline settings with limited flooding and erosion hazards and limited lateral constraints (e.g., buildings are located far from the top of bank), stabilization techniques using vegetation alone should be used. In some cases, even moderate bank erosion can be addressed through the reshaping of the banks in combination with natural fabrics or fibers, and vigorous woody vegetation (Figure 6.4). The NRPC Handbook presents many options for vegetation-based techniques that can improve littoral habitat.

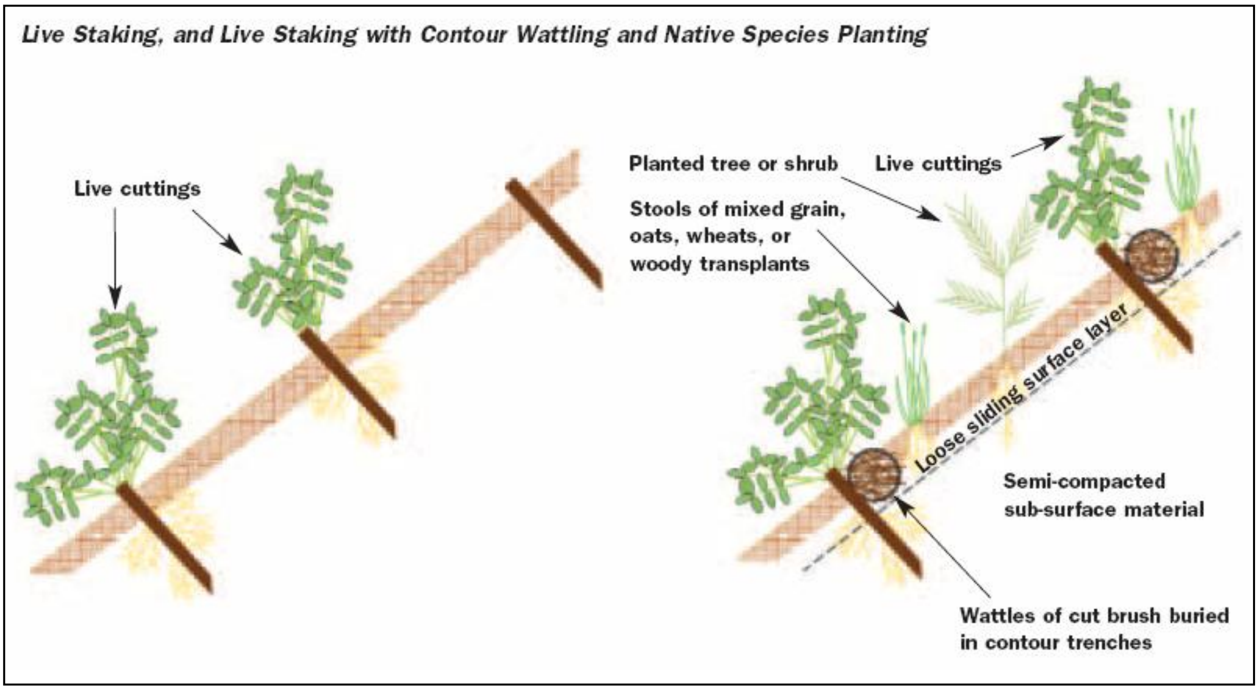


Figure 6.4: Example stabilization approach using natural fibers and vegetation to improve the littoral zone (NRPC, 2004).

6.2.3 Erosion Hazard Setbacks

There is a wide range of soil parent material along the shorelines of Lake Champlain. Early Holocene deposits of fine grained sediments (e.g., silts and clays) along the lake's shoreline are associated with the retreat of the Laurentide Ice Sheet and the subsequent formation of Glacial Lake Vermont and the Champlain Sea (Wright, 2003). Glacial melt water and sediment carried by the Winooski and Lamoille Rivers deposited vast areas of sand along former delta areas; today many of these sand terraces form tall banks of highly erodible soils along the shoreline. Areas of lacustrine deposits (i.e., old lake bottom) and glacial till along the shoreline are generally more resistant to erosion due to the soil cohesiveness or larger rock substrates.

During our detailed study of Malletts Bay following historic flooding in spring 2011, we observed many different configurations of soils, bank relief, and exposure to wind and wave energy in the riparian areas adjacent the littoral sampling sites. Although we did not find significant correlations between bank erosion and degradation of the adjacent littoral habitat in our study area, we did observe stark differences between developed and undeveloped banks in areas prone to erosion (Figure 6.5). These areas were most often found where there was a combination of the following characteristics: (1) tall banks with erodible sandy outwash soils; and (2) north or south aspects where wind energy and wave potential are greatest.

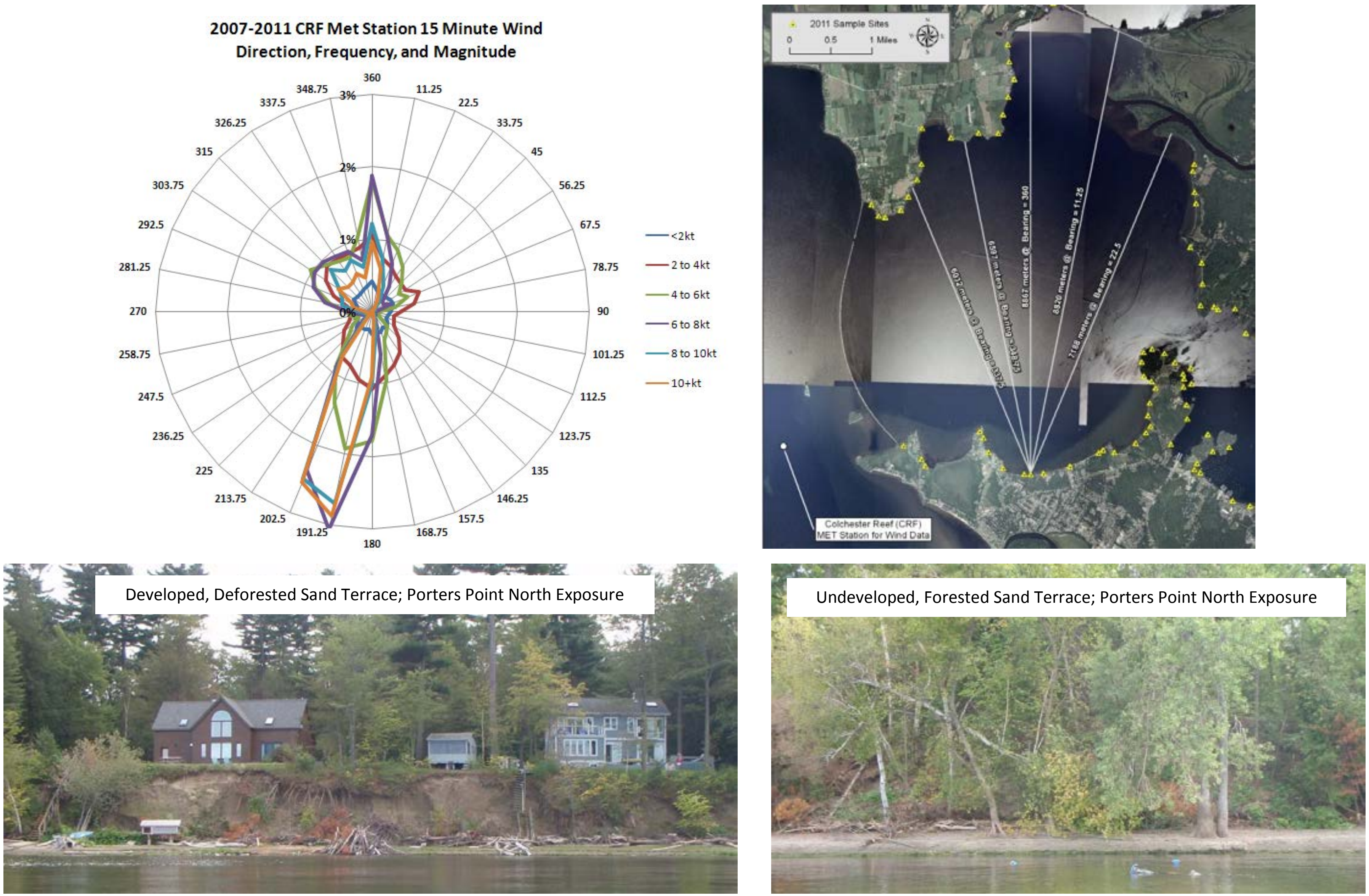


Figure 6.5: Heightened erosion hazards along sandy banks with high wind and wave exposure in Malletts Bay, VT.

Erosion along steep, lakeshore embankments is aggravated by the loss of vegetation associated with human development (Jennings *et al.*, 2003). Loss of natural woody vegetation decreases bank resistance to erosion and reduces woody debris inputs to the littoral zone with a corresponding decrease in roughness (e.g., coarse woody debris) on the lower bank. This loss of roughness increases the susceptibility of the shoreline and lower banks to the erosive power of wave action. Severe bank erosion delivers large quantities of fine sediment and nutrients to the lake, degrading water quality and impacting aquatic habitat.

Most municipal shoreline ordinances in Vermont focus on the setback distance of buildings from the water's edge; fewer than half of adopted ordinances prescribe a distance for maintaining a vegetative buffer (VTDEC, 2013). In areas along Lake Champlain prone to severe bank erosion, science-based shoreline setbacks and vegetated buffer ordinances accounting for soil erodibility and exposure to wind and wave energy are needed. We believe this approach would be more effective than standard ordinances at mitigating erosion hazards and impacts on the littoral zone and water quality. We recommend further detailed study of shoreline erosion hazards in Lake Champlain to support the development of erosion hazard mapping and setback guidance for lakeshore municipalities. While we recognize that it may not be practical for some municipalities to vary their setback distances based on erosion hazards, we suspect that many will consider this guidance in the wake of the extensive erosion issues caused by the 2011 flood. At a minimum, this guidance would be a valuable tool for local boards and commissions tasked with reviewing the merits of site-specific proposals for shoreline development.

7. Summary and Conclusions

Lake Champlain is a dynamic and diverse ecosystem shaped by substantial variability in hydrologic, geologic, geomorphologic, and climatic features and processes. The littoral zone of the lake is strongly influenced by seasonal changes in lake hydrology, large tributary inputs of sediment and organic matter, diverse shoreline geology and geomorphic forms, and stark differences in wind and wave exposure dependent on shoreline aspect. The littoral habitat represents a land-water interface encompassing myriad terrestrial and aquatic influences. The resulting ecotone is highly variable and sensitive to both natural gradients and anthropogenic impacts.

The goal of this study was to better understand the effects of lakeshore development on littoral habitat in Lake Champlain. Our study was designed to utilize a relatively small set of representative sample points on the lake's shoreline to model conditions in the greater lake. We chose Malletts Bay in Vermont as our principal study area due to its heterogeneity in both natural gradients (e.g., substrate type and wind exposure) and shoreline land cover. After conducting the study and observing this heterogeneity in great detail, we now have a greater appreciation for Malletts Bay's littoral habitat as an excellent representation of a majority of the Lake Champlain shoreline. However, we recognize there are limitations on using this study to infer the condition of lake-wide littoral habitat. We recommend that LCBP and other stakeholders support further study of lakeshore development as an ecosystem stressor in other areas of the lake.

The record Lake Champlain flooding in spring 2011 coincided with the anticipated start date of our field study. Although our field work was delayed, we completed 85 percent of our sampling program during a period of slightly above-average lake water conditions prior to the influence of Tropical Storm Irene in August, 2011. Since our dataset does not include any sampling prior to spring flooding, and no prior littoral habitat studies have been published on Lake Champlain, it is impossible to estimate the degree of influence the flooding had on our results. Only a future longitudinal study of the Malletts Bay study sites would allow for exploration of the immediate and persistent effects of the flood on the littoral zone.

Our intensive study of Malletts Bay included detailed mapping of land cover over the entire shoreline area. The littoral habitat sampling covered a total of 90 sites for riparian, structural, and vegetative data, 33 sites for macroinvertebrates, and 35 sites for fish. Key findings from the study and data analysis include:

- Shoreline development has a cascading, and sometimes indirect effect on littoral habitat quality. As shoreline development increases, riparian vegetation decreases, resulting in decreased shading, habitat cover, and inputs of woody debris and organic matter to the littoral zone. The decrease of woody debris and organic matter in littoral habitats reduces substrate available for biota. These results are generally consistent with findings from previous inland lake studies in Vermont.
- We found that variability in wind exposure and littoral slope significantly influenced some characteristics of littoral habitat such as biotic richness and retention of organic matter. These relationships were statistically significant even when their influence relative to shoreline development was considered. However, the relative influence of these natural gradients on littoral habitat was typically less than that of shoreline development. These findings expand our understanding of the relative effect of shoreline development on littoral habitat in Lake Champlain and the region.

- To address the variability in natural littoral substrate in our study, we stratified sites based on substrate type. We also varied our biota sampling methods based on substrate type. We found this approach was important for addressing the primary research question because we expected that large differences in physical habitat across substrate types would override the development effect on littoral habitat.
- In rocky substrates, we found a significant increase in pollution-sensitive macroinvertebrate taxa richness with increasing shoreline development. Although not intuitive, this result is entirely consistent with findings from the inland lakes study. We suspect this response is caused by a combination of increased sunlight and nutrient availability in developed rocky shorelines. Both of these factors tend to increase food availability for many taxa within the macroinvertebrate communities we found most responsive to development (i.e., COTE). The nature and intensity of development typical of rocky shorelines in Malletts Bay (i.e., low-density residential development) do not appear to cause severe increases in runoff or erosion to a degree that would impact these pollution-sensitive taxa. This trend, combined with potential increases in nutrient availability, may explain why this stressor-response relationship is the opposite of trends found in coarse-bottomed streams in Vermont (Fitzgerald *et al.*, 2012) and throughout the country (CWP, 2003), whereby increasing levels of development in upslope watersheds results in reduced richness of pollution-sensitive taxa.

Overall, the results of our Malletts Bay study indicate both broad patterns in the response of littoral habitat quality to shoreline development (e.g., reduced tree cover) regardless of natural setting, as well as littoral habitat responses that are unique to site-specific natural settings and gradients (e.g., substrate type, littoral slope, etc.). Despite the fact that changes to some littoral habitat characteristics vary depending on the natural setting, our study strongly indicates that high-intensity shoreline development significantly alters the natural character and condition of each of the substrate types we studied. The preservation and enhancement of natural ecosystem variability is a prominent goal of many ecosystem restoration programs, including those in the Lake Champlain Basin (LCBP, 2010). The preservation of natural ecosystem variability sustains the myriad ecosystem services that society values such as fisheries habitat and clean water. In recognizing that Lake Champlain contains great variability in littoral habitats and resulting ecosystem services, we have outlined below, based on our study results, the general characteristics for natural conditions of the broad substrate types observed in Lake Champlain. These natural characteristics provide a reference for understanding the degree of departure from natural conditions at developed shoreline sites, as outlined in detail in Section 3 for the various substrate types.

Rocky Substrates: The shoreland area of rocky littoral substrates is typically composed of bedrock ledge or other coarse glacial deposits (e.g., cobbles and boulders) that are resistant to erosion. Shoreland vegetation varies widely, but is often dominated by coniferous trees (e.g., cedar and hemlock) and limited growth in the understory. The littoral zones are generally characterized by limited substrate suitable for macrophyte rooting and dense colonization of macroinvertebrates. Aquatic biota habitat in rocky substrates depends on the configuration of the rock substrates in littoral zone; we observed that rocky ledges, fractured bedrock, and the presence of large boulders tend to enhance the retention of organic matter and increase habitat availability. Littoral slope and shoreline exposure to wind and wave action have a strong influence on retention of organic matter, and the stability of the substrates.

Sandy Substrates: The shoreland area of sandy littoral substrates often contains a mixture of soil types that are susceptible to erosion (e.g., sands and gravels). Shoreland vegetation typically includes a mixture of coniferous and deciduous trees with moderate to dense understory growth. Woody vegetation typically extends down to the high water mark, providing shade and inputs of woody debris and other organic matter to the littoral zone. Beach widths tend to be greater in natural sandy shores due to retention of woody debris and other substrates. The littoral zones are generally characterized by sandy and gravelly substrates suitable for dense macrophyte rooting and low to moderate density of macroinvertebrate colonization. Aquatic biota habitat in sandy substrates depends on the density of macrophytes and exposure to wind and wave action.

Macrophyte/Muck Substrates: The shoreland area of macrophyte littoral substrates is typically comprised of soils of lacustrine origin that are moderately resistant to erosion (e.g., clays and silty loams). Shoreland vegetation typically includes a mixture of coniferous and deciduous trees with dense understory growth; the higher nutrient availability in these soils allows for greater productivity in all vegetative strata. Perennial vegetation typically extends down to the high water mark or below, providing shade and inputs of woody debris and other organic matter to the littoral zone. The littoral zones are characterized by silty substrates suitable for dense and rich macrophyte colonization. The abundance and variability of macrophyte growth rooting allows for dense macroinvertebrate colonization. Aquatic biota habitat in macrophyte substrates depends on the density of macrophytes and exposure to wind and wave action.

Our follow-up validation study provided insight into the effect of development on littoral habitat in the larger lake ecosystem beyond Malletts Bay. Our stratified sampling design targeted undeveloped and highly developed sites in each of the three substrate types previously sampled in Malletts Bay and revealed the same general trends in the stressor-response relationships for a subset of the metrics calculated. With increasing shoreline development, we found a corresponding decrease in tree cover and woody debris in the littoral zone. In rocky substrates, macroinvertebrate richness at the “high” and “low” development sites matched the trend of increasing richness with increasing development observed in Malletts Bay and other inland lake studies in Vermont.

In conclusion, our findings support limiting shoreline development and maintaining healthy riparian buffers to sustain critical littoral habitat in Lake Champlain. Healthy littoral zones provide essential forage and nursery habitat for fish, improve economically important scenic value of the shoreline, and reduce erosion damage of flooding anticipated to increase under most models of climate change. While more study of shoreline development is needed across different areas of the lake to better understand the relative influence of natural gradients and human stressors, there is sufficient evidence to support aggressive actions to mitigate development impacts on these critical zones of Lake Champlain. Our recommendations for mitigation are consistent with those made by others in Vermont and the region, and build upon a body of technical knowledge and management practices specific to Lake Champlain. Other parallel planning efforts related to littoral habitat quality, such as shoreline erosion hazard planning, are equally important in the broader effort to develop holistic planning strategies for Lake Champlain’s shorelines.

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APPENDIX A

LULC DATA

Malletts Bay Study Sites LULC Data

				LULC % of 50m buffer														
Final Site ID	Littoral Substrate	15mX50m Score	Development Class	Agricultural	Barren - Bare Rock	Barren - Beach	Brush - Transitional	Forest - Coniferous	Forest - Deciduous	Forest - Mixed	Open Water	Urban - Commerical	Urban - Open Space	Urban - Residential	Urban - Transportation	Wetland - Emergent	Wetland - Forested	Wetland - Scrub/Shrub
2	Macro	4.48	High	0	2	2	0	50	0	2	0	0	28	10	3	0	2	0
3	Macro	6.54	High	0	0	0	15	0	0	0	0	0	61	8	11	0	6	0
4	Macro	0.00	Low	0	0	0	0	20	0	0	0	0	0	0	0	72	9	0
5	Macro	8.11	High	0	0	3	0	0	7	0	0	0	55	5	20	10	0	0
6	Macro	4.60	High	0	0	13	20	0	0	0	0	0	35	12	21	0	0	0
7	Sandy	1.89	High	0	0	10	41	0	0	0	0	0	35	0	14	0	0	0
8	Rocky	6.19	High	0	6	0	0	0	19	19	0	0	30	11	15	0	0	0
9	Rocky	7.01	High	0	0	0	7	8	6	14	0	0	38	19	9	0	0	0
10	Rocky	0.50	Low	0	0	0	0	69	0	16	0	0	12	1	1	0	0	0
11	Rocky	1.48	Low	0	6	0	18	60	3	0	0	0	9	3	0	0	0	0
12	Sandy	3.16	High	0	0	32	0	0	0	0	0	0	36	13	20	0	0	0
13	Macro	0.00	Low	0	0	14	0	50	4	19	3	0	0	0	0	0	10	0
14	Sandy	5.20	High	0	1	3	0	16	0	49	0	0	18	8	5	0	0	0
15	Rocky	5.02	High	0	7	0	38	0	12	0	0	0	38	0	5	0	0	0
16	Rocky	1.70	Low	0	9	0	2	0	0	41	0	0	48	0	0	0	0	0
18	Sandy	2.29	High	0	0	0	0	0	41	30	0	0	25	3	0	0	0	0
19	Macro	3.13	Low	0	0	0	0	0	37	0	0	4	42	9	8	0	0	0
20	Rocky	0.00	Low	0	0	3	55	41	0	0	0	0	0	0	0	0	0	0
21	Rocky	2.17	Low	0	0	15	0	0	10	25	0	0	51	0	0	0	0	0
22	Macro	2.91	Low	0	0	7	18	0	0	0	0	0	41	9	4	20	0	0
23	Sandy	3.91	High	0	0	23	0	0	0	2	0	0	63	11	0	0	0	0
24	Sandy	0.00	Low	0	0	27	0	0	0	37	1	0	0	0	0	22	13	0
25	Rocky	0.00	Low	0	9	0	45	46	0	0	0	0	0	0	0	0	0	0
26	Sandy	2.14	High	0	0	8	0	0	0	41	0	0	33	18	0	0	0	0
29	Sandy	1.06	Low	0	0	15	3	0	1	47	0	0	31	0	2	0	0	0
30	Sandy	0.19	Low	0	0	24	1	0	0	69	0	0	4	0	1	0	0	0
31	Sandy	2.44	High	0	0	14	0	0	28	6	0	0	24	5	23	0	0	0
32	Sandy	3.21	High	0	2	10	28	0	0	0	0	0	30	5	25	0	0	0
33	Macro	1.43	Low	0	0	0	7	0	51	0	0	0	32	4	4	3	0	0
34	Macro	1.88	Low	0	0	0	75	0	0	0	0	0	21	0	0	4	0	0
35	Macro	2.44	Low	0	0	0	24	6	0	0	0	0	56	11	1	3	0	0
40	Sandy	5.58	High	0	2	6	0	0	0	20	0	2	67	1	1	0	0	0
41	Macro	0.97	Low	0	0	4	29	1	0	50	0	0	0	16	0	0	0	0
42	Sandy	4.13	High	0	0	9	16	0	0	0	0	0	41	11	23	0	0	0
43	Sandy	0.00	Low	0	0	33	0	0	0	26	10	0	0	0	0	12	19	0
44	Sandy	2.73	High	0	0	11	21	0	0	0	0	0	54	10	3	0	0	0
45	Sandy	5.52	High	0	1	9	0	0	0	31	0	0	36	22	1	0	0	0
46	Rocky	0.00	Low	0	7	0	0	93	0	0	0	0	0	0	0	0	0	0
47	Rocky	1.29	Low	0	0	0	24	4	0	51	0	0	0	0	21	0	0	0
48	Sandy	1.57	High	0	3	0	25	0	0	50	0	0	6	1	15	0	0	0
49	Sandy	10.61	High	0	0	0	0	0	0	0	0	0	62	21	16	0	0	0
50	Sandy	6.29	High	0	0	7	0	0	0	11	0	0	49	23	10	0	0	0
51	Sandy	2.26	High	0	0	18	0	0	24	0	0	0	42	15	2	0	0	0
52	Sandy	1.14	Low	0	0	15	0	0	0	48	0	1	35	0	0	0	0	0
53	Rocky	0.68	Low	0	0	0	0	0	0	87	0	0	4	1	9	0	0	0
54	Rocky	0.00	Low	0	2	0	0	23	0	75	0	0	0	0	0	0	0	0
55	Rocky	0.00	Low	0	7	0	0	40	0	54	0	0	0	0	0	0	0	0
56	Rocky	0.00	Low	0	4	0	0	95	1	0	0	0	0	0	0	0	0	0
57	Rocky	5.86	High	0	6	1	23	0	0	32	0	0	25	6	7	0	0	0
58	Rocky	0.00	Low	0	0	0	0	33	0	67	0	0	0	0	0	0	0	0
59	Rocky	1.44	Low	1	0	0	6	24	0	40	0	0	22	5	2	0	0	0
60	Rocky	1.88	Low	0	0	2	41	6	0	4	0	0	33	8	4	0	0	0

Final Site ID	Littoral Substrate	15mX50m Score	Development Class	Agricultural	Barren - Bare Rock	Barren - Beach	Brush - Transitional	Forest - Coniferous	Forest - Deciduous	Forest - Mixed	Open Water	Urban - Commerical	Urban - Open Space	Urban - Residential	Urban - Transportation	Wetland - Emergent	Wetland - Forested	Wetland - Scrub/Shrub
61	Rocky	4.47	High	0	0	0	12	13	18	4	0	0	41	9	3	0	0	0
62	Rocky	2.54	Low	0	0	0	10	0	21	0	0	0	53	9	7	0	0	0
63	Rocky	6.09	High	0	0	0	7	0	9	0	0	0	79	3	2	0	0	0
64	Rocky	6.05	High	0	4	0	6	0	0	30	0	0	43	10	7	0	0	0
65	Rocky	0.00	Low	0	0	0	0	67	33	0	0	0	0	0	0	0	0	0
66	Rocky	0.57	Low	0	0	0	32	39	0	20	0	0	2	2	7	0	0	0
67	Sandy	2.02	High	24	0	0	33	0	0	0	0	0	41	2	0	0	0	0
68	Rocky	3.80	High	0	0	0	16	0	9	23	0	0	46	2	4	0	0	0
69	Rocky	4.86	High	0	0	0	7	0	3	22	0	0	50	11	8	0	0	0
70	Rocky	4.55	High	0	0	0	2	0	14	17	0	0	58	4	4	0	0	0
71	Rocky	1.10	Low	0	2	0	0	56	0	23	0	0	3	5	11	0	0	0
72	Rocky	0.78	Low	0	5	0	0	60	0	17	0	0	11	0	7	0	0	0
73	Rocky	1.37	Low	0	9	0	0	0	0	60	0	0	16	15	0	0	0	0
74	Rocky	2.79	Low	0	3	0	0	66	0	0	0	0	11	17	3	0	0	0
75	Sandy	0.44	Low	0	0	0	0	0	19	0	0	0	15	0	0	0	60	6
76	Rocky	0.73	Low	0	7	0	4	63	0	12	0	0	1	4	8	0	0	0
77	Rocky	1.35	Low	0	4	0	0	38	0	25	0	0	20	10	2	0	0	0
78	Sandy	1.23	Low	0	0	15	0	0	0	58	0	10	13	0	4	0	0	0
79	Sandy	0.76	Low	0	0	6	0	6	5	64	0	0	13	0	6	0	0	0
80	Sandy	0.56	Low	0	0	13	2	0	38	38	0	0	0	5	4	0	0	0
81	Rocky	1.17	Low	0	0	0	0	13	0	57	0	0	22	8	0	0	0	0
82	Sandy	3.45	High	0	8	10	10	0	8	0	0	0	63	1	0	0	0	0
83	Sandy	0.00	Low	0	12	0	0	57	0	31	0	0	0	0	0	0	0	0
84	Rocky	0.32	Low	0	0	0	0	74	0	19	0	0	3	4	0	0	0	0
85	Rocky	2.58	Low	0	18	0	1	23	0	10	0	0	37	9	2	0	0	0
86	Rocky	0.00	Low	0	0	0	0	38	0	62	0	0	0	0	0	0	0	0
87	Rocky	1.76	Low	0	3	0	0	64	0	16	0	0	4	10	3	0	0	0
88	Macro	4.08	High	0	0	20	0	0	0	0	0	0	67	11	2	0	0	0
89	Rocky	9.70	High	0	0	0	0	6	0	1	0	0	68	14	11	0	0	0
90	Rocky	6.63	High	0	6	0	14	0	11	0	0	0	40	12	17	0	0	0
91	Sandy	4.60	High	0	0	17	0	0	0	0	0	0	56	17	10	0	0	0
92	Macro	6.13	High	0	0	6	0	0	7	0	0	0	65	14	7	0	0	0
93	Sandy	0.17	Low	0	0	8	0	0	0	87	0	0	5	0	0	0	0	0
94	Rocky	4.40	High	0	0	0	1	0	0	32	0	16	27	0	17	6	0	0
95	Macro	1.74	Low	29	0	2	20	0	7	0	0	0	28	0	13	0	0	0
96	Sandy	4.86	High	0	0	17	0	0	3	2	0	0	52	10	15	0	0	0
97	Sandy	0.00	Low	0	0	0	0	86	0	14	0	0	0	0	0	0	0	0
98	Macro	7.37	High	0	0	3	0	0	0	0	0	0	91	6	0	0	0	0

Validation Study LULC Development Data

Final Site ID	Littoral Substrate	15mX50m Score	Development Class	LULC % of 50m buffer Undeveloped	Outdoor Developed	Built Developed
101	Macro	0	L	100%	0%	0%
102	Macro	4	H	48%	39%	13%
103	Rocky	8.25	H	31%	38%	31%
104	Sandy	0.21	L	93%	7%	0%
105	Sandy	7.37	H	26%	48%	26%
106	Rocky	0	L	100%	0%	0%
107	Sandy	5.94	H	18%	62%	21%
108	Macro	0	L	100%	0%	0%
109	Macro	7.91	H	15%	72%	12%
110	Sandy	0	L	100%	0%	0%
111	Rocky	0	L	100%	0%	0%
112	Rocky	6	H	37%	57%	5%
113	Rocky	0.19	L	97%	0%	3%
114	Rocky	4.34	H	90%	3%	7%
115	Sandy	1.92	H	59%	33%	8%
116	Macro	6.33	H	23%	76%	1%
117	Sandy	0.11	L	96%	4%	0%
118	Macro	1.36	L	65%	26%	9%

APPENDIX B

STRUCTURAL, VEGETATIVE, AND BIOTA DATA

Date ____________________ Personnel ____________________________

Site _____________________ Development Level ____________________________

Bank Slope and Texture	Slope	**Texture (%) and Cohesivity (yes or no)**					
		Bedrock	Boulder/cobble	Gravel	Sand	Silt/clay	
Bank Erosion	exposed slope parallel transect (%)		**Beach Condition & Width (m)**				
Buffer Width (circle)	>30 m	16 – 30 m	9 – 15 m	4 – 8 m	0 – 3 m		
Bank Canopy (circle)	76 – 100%	51 – 75%	26 – 50%	1-25%	0%		
Bank and Buffer Vegetation	**Trees**	Cover (%)	Invasives (%)	Conifer (%)	Deciduous (%)		
	Shrubs/Saps	Cover (%)	Invasives (%)	WADs(%)	Evergreen (%)	Decid. (%)	
	Herbs	Cover (%)	Invasives (%)	Grasses (%)	Forbs (%)		
Littoral Slope (%)	Other development features/comments:						

Transect 1: 0.5m depth - or - 10m from shoreline (circle)							
Sediment type (% Cover)							
Bedrock	Cobble	Floc	Organic Det.	Sand	Gravel	Silt	Woody Det.
Littoral habitat variables							
Embedd (%)	Large CWD (ct)	MCWD (%)	FCWD (%)	Leaf Litter (%)	Aufwuchs (%)	Org. Detritus (%)	

Macrophyte Species	**Cover%**	**Comments**

Transect 2: 1m depth - or - 20m from shoreline (circle)							
Sediment type (% Cover)							
Bedrock	Cobble	Floc	Organic Det.	Sand	Gravel	Silt	Woody Det.

Littoral habitat variables						
Embedd (%)	Large CWD (ct)	MCWD (%)	FCWD (%)	Leaf Litter (%)	Aufwuchs (%)	Org. Detritus (%)

Macrophyte Species	**Cover%**	**Comments**

Notes

2011 Malletts Bay Structural/Biota Site ID's

Site ID	Substrate	15mX50m Score	Development Class	X Coordinate	Y Coordinate	Structural Assessment	Inverts Sampled	Fish Sampled
2	Macro	4.48	High	-73.22362	44.55499	Yes	Yes	
3	Macro	6.54	High	-73.22746	44.55285	Yes	Yes	Yes
4	Macro	0.00	Low	-73.22812	44.55176	Yes	Yes	Yes
5	Macro	8.11	High	-73.22663	44.55123	Yes	Yes	Yes
6	Macro	4.60	High	-73.21857	44.54631	Yes		Yes
7	Sandy	1.89	High	-73.20746	44.54626	Yes	Yes	Yes
8	Rocky	6.19	High	-73.19236	44.55592	Yes	Yes	Yes
9	Rocky	7.01	High	-73.19312	44.55706	Yes	Yes	Yes
10	Rocky	0.50	Low	-73.19038	44.56343	Yes	Yes	Yes
11	Rocky	1.48	Low	-73.19122	44.56434	Yes	Yes	Yes
12	Sandy	3.16	High	-73.18438	44.58075	Yes	Yes	Yes
13	Macro	0.00	Low	-73.19207	44.58218	Yes	Yes	Yes
14	Sandy	5.20	High	-73.20387	44.57793	Yes		
15	Rocky	5.02	High	-73.20747	44.57712	Yes	Yes	Yes
17	Rocky	0.15	Low	-73.21398	44.57690	No	Yes	Yes
16	Rocky	1.70	Low	-73.20910	44.57417	Yes	Yes	Yes
18	Sandy	2.29	High	-73.22824	44.59859	Yes	Yes	Yes
19	Macro	3.13	Low	-73.26387	44.63356	Yes		Yes
20	Rocky	0.00	Low	-73.27712	44.61059	Yes	Yes	Yes
21	Rocky	2.17	Low	-73.28202	44.61060	Yes	Yes	Yes
22	Macro	2.91	Low	-73.29531	44.55320	Yes		Yes
23	Sandy	3.91	High	-73.25875	44.55210	Yes	Yes	Yes
24	Sandy	0.00	Low	-73.25171	44.55450	Yes	Yes	Yes
25	Rocky	0.00	Low	-73.22907	44.56965	Yes	Yes	Yes
26	Sandy	2.14	High	-73.26835	44.55061	Yes	Yes	Yes
27	Sandy	2.34	Low	-73.24388	44.55557	No	Yes	Yes
29	Sandy	1.06	Low	-73.23888	44.56726	Yes	Yes	Yes
30	Sandy	0.19	Low	-73.20617	44.54661	Yes	Yes	Yes
31	Sandy	2.44	High	-73.20361	44.54743	Yes	Yes	Yes
32	Sandy	3.21	High	-73.19797	44.54998	Yes	Yes	Yes
33	Macro	1.43	Low	-73.23108	44.56856	Yes	Yes	Yes
34	Macro	1.88	Low	-73.23096	44.56629	Yes	Yes	Yes
35	Macro	2.44	Low	-73.23080	44.56776	Yes	Yes	Yes
40	Sandy	5.58	High	-73.21427	44.54547	Yes		
41	Macro	0.97	Low	-73.21192	44.54550	Yes	Yes	Yes
42	Sandy	4.13	High	-73.20076	44.54856	Yes		
43	Sandy	0.00	Low	-73.25061	44.55501	Yes		
44	Sandy	2.73	High	-73.23787	44.56603	Yes		
45	Sandy	5.52	High	-73.23312	44.57060	Yes		
46	Rocky	0.00	Low	-73.22894	44.56683	Yes		
47	Rocky	1.29	Low	-73.23925	44.56345	Yes		
48	Sandy	1.57	High	-73.23963	44.56117	Yes		
49	Sandy	10.61	High	-73.23903	44.55930	Yes		
50	Sandy	6.29	High	-73.24011	44.55817	Yes		
51	Sandy	2.26	High	-73.24260	44.55632	Yes		
52	Sandy	1.14	Low	-73.26525	44.55084	Yes		

2011 Malletts Bay Structural/Biota Site ID's Continued

Site ID	Substrate	15mX50m Score	Development Class	X Coordinate	Y Coordinate	Structural Assessment	Inverts Sampled	Fish Sampled
53	Rocky	0.68	Low	-73.24073	44.56815	Yes		
54	Rocky	0.00	Low	-73.24133	44.57064	Yes		
55	Rocky	0.00	Low	-73.24083	44.57232	Yes		
56	Rocky	0.00	Low	-73.23877	44.57293	Yes		
57	Rocky	5.86	High	-73.21955	44.55573	Yes		
58	Rocky	0.00	Low	-73.27602	44.61394	Yes		
59	Rocky	1.44	Low	-73.27477	44.61701	Yes		
60	Rocky	1.88	Low	-73.30824	44.59781	Yes		
61	Rocky	4.47	High	-73.30647	44.59582	Yes		
62	Rocky	2.54	Low	-73.30480	44.59560	Yes		
63	Rocky	6.09	High	-73.30098	44.59690	Yes		
64	Rocky	6.05	High	-73.27332	44.62015	Yes		
65	Rocky	0.00	Low	-73.27461	44.62322	Yes		
66	Rocky	0.57	Low	-73.28884	44.60977	Yes		
67	Sandy	2.02	High	-73.29593	44.61136	Yes		
68	Rocky	3.80	High	-73.29599	44.60507	Yes		
69	Rocky	4.86	High	-73.29701	44.60231	Yes		
70	Rocky	4.55	High	-73.29910	44.59930	Yes		
71	Rocky	1.10	Low	-73.22365	44.58039	Yes		
72	Rocky	0.78	Low	-73.22258	44.57993	Yes		
73	Rocky	1.37	Low	-73.21838	44.58012	Yes	Yes	Yes
74	Rocky	2.79	Low	-73.21568	44.57584	Yes		
75	Sandy	0.44	Low	-73.18733	44.58191	Yes	Yes	Yes
76	Rocky	0.73	Low	-73.18810	44.56799	Yes		
77	Rocky	1.35	Low	-73.21285	44.57528	Yes		
78	Sandy	1.23	Low	-73.22880	44.60545	Yes		
79	Sandy	0.76	Low	-73.22912	44.60429	Yes		
80	Sandy	0.56	Low	-73.22865	44.60055	Yes		
81	Rocky	1.17	Low	-73.22957	44.59091	Yes		
82	Sandy	3.45	High	-73.22675	44.58816	Yes		
83	Sandy	0.00	Low	-73.22650	44.58442	Yes		
84	Rocky	0.32	Low	-73.22694	44.58063	Yes		
85	Rocky	2.58	Low	-73.23576	44.57215	Yes		
86	Rocky	0.00	Low	-73.22993	44.56069	Yes		
87	Rocky	1.76	Low	-73.22488	44.55800	Yes		
88	Macro	4.08	High	-73.29427	44.55197	Yes		Yes
89	Rocky	9.70	High	-73.28103	44.55810	Yes		
90	Rocky	6.63	High	-73.28005	44.55700	Yes		
91	Sandy	4.60	High	-73.27881	44.55446	Yes		
92	Sandy	6.13	High	-73.27512	44.55167	Yes		
93	Sandy	0.17	Low	-73.26998	44.55062	Yes		
94	Macro	4.40	High	-73.23018	44.56317	Yes		
95	Macro	1.74	Low	-73.24781	44.55466	Yes		
96	Sandy	4.86	High	-73.29974	44.55548	Yes		
97	Rocky	0.00	Low	-73.27502	44.62624	Yes		
98	Macro	7.37	High	-73.23396	44.55620	Yes	Yes	

2012 Validation Structural/Biota Site ID's

Site ID	Substrate	15mX50m Score	Development Class	X Coordinate	Y Coordinate	Structural Assessment	Inverts Sampled	Fish Sampled
101	Macro	0	Low	-73.31834	44.65455	Yes		
102	Macro	4	High	-73.31700	44.65304	Yes		
103	Rocky	8.25	High	-73.30546	44.65374	Yes		
104	Sandy	0.21	Low	-73.30140	44.65086	Yes	Yes	Yes
105	Sandy	7.37	High	-73.29740	44.65000	Yes	Yes	Yes
106	Rocky	0	Low	-73.29107	44.65705	Yes		
107	Sandy	5.94	High	-73.25193	44.42198	Yes		
108	Macro	0	Low	-73.24452	44.41556	Yes	Yes	Yes
109	Macro	7.91	High	-73.24530	44.41391	Yes	Yes	Yes
110	Sandy	0	Low	-73.24356	44.41159	Yes		
111	Rocky	0	Low	-73.23917	44.41025	Yes		
112	Rocky	6	High	-73.24546	44.41771	Yes		
113	Rocky	0.19	Low	-73.29210	44.28613	Yes	Yes	Yes
114	Rocky	4.34	High	-73.29303	44.27745	Yes	Yes	Yes
115	Sandy	1.92	High	-73.28747	44.28821	Yes		
116	Macro	6.33	High	-73.28678	44.29511	Yes		
117	Sandy	0.11	Low	-73.28820	44.29579	Yes		
118	Macro	1.36	Low	-73.28635	44.28876	Yes		

				Littoral Substrate							Littoral Habitat							Macrophyte Metrics			
Final ID	Substrate	15mX50m Score	Development Class	Bedrock %	Cobble %	Boulder %	Sediment Organic Detritus %	Sand %	Gravel %	Silt %	Embeddedness	LWD/100m2	MCWD %	FCWD %	Leaf Litter %	Aufwuchs %	Habitat Organic Detritus %	Macrophyte abundance	Macrophyte Richness	Macrophyte % Dominance	Invasive Macrophyte %
2	Macro	4.48	H	0	0	0	20	5	0	75		0	2	1	0	0	65	152.7	14	36	0.1
3	Macro	6.54	H	0	0	0	40	0	0	60		1	1.5	1	1	0	80	177.5	13	23.7	0
4	Macro	0.00	L	0	0	0	22.5	22.5	0	55		0	2.5	1	0	0	50	132.3	14	20.4	0.2
5	Macro	8.11	H	0	0	0	0	35	0	65		0	2	0.5	4.5	0	75	174.6	12	37.2	0.2
6	Macro	4.60	H	0	0	0	0	60	0	40	0	0	1.5	4	2.5	0	72.5	229.6	16	34.8	0
7	Sandy	1.89	H	0	0	0	0	42.5	0	57.5		5	25.5	47.5	2.5	0	7.5	63.6	7	78.6	0
8	Rocky	6.19	H	37.5	15	32.5	0	5	7.5	2.5	25	0	1.5	0.5	0	75	30	84	6	69.6	2.5
9	Rocky	7.01	H	15	32.5	20	0	0	32.5	0	0	0	5	5.5	1	55	12.5	5	3	60	1
10	Rocky	0.50	L	10	35	15	0	20	20	0	45	6	2	3.5	0.5	50	25	9.6	4	53.1	0
11	Rocky	1.48	L	100	0	0	0	0	0	0	0	0	0	0	0	100	15	0	0	0	0
12	Sandy	3.16	H	0	0	0	0	99	0	1		2	5	2.5	0	0	2.5	206	14	36.4	3.6
13	Macro	0.00	L	0	0	0	0	20	0	80		1	1.5	0	0	0	15	285	4	36.8	0
14	Sandy	5.20	H	0	0	0	0	50	0	50		1	1.05	52.5	2.5	0	32.5	63	5	23.8	0
15	Rocky	5.02	H	0	80	2.5	0	5	12.5	0	22.5	4	3	1	0	90	100	94.4	13	42.4	1
16	Rocky	1.70	L	15	12.5	0	0	47.5	0	25	30	6	2.5	0	2.5	30	10	34.1	4	58.7	0
18	Sandy	2.29	H	0	0	0	0	87.5	0	12.5		1	1.5	1.5	0.5	0	4	15.2	3	98.7	0
19	Macro	3.13	L	0	0	0	0	75	0	25		2	3.5	1	4.5	0	52.5	135.2	10	40.7	0.1
20	Rocky	0.00	L	75	15	0	0	1.5	8.5	0	2.5	0	0	0	0	70	10	0	0	0	0
21	Rocky	2.17	L	0	85	0	0	7.5	7.5	0	30	1	0	0	0	40	40	2	1	100	0
22	Macro	2.91	L	0	0	0	0	42.5	17.5	40		0	1.5	3.5	0	0	67.5	76.2	8	70.9	0
23	Sandy	3.91	H	0	0	0	0	77.5	10	12.5		0	1.5	1.5	0	0	7.5	37	2	94.6	0
24	Sandy	0.00	L	0	0	0	0	82.5	5	12.5		0	0	0	0	0	5.5	16	2	93.8	0
25	Rocky	0.00	L	0	55	0	0	7.5	37.5	0	22.5	0	1.5	4	2.5	40	32.5	255.1	11	31.4	0.1
26	Sandy	2.14	H	0	0	0	0	65	0	35		10	35	35	2.5	0	30	69	3	94.2	0
29	Sandy	1.06	L	0	20	0	0	55	10	15	40	1	2.5	1	0	15	47.5	152.7	8	62.2	0
30	Sandy	0.19	L	0	0	0	0	10	0	90		3	3	15	7.5	0	25	38.2	5	85.1	0.1
31	Sandy	2.44	H	0	0	0	0	25	0	75		2	0.5	25	7.5	0	12.5	99.2	5	95.8	1
32	Sandy	3.21	H	0	0	0	0	42.5	0	57.5	0	0	0	47.5	2.5	0	1.5	49.5	5	42.4	0
33	Macro	1.43	L	0	0	0	15	0	0	85		1	6	6	1	0	60	210.6	17	54.6	0.2
34	Macro	1.88	L	0	0	0	15	7.5	0	77.5		0	1	1.5	1	0	57.5	118	17	33.9	0.1
35	Macro	2.44	L	0	0	0	15	0	0	85		0	1.5	1.5	0.5	0	50	176.8	13	37.9	0.1
40	Sandy	5.58	H	0	0.5	0	10	69	0	20		2	0	0.5	1.5	0	30	216	7	38.2	0
41	Macro	0.97	L	0	0	0	0	35	0	65		8	1.5	1	0.75	0	30	107.9	9	49.1	0.2
42	Sandy	4.13	H	0	0	0	0	62.5	0	37.5		0	1.5	3	0.5	0	6.5	83.3	9	72	0.1
43	Sandy	0.00	L	0	0	0	0	100	0	0		0	0.5	1.05	1.05	0	1.05	0	0	0	0
44	Sandy	2.73	H	0	0	0	0	70	0	30		1	4	12.5	0	0	5	27	3	74.1	0
45	Sandy	5.52	H	0	0	0	0	80	0	20		0	1.5	2	0	0	5	153.8	8	65	0
46	Rocky	0.00	L	10	67.5	0	0	5	17.5	0	17.5	0	0	2.5	0	50	20	277	9	25.3	0
47	Rocky	1.29	L	0	40	0	0	52.5	0	7.5	70	1	1	1.5	0	20	4	185.6	5	49	0
48	Sandy	1.57	H	0	0	0	0	85	0	15		0	2.5	1	0	0	1	34.3	6	58.6	0
49	Sandy	10.61	H	0	0	0	0	80	0	20		1	6.5	5.5	0.5	0	3	0.1	1	100	0
50	Sandy	6.29	H	0	0	0	0	80	0	20		0	1.5	1.5	1	0	1.5	2	1	100	0
51	Sandy	2.26	H	0	0	0	0	80	0	20		1	5.5	1.5	0	0	7.5	0	0	0	0
52	Sandy	1.14	L	0	0	0	0	97.5	0	2.5		8	30.5	6	0	0	20	50	1	100	0

Malletts Bay Structural Data

Final ID	Substrate	15mX50m Score	Development Class	Bedrock %	Cobble %	Boulder %	Sediment Organic Detritus %	Sand %	Gravel %	Silt %	Embeddedness	LWD/100m2	MCWD %	FCWD %	Leaf Litter %	Aufwuchs %	Habitat Organic Detritus %	Macrophyte abundance	Macrophyte Richness	Macrophyte % Dominance	Invasive Macrophyte %
53	Rocky	0.68	L	0	45	0	0	46.5	0	8.5	10	0	1	0.5	0	8	2	11.4	5	74.6	0
54	Rocky	0.00	L	12.5	42.5	0	0	20	22.5	2.5	2.5	0	2	8.5	0	12.5	7.5	0.3	2	66.7	0
55	Rocky	0.00	L	50	37.5	0	0	0	12.5	0	0	0	1.5	0.5	0	30	0.5	2.2	3	90.9	0
56	Rocky	0.00	L	5	82.5	0	0	7.5	5	0	0	0	0	0.5	0	55	0.5	2.2	2	90.9	0
57	Rocky	5.86	H	100	0	0	0	0	0	0	0	0	1.5	2.5	3	50	80	4.3	5	69.8	0
58	Rocky	0.00	L	20	76.5	0	0	2	1.5	0	2.5	0	0	0.5	0	75	60	9.7	4	61.9	0
59	Rocky	1.44	L	0	87.5	0	0	5	7.5	0	17.5	0	0	0	0	40	25	3.5	4	85.7	0
60	Rocky	1.88	L	0	86	0	0	7.5	6.5	0	5	0	0	0	0	50	50	15.2	7	33.6	0
61	Rocky	4.47	H	0	75	10	0	0	15	0	3.5	0	0	0	0.05	85	25	4.2	3	71.4	0
62	Rocky	2.54	L	57.5	40.5	0	0	1.5	0.5	0	7.5	0	0	0	0	25	12.5	5.6	5	44.6	0
63	Rocky	6.09	H	0	90	0	0	0	5	5	25	0	0	0.5	0	30	40	0	0	0	0
64	Rocky	6.05	H	0	85	0	0	5	10	0	15	0	0	0	0	55	40	2.1	2	95.2	0
65	Rocky	0.00	L	0	85	0	0	12.5	2.5	0	25	10	1	1.5	0	60	100	26.3	6	53.2	0
66	Rocky	0.57	L	0	85	0	0	7.5	7.5	0	12.5	0	0.05	0	0	45	25	33.3	4	45.3	0
67	Sandy	2.02	H	0	11	0	0	89	0	0	65	1	0.5	0.5	0	0	2.5	46.1	6	54.2	0
68	Rocky	3.80	H	0	85	0	0	3	11.5	0.5	15	0	0	0	0	25	50	78.3	6	40.9	0
69	Rocky	4.86	H	0	85	0	0	0	15	0	2.5	0	0	0	0	30	35	3.1	2	96.8	0
70	Rocky	4.55	H	0	85	0	0	0.5	14.5	0	7.5	0	0	0	0	30	45	4.1	3	48.8	0
71	Rocky	1.10	L	0	100	0	0	0	0	0	0	27	1	0	0.1	100	20	3.4	4	88.2	0
72	Rocky	0.78	L	7.5	15	77.5	0	0	0	0	0	5	1.55	0.5	0	90	20	8.3	6	48.2	0
73	Rocky	1.37	L	4	80	0	0	3.5	12.5	0	2.5	0	0.5	0.5	0.5	60	45	97.6	6	35.9	0
74	Rocky	2.79	L	30	50	20	0	0	0	0	0	0	0.05	0.55	0	80	12.5	31.1	6	35.4	0.1
75	Sandy	0.44	L	0	0	0	0	100	0	0		6	6.5	2.5	0	0	1	201.6	6	42.2	0
76	Rocky	0.73	L	92.5	7.5	0	0	0	0	0	0	0	1	0	0	100	60	2.1	3	47.6	0
77	Rocky	1.35	L	12.5	42.5	37.5	0	7.5	0	0	17.5	0	7	15.5	1	100	25	68.5	12	29.2	0
78	Sandy	1.23	L	0	0	0	0	67.5	0	32.5		7	26.5	13.5	0.5	0	31	7.6	1	100	0
79	Sandy	0.76	L	0	0	0	0	80	7.5	12.5		5	5	5.5	1	0	36	91	3	76.9	0
80	Sandy	0.56	L	0	10	2.5	0	81.5	2.5	3.5	40	1	1.5	1	0	10	1.5	20.1	1	100	0
81	Rocky	1.17	L	0	27.5	60	0	3	8.5	1	0	0	2	1	0.5	30	90	8.2	6	31.7	0
82	Sandy	3.45	H	0	0	0	0	95	0	5		0	1.5	1	0	0	7.5	0	0	0	0
83	Sandy	0.00	L	0	2.5	0	0	67.5	27.5	2.5	0	0	1.5	0.5	0	0	1.5	0.1	1	100	0
84	Rocky	0.32	L	15	22.5	55	0	0	7.5	0	5	0	2.5	1	0.5	45	10	6.2	7	32.3	0
85	Rocky	2.58	L	0	30	0	0	32.5	35	2.5	17.5	0	0	0	0.5	15	12.5	19.2	5	78.1	0
86	Rocky	0.00	L	57.5	12.5	25	0	0	5	0	0	17	20	11.5	0	65	12.5	32.1	3	93.5	0
87	Rocky	1.76	L	7.5	80	7.5	0	0	5	0	0	0	1.5	1	0	32.5	55	42.4	7	59	0
88	Macro	4.08	H	0	17.5	10	0	5	10	57.5	32.5	1	1.5	0.5	2.5	15	65	103.5	15	26.1	0
89	Rocky	9.70	H	0	72.5	0	0	15	12.5	0	7.5	0	0.5	3	0.5	12.5	1.5	0	0	0	0
90	Rocky	6.63	H	0	65	5	0	5	25	0	2.5	0	1	1	0.5	25	7.5	2.4	5	83.3	0
91	Sandy	4.60	H	0	27.5	0	0	45	20	7.5	5	0	20	10	0	15	40	66	3	90.9	0
92	Sandy	6.13	H	0	27.5	5	0	50	15	2.5	0	0	5	3.5	7.5	15	6.5	5	1	100	0
93	Sandy	0.17	L	0	0	0	0	85	12.5	2.5		11	13	45	2.5	0	18.5	5.1	2	98	0
94	Macro	4.40	H	0	0	0	0	42.5	0	57.5		3	4	20	2.5	0	42.5	133.2	11	41.3	0
95	Macro	1.74	L	0	0	0	0	45	0	55		4	2	4	0	0	82.5	37.1	11	27	4
96	Sandy	4.86	H	0	0	0	0	85	0	15	0	0	1	0.5	1	0	32.5	105	2	85.7	0
97	Rocky	0.00	L	0	37.5	0	0	22.5	10	30	17.5	0	1	1.5	2.5	0	52.5	33	4	60.6	0
98	Macro	7.37	H	0	0	0	0	0	45	55		0	0	0.5	0	0	85	157.4	13	44.5	1.1

Malletts Bay Structural Data

				Bank/Shoreline					Bank Substrate					Bank Vegetation												
Final ID	Substrate	15mX50m Score	Development Class	Bank slope %	Exposed slope %	Beach Width (m)	Bank Armor %	WEP 10+	Bedrock	Boulder/ Cobble	Gravel	Sand	Silt/Clay	tree cover	invasive tree	conifer tree	deciduous tree	shrub cover	invasive s/s	WAD s/s	evergreen s/s	deciduous s/s	herb cover	invasive herb	grasses	forbs
2	Macro	4.48	H	20	0	10	0	1.82	30	20	20	30	0	80	0	0	100	30	40	60	0	0	60	80	10	10
3	Macro	6.54	H	15	0	0	0	3.62	0	0	0	20	80	60	0	0	100	10	30	35	0	35	90	80	10	10
4	Macro	0.00	L	5	0	30	0	1.85	0	0	0	80	20	70	0	0	100	90	0	40	0	60	70	20	30	50
5	Macro	8.11	H	18	15	0	0	0.86	0	0	0	100	0	0	0	0	0	2	0	0	0	100	100	0	95	5
6	Macro	4.60	H	45	0	13	20	3.28	0	0	0	100	0	20	0	0	100	40	0	0	0	100	90	0	15	85
7	Sandy	1.89	H	100	20	15	0	12.44	0	0	0	100	0	0	0	0	0	80	0	10	45	45	90	0	50	50
8	Rocky	6.19	H	70	0	4	0	3.62	100	0	0	0	0	0	0	0	0	5	0	0	0	100	90	0	99	1
9	Rocky	7.01	H	40	0	8	0	8.89	70	30	0	0	0	40	0	10	90	60	5	0	15	80	50	5	5	90
10	Rocky	0.50	L	78	50	0	0	1.10	60	30	0	10	0	75	0	20	80	20	0	50	50	0	5	0	0	100
11	Rocky	1.48	L	18	0	0	0	2.03	50	30	0	20	0	70	0	30	70	10	0	100	0	0	5	0	0	100
12	Sandy	3.16	H	2	0	12	0	16.18	0	0	0	100	0	5	0	0	0	100	0	0	0	0	5	100	0	0
13	Macro	0.00	L	113	15	18	0	46.16	0	0	0	30	70	90	0	30	70	60	0	90	0	10	15	0	0	100
14	Sandy	5.20	H	20	0	5	60	32.04	0	5	0	95	0	30	10	15	75	30	80	20	0	0	100	90	0	10
15	Rocky	5.02	H	17	0	2	0	0.00	0	0	0	100	0	30	0	85	15	0	0	0	0	0	50	90	0	10
16	Rocky	1.70	L	36	10	0	0	0.01	80	0	0	10	10	80	0	40	60	70	0	50	50	0	40	0	50	50
18	Sandy	2.29	H	90	10	13	0	5.71	0	30	0	70	0	60	0	20	80	20	0	0	0	100	60	20	20	60
19	Macro	3.13	L	15.6	0	3	0	59.02	0	50	30	20	0	40	0	0	100	0	0	0	0	0	60	0	80	20
20	Rocky	0.00	L	56	0	14	0	27.89	0	0	0	60	40	40	0	85	15	80	35	0	35	30	35	60	15	25
21	Rocky	2.17	L	60	0	17	0	50.11	0	0	60	30	10	25	100	0	0	0	0	0	0	0	50	100	0	0
22	Macro	2.91	L	15.6	20	50	0	0.00	0	0	0	100	0	10	0	0	100	5	100	0	0	0	100	40	60	0
23	Sandy	3.91	H	67	0	8	100	26.33	50	0	0	50	0	0	0	0	0	0	0	0	0	0	95	100	0	0
24	Sandy	0.00	L	1	0	16.9	0	22.10	0	0	0	100	0	70	0	30	70	90	0	80	5	15	50	0	0	100
25	Rocky	0.00	L	65	0	0	0	0.87	100	0	0	0	0	50	0	100	0	60	0	0	100	0	5	0	100	0
26	Sandy	2.14	H	100	35	8	0	31.65	0	0	15	85	0	40	0	80	20	15	0	20	0	80	20	60	15	25
29	Sandy	1.06	L	100	0	20	0	17.79	0	0	20	80	0	90	0	50	50	30	0	0	50	50	10	0	0	100
30	Sandy	0.19	L	111	10	20	0	17.08	0	0	0	100	0	70	0	80	20	80	0	0	80	20	40	0	0	100
31	Sandy	2.44	H	89	30	15	0	17.46	0	0	0	100	0	80	0	0	100	30	0	0	0	100	100	10	0	90
32	Sandy	3.21	H	150	100	5	10	15.82	0	0	0	100	0	20	0	0	100	5	0	0	0	100	50	0	70	30
33	Macro	1.43	L	29	40	16	0	0.03	0	0	0	10	90	60	0	0	100	70	0	20	0	80	80	20	30	50
34	Macro	1.88	L	30	60	12	0	0.00	0	0	5	15	80	15	0	0	100	90	0	70	0	30	50	20	15	65
35	Macro	2.44	L	55	10	10	0	0.03	0	0	0	10	90	30	0	100	0	80	0	60	0	40	70	15	50	35
40	Sandy	5.58	H	78	0	5	60	12.59	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	100	0	0
41	Macro	0.97	L	45	15	10	0	13.04	0	0	0	100	0	90	0	50	50	60	0	20	40	40	70	0	10	90
42	Sandy	4.13	H	100	2	5	70	17.11	0	0	0	100	0	0	0	0	0	0	0	0	0	0	100	75	5	20
43	Sandy	0.00	L	1	0	14	0	22.10	0	0	5	95	0	70	0	10	90	40	10	0	10	90	40	20	0	80
44	Sandy	2.73	H	100	15	12	0	10.16	0	10	50	30	10	0	0	0	0	90	20	10	35	35	10	0	0	100
45	Sandy	5.52	H	15	0	10	0	0.09	0	0	20	80	0	0	0	0	0	0	0	0	0	0	100	100	0	0
46	Rocky	0.00	L	30	0	0	0	9.24	80	0	0	20	0	100	5	65	30	40	0	70	20	10	10	0	0	100
47	Rocky	1.29	L	150	0	9.4	0	18.10	80	0	0	10	10	95	0	85	15	70	0	20	30	50	20	0	0	100
48	Sandy	1.57	H	150	15	6.4	0	5.57	30	5	5	50	10	70	0	50	50	40	0	20	60	20	80	0	60	40
49	Sandy	10.61	H	70	0	5.75	100	14.79	90	0	0	10	0	20	0	0	100	0	0	0	0	0	0	0	0	0
50	Sandy	6.29	H	20	0	6	90	19.06	0	100	0	0	0	70	0	0	100	20	100	0	0	0	50	80	10	10
51	Sandy	2.26	H	32	15	14.5	0	20.79	0	5	10	80	5	70	0	0	100	40	0	40	0	60	10	0	0	100
52	Sandy	1.14	L	35	0	16	0	29.08	0	0	20	80	0	90	0	20	80	70	0	60	0	40	30	0	0	100

Malletts Bay Structural Data

Final ID	Substrate	15mX50m Score	Development Class	Bank slope %	Exposed slope %	Beach Width (m)	Bank Armor %	WEP 10+	Bedrock	Boulder/ Cobble	Gravel	Sand	Silt/Clay	tree cover	invasive tree	conifer tree	deciduous tree	shrub cover	invasive s/s	WAD s/s	evergreen s/s	deciduous s/s	herb cover	invasive herb	grasses	forbs
53	Rocky	0.68	L	150	0	7.3	0	9.32	90	0	0	10	0	100	0	60	40	50	0	20	70	10	10	0	0	100
54	Rocky	0.00	L	150	0	0	0	5.98	90	0	0	10	0	100	0	70	30	30	0	0	50	50	20	0	67	33
55	Rocky	0.00	L	92	10	10	0	20.37	20	0	40	30	10	100	0	50	50	75	0	60	30	10	30	0	0	100
56	Rocky	0.00	L	132	10	12	0	22.14	80	0	0	0	20	100	0	90	10	20	0	70	30	0	10	0	0	100
57	Rocky	5.86	H	30	0	8	0	0.00	70	0	0	30	0	2	0	100	0	15	0	0	98	2	20	0	60	40
58	Rocky	0.00	L	170	0	5	0	0.01	100	0	0	0	0	90	0	35	65	60	10	0	70	20	0	0	0	0
59	Rocky	1.44	L	160	30	4	0	0.01	80	0	10	10	0	20	0	60	40	60	30	10	35	25	15	60	10	30
60	Rocky	1.88	L	100	0	10	0	5.12	0	75	20	5	0	40	0	60	40	60	30	5	40	25	40	0	30	70
61	Rocky	4.47	H	55	0	15	0	21.03	0	55	40	5	0	20	0	0	100	5	0	0	100	0	50	100	0	0
62	Rocky	2.54	L	100	0	7	0	0.78	20	60	30	10	0	60	0	0	100	70	30	10	30	30	10	0	20	80
63	Rocky	6.09	H	89	30	17	0	19.44	0	0	0	60	40	0	0	0	0	0	0	0	0	0	75	100	0	0
64	Rocky	6.05	H	178	0	4	0	0.01	100	0	0	0	0	0	0	0	0	10	0	0	100	0	40	100	0	0
65	Rocky	0.00	L	156	30	3	0	0.02	100	0	0	0	0	90	0	40	60	20	10	0	90	0	0	0	0	0
66	Rocky	0.57	L	133	35	14	0	1.03	20	10	10	40	20	20	0	20	80	30	20	0	60	20	50	60	25	15
67	Sandy	2.02	H	120	0	10	0	0.01	0	0	15	85	0	20	0	0	100	70	10	20	0	70	10	0	0	100
68	Rocky	3.80	H	25	0	24	0	0.02	0	0	15	85	0	20	0	0	100	0	0	0	0	0	40	100	0	0
69	Rocky	4.86	H	150	0	6	0	0.01	80	20	0	0	0	0	0	0	0	30	25	0	10	65	40	95	0	5
70	Rocky	4.55	H	150	0	5	0	0.01	95	5	0	0	0	10	0	0	100	30	60	10	10	20	35	90	0	10
71	Rocky	1.10	L	41	10	12	0	24.60	10	5	0	75	10	75	0	75	25	50	0	15	85	0	25	0	10	90
72	Rocky	0.78	L	45	0	0	0	33.77	90	0	0	10	0	70	0	50	50	25	0	100	0	0	75	0	90	10
73	Rocky	1.37	L	38	0	2	0	3.09	20	5	0	60	15	70	0	0	100	25	0	70	10	20	100	0	75	25
74	Rocky	2.79	L	15	0	0	0	28.46	90	0	0	10	0	40	0	90	10	20	0	40	60	0	20	0	20	80
75	Sandy	0.44	L	0.5	0	10	0	42.20	0	0	0	100	0	40	0	0	100	50	0	100	0	0	60	0	10	90
76	Rocky	0.73	L	24	0	0	0	7.79	50	10	0	40	0	80	0	90	10	5	0	100	0	0	60	80	0	20
77	Rocky	1.35	L	42	0	6	0	14.40	40	0	0	60	0	100	0	50	50	30	0	40	60	0	40	0	50	50
78	Sandy	1.23	L	160	10	15	0	6.26	0	0	10	90	0	40	0	30	70	60	0	0	20	80	80	0	15	85
79	Sandy	0.76	L	130	0	18	0	8.82	0	0	0	100	0	90	0	30	70	40	0	2	20	78	60	0	20	80
80	Sandy	0.56	L	100	0	15	60	3.54	0	10	0	90	0	100	0	20	80	20	10	0	0	90	90	0	5	95
81	Rocky	1.17	L	200	0	0	0	4.85	95	3	2	0	0	100	0	60	40	20	0	0	60	40	40	0	60	40
82	Sandy	3.45	H	90	10	12	80	3.89	0	50	0	50	0	100	0	0	100	60	0	0	0	100	50	0	20	80
83	Sandy	0.00	L	170	2	12	0	6.71	90	0	8	0	2	100	0	85	15	20	0	0	100	0	30	0	10	90
84	Rocky	0.32	L	60	15	4	0	1.91	20	70	0	10	0	90	0	60	40	10	80	0	0	20	10	25	25	50
85	Rocky	2.58	L	30	0	10	0	21.32	0	0	0	100	0	0	0	0	0	2	100	0	0	0	80	0	100	0
86	Rocky	0.00	L	45	0	4	0	0.02	50	50	0	0	0	100	0	70	30	40	0	0	60	40	20	0	30	70
87	Rocky	1.76	L	160	0	2	0	1.66	100	0	0	0	0	70	0	50	50	10	0	0	0	100	20	20	10	70
88	Macro	4.08	H	32	0	6	0	0.02	0	0	60	40	0	0	0	0	0	2	0	0	100	0	100	0	100	0
89	Rocky	9.70	H	66.7	0	3	0	13.15	40	60	0	0	0	5	0	100	0	15	0	0	70	30	70	10	85	5
90	Rocky	6.63	H	88.9	0	0	0	0.02	0	100	0	0	0	0	0	0	0	60	0	0	0	100	30	0	5	95
91	Sandy	4.60	H	21	0	4	0	15.73	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	Sandy	6.13	H	133	30	0	80	20.50	20	40	0	40	0	60	0	30	70	30	0	0	50	50	20	0	0	100
93	Sandy	0.17	L	89	35	8	0	0.01	0	0	20	80	0	70	0	40	60	60	0	0	20	80	40	20	0	80
94	Macro	4.40	H	33	0	3	0	0.00	0	0	0	50	50	60	0	30	70	40	0	80	0	20	15	0	0	100
95	Macro	1.74	L	18	40	20	0	0.01	0	0	0	100	0	0	0	0	0	0	0	0	0	0	100	0	95	5
96	Sandy	4.86	H	9	0	6	0	31.65	0	10	60	30	0	15	0	0	100	0	0	0	0	0	5	0	100	0
97	Rocky	0.00	L	133	0	3	0	2.34	80	0	5	15	0	100	0	70	30	30	50	0	50	0	5	0	0	100
98	Macro	7.37	H	22.2	0	4	0	4.20	0	0	0	100	0	0	0	0	0	0	0	0	0	0	100	0	100	0

Malletts Bay Structural Data

				Macrophyte Species Cover from combined shallow and deep transects																																						
Final ID	Substrate	15mX50m Score	Development Class	*Bulrush*	*Ceratophyllum*	*Carex*	*Chara*	*Elatine*	*E. canadensis*	*E. nuttalli*	*Green Algae #1*	*Green Lichen*	*Isoetes*	*M. Alterniflorum*	*M.sibericum*	*M. spicatum*	*M. tenellum*	*Megolodonta*	*N. flexilis*	*N. guad*	*Nitella*	*Nuphar*	*Nymphaea*	*Periphyton*	*P. amplifolius*	*P. bicuspulatus*	*P. crispus*	*P. epihydrus*	*P. gramineus*	*P. Narrow Leaf*	*P. Narrow Leaf #2*	*P. Narrow Leaf #3*	*P. perfoliatus*	*P. richardsonii*	*P. robbinsii*	*P. spirillus*	*P. zosteriformis*	*Pontederia*	*Sagittaria*	*Sedge*	*Vallisneria*	*Zosterella*
2	Macro	4.48	H	0	1	0	2	0	7	0	0	0	0	0	0	0.1	0	12	5	40	0	0	0	0	2	0	0	0	4	0	0	0	1.1	11	8	0	0	0	0	0	5	55
3	Macro	6.54	H	0	1	0	0	0	8	0	0	0	0	0	0	0	0	3	0	42	0	15	25	0	0	0	0	3	1	0	0	0	0	1	22	0	0	17	0	0	23	17
4	Macro	0.00	L	0	1	0	5	0	1.1	0	0	0	0	0	0	0.2	0	8	4	25	0	15	15	0	0	3	0	0	0	0	0	0	0	0	3	0	0	10	0	0	27	15
5	Macro	8.11	H	0	0	0	0	0	10	0	0	0	0	0.1	0	0.2	65	0.2	0	0	0	10	0	0	0	0	0	0	5	0	0	0	12	10	5.1	0	0	0	0	0	40	17
6	Macro	4.60	H	0	0	0	5	0	20	20	0	0	15	3	0	0	0	0	3	3	0	0	0.1	10	0	0	0	0	10	0	0	0	7.5	8	2	0	0	0	30	0	80	13
7	Sandy	1.89	H	0	0	0	0	0.1	2.5	3.5	0	0	0	0	0	0	0	0	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	50	0
8	Rocky	6.19	H	0	0	0	0	0	0	8.5	0	0	0	0	0	2.5	0	0	6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	59	7.5
9	Rocky	7.01	H	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
10	Rocky	0.50	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	1	0	0	0	1	0	0	0	0	0	0	5.1	0
11	Rocky	1.48	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Sandy	3.16	H	0	0	0	2	0	5	25	0	0	0	0	0	1.1	0	0	0	75	10	0	0	15	0	0.2	2.5	0	5	0.1	0	0	2.5	2.5	0	0	0	0	0	0	60	0
13	Macro	0.00	L	0	0	0	0	0	105	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	100	0
14	Sandy	5.20	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	15	15	3	0	0	0	0	0	0	0	0	0	15	0
15	Rocky	5.02	H	0	0	0	0	0	2.5	7.5	0	0	0	0	0	1	0	0	11	9.5	0.1	0	0	15	0	2.6	0	0	0	0	0	0	0	1	0.1	0.1	0	0	0	0	40	4.5
16	Rocky	1.70	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.1	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	1	0	0	0	0	20	0
18	Sandy	2.29	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
19	Macro	3.13	L	0	0	1	0	0.1	23	0	0	0	0	0	1	0.1	0	0	3	5	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	35	55
20	Rocky	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Rocky	2.17	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
22	Macro	2.91	L	8	0	8	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0.1	0	0	0	1.1	0	54	0
23	Sandy	3.91	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	35	0
24	Sandy	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	15	0
25	Rocky	0.00	L	0	0	0	8.5	0	1	6	0	0	0	0	0	0.1	0	0	80	25	0	0	0	80	0	0	0	0	1	10	0	0	0	0	0	0	0	0	0	0	35	8.5
26	Sandy	2.14	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	65	0
29	Sandy	1.06	L	0	0	0	95	0	0	1	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	2	5.1	0	0	0	0.1	2	0	0	0	0	0	18	0
30	Sandy	0.19	L	0	0	0	0	0	0	0.1	0	0	0	0	0	0.1	0	0	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	33	0
31	Sandy	2.44	H	0	0	0	0	0	0.1	0	0	0	0	0	0	1	0	0	2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	95	0
32	Sandy	3.21	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	10	0	0	0	0	0	0	0	7.5	0	0	0	6	0	0	0	0	0	0	0	21	0
33	Macro	1.43	L	0	0.1	0	0.1	0	20	4	3	0	0	0	0.2	0.2	0	0	5	25	0	0	5	0	0	0	0	0	0	0.2	0.1	0	0.1	5.1	8	0	0	0	0	0	20	115
34	Macro	1.88	L	0	0.1	0	0.1	0	13	0.1	0	0	0	0.1	0.1	0.1	13	0	3	40	0	0	0	0	0	0.1	0	0	0	0.1	0	0	1.1	2	0	0	0	0	0.1	0	20	25
35	Macro	2.44	L	0	0.1	0	0	0	12	10	0	0	0	0	0.2	0.1	0	0.2	3	50	0	0	0	0	0	0	0	0	0	0.1	0	0	0.1	4	0	0	0	0	0	0	67	30
40	Sandy	5.58	H	0	0	0	5	0	5	0	0	0	0	0	0	0	0	0	75	0	0	0	0	0	0	0	0	0	0	0	0	0	5	3.5	0	0	0	0	40	0	83	0
41	Macro	0.97	L	0	0	0	0	1	0	1	0	0	0.1	0	0	0.2	0	0	53	0	0	0	0	0	0	0	0	0	0	0.1	0	0	2	0	0.5	0	0	0	0	0	50	0
42	Sandy	4.13	H	0	0	0	1	0	0	0	0	0	0	0	0	0.1	0	0	2	0	0	0	0	0	0	0.1	0	0	10	0.1	0	0	5	0	0	0	0	0	5	0	60	0
43	Sandy	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	Sandy	2.73	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	20	0
45	Sandy	5.52	H	0	0	0	0.1	0	0	0.1	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	10	0	0	18	1	0.1	0	0	0	0	0	100	0
46	Rocky	0.00	L	0	1	0	0	0	7.5	8.5	0	0	0	0	0	0	0	0	45	10	0	0	0	70	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	40	65
47	Rocky	1.29	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.5	0.1	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	61	0	91	0
48	Sandy	1.57	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0.1	0	0	0	0	0	0	0	0.1	0	0	0	0	12	0	0	0	0	1	0	20	0
49	Sandy	10.61	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0
50	Sandy	6.29	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
51	Sandy	2.26	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	Sandy	1.14	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0

Malletts Bay Structural Data

Final ID	Substrate	15mX50m Score	Development Class	Bulrush	Ceratophyllum	Carex	Chara	Elatine	E. canadensis	E. nuttalli	Green Algae #1	Green Lichen	Isoetes	M. Alterniflorum	M.sibericum	M. spicatum	M. tenellum	Megolodonta	N. flexilis	N. guad	Nitella	Nuphar	Nymphaea	Periphyton	P. amplifolius	P. bicuspulatus	P. crispus	P. epihydrus	P. gramineus	P. Narrow Leaf	P. Narrow Leaf #2	P. Narrow Leaf #3	P. perfoliatus	P. richardsonii	P. robbinsii	P. spirillus	P. zosteriformis	Pontederia	Sagittaria	Sedge	Vallisneria	Zosterella
53	Rocky	0.68	L	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	2.6	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0	0	0	0	0	8.5	0
54	Rocky	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0
55	Rocky	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0.1	0
56	Rocky	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
57	Rocky	5.86	H	0	0.1	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.1	0	0	0	0	0	0	0	0	0	0	3	0
58	Rocky	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	2.5	0
59	Rocky	1.44	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.1	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0.2	0
60	Rocky	1.88	L	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0.1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	5.1	5
61	Rocky	4.47	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	3
62	Rocky	2.54	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2.5	0.1
63	Rocky	6.09	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	Rocky	6.05	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
65	Rocky	0.00	L	0	0	0	0	0	0.1	0	0	5.1	0	0	0	0	0	0	4	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	3
66	Rocky	0.57	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	3.1	0	0	0	0	0	0	0	0	0	0	15	0.1
67	Sandy	2.02	H	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3	25	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	10	2.1
68	Rocky	3.80	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	20	0	0	0	0	0	0	0	0	0.1	7	0	0	0	0	0	0	0	0	0	0	32	3.1
69	Rocky	4.86	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
70	Rocky	4.55	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
71	Rocky	1.10	L	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	3	0
72	Rocky	0.78	L	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0.1	0	0	0	0	0	0.1	0	0	0	0	0	0	0.1	0	0	0	4	0
73	Rocky	1.37	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	20	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	2.6	2.5	0	0	0	33	0
74	Rocky	2.79	L	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	3.5	7.5	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	4	0	0	0	11	0
75	Sandy	0.44	L	0	0	0	25	0	6	0	0	0	0	0	0	0	0	0	0	85	0	0	0	0	0	0	0	0	0	0	0	0	5.5	0	0	0	0.1	0	0	0	80	0
76	Rocky	0.73	L	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	1	0
77	Rocky	1.35	L	0	0	0	4	0	2	3	0	0	0	0	0	0	0	0	10	14	2	0	0	2.5	0	5	0	0	0	4	1	0	0	0	0	0	1	0	0	0	20	0
78	Sandy	1.23	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.6	0
79	Sandy	0.76	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	1	0	0	0	0	0	0	0	70	0
80	Sandy	0.56	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0
81	Rocky	1.17	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2.6	2.5	0	0	0	0	0.1	0	0	0	0	1	0
82	Sandy	3.45	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	Sandy	0.00	L	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	Rocky	0.32	L	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0.1	0	0	0	0	0.1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
85	Rocky	2.58	L	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	3	0	0	0.1	1	0	0	0	0	0	0	0	0	0	0	0	0
86	Rocky	0.00	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	30	0
87	Rocky	1.76	L	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	2	0	0	0	25	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	15	0.1
88	Macro	4.08	H	0	1	0	0	0	5	0	0	0	0	0	0	0	0	0	24	6	8	0	0.1	0	0	0	0	0	3	1.1	0.1	0	2	0	0.1	0	1	0	5	0	27	20
89	Rocky	9.70	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	Rocky	6.63	H	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0	0	0	0	0	2	0
91	Sandy	4.60	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5	0	0	0	0	0	0	60	0
92	Sandy	6.13	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
93	Sandy	0.17	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0.1
94	Macro	4.40	H	0	0	0	0	0	3	1	0	0	0	0	0	0	0	1	0	50	0	0	0	0	0	0	0	0	1	0	0	0	0.1	1	10	0	0	0	1	0	10	55
95	Macro	1.74	L	0	0	0	0	0	3	3	0	0	0	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	1	0.1	0	0	2	7	0	0	0	0	1	0	10	5
96	Sandy	4.86	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	90	0
97	Rocky	0.00	L	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	20	0
98	Macro	7.37	H	0	5	0	2	0	6	0	0	0	0	0	0.1	1.1	0	0	0	6	0	0	0	0	0	0	0	0	2	0.1	0	0	0	3	22	0	0	0	0	0.1	40	70

Validation Study Structural Data

				Bank/Shoreline				Bank Substrate					Bank Vegetation												
Final ID	Substrate	15mX50m Score	Development Class	Bank slope (deg)	Exposed slope %	Beach Width (m)	Bank Armor %	Bedrock	Boulder/ Cobble	Gravel	Sand	Silt/Clay	tree cover	invasive tree	conifer tree	deciduous tree	shrub cover	invasive s/s	WAD s/s	evergreen s/s	deciduous s/s	herb cover	invasive herb	grasses	forbs
101	Macro	0	L	30	30	6	0	0	80	20	0	0	40	0	50	50	60	5	40	0	100	50	2	10	90
102	Macro	4	H	5	0	10	100	0	72	28	0	0	5	0	0	100	0	0	0	0	0	80	5	70	30
103	Rocky	8.25	H	45	20	5	100	0	90	5	5	0	0	0	0	0	20	0	50	0	100	70	0	70	30
104	Sandy	0.21	L	10	0	5	0	0	80	0	20	0	90	0	0	100	80	0	10	0	100	60	0	30	70
105	Sandy	7.37	H	15	5	2	100	0	40	0	60	0	0	0	0	0	0	0	0	0	0	70	0	80	20
106	Rocky	0	L	80	5	3	0	80	0	10	10	0	100	0	20	80	60	20	0	50	50	10	0	0	100
107	Sandy	5.94	H	10	0	10	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108	Macro	0	L	15	0	15	0	0	50	50	0	0	100	0	0	100	60	10	0	0	100	40	0	30	70
109	Macro	7.91	H	30	0	10	100	0	0	0	100	0	0	0	0	0	0	0	0	0	0	100	2	90	10
110	Sandy	0	L	5	0	10	0	0	0	100	0	0	90	0	0	100	70	0	20	0	100	100	0	20	80
111	Rocky	0	L	25	15	15	0	40	40	0	20	0	100	0	70	30	20	0	10	0	100	30	0	0	100
112	Rocky	6	H	45	0	10	100	0	50	0	50	0	0	0	0	0	10	0	0	0	100	100	10	90	10
113	Rocky	0.19	L	42	0	5	0	0	90	0	10	0	100	0	90	10	10	0	0	0	100	40	0	0	100
114	Rocky	4.34	H	77	0	3	100	0	100	0	0	0	50	0	100	0	30	0	0	0	100	20	0	0	100
115	Sandy	1.92	H	14	60	25	40		70	0	30	0	5	0	100	0	15	0	0	0	100	90	0	50	50
116	Macro	6.33	H	18	0	3	100		70	20	10	0	5	0	0	100	0	0	0	0	0	60	0	80	20
117	Sandy	0.11	L	5	0	15	0	0	0	0	30	70	100	0	0	100	80	2	30	0	68	60	0	50	50
118	Macro	1.36	L	7	0	3	0	0	60	40	0	0	100	0	10	90	100	2	10	0	88	20	0	50	50

Validation Study Structural Data

				Littoral Substrate							Littoral Habitat							Macrophyte Metrics			
Final ID	Substrate	15mX50m Score	Development Class	Bedrock %	Cobble %	Boulder %	Sediment Organic Detritus %	Sand %	Gravel %	Silt %	Embeddedness	LWD/100m2	MCWD %	FCWD %	Leaf Litter %	Aufwuchs %	Habitat Organic Detritus %	Macrophyte abundance	Macrophyte Richness	Macrophyte % Dominance	Invasive Macrophyte %
101	Macro	0	L	0	0	0	0	87.5	0	12.5	0	2	1.5	5	0	0	1.5	101	12	39.5	0.01
102	Macro	4	H	0	0	0	0	77.5	0	22.5	0	0	15.5	3	0	0	3.5	75.3	12	66.4	4.98
103	Rocky	8.25	H	0	65	0	0	15	10	10	50	0	0	1	0	100	10	30.5	6	65.5	0.02
104	Sandy	0.21	L	0	5	0	0	92.5	2.5	0	20	0	1	1	0	50	2	30.3	9	33	0.05
105	Sandy	7.37	H	0	0	0	0	99	0	1	0	2	2.5	1	0	0	2.5	27.5	7	68.2	4.55
106	Rocky	0	L	0	90	0	0	5	5	0	35	0	1	0	0.5	100	10	25	5	70	20
107	Sandy	5.94	H	0	0	30	0	60	5	5	20	3	32.5	5	2.5	100	17.5	45.5	6	71.4	0.01
108	Macro	0	L	0	0	0	0	0	0	100	20	7	3	1	0	0	5	130	9	38.4	4.22
109	Macro	7.91	H	0	0.5	0	0	0	15	84.5	0	1	12.5	4	0	0	1.5	84	9	44.6	1.19
110	Sandy	0	L	0	0	1	0	85	0	14	0	17	35	10	0	0	7.5	59	8	50.8	4.66
111	Rocky	0	L	0	90	0	0	2.5	7.5	0	25	10	2	0.5	0	100	3.5	38.3	8	39.2	2.61
112	Rocky	6	H	0	95	0	0	5	0	0	65	0	5	1	0	100	1	33	6	60.6	0.02
113	Rocky	0.19	L	0	25	75	0	0	0	0	0	0	0	0	0	100	1	0.52	3	97.1	0
114	Rocky	4.34	H	0	55	40	0	2.5	2.5	0	12.5	10	0.5	0.5	0	100	1	6.02	5	83.1	0
115	Sandy	1.92	H	0	15	15	0	45	5	20	70	0	0.5	0	0	0	5	117	7	38.5	0.85
116	Macro	6.33	H	0	0	0	0	50	0	50	0	0	0	0	0	0	5	124	7	34.4	0
117	Sandy	0.11	L	0	0	0	0	30	0	70	0	1	0.5	0	0	0	1.5	31.3	4	56	0
118	Macro	1.36	L	0	0	0	0	0	0	100	0	5	0	0	0	0	1.5	117	6	77.2	0

Validation Study Structural Data

				Macrophyte Species from Combined Transects																				
Final ID	Substrate	15mX50m Score	Development Class	*Ceratophyllum*	*Chara*	*E. canadensis*	*E. nuttalli*	*M. Alterniflorum*	*M.sibericum*	*M. spicatum*	*Megolodonta*	*N. flexilis*	*Nitella*	*P. crispus*	*P. gramineus*	*P. Narrow Leaf*	*P. perfoliatus*	*P. richardsonii*	*P. robbinsii*	*P. zosteriformis*	*Ranunculus*	*Sparganium*	*Vallisneria*	*Zosterella*
101	Macro	0	L	0	0	12.5	0	0	0.01	0.005	6.25	1.25	0	0.005	0	0	1.25	5	3.75	1.25	0	0	30	40
102	Macro	4	H	0.005	0	3	0	0	0	3.75	0.5	3	0.005	0	0	0.005	1.25	0	2.5	3.75	0	0	7.5	50
103	Rocky	8.25	H	0	0	0	0	0	0	0.005	0	0.5	0	0	0.005	0	0	0	0	0	0.005	0	10	20
104	Sandy	0.21	L	0	0	1.25	0	0	0	0.01	0	0	10	0.005	0	0.005	6	0	0	0	0	0.5	5	7.5
105	Sandy	7.37	H	0	0	0.5	0	0	0	1.25	0	0.5	18.75	0	0	0	2.5	0	0	0	0	0	3	1
106	Rocky	0	L	0	0	1.5	0	0	0	5.005	0	1	0	0	0	0	0	0	0	0	0	0	0.005	17.5
107	Sandy	5.94	H	0	0	0	0.5	0	0.005	0.005	0	0	0	0	0	0	0	0	0	0.005	0	0	12.5	32.5
108	Macro	0	L	0	0	50	0	0	0.5	0.5	0	0	0	5	0	1.25	5	0	0	0.5	0	0	17.5	50
109	Macro	7.91	H	0	0	30	5	0	0.01	1	0	0.5	0	0	0	0	4	0	0	1	0	0	5	37.5
110	Sandy	0	L	0	0	3.75	1.25	1	0	1.75	0	0	0	0	0	2.5	12.5	0	0	0	0	0	6.25	30
111	Rocky	0	L	0	0	4.25	3.75	0.5	0	0.5	0	0.5	0	0	0	1.25	0	0	0	0	0	0	15	12.5
112	Rocky	6	H	0	0	5	0	0	0	0.005	0	0	0	0	0	0	0.5	0	0	0.005	0	0	20	7.5
113	Rocky	0.19	L	0	0	0.505	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0	0.01
114	Rocky	4.34	H	0	0.005	0.505	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	5	0.01
115	Sandy	1.92	H	1	0	15	15	0	0.005	1	0	0	0	0	0	0	0	0	0	0	0	0	40	45
116	Macro	6.33	H	0	0	0.505	0	0	0.5	0	0	27.5	0	0	0	0	42.5	0	0	0	0	5	40	7.5
117	Sandy	0.11	L	0	0	0	0	0	0	0	0	3.75	0	0	0	0	5	0	0	0	0	0	17.5	5
118	Macro	1.36	L	0.005	0	17.5	0	0	1.5	0	0.005	0	0	0	0	0	0	0	0	0	0	0	7.5	90

Malletts Bay Macroinvertebrate Taxa Summary

Macroinvertebrate Taxa					Totals by Substrate		
Phylum	Class	Order	Family	Genus	Macrophyte (n=10)	Rocky (n=11)	Sandy (n=12)
Annelida	Hirudinea				21	3	105
Annelida	Oligochaeta				1695	36	1005
Annelida					0	13	0
Arthropoda	Arachnida	Hydracarina	Acari		118	2	0
Arthropoda	Branchiopoda	Dadocera			127	26	0
Arthropoda	Entognatha	Collembola	Entomobryidae		0	1	0
Arthropoda	Entognatha	Collembola			0	2	0
Arthropoda	Insecta	Coleoptera	Dytricidae	Gyrinus	0	0	1
Arthropoda	Insecta	Coleoptera	Elmidae	Dubiraphia	7	27	65
Arthropoda	Insecta	Coleoptera	Elmidae	Macronychus	0	1	0
Arthropoda	Insecta	Coleoptera	Elmidae	Microcylloepus	0	4	0
Arthropoda	Insecta	Coleoptera	Elmidae	Optioservus	1	1	1
Arthropoda	Insecta	Coleoptera	Elmidae	Oulimnius	0	0	4
Arthropoda	Insecta	Coleoptera	Elmidae	Stenelmis	0	224	8
Arthropoda	Insecta	Coleoptera	Elmidae		0	4	0
Arthropoda	Insecta	Coleoptera	Psephenidae	Ectopria	0	32	0
Arthropoda	Insecta	Coleoptera	Psephenidae	Psephenus	0	321	0
Arthropoda	Insecta	Diptera	Athericidae	Atherix	1	0	0
Arthropoda	Insecta	Diptera	Ceratopogonidae		1	15	103
Arthropoda	Insecta	Diptera	Chironomidae		2966	990	2687
Arthropoda	Insecta	Diptera	Dixidae	Dixia	0	14	0
Arthropoda	Insecta	Diptera	Empididae		0	1	0
Arthropoda	Insecta	Diptera	Psychodidae		0	0	20
Arthropoda	Insecta	Diptera	PUPAE		83	23	62
Arthropoda	Insecta	Diptera	Sciomyzidae		0	1	0
Arthropoda	Insecta	Diptera	Simuliidae		0	1	0
Arthropoda	Insecta	Diptera	Tipulidae	Dicranota	0	1	0
Arthropoda	Insecta	Diptera			1	0	0
Arthropoda	Insecta	Ephemeroptera			0	2	0
Arthropoda	Insecta	Ephemeroptera	Baetidae	baetis	172	0	0
Arthropoda	Insecta	Ephemeroptera	Baetidae	callibaetis	31	0	0
Arthropoda	Insecta	Ephemeroptera	Baetidae	procloeon	163	0	0
Arthropoda	Insecta	Ephemeroptera	Baetidae	pseudocloeon	4	0	0
Arthropoda	Insecta	Ephemeroptera	Baetidae		301	2	6
Arthropoda	Insecta	Ephemeroptera	Caenidae	Caenis	1	43	24
Arthropoda	Insecta	Ephemeroptera	Caenidae		0	1	0
Arthropoda	Insecta	Ephemeroptera	Ephemeridae	Eurylophella	100	0	0
Arthropoda	Insecta	Ephemeroptera	Ephemeridae	Hexagenia	0	8	0
Arthropoda	Insecta	Ephemeroptera	Ephemeridae		12	0	0
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	Stenacron	0	265	0
Arthropoda	Insecta	Ephemeroptera	Heptageniidae		0	56	0
Arthropoda	Insecta	Hemiptera	Belosomatidae	Belostoma	3	0	0
Arthropoda	Insecta	Hemiptera	Corixidae		0	0	3
Arthropoda	Insecta	Hemiptera	Pleidae		0	0	1
Arthropoda	Insecta	Hemiptera			4	0	0
Arthropoda	Insecta	Lepidoptera			24	0	1
Arthropoda	Insecta	Lepidoptera	Crambidae		51	0	0
Arthropoda	Insecta	Lepidoptera	Pyralidae		0	1	2
Arthropoda	Insecta	Megaloptera	Corydalidae		1	0	0
Arthropoda	Insecta	Megaloptera	Corydalidae	Nigronia	0	8	0
Arthropoda	Insecta	Megaloptera	Sialidae	Sialis	0	62	14
Arthropoda	Insecta	Neuroptera	Sisyridae	Climacia	4	1	0
Arthropoda	Insecta	Neuroptera	Sisyridae	Sisyra	0	1	0
Arthropoda	Insecta	Neuroptera			0	0	1
Arthropoda	Insecta	Odonata	Aeshnidae	Anax	1	0	0
Arthropoda	Insecta	Odonata	Coenagrionidae	Amphiagrion	6	0	0
Arthropoda	Insecta	Odonata	Coenagrionidae	Argia	1	15	0
Arthropoda	Insecta	Odonata	Coenagrionidae	Enallagma	15	2	3
Arthropoda	Insecta	Odonata	Coenagrionidae	Nehalennia	1	0	0
Arthropoda	Insecta	Odonata	Coenagrionidae		53	2	17
Arthropoda	Insecta	Odonata	Libellulidae	Leucorrninia	0	2	1
Arthropoda	Insecta	Odonata	Libellulidae		5	9	2

Malletts Bay Macroinvertebrate Taxa Summary

Phylum	Class	Order	Family	Genus	Macrophyte (n=10)	Rocky (n=11)	Sandy (n=12)
Arthropoda	Insecta	Plecoptera	Perlidae	Acroneuria	0	7	0
Arthropoda	Insecta	Trichoptera			1	1	2
Arthropoda	Insecta	Trichoptera (PUPAE)			4	6	19
Arthropoda	Insecta	Trichoptera	Apataniidae	Apatania	8	0	0
Arthropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche	0	2	9
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	0	7	2
Arthropoda	Insecta	Trichoptera	Hydropsychidae		0	1	0
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Agraylea	0	1	0
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ithytrichia	0	1	0
Anthropoda	Insecta	Trichoptera	Hydroptilidae	Oxyethira	22	0	0
Arthropoda	Insecta	Trichoptera	Hydroptilidae		13	0	0
Arthropoda	Insecta	Trichoptera	Leptoceridae	Ceraclea	0	14	6
Arthropoda	Insecta	Trichoptera	Leptoceridae	Leptocerus	1	0	0
Arthropoda	Insecta	Trichoptera	Leptoceridae	Nectopsyche	1757	0	1
Arthropoda	Insecta	Trichoptera	Leptoceridae	Oecetis	26	0	8
Arthropoda	Insecta	Trichoptera	Leptoceridae		4	1	1
Arthropoda	Insecta	Trichoptera	Limnephilidae	Pycnopsyche	0	1	0
Arthropoda	Insecta	Trichoptera	Limnephilidae	Philocasca	0	1	0
Arthropoda	Insecta	Trichoptera	Limnephilidae		0	0	1
Arthropoda	Insecta	Trichoptera	Philopotamidae	Wormaldia	19	0	0
Arthropoda	Insecta	Trichoptera	Polycentropodidae	Cernotina	0	5	1
Arthropoda	Insecta	Trichoptera	Polycentropodidae	Polycentropus	0	183	33
Arthropoda	Insecta	Trichoptera	Polycentropodidae		0	25	4
Arthropoda	Insecta	Trichoptera	Uenoidae	Neophylax	0	43	0
Arthropoda	Malacostraca	Amphipoda	Crangonyctidae	Crangonyx	0	1	0
Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammarus	193	201	766
Arthropoda	Malacostraca	Amphipoda	Hyalellidae	Hyallela	3515	154	98
Arthropoda	Malacostraca	Amphipoda	Pontoporeiidae	Pontoporaeia	0	1	2
Arthropoda	Malacostraca	Amphipoda			26	22	38
Arthropoda	Malacostraca	Decapoda	Astacidae		0	6	3
Arthropoda	Malacostraca	Decapoda	Palaemonidae	Palaemonetes	0	2	0
Arthropoda	Malacostraca	Isopoda	Asellidae		0	0	17
Arthropoda	Malacostraca	Isopoda	Asellidae	Caecidotea	0	3	223
Arthropoda	Malacostraca	Isopoda			0	16	0
Arthropoda	Maxillopoda	Copepoda			0	1	1
Mollusca	Bivalvia	Unionoida	Unionidae	Elliptio lampsilis	0	1	2
Mollusca	Bivalvia	Unionoida	Unionidae	Elliptio complanata	0	25	79
Mollusca	Bivalvia	Veneroida	Dreissenidae	Dreissena polymorpha	0	46	7
Mollusca	Bivalvia	Veneroida	Sphaeriidae		0	82	2195
Mollusca	Bivalvia				55	1	17
Mollusca	Gastropoda				7	5	17
Mollusca	Gastropoda	Pulmonata	Physidae		416	120	34
Mollusca	Gastropoda	Pulmonata	Lymnaidae		15	47	118
Mollusca	Gastropoda	Pulmonata	Planorbidae		1792	8	41
Mollusca	Gastropoda	Pulmonata			0	2	0
Mollusca	Gastropoda	Prosobranchia	Bithyniidae		1	7	30
Mollusca	Gastropoda	Prosobranchia	Hydrobiidae		12322	286	850
Mollusca	Gastropoda	Prosobranchia	Pleuroceridae		0	36	0
Mollusca	Gastropoda	Prosobranchia	Pomatiopsidae		0	18	31
Mollusca	Gastropoda	Prosobranchia	Valvatidae		742	9	18
Mollusca	Gastropoda	Prosobranchia	Viviparidae		1	58	52
Mollusca	Gastropoda				0	18	3
Nematoda					0	0	25
Nematomorpha					0	2	1

			Macroinvertebrate Metrics													
Final ID	Substrate	50'x50m score	Invert Abundance	Invert richness	EPT Richness	ETO Richness	COTE Richness	Family Richness	Invert %Dominance	%COTE	%COTE/COTE+ Chrio+Oligo	EPT/EPT+Chiro	%Oligo	%Trichop	Invert Shannon Index
2	Macro	4.48	1404	14	3	4	4	14	25.07	24.79	0.44	0.49	7.12	21.94	2.04
3	Macro	6.54	398	19	5	9	9	18	27.39	5.78	0.39	0.27	0	1.51	2.03
4	Macro	0.00	818	22	7	10	10	17	37.04	11.98	0.36	0.32	3.55	2.93	2.02
5	Macro	8.11	438	20	4	4	4	20	52.05	1.37	0.55	0.07	0.91	0.68	1.71
7	Sandy	1.89	1055	18	1	2	4	16	30.62	3.13	0.09	0.19	30.62	0	1.91
8	Rocky	6.19	477	26	6	10	14	20	55.14	20.55	0.87	0.14	1.26	2.1	1.95
9	Rocky	7.01	222	27	7	8	13	25	34.23	64.41	1	0.74	0	7.66	2.42
10	Rocky	0.50	210	27	5	6	8	24	20	31.9	1	0.53	0	13.81	2.8
11	Rocky	1.48	357	28	4	7	10	26	17.65	39.78	0.9	0.62	3.92	21.01	2.74
12	Sandy	3.16	311	17	1	1	1	16	28.62	1.61	0.22	0.5	5.79	1.61	2.13
13	Macro	0.00	1928	17	5	7	7	13	42.53	59.13	0.71	0.93	19.71	42.95	1.91
15	Rocky	5.02	564	25	5	7	12	22	27.66	49.47	1	0.47	0	7.09	2.45
16	Rocky	1.70	302	31	6	8	12	28	13.25	43.71	0.99	0.67	0.66	7.95	2.95
17	Rocky	0.15	223	22	4	4	5	21	35.43	7.17	0.89	0.34	0.9	2.24	2.43
18	Sandy	2.29	467	13	2	2	3	14	29.12	3	0.09	0.06	23.77	1.93	1.84
20	Rocky	0.00	273	17	5	5	8	15	57.51	69.23	1	0.37	0	2.56	1.63
21	Rocky	2.17	228	18	5	5	7	18	37.72	25.88	1	0.28	0	7.02	1.98
23	Sandy	3.91	771	18	3	4	5	17	38.52	2.2	0.74	0.03	0.78	0.65	1.63
24	Sandy	0.00	1668	16	4	4	5	15	59.23	2.4	0.63	0.03	1.44	1.68	1.42
25	Rocky	0.00	318	30	6	6	10	26	16.98	32.7	0.95	0.79	1.89	14.15	2.77
26	Sandy	2.14	339	15	1	1	3	13	44.54	0.88	0.43	0.14	1.18	0	1.23
27	Sandy	2.40	1336	11	1	1	2	11	59.28	1.5	0.22	0.01	3.29	0	1.31
29	Sandy	1.06	225	22	7	6	9	20	41.78	15.56	0.95	0.1	0.89	1.33	1.96
30	Sandy	0.19	604	13	2	2	4	12	32.78	2.15	0.09	0.13	19.21	0.17	1.78
31	Sandy	2.44	295	14	2	3	4	13	30.85	2.71	0.14	0.03	14.58	1.02	1.85
32	Sandy	3.21	431	22	4	4	6	19	36.66	4.18	0.38	0.09	6.03	3.25	1.73
33	Macro	1.43	1122	18	6	6	7	15	50.81	6.76	0.34	0.46	5.13	2.77	1.54
34	Macro	1.88	5846	18	5	6	7	16	61.34	1.77	0.16	0.22	4.11	0.74	1.43
35	Macro	2.44	7141	18	5	5	6	16	42.34	1.93	0.07	0.09	6.75	0.5	1.55
41	Macro	0.97	1352	17	4	5	5	16	23.3	23.3	0.43	0.5	7.25	14.64	2.16
73	Rocky	1.37	301	25	4	5	9	24	58.8	16.28	0.84	0.2	1.33	6.98	1.83
75	Sandy	0.44	1948	16	6	6	6	13	65.5	6.98	0.41	0.49	2.67	3.9	1.3
98	Macro	7.37	2204	11	2	2	2	11	45.55	6.35	0.39	0.76	7.8	6.17	1.47

Validation Study Macroinvertebrate Data

					Sandy		Macrophyte		Rocky	
				Site	**104**	**105**	**108**	**109**	**113**	**114**
Class	Order	Family	Genus	**Development**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Arachnida	Hydracarina	Acari			6	75	32	170	40	36
Bivalvia	Veneroida	Dreissenidae	Dreissenna		46	137	72	141	1040	712
Bivalvia	Veneroida	Sphaeriidae			290	480	0	0	0	0
Gastropoda	Prosobranchia	Bythinidae			2	7	4	13	100	244
Gastropoda	Prosobranchia	Hydrobidae			31	34	88	185	320	404
Gastropoda	Pulmonata	Physidae			6	4	588	329	88	68
Gastropoda	Pulmonata	Planorbidae			88	44	148	51	72	184
Gastropoda	Pulmonata	Viviparidae			4	0	0	0	0	0
Hirudinea					0	2	4	5	0	4
Insecta	Coleoptera	Elmidae	unid		2	0	0	0	0	0
Insecta	Coleoptera	Elmidae	Dubiraphia		27	22	20	16	0	0
Insecta	Coleoptera	Elmidae	Stenelmis		0	0	0	0	0	28
Insecta	Coleoptera	Hydrophilidae	Berosus		2	0	0	0	0	0
Insecta	Coleoptera	Psephenidae	Ectopria		0	0	0	0	4	4
Insecta	Coleoptera	Psephenidae	Psephenus		0	0	0	0	8	16
Insecta	Diptera	Chironomidae	unid		81	200	36	190	344	68
Insecta	Diptera	Pupae	unid		0	0	0	76	4	4
Insecta	Diptera	Tipulidae	Tipula		0	0	0	0	4	0
Insecta	Ephemeroptera	Baetidae	unid		0	6	0	2	0	8
Insecta	Ephemeroptera	Baetidae	Baetis		5	0	0	0	48	0
Insecta	Ephemeroptera	Baetidae	Procleon		2	0	0	0	0	0
Insecta	Ephemeroptera	Heptagenidae	unid		0	0	0	0	0	24
Insecta	Ephemeroptera	Heptagenidae	Epeorus		0	0	0	0	0	4
Insecta	Ephemeroptera	Heptagenidae	Heptagenia		2	0	0	0	16	28
Insecta	Ephemeroptera	Heptagenidae	Stenacron		0	0	0	0	16	16
Insecta	Ephemeroptera	Calopterygidae	unid		0	0	4	4	0	0
Insecta	Ephemeroptera	Coenagrionidae	unid		2	0	0	0	0	0
Insecta	Lepidoptera	Crambidae	unid		0	2	0	0	8	4
Insecta	Lepidoptera	Crambidae	Petrophila		0	0	4	12	4	8
Insecta	Lepidoptera	Crambidae	Synclita		3	0	48	48	0	0
Insecta	Lepidoptera	Crambidae	Paraponyx		0	0	8	2	0	0
Insecta	Decapoda				2	0	0	0	0	0
Insecta	Megaloptera	Corydalidae	Nigrona		0	0	0	0	12	16
Insecta	Trichoptera	Brachycentridae	Microsema		0	0	0	0	0	144
Insecta	Trichoptera	Lepidostomatidae	Lepidostoma		0	0	0	0	0	4
Insecta	Trichoptera	Leptoceridae	unid		2	0	0	0	0	0
Insecta	Trichoptera	Leptoceridae	Ceraclea		0	0	0	0	4	0
Insecta	Trichoptera	Leptoceridae	Leptocerus		0	0	24	38	0	0
Insecta	Trichoptera	Leptoceridae	Nectopsyche		74	99	0	5	0	0
Insecta	Trichoptera	Leptoceridae	Oecetis		7	15	0	0	0	36
Insecta	Trichoptera	Limnephilidae	Pycnopsyche		0	2	0	0	0	0
Insecta	Trichoptera	Hydroptilidae	unid		11	6	8	65	0	0
Insecta	Trichoptera	Hydroptilidae	Agraylea		15	4	16	28	52	0
Insecta	Trichoptera	Hydroptilidae	Hydroptila		10	0	0	32	0	4
Insecta	Trichoptera	Hydroptilidae	Oxyethira		0	2	16	5	0	0
Insecta	Trichoptera	Hydroptilidae	Stactiobella		14	0	28	27	0	0
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche		0	0	0	0	0	8
Insecta	Trichoptera	Helicopsychidae	Helicopsyche		0	0	0	0	0	180
Insecta	Trichoptera	Polycentropidae	unid		0	0	0	0	0	4
Malacostraca	Amphipoda	Gammaridae	Gammarus		89	38	32	106	60	144
Malacostraca	Amphipoda	Hyalellidae	Hyalella		0	0	0	5	356	24
Oligochaeta					217	50	24	83	0	4

2011 Malletts Bay Study - Fish Data

Adult Fish				Species Count																												
Site	Substrate	15mX50m Score	replicate	Alewife	Bluegill	Bluntnose Minnow	Brassy Minnow	Bridle Shiner	Brook Silverside	Brown Bullhead	Chain Pickerel	Crappie	E. Silvery Minnow	Emerald Shiner	Fallfish	Golden Shiner	Banded Killifish	Lake Chub	Largemouth Bass	Logperch	Mimic Shiner	Northern Pike	Pumpkinseed Sunfish	Rock Bass	Smallmouth Bass	Spotfin Shiner	Spottail Shiner	Tench	Tessellated Darter	White Perch	White Sucker	Yellow Perch
3	macrophyte	6.54	1	0	1	0	0	3	0	0	0	0	0	0	0	2	0	0	2	0	0	5	5	1	0	0	0	0	0	0	0	3
3	macrophyte	6.54	2	0	1	0	0	3	9	0	0	0	0	0	0	0	0	0	0	0	0	1	7	0	0	0	2	0	2	0	0	2
4	macrophyte	0.00	1	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	1
4	macrophyte	0.00	2	0	13	0	0	2	2	0	0	0	0	0	0	2	1	0	5	0	0	1	19	0	0	0	0	0	0	0	0	3
4	macrophyte	0.00	3	0	11	0	0	0	10	0	0	0	0	0	0	6	0	0	1	0	0	0	26	0	0	0	0	0	0	0	0	23
5	sandy	8.11	1	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	5	1	0	0	0	1	0	0	0	5
5	sandy	8.11	2	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	12	0	0	0	0	0	0	0	0	10
6	sandy	4.60	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	11
6	sandy	4.60	2	0	5	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	12	0	0	0	5	0	0	0	0	7
7	sandy	1.89	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
7	sandy	1.89	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
8	rocky	6.19	1	0	0	0	0	0	4	0	0	1	0	9	0	2	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	2
8	rocky	6.19	2	1	5	0	0	0	15	0	0	1	4	19	0	6	0	0	4	0	0	0	8	2	0	0	3	0	0	0	0	13
9	rocky	7.01	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0
9	rocky	7.01	2	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	7	0	0	0	0	5
10	rocky	0.50	1	0	8	0	0	0	0	0	0	6	0	0	0	0	0	0	1	0	0	0	3	0	1	0	0	0	0	0	0	12
10	rocky	0.50	2	0	5	0	0	0	0	0	2	3	0	0	0	1	0	0	4	0	0	0	2	1	2	0	2	0	0	0	0	12
11	rocky	1.48	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	0	6	0	0	0	0	0	0	0
11	rocky	1.48	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	6	0	1	0	0	0	0	0
12	sandy	3.16	1	0	0	0	0	0	0	0	0	0	0	6	0	0	1	0	1	0	0	0	0	0	0	0	9	0	0	0	1	16
12	sandy	3.16	2	0	0	0	0	0	0	0	0	0	0	37	0	0	6	0	6	0	12	1	0	0	3	0	25	0	0	0	4	16
13	sandy	0.00	1	0	0	0	0	0	0	0	0	0	0	12	0	0	13	0	3	0	0	0	0	0	0	2	82	0	0	1	0	31
13	sandy	0.00	2	0	0	0	0	0	0	0	0	0	0	14	0	0	8	6	3	0	0	0	1	0	0	0	1	0	3	0	0	3
15	rocky	5.02	1	0	3	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	3	0	4	0	0	11
15	rocky	5.02	2	0	4	0	0	0	0	0	5	1	0	0	0	0	0	0	1	0	0	0	14	1	1	0	0	0	0	0	0	13
16	rocky	1.70	1	0	11	0	0	4	62	0	0	0	0	0	0	0	0	0	4	0	0	0	2	3	5	0	0	0	0	0	0	6
16	rocky	1.70	2	0	1	0	0	0	3	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
17	rocky	0.15	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	3	1	0	0	0	0	2	0	0	13
17	rocky	0.15	2	0	3	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0	0	0	4	1	0	0	0	0	0	0	0	6
18	sandy	2.29	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0
18	sandy	2.29	2	0	0	0	0	0	0	0	0	0	68	16	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	1	0	0
19	macrophyte	3.13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	macrophyte	3.13	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
20	rocky	0.00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
20	rocky	0.00	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
21	rocky	2.17	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	11
21	rocky	2.17	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3
22	macrophyte	2.91	1	0	1	0	0	5	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	macrophyte	2.91	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	sandy	3.91	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
23	sandy	3.91	2	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
24	sandy	0.00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
24	sandy	0.00	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
25	rocky	0.00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	4	1	0	0	0	0	0	0	0	30
25	rocky	0.00	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	7
26	sandy	2.14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
26	sandy	2.14	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	sandy	2.40	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	sandy	2.40	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	rocky	1.06	1	0	0	0	0	0	0	0	0	0	0	0	0	0	75	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0

Malletts Bay Fish Data

Adult Fish Continued

Site	Substrate	15mX50m Score	replicate	Alewife	Bluegill	Bluntnose Minnow	Brassy Minnow	Bridle Shiner	Brook Silverside	Brown Bullhead	Chain Pickerel	Crappie	E. Silvery Minnow	Emerald Shiner	Fallfish	Golden Shiner	Banded Killifish	Lake Chub	Largemouth Bass	Logperch	Mimic Shiner	Northern Pike	Pumpkinseed Sunfish	Rock Bass	Smallmouth Bass	Spotfin Shiner	Spottail Shiner	Tench	Tessellated Darter	White Perch	White Sucker	Yellow Perch
29	rocky	1.06	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	0	0	0	0	0	1	1
30	sandy	0.19	1	0	0	0	0	0	1	0	0	0	0	0	0	0	18	0	2	0	0	0	0	0	0	0	14	0	0	0	1	1
30	sandy	0.19	2	0	0	0	0	0	1	0	0	0	0	0	1	0	10	0	4	0	0	0	0	0	0	0	33	0	0	0	0	0
31	sandy	2.44	1	0	1	7	0	0	3	0	0	0	0	2	0	0	33	0	0	0	0	0	8	0	0	12	178	0	0	0	0	0
31	sandy	2.44	2	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	5	0	0	5	8	0	0	0	0	1
32	sandy	3.21	1	0	1	0	2	0	0	0	0	0	0	0	0	0	34	0	0	0	0	0	9	0	0	0	1	0	0	1	0	1
32	sandy	3.21	2	0	0	1	0	0	0	0	0	0	0	0	0	0	10	0	1	0	0	0	0	0	0	8	4	0	0	0	0	0
33	macrophyte	1.43	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	macrophyte	1.43	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	macrophyte	1.88	1	0	8	0	0	0	9	0	1	0	0	5	0	0	1	0	5	0	0	0	5	0	1	0	0	0	0	0	0	22
34	macrophyte	1.88	2	0	3	0	0	1	17	0	0	0	0	4	0	0	10	0	0	0	0	0	2	1	0	0	1	0	0	0	0	29
35	macrophyte	2.44	1	0	18	0	0	0	18	0	1	0	0	1	0	3	1	0	7	0	0	0	5	3	0	0	1	0	0	4	0	7
35	macrophyte	2.44	2	0	6	0	0	1	6	0	3	0	0	2	0	0	2	0	8	0	0	0	3	3	0	0	1	0	2	1	0	9
41	macrophyte	0.97	1	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	macrophyte	0.97	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	rocky	1.37	1	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	rocky	1.37	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	sandy	0.44	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	sandy	0.44	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	macrophyte	4.08	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	macrophyte	4.08	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Malletts Bay Fish Data

YOY (Young of Year)

Site	Substrate	15mX50m Score	replicate	Alewife	Bluegill	Bluntnose Minnow	Brassy Minnow	Bridle Shiner	Brook Silverside	Brown Bullhead	Chain Pickerel	Crappie	E. Silvery Minnow	Emerald Shiner	Fallfish	Golden Shiner	Banded Killifish	Lake Chub	Largemouth Bass	Logperch	Mimic Shiner	Northern Pike	Pumpkinseed Sunfish	Rock Bass	Smallmouth Bass	Spotfin Shiner	Spottail Shiner	Tench	Tessellated Darter	White Perch	White Sucker	Yellow Perch
3	macrophyte	6.54	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	macrophyte	6.54	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	macrophyte	0.00	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	macrophyte	0.00	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	macrophyte	0.00	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	sandy	8.11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
5	sandy	8.11	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	sandy	4.60	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	sandy	4.60	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	sandy	1.89	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
7	sandy	1.89	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
8	rocky	6.19	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
8	rocky	6.19	2	1	1	0	0	0	1	0	0	1	1	1	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1
9	rocky	7.01	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
9	rocky	7.01	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
10	rocky	0.50	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
10	rocky	0.50	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
11	rocky	1.48	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
11	rocky	1.48	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
12	sandy	3.16	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
12	sandy	3.16	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
13	sandy	0.00	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
13	sandy	0.00	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
15	rocky	5.02	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0
15	rocky	5.02	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
16	rocky	1.70	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	rocky	1.70	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	rocky	0.15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
17	rocky	0.15	2	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1
18	sandy	2.29	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0
18	sandy	2.29	2	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
19	macrophyte	3.13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	macrophyte	3.13	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	rocky	0.00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
20	rocky	0.00	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
21	rocky	2.17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
21	rocky	2.17	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
22	macrophyte	2.91	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	macrophyte	2.91	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	sandy	3.91	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
23	sandy	3.91	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
24	sandy	0.00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
24	sandy	0.00	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
25	rocky	0.00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
25	rocky	0.00	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
26	sandy	2.14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	sandy	2.14	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	sandy	2.40	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	sandy	2.40	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	rocky	1.06	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
29	rocky	1.06	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1

Malletts Bay Fish Data

YOY Continued

Site	Substrate	15mX50m Score	replicate	Alewife	Bluegill	Bluntnose Minnow	Brassy Minnow	Bridle Shiner	Brook Silverside	Brown Bullhead	Chain Pickerel	Crappie	E. Silvery Minnow	Emerald Shiner	Fallfish	Golden Shiner	Banded Killifish	Lake Chub	Largemouth Bass	Logperch	Mimic Shiner	Northern Pike	Pumpkinseed Sunfish	Rock Bass	Smallmouth Bass	Spotfin Shiner	Spottail Shiner	Tench	Tessellated Darter	White Perch	White Sucker	Yellow Perch
30	sandy	0.19	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
30	sandy	0.19	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
31	sandy	2.44	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
31	sandy	2.44	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	sandy	3.21	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
32	sandy	3.21	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
33	macrophyte	1.43	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	macrophyte	1.43	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	macrophyte	1.43	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	macrophyte	1.88	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
34	macrophyte	1.88	2	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1
35	macrophyte	2.44	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1
35	macrophyte	2.44	2	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1
41	macrophyte	0.97	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	macro	0.97	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	rocky	1.37	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	rocky	1.37	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	sandy	0.44	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	sandy	0.44	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	macrophyte	4.08	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	macrophyte	4.08	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Malletts Bay Fish Data

Adult combined seines

Site	Substrate	15mX50m Score	replicate	Alewife	Bluegill	Bluntnose Minnow	Brassy Minnow	Bridle Shiner	Brook Silverside	Brown Bullhead	Chain Pickerel	Crappie	E. Silvery Minnow	Emerald Shiner	Fallfish	Golden Shiner	Banded Killifish	Lake Chub	Largemouth Bass	Logperch	Mimic Shiner	Northern Pike	Pumpkinseed Sunfish	Rock Bass	Smallmouth Bass	Spotfin Shiner	Spottail Shiner	Tench	Tessellated Darter	White Perch	White Sucker	Yellow Perch
3	macrophyte	6.54	both	0	2	0	0	6	9	0	0	0	0	0	0	2	0	0	2	0	0	6	12	1	0	0	2	0	2	0	0	5
4	macrophyte	0.00	both	0	25	0	0	3	12	0	1	0	0	0	0	8	1	0	7	0	0	1	49	0	0	0	0	0	0	0	0	27
5	sandy	8.11	both	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	17	1	0	0	0	1	0	0	0	15
6	sandy	4.60	both	0	8	0	0	0	0	0	1	0	0	0	0	0	1	0	3	0	0	1	15	0	0	0	5	0	0	0	0	18
7	sandy	1.89	both	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0
8	rocky	6.19	both	1	5	0	0	0	19	0	0	2	4	28	0	8	0	0	4	0	0	0	9	2	0	0	6	0	0	0	0	15
9	rocky	7.01	both	0	2	0	0	0	2	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	34	0	0	0	0	5
10	rocky	0.50	both	0	13	0	0	0	0	0	2	9	0	0	0	1	0	0	5	0	0	0	5	1	3	0	2	0	0	0	0	24
11	rocky	1.48	both	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	3	0	12	0	1	0	0	0	0	0
12	sandy	3.16	both	0	0	0	0	0	0	0	0	0	0	43	0	0	7	0	7	0	12	1	0	0	3	0	34	0	0	0	5	32
13	sandy	0.00	both	0	0	0	0	0	0	0	0	0	0	26	0	0	21	6	6	0	0	0	1	0	0	2	83	0	3	1	0	34
15	rocky	5.02	both	0	7	0	0	0	1	0	7	1	0	0	0	0	0	0	1	0	0	0	18	1	1	0	3	0	4	0	0	24
16	rocky	1.70	both	0	12	0	0	4	65	0	0	1	0	0	0	0	0	0	4	1	0	0	2	3	6	0	0	0	0	0	0	6
17	rocky	0.15	both	0	3	0	0	0	0	0	0	2	0	2	0	0	2	0	1	0	0	0	7	2	0	0	0	0	2	0	0	19
18	sandy	2.29	both	0	0	0	0	0	0	0	0	0	68	17	0	0	0	0	0	0	0	0	0	0	1	0	37	0	0	2	0	0
19	macrophyte	3.13	both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
20	rocky	0.00	both	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
21	rocky	2.17	both	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	14
22	macrophyte	2.91	both	0	1	0	0	6	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	sandy	3.91	both	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
24	sandy	0.00	both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	2
25	rocky	0.00	both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	4	1	3	0	0	0	0	0	0	37
26	sandy	2.14	both	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
27	sandy	2.40	both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	rocky	1.06	both	0	1	0	0	0	0	0	0	0	0	0	0	0	75	0	2	0	0	0	0	1	2	0	1	0	0	0	1	1
30	sandy	0.19	both	0	0	0	0	0	2	0	0	0	0	0	1	0	28	0	6	0	0	0	0	0	0	0	47	0	0	0	1	1
31	sandy	2.44	both	0	2	7	0	0	3	0	0	0	0	2	0	0	34	0	0	0	0	0	13	0	0	17	186	0	0	0	0	1
32	sandy	3.21	both	0	1	1	2	0	0	0	0	0	0	0	0	0	44	0	1	0	0	0	9	0	0	8	5	0	0	1	0	1
33	macrophyte	1.43	both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	macrophyte	1.88	both	0	11	0	0	1	26	0	1	0	0	9	0	0	11	0	5	0	0	0	7	1	1	0	1	0	0	0	0	51
35	macrophyte	2.44	both	0	24	0	0	1	24	0	4	0	0	3	0	3	3	0	15	0	0	0	8	6	0	0	2	0	2	5	0	16
41	macrophyte	0.97	both	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	rocky	1.37	both	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	sandy	0.44	both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	macrophyte	4.08	both	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

2012 Validation Study - Fish Data

Adult Fish

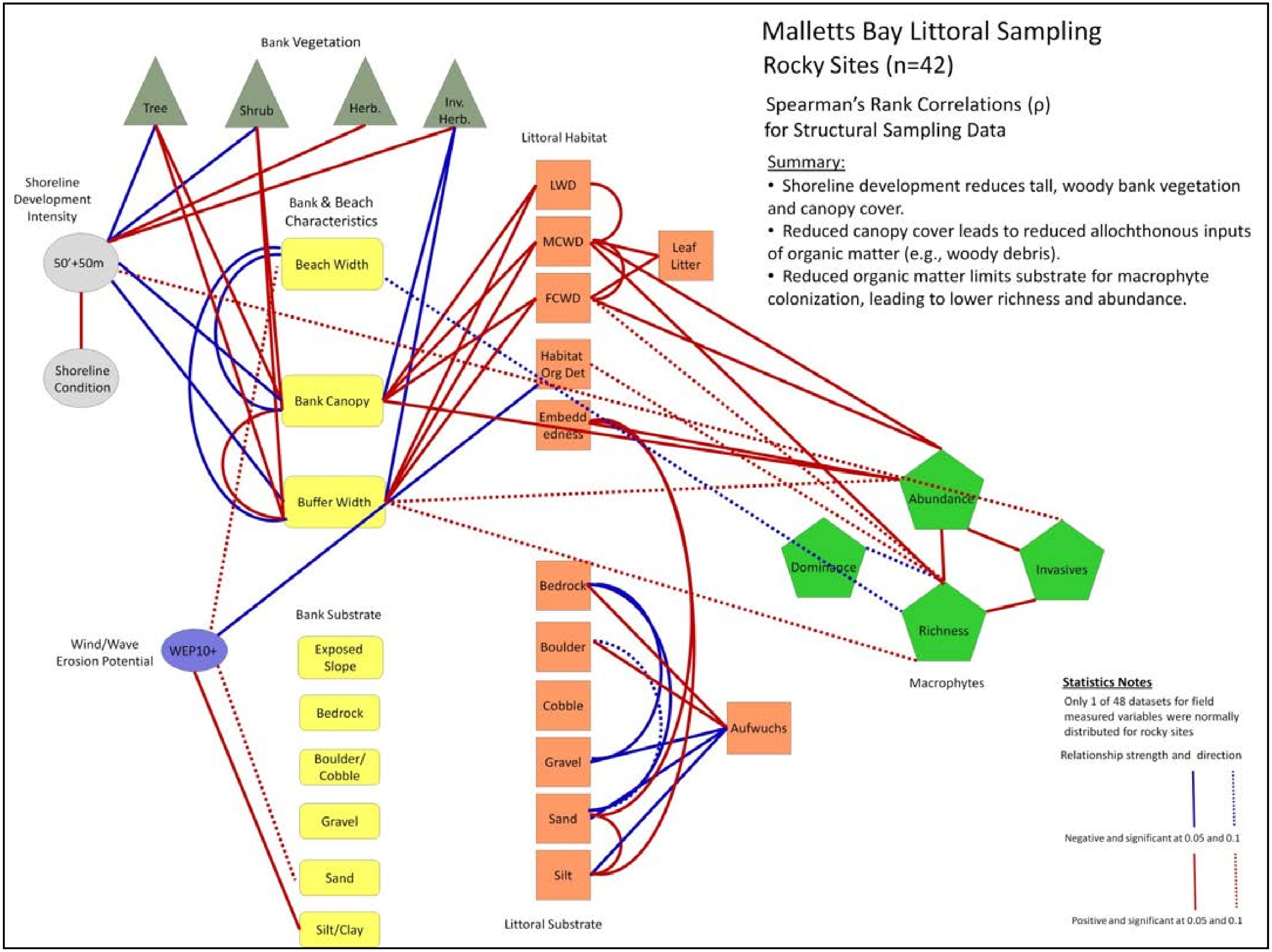
Site	Substrate	15mX50m Score	Replicate	Blacknose Dace	Bluegill	Brown Bullhead	Carp	Emerald Shiner	Banded Killifish	Largemouth Bass	Logperch	Longnose Dace	Northern Pike	Pumpkinseed Sunfish	Smallmouth Bass	Rock Bass	Spottail Shiner	Tesselated Darter	Tench	Yellow Perch
				Species Count																
4	Sandy	0.21	1	no catch																
4	Sandy	0.21	2	no catch																
5	Sandy	7.37	1																	
5	Sandy	7.37	2					394	31	1								2		
8	Macro	0	1			3							1						1	8
8	Macro	0	2		1	10	1		55					1			1	10		2
9	Macro	7.91	1	9													17			10
9	Macro	7.91	2				1		1			2					4			16
13	Rocky	0.19	1								2					1				61
13	Rocky	0.19	2	no catch																
13	Rocky	0.19	3	no catch - resampled due to zebra mussel difficulties																
14	Rocky	4.34	1												2					3
14	Rocky	4.34	2												1					
YOY (Young of Year)																				
4	Sandy	0.21	1						45									2		
4	Sandy	0.21	2						33									27		
5	Sandy	7.37	1						6											
5	Sandy	7.37	2																	
8	Macro	0	1		5					3						2			1	
8	Macro	0	2		16							1					2		1	
9	Macro	7.91	1		1					1						2			3	
9	Macro	7.91	2		25	1				1						4			6	
13	Rocky	0.19	1																	
13	Rocky	0.19	2	no catch																
13	Rocky	0.19	3	no catch - resampled due to zebra mussel difficulties																
14	Rocky	4.34	1																	
14	Rocky	4.34	2																	
Adult combined seines																				
4	Sandy	0.21	both	no catch																
5	Sandy	7.37	both	0	0	0	0	394	31	1	0	0	0	0	0	0	0	2	0	0
8	Macro	0	both	0	1	13	1	0	55	0	0	0	1	1	0	0	1	10	1	10
9	Macro	7.91	both	9	0	0	1	0	1	0	0	2	0	0	0	0	21	0	0	26
13	Rocky	0.19	both	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	61
14	Rocky	4.34	both	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	3
Adult/YOY combined seines																				
4	Sandy	0.21	both	0	0	0	0	0	78	0	0	0	0	0	0	0	0	29	0	0
5	Sandy	7.37	both	0	0	0	0	394	37	1	0	0	0	0	0	0	0	2	0	0
8	Macro	0	both	0	22	13	1	0	55	3	0	1	1	1	0	2	3	10	3	10
9	Macro	7.91	both	9	26	1	1	0	1	2	0	2	0	0	0	6	21	0	9	26
13	Rocky	0.19	both	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	61
14	Rocky	4.34	both	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	3

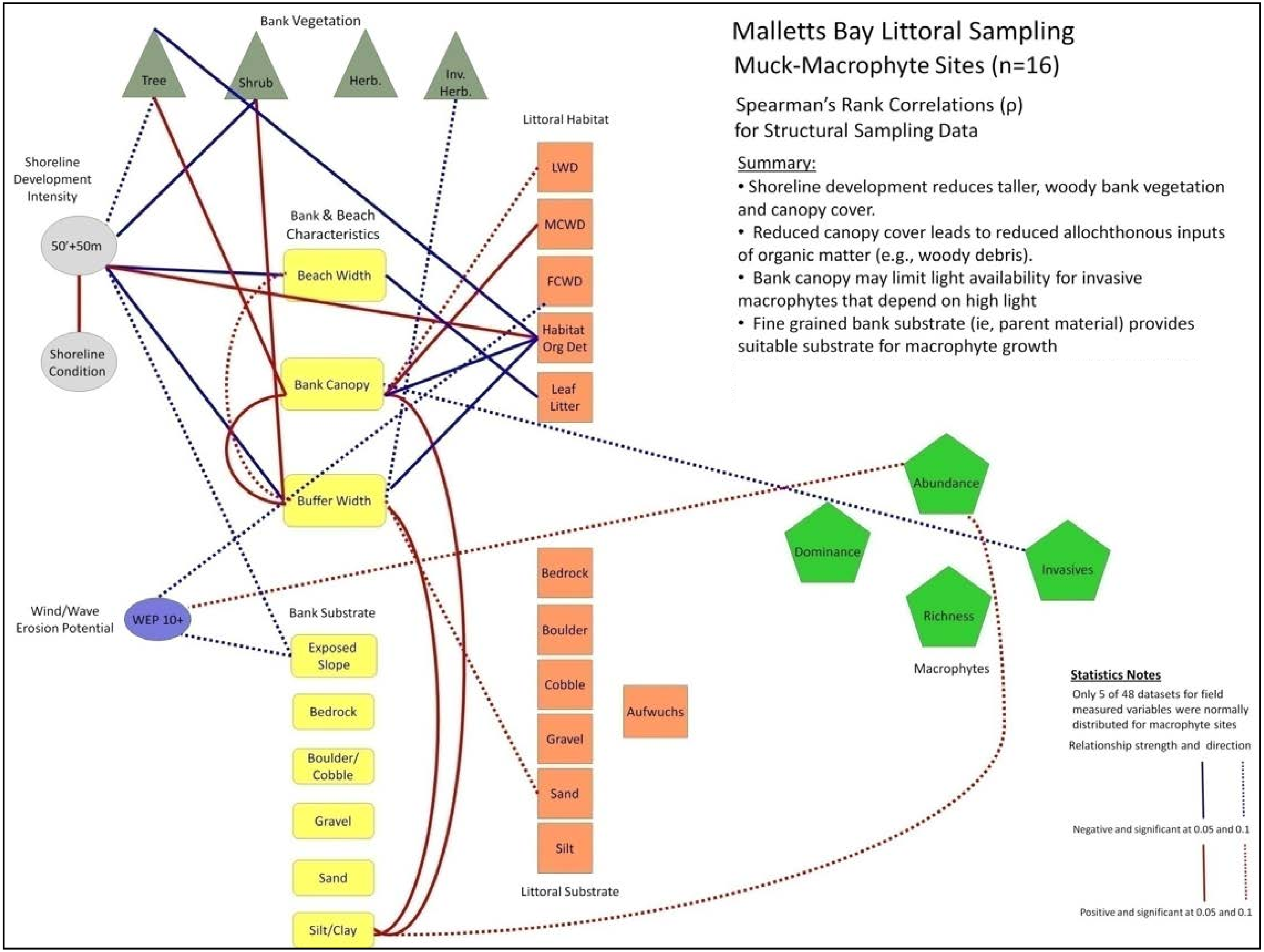
APPENDIX C

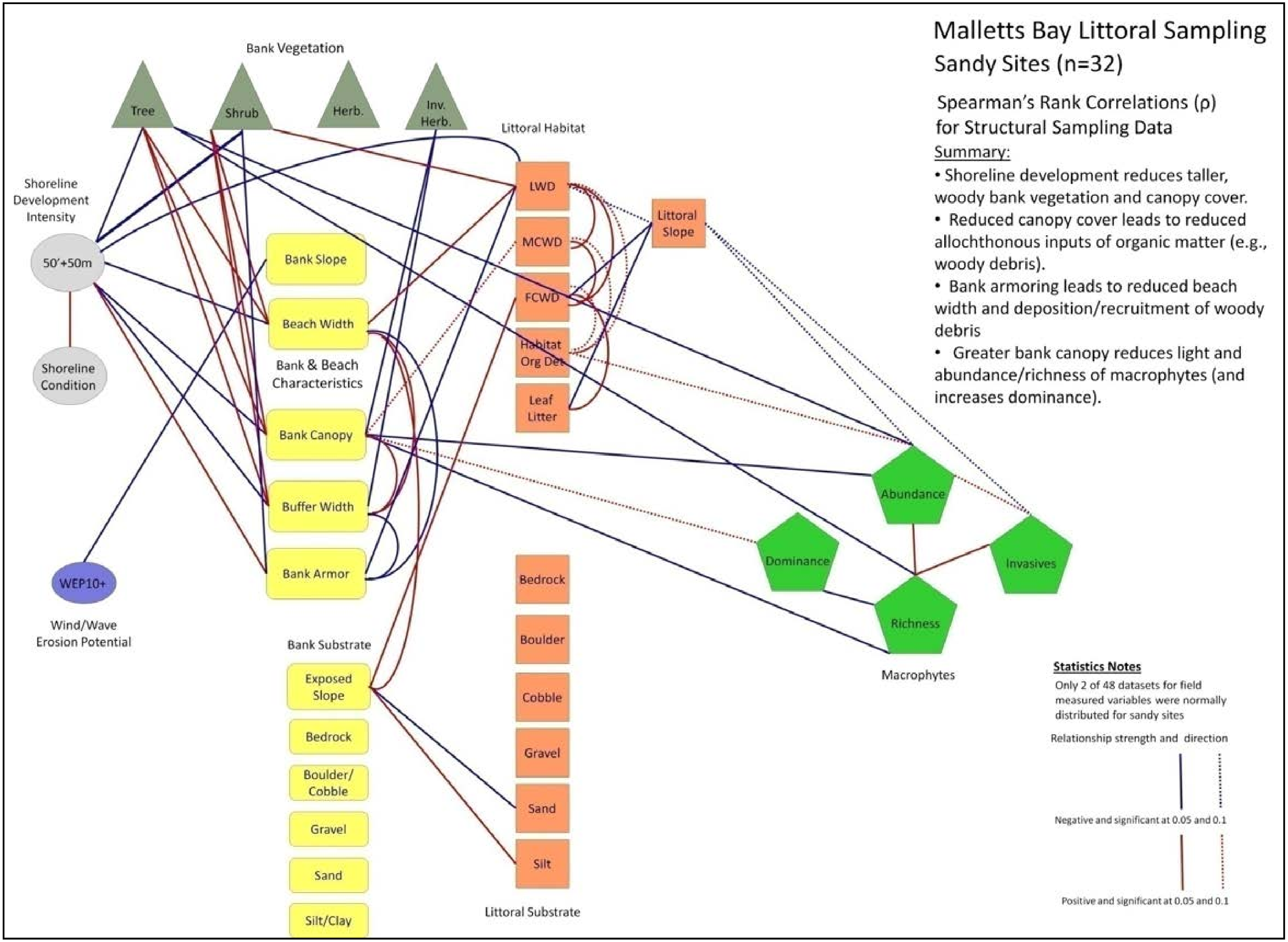
SUPPORTING STATISTICAL RESULTS

Correlation Visualization Diagrams (CVDs)

CVDs were developed to help visualize the complex relationships and non-parametric correlations between shoreline development, natural gradients, and littoral habitat. Diagrams for each substrate type are shown below.



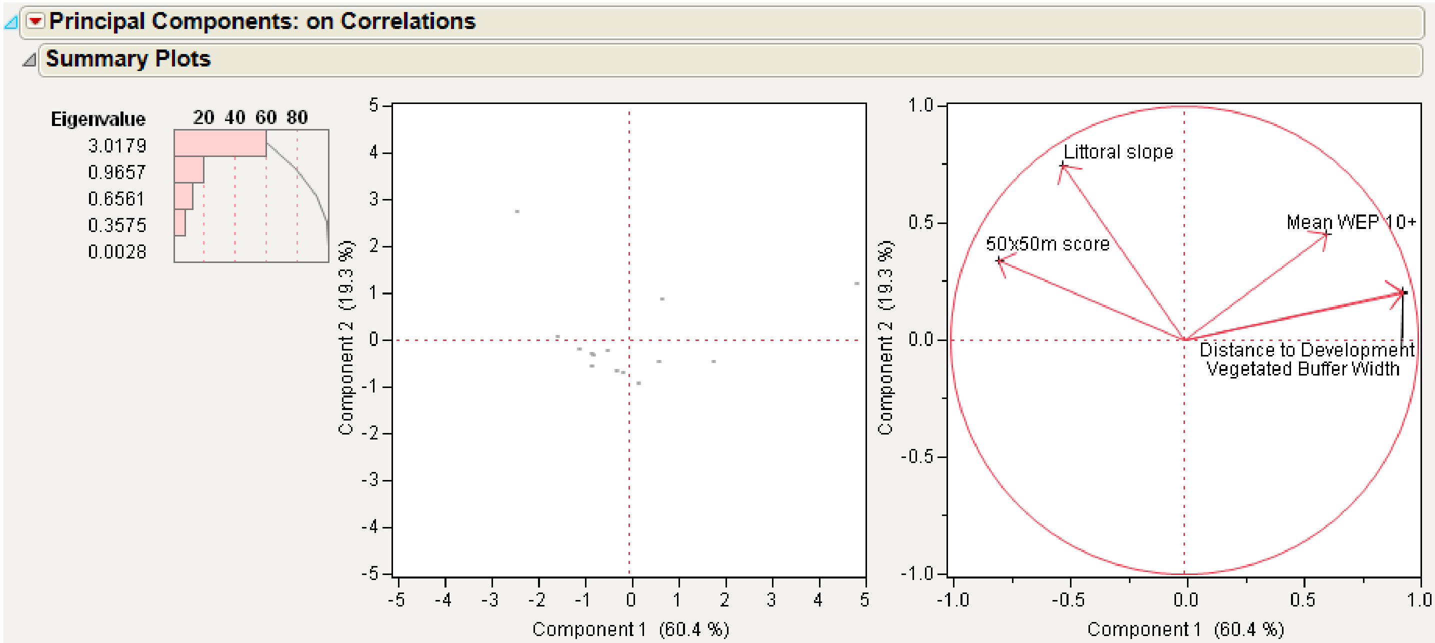

Malletts Bay Littoral Sampling
Muck-Macrophyte Sites (n=16)
Spearman's Rank Correlations (ρ)
for Structural Sampling Data
Summary:
• Shoreline development reduces taller, woody bank vegetation and canopy cover.
• Reduced canopy cover leads to reduced allochthonous inputs of organic matter (e.g., woody debris).
• Bank canopy may limit light availability for invasive macrophytes that depend on high light
• Fine grained bank substrate (ie, parent material) provides suitable substrate for macrophyte growth
Bank Vegetation
Tree
Shrub
Herb.
Inv. Herb.
Shoreline Development Intensity
50'+50m
Shoreline Condition
Bank & Beach Characteristics
Beach Width
Bank Canopy
Buffer Width
Littoral Habitat
LWD
MCWD
FCWD
Habitat Org Det
Leaf Litter
Wind/Wave Erosion Potential
WEP 10+
Bank Substrate
Exposed Slope
Bedrock
Boulder/ Cobble
Gravel
Sand
Silt/Clay
Bedrock
Boulder
Cobble
Gravel
Sand
Silt
Littoral Substrate
Aufwuchs
Abundance
Dominance
Invasives
Richness
Macrophytes
Statistics Notes
Only 5 of 48 datasets for field measured variables were normally distributed for macrophyte sites
Relationship strength and direction
Negative and significant at 0.05 and 0.1
Positive and significant at 0.05 and 0.1


Malletts Bay Littoral Sampling
Sandy Sites (n=32)
Spearman's Rank Correlations (ρ)
for Structural Sampling Data
Summary:
• Shoreline development reduces taller, woody bank vegetation and canopy cover.
• Reduced canopy cover leads to reduced allochthonous inputs of organic matter (e.g., woody debris).
• Bank armoring leads to reduced beach width and deposition/recruitment of woody debris
• Greater bank canopy reduces light and abundance/richness of macrophytes (and increases dominance).
Bank Vegetation
Tree
Shrub
Herb.
Inv. Herb.
Littoral Habitat
LWD
MCWD
FCWD
Habitat Org Det
Leaf Litter
Littoral Slope
Shoreline Development Intensity
50'+50m
Shoreline Condition
Bank Slope
Beach Width
Bank & Beach Characteristics
Bank Canopy
Buffer Width
Bank Armor
WEP10+
Wind/Wave Erosion Potential
Bank Substrate
Exposed Slope
Bedrock
Boulder/ Cobble
Gravel
Sand
Silt/Clay
Bedrock
Boulder
Cobble
Gravel
Sand
Silt
Littoral Substrate
Abundance
Dominance
Invasives
Richness
Macrophytes
Statistics Notes
Only 2 of 48 datasets for field measured variables were normally distributed for sandy sites
Relationship strength and direction
Negative and significant at 0.05 and 0.1
Positive and significant at 0.05 and 0.1

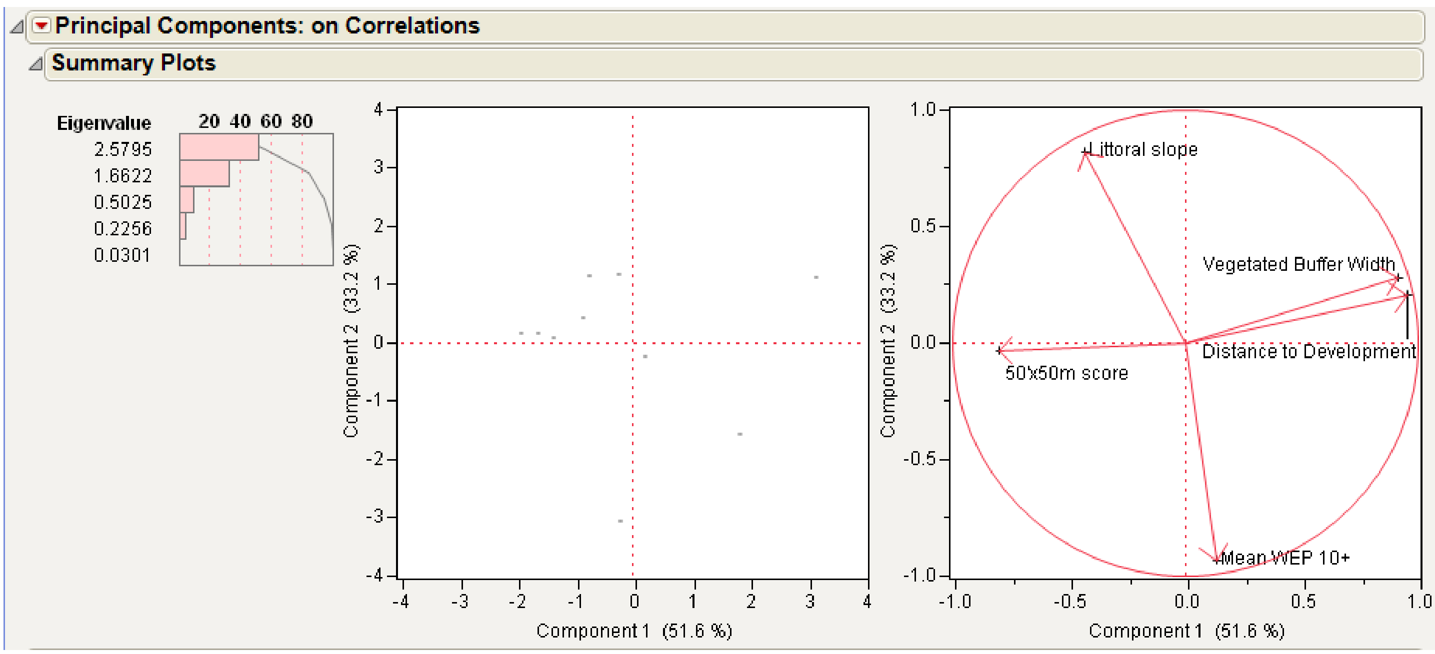
Principal Component (PCA) Outputs

Two sets of PCA axes were created to explain the variation in biotic data from Malletts Bay sites. These components reduced collinearity among development and natural gradient data we collected. The first PCA included: 15mX50m development score, distance to development, vegetated buffer width, littoral slope, and WEP. This model explained approximately 70% to 80% of the variability in the predictor variables within the first two axes for all substrates.

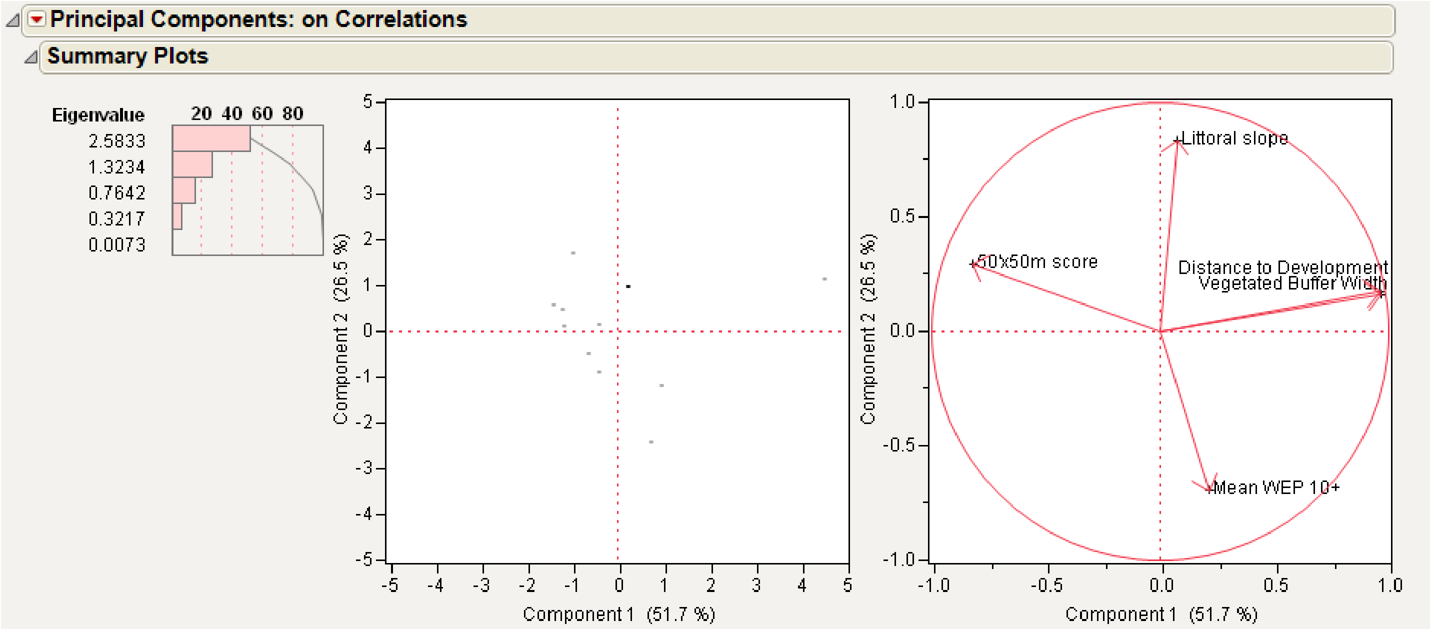
PCA1 – Macrophyte Sites



PCA1 – Rocky Sites

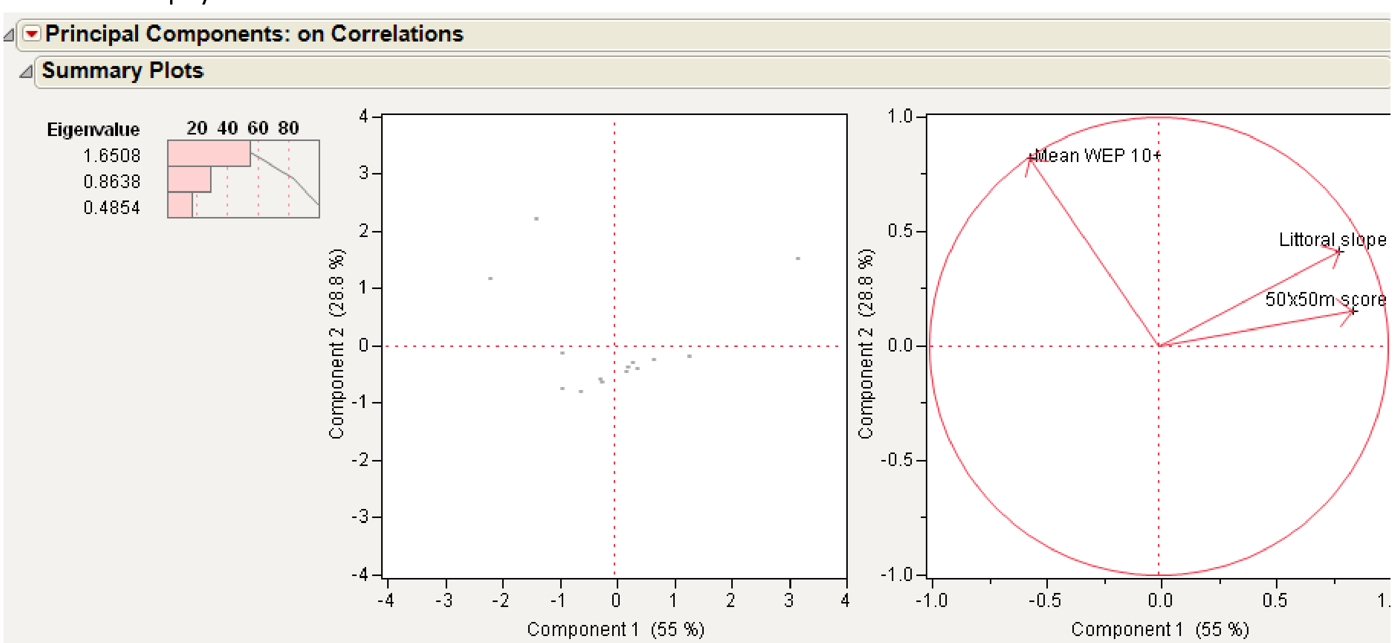


PCA1 – Sandy Sites

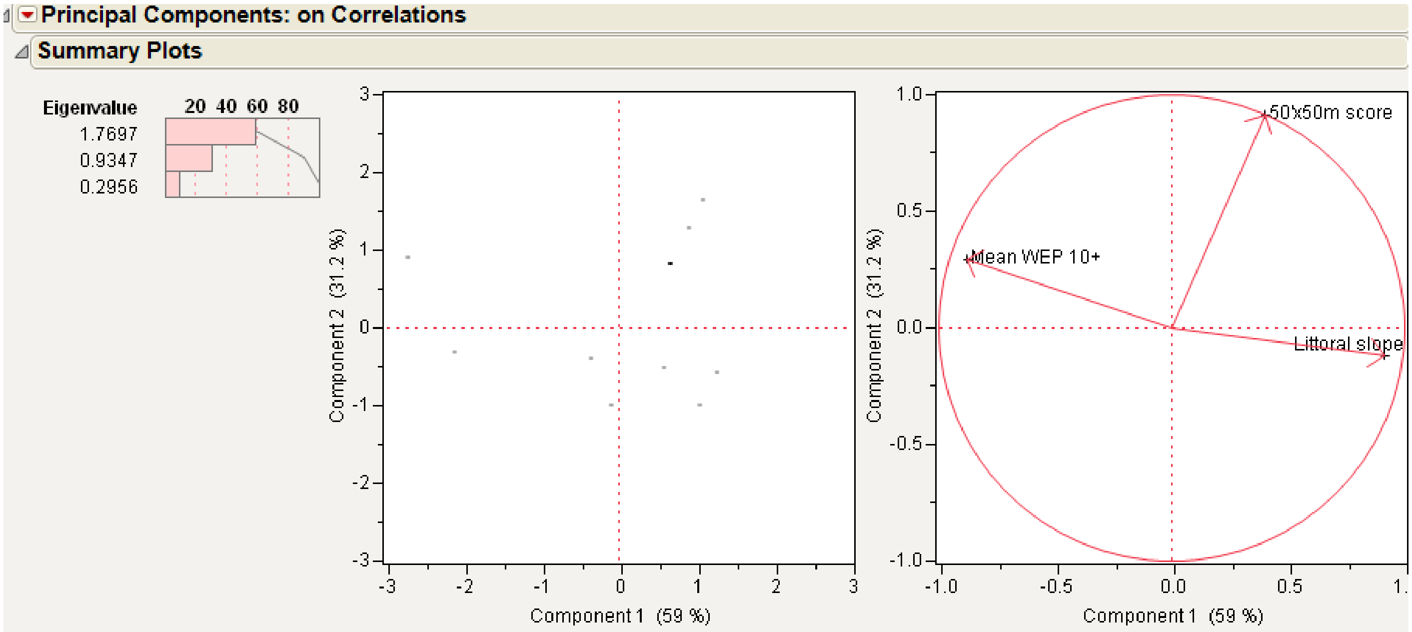


The second PCA included 15mX50m development score, littoral slope, and WEP. This model explained approximately 90% of the variability in the predictor variables within the first two axes for all substrates. This increase over PCA 1 is partly due to a reduced number of input parameters in the PCA.

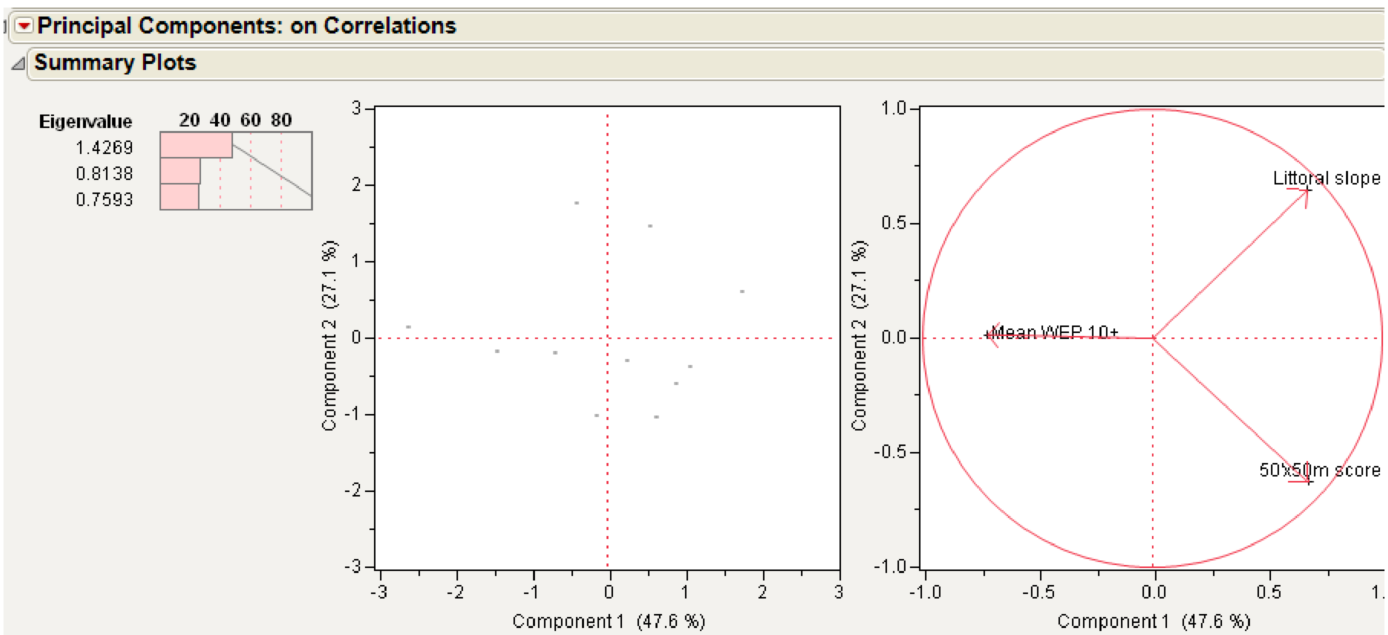
PCA2 – Macrophyte Sites



PCA2 – Rocky Sites



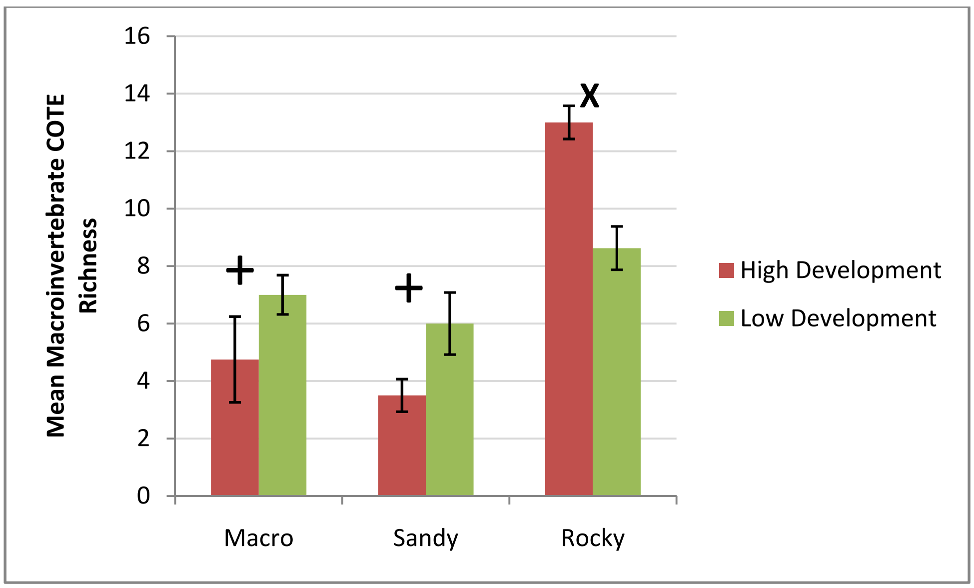
PCA2 – Sandy Sites

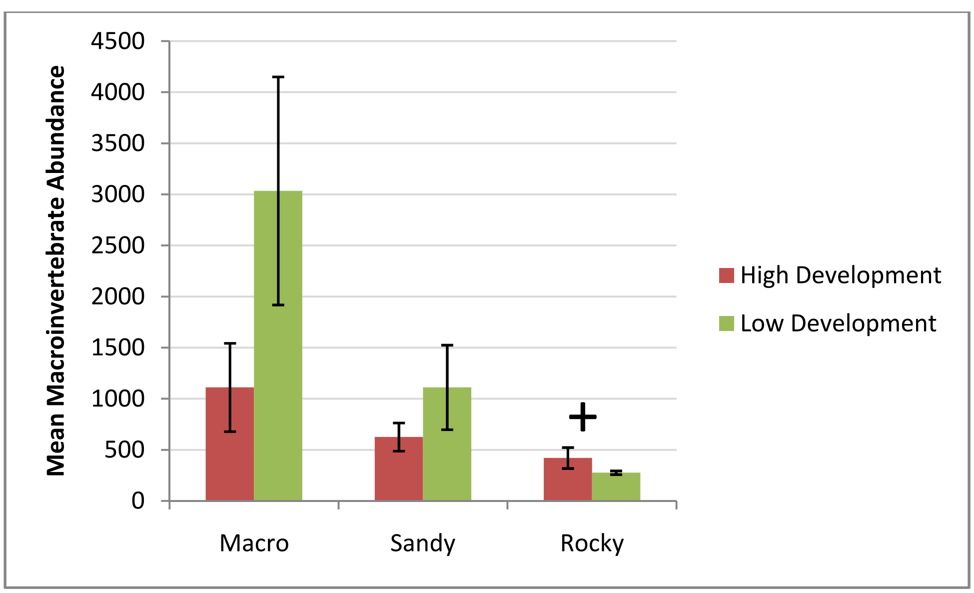


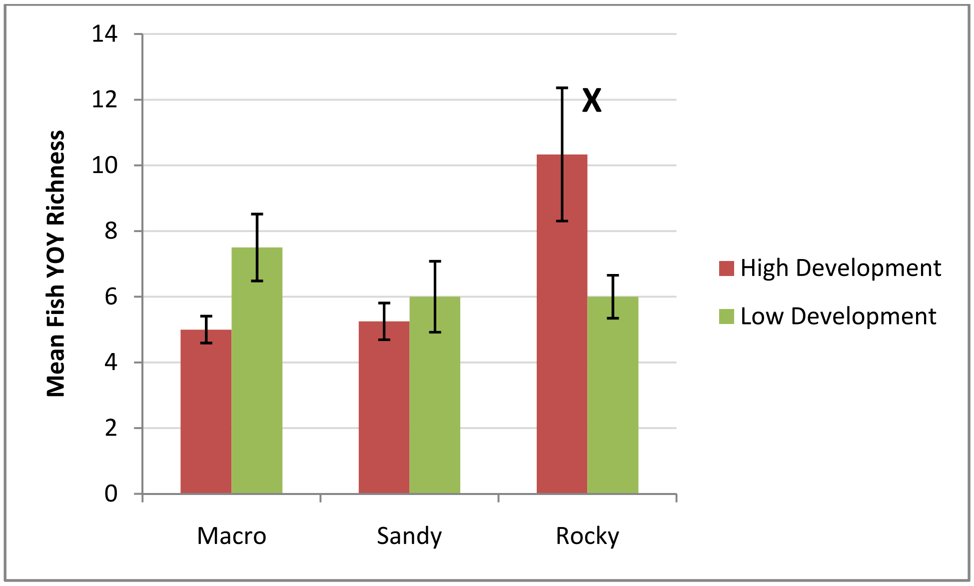
Shoreline development statistics for model matrix development

Multiple regressions, correlations, ANOVA, and Wilcoxon Rank Sum analyses were used to define the effects of development, littoral slope, and WEP on littoral habitat, macrophytes, and biotic communities as described in section 4. Additional figures and significant results for these analyses are presented below. "**X**" on figures represents non-parametric significant difference, "**+**" denotes ANOVA significance, however most populations are not normally distributed.

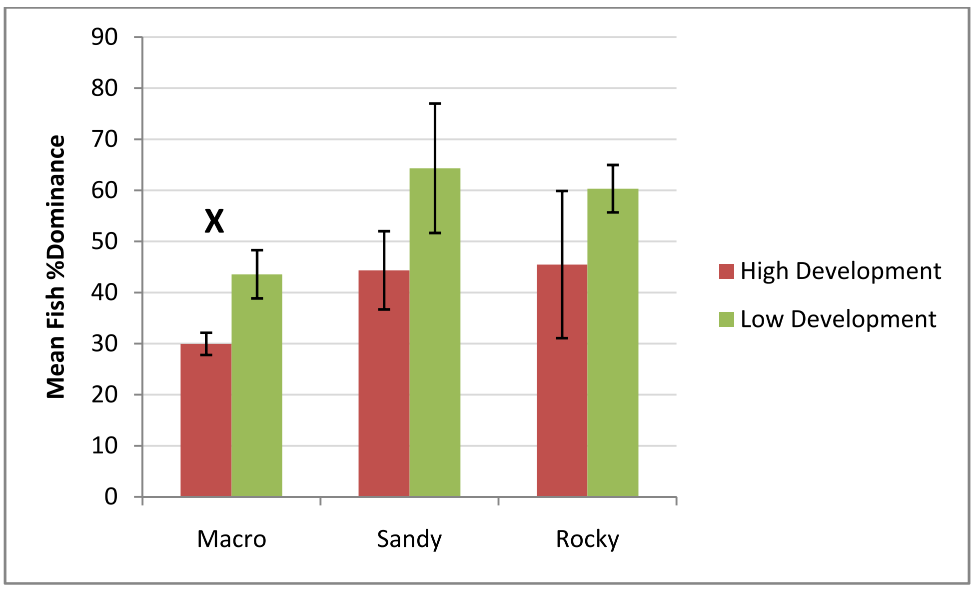
Substrate	Factor	F Ratio	p-value	M-W Z	M-W prob<Z
Macrophyte	COTE Richness	3.548	0.0964	-1.4	0.16
Rocky	COTE Richness	-7.354	0.0239	2.26	0.024
Sandy	COTE Richness	3.823	0.0791	1.81	0.071
Rocky	Invert Abundance	-3.428	0.0971	0.92	0.35
Rocky	Fish YOY Richness	-7.353	0.0239	1.97	0.049
Macrophyte	Fish %Dominance	3.383	0.0957	-1.95	0.051







Mean Fish YOY Richness
14
12
10
8
6
4
2
0
X
Macro
Sandy
Rocky
High Development
Low Development

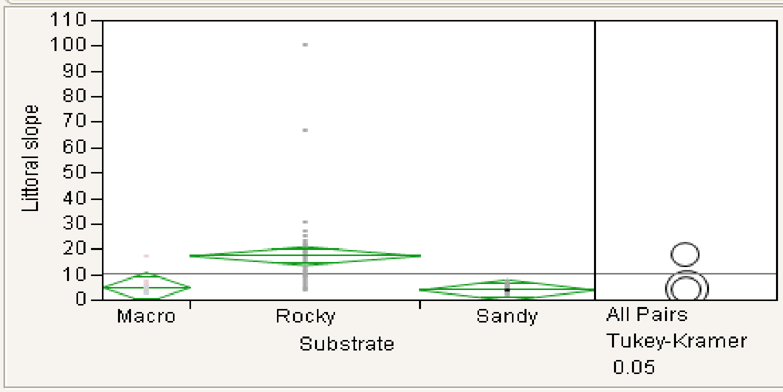


Mean Fish %Dominance
90
80
70
60
50
40
30
20
10
0
X
Macro
Sandy
Rocky
High Development
Low Development

Natural gradient statistics for model matrix development

Threshold values for WEP and littoral slope were developed to identify and classify sites for the model matrix. Littoral slope in Malletts Bay was significantly higher at the rocky sites compared to the soft bottom sites (sandy and macrophyte) as shown in the ANOVA with Tukey-Kramer HSD below.

Oneway Analysis of Littoral slope By Substrate



Oneway Anova

Summary of Fit

Rsquare	0.239372
Adj Rsquare	0.221886
Root Mean Square Error	11.85813
Mean of Response	10.45922
Observations (or Sum Wgts)	90

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Substrate	2	3849.930	1924.96	13.6896	<.0001*
Error	87	12233.533	140.62		
C. Total	89	16083.463			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Macro	16	5.0444	2.9645	-0.85	10.937
Rocky	42	17.4407	1.8297	13.80	21.078
Sandy	32	4.0034	2.0962	-0.16	8.170

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.38450	0.05

Abs(Dif)-HSD

	Rocky	Macro	Sandy
Rocky	-6.1703	4.0894	6.8025
Macro	4.0894	-9.9970	-7.6167
Sandy	6.8025	-7.6167	-7.0689

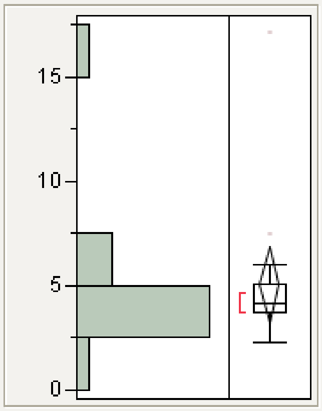
Positive values show pairs of means that are significantly different.

Level			Mean
Rocky	A		17.440714
Macro		B	5.044375
Sandy		B	4.003438

We identified a littoral slope of 6.5% as a cutoff for predicting substrate type (hard/soft) at a site. The distributions of littoral slope show that this threshold would correctly classify approximately 90% of our sites as soft or hard substrate.

Distributions Substrate=Macro

Littoral slope



Quantiles

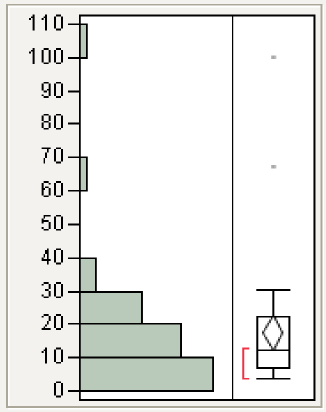
100.0%	maximum	17.1
99.5%		17.1
97.5%		17.1
90.0%		10.31
75.0%	quartile	5.0725
50.0%	median	4.125
25.0%	quartile	3.75
10.0%		2.431
2.5%		2.27
0.5%		2.27
0.0%	minimum	2.27

Moments

Mean	5.044375
Std Dev	3.4461572
Std Err Mean	0.8615393
Upper 95% Mean	6.8807026
Lower 95% Mean	3.2080474
N	16

Distributions Substrate=Rocky

Littoral slope



Quantiles

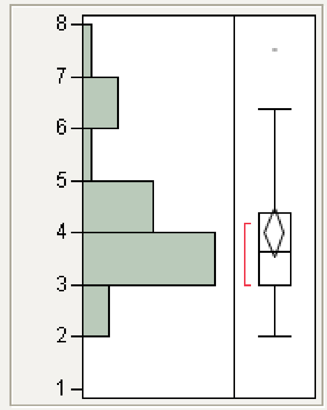
100.0%	maximum	100
99.5%		100
97.5%		97.5025
90.0%		29.1
75.0%	quartile	22.375
50.0%	median	12.185
25.0%	quartile	7.15
10.0%		5.83
2.5%		3.7135
0.5%		3.67
0.0%	minimum	3.67

Moments

Mean	17.440714
Std Dev	17.109667
Std Err Mean	2.6400789
Upper 95% Mean	22.772462
Lower 95% Mean	12.108967
N	42

Distributions Substrate=Sandy

Littoral slope



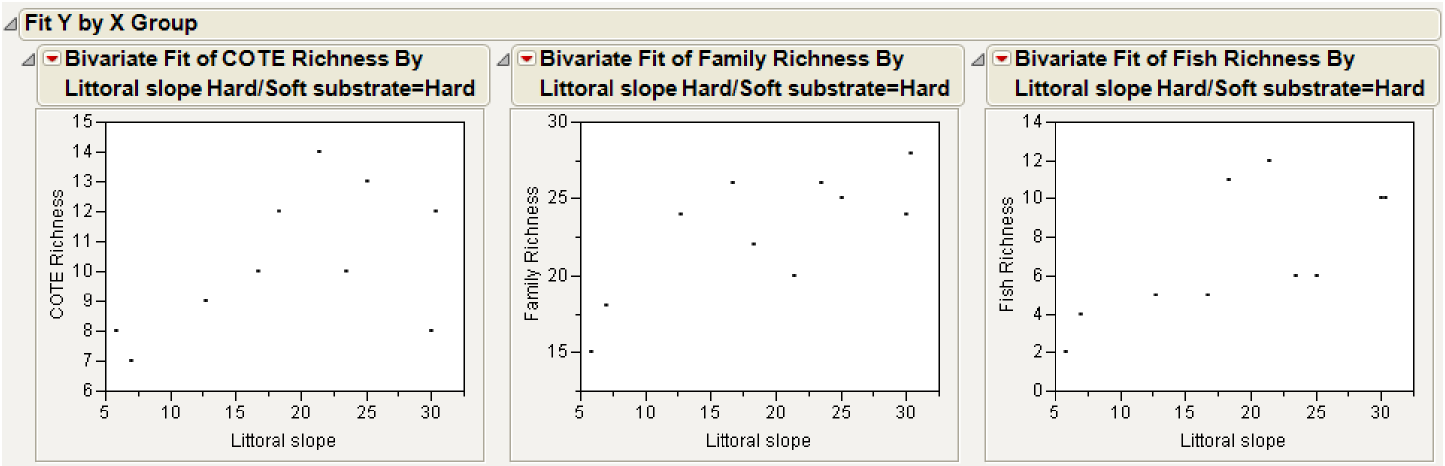
Quantiles

100.0%	maximum	7.5
99.5%		7.5
97.5%		7.5
90.0%		6.205
75.0%	quartile	4.375
50.0%	median	3.625
25.0%	quartile	3
10.0%		2.65
2.5%		2
0.5%		2
0.0%	minimum	2

Moments

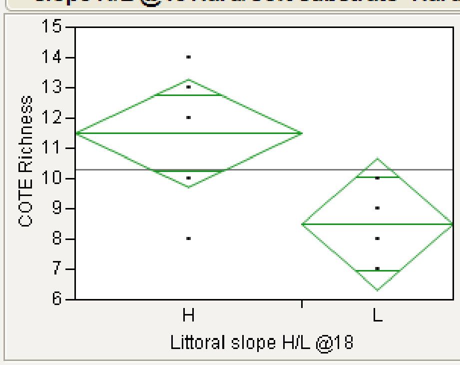
Mean	4.0034375
Std Dev	1.3078488
Std Err Mean	0.2311972
Upper 95% Mean	4.4749673
Lower 95% Mean	3.5319077
N	32

Littoral slope was shown to have significant effect on biotic communities at the rocky sites. We identified a littoral slope threshold of 18% at the rocky sites to characterize this effect, based on the following graphs of slope versus COTE, invertebrate family, and fish richness.



We tested the 18% littoral slope threshold and found significant effects with both fish and macroinvertebrates at hard substrate sites.

Oneway Analysis of COTE Richness By Littoral slope H/L @18 Hard/Soft substrate=Hard



Missing Rows 1

Oneway Anova

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
H	6	42.000	33.000	7.00000	1.829
L	4	13.000	22.000	3.25000	-1.829

2-Sample Test, Normal Approximation

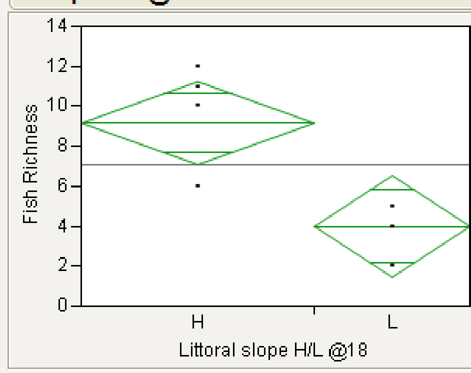
S	Z	Prob>|Z|
13	-1.82891	0.0674

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.7500	1	0.0528

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Fish Richness By Littoral slope H/L @18 Hard/Soft substrate=Hard



Missing Rows 1

Oneway Anova

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
H	6	45.000	33.000	7.50000	2.474
L	4	10.000	22.000	2.50000	-2.474

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
10	-2.47441	0.0133*

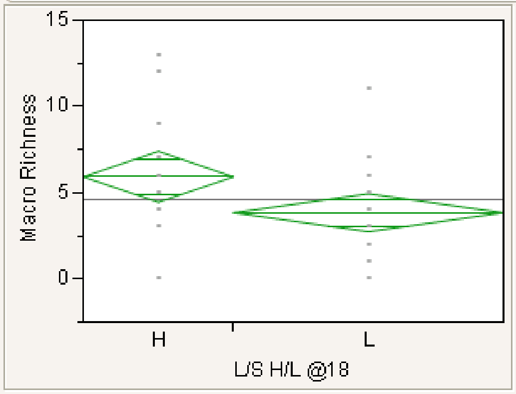
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.6667	1	0.0098*

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

The littoral slope threshold of 18% was also significant with macrophyte richness at the rocky sites.

Oneway Analysis of Macro Richness By L/S H/L @18 Hard/Soft substrate=Hard



Oneway Anova

Summary of Fit

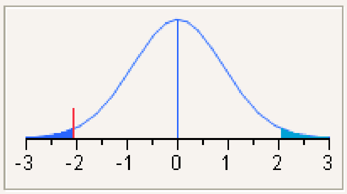
Rsquare	0.116012
Adj Rsquare	0.093913
Root Mean Square Error	2.821085
Mean of Response	4.595238
Observations (or Sum Wgts)	42

t Test

L-H

Assuming equal variances

Difference	-2.0815	t Ratio	-2.29118
Std Err Dif	0.9085	DF	40
Upper CL Dif	-0.2454	Prob > |t|	0.0273*
Lower CL Dif	-3.9176	Prob > t	0.9864
Confidence	0.95	Prob < t	0.0136*



Analysis of Variance

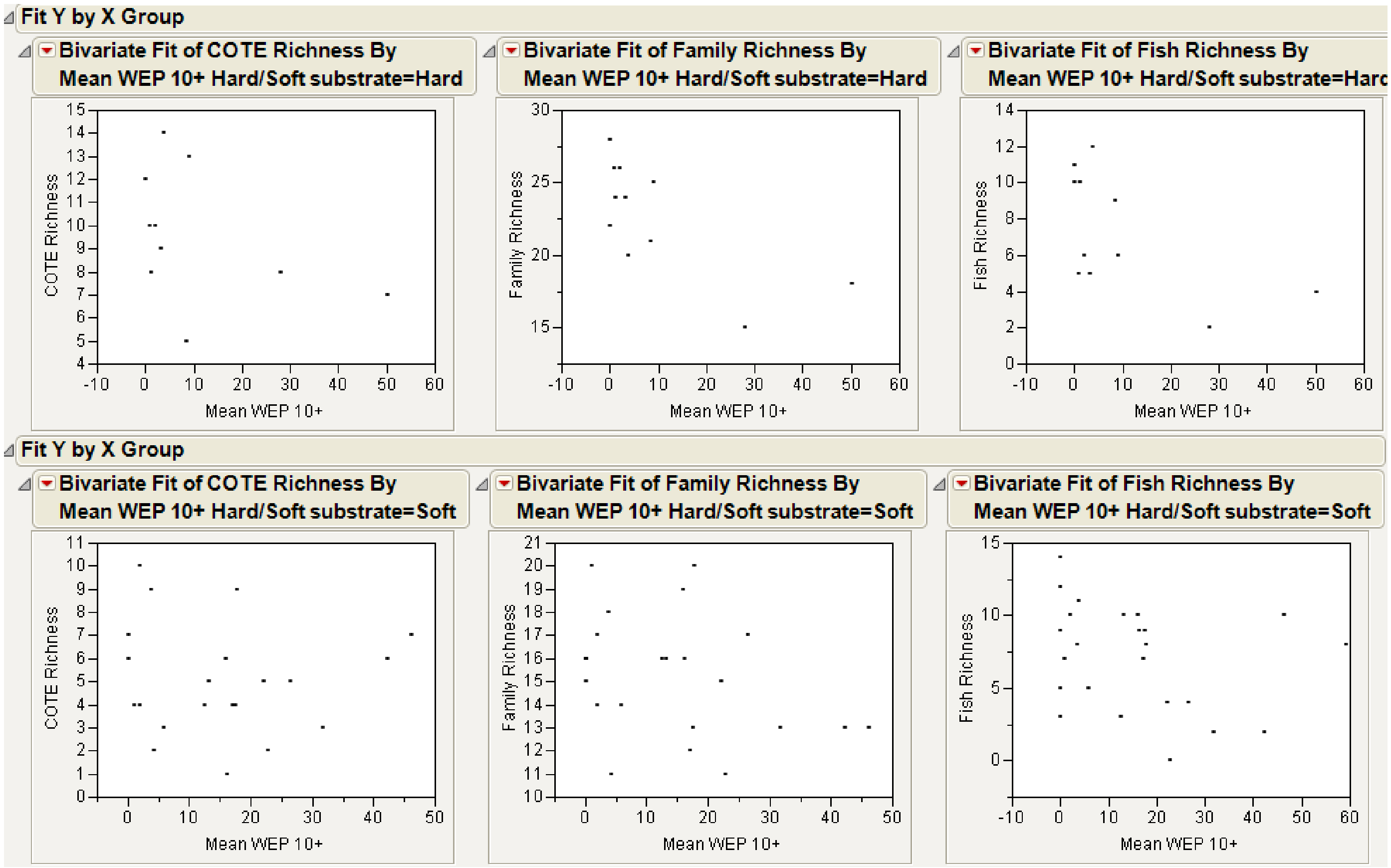
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
L/S H/L @18	1	41.77831	41.7783	5.2495	0.0273*
Error	40	318.34074	7.9585		
C. Total	41	360.11905			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
H	15	5.93333	0.72840	4.4612	7.4055
L	27	3.85185	0.54292	2.7546	4.9491

Std Error uses a pooled estimate of error variance

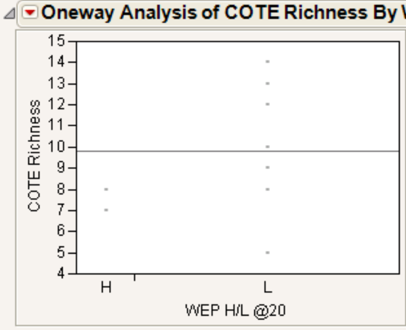
A threshold for the effects of WEP was determined through a similar process. Plots of WEP versus biotic and structural data were analyzed to identify a threshold of WEP=20.



These data were then split at this threshold and analyzed for significance of WEP on structural and biotic parameters. The sample size for rocky high WEP sites was too small to test for significance; however the relationship below suggests that a high level of significance would be supported with a larger sample size.

Fit Y by X Group

Oneway Analysis of COTE Richness By WEP H/L @20 Hard/Soft substrate=Hard



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
H	2	5.500	12.000	2.75000	-1.424
L	9	60.500	54.000	6.72222	1.424

2-Sample Test, Normal Approximation

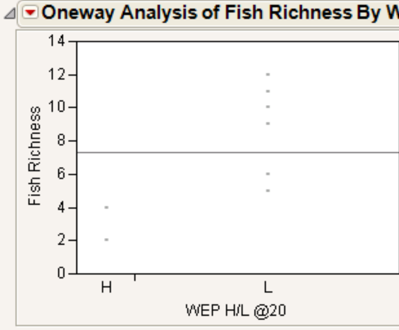
S	Z	Prob>|Z|
5.5	-1.42396	0.1545

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.3797	1	0.1229

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Oneway Analysis of Fish Richness By WEP H/L @20 Hard/Sof



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
H	2	3.000	12.000	1.50000	-2.017
L	9	63.000	54.000	7.00000	2.017

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
3	-2.01727	0.0437*

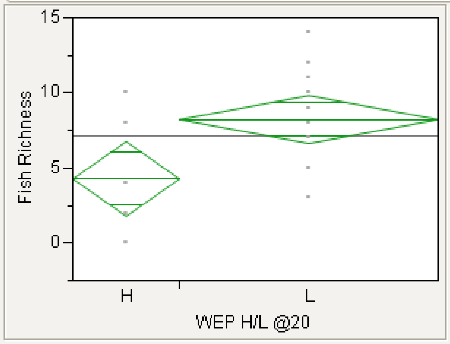
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.5622	1	0.0327*

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

Sample size at the soft substrate sites was large enough to identify the WEP threshold significance with fish richness.

Oneway Analysis of Fish Richness By WEP H/L @20 Hard/Soft substrate=Soft



Missing Rows 2

Oneway Anova

Summary of Fit

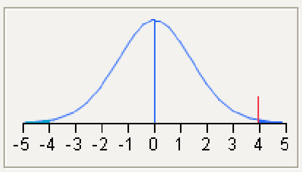
Rsquare	0.259695
Adj Rsquare	0.226045
Root Mean Square Error	3.165779
Mean of Response	7.083333
Observations (or Sum Wgts)	24

t Test

L-H

Assuming equal variances

Difference	3.94958	t Ratio	2.778038
Std Err Dif	1.42172	DF	22
Upper CL Dif	6.89804	Prob > |t|	0.0110*
Lower CL Dif	1.00112	Prob > t	0.0055*
Confidence	0.95	Prob < t	0.9945



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
WEP H/L @20	1	77.34594	77.3459	7.7175	0.0110*
Error	22	220.48739	10.0222		
C. Total	23	297.83333			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
H	7	4.28571	1.1966	1.8042	6.7672
L	17	8.23529	0.7678	6.6429	9.8276

Std Error uses a pooled estimate of error variance

APPENDIX D

SITE PHOTOGRAPHS


Site 2


Site 3


Site 4


Site 5


Site 6


Site 7


Site 8


Site 9


Site 10


Site 11


Site 12


Site 13


Site 14


Site 15


Site 16


Site 18


Site 19

Site 20

Site 21

Site 22


Site 23


Site 24


Site 25


Site 26


Site 29


Site 30


Site 31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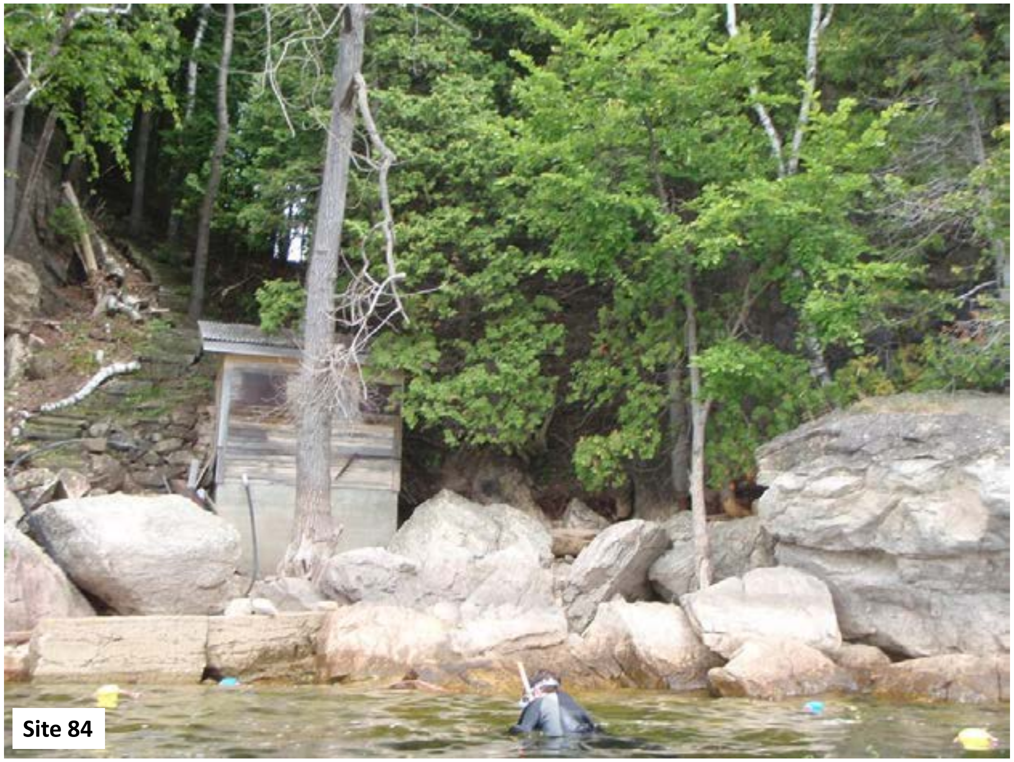
Site 80

Site 81

Site 82

Site 83



Site 84


Site 85


Site 86


Site 87


Site 88

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Site 92


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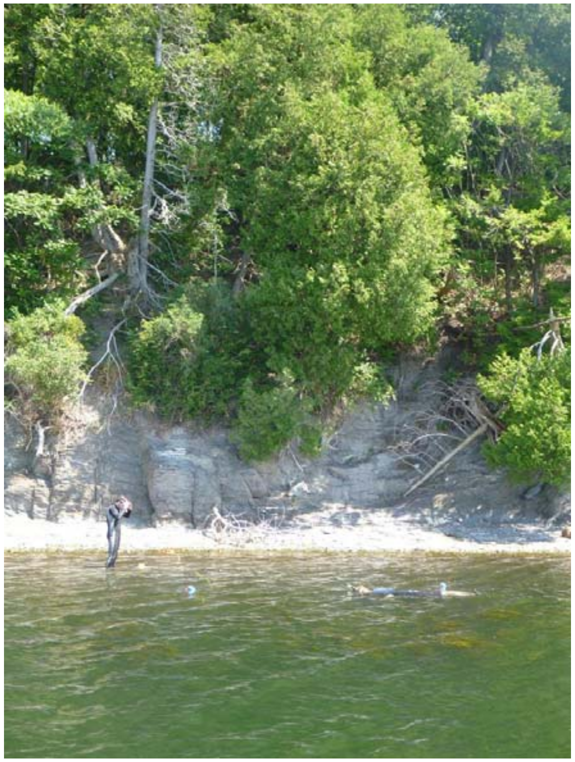
Site 101

Site 102


Site 103


Site 104


Site 105


Site 106


Site 107


Site 108


Site 109


Site 110


Site 111


Site 112


Site 113


Site 114


Site 115


Site 116


Site 117


Site 118

APPENDIX E

GIS MODEL USER GUIDANCE

Littoral Habitat Model – User Documentation

Overview

The Littoral Habitat Model (LHM) was developed as part of a research study titled "Measuring and Modeling the Effects of Lakeshore Development on Littoral Habitat and Biota in Malletts Bay, Vermont" and funded through the Lake Champlain Basin Program. The project was completed by Fitzgerald Environmental Associates, LLC. (FEA) under contract to the New England Interstate Water Pollution Control Commission from 2011 to 2013. Britt Haselton of Tierra Environmental (subcontractor to FEA) was responsible for the development of the LHM scripts and interface. The research study established statistically significant relationships between shoreline characteristics and various littoral habitat metrics, including biotic (macroinvertebrate) richness, macrophyte richness, and coarse woody debris habitat. Among the study's products were matrices summarizing these relationships and qualitative predictions of littoral habitat metrics.

The LHM has the principal function of placing particular shoreline points of interest into various categories summarized in the habitat matrices, and then using these categories to qualitatively predict biotic richness, macrophyte richness, and woody debris habitat. It has three input parameters: (1) littoral slope, an automated calculation used to predict substrate type; (2) development intensity, a user-defined selection based on guided interpretation of aerial imagery; and (3) wind erosion potential (WEP), an automated calculation based on shoreline bearing, fetch, and generalized wind speeds.

The model was built using ArcGIS ModelBuilder v. 10.1, which allows for the creation of complex models that efficiently utilize the entire suite of ArcGIS analysis tools by linking many tools together into one step. To run the model for a point of interest on the Lake Champlain shoreline, a user first edits (in ArcMap) an existing polyline feature class to represent fetch length and direction from the point of interest, and then selects a development intensity of "high" or "low" from a dropdown menu. The model is then run. The output is a table containing predicted substrate type and qualitative values for WEP, biotic richness, woody debris habitat, and macrophyte richness.

Use

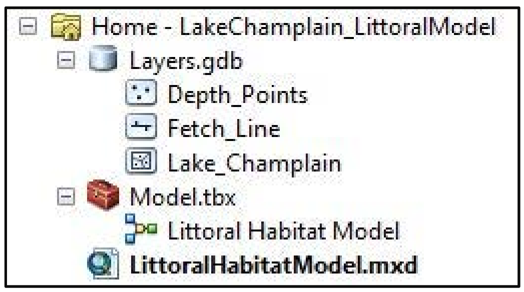
The LHM is free to use and improve. It is intended for use by natural resource professionals proficient in the use of ArcGIS. There are important assumptions and caveats that apply to its use; read the accompanying Technical Report carefully. If the model is used for published research, please cite the aforementioned Technical Report.

Model Package

The model and associated map and data files are included in a folder named "LakeChamplain_LittoralModel." This folder includes the following elements:

1. A file geodatabase containing three feature classes: ***Depth_Points*** (a grid of bathymetry points); ***Fetch_Line*** (an empty polyline layer that is edited by the user); and ***Lake_Champlain*** (a polygon feature class depicting the lake).
2. A toolbox containing the LHM.
3. An ArcGIS 10.1 map document.
4. A PDF depicting a diagram of the model.

In ArcCatalog, the LHM folder looks like this:



Model Components

The LHM streamlines 35 individual processing steps and incorporates a number of ArcGIS tools and functions to populate the output table. The following is a summary of the principal processes. To explore the model fully, it can be viewed in the ArcGIS ModelBuilder platform. In addition, please refer to the PDF depicting a diagram of the model.

Littoral Slope

Littoral slope is calculated by selecting for all bathymetry depth points[1] (in the *Depth_Points* feature class) within 30m (98.425 ft) of the shoreline point of interest, and then using the Summary Statistics tool to extract the deepest point, [MIN_FEET_DPTH]. The Calculate Field tool is then used to generate percent slope by the following VB Script expression: ([MIN_FEET_DPTH]/98.425)*100, where [MIN_FEET_DPTH] represents the rise of the slope and 98.425 represents the run of the slope. (We assume that the minimum depth point occurs at the greatest distance from shore.)

WEP

See Section 2.3 of the Technical Report for a full description of the WEP metric. The modeled WEP calculation is a simplified version of that described in the Technical Report. (For instance, it relies on one fetch line rather than five radiating lines as described in the report.) WEP is calculated by using the Linear Directional Mean script in ArcToolbox, which generates the direction and length of the input fetch

[1] The bathymetry dataset was produced for a "Whole Lake Survey" by lake researchers at Middlebury College. It includes a 10x10m grid of points covering the entire lake; each point is attributed with water depth (in feet).

line. The Calculate Field tool is used to generate a wind score (based on shoreline bearing and mean wind speeds) and a fetch score (based on fetch length), which are combined to generate an overall WEP score.

Development
User-defined parameter based on interpretation of aerial imagery.

Qualitative Predictions of Habitat Values
For each of the habitat fields, a custom block of code is used in the Calculate Field tool to attribute the field with relative habitat values. Each of the code blocks consists of a series of if-then statements based on the relationships found in the littoral habitat matrices.

Instructions

> **Software note:** The LHM and associated maps and data were created in ArcMap v. 10.1. The model may be used in ArcMap versions other than 10.1, but these versions are not supported in this documentation.

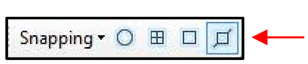
1. Unzip the compressed folder into a root directory of your choice (e.g., C:\LittoralHabitatModel).

2. Open "LittoralHabitatModel.mxd."

3. Add the best available aerial imagery for your area of interest. Bing Maps© imagery or World Imagery server basemaps in ArcMap 10.1 are recommended. Base map imagery services are also available through the Vermont Center for Geographic Information (www.vcgi.vermont.gov) and the New York State GIS Clearinghouse (http://gis.ny.gov/?nysgis=).

4. Navigate to a point of interest along the Lake Champlain shoreline, and zoom to a scale that encompasses your shoreline point of interest and the shoreline directly across the lake.

5. Start an editing session. In the ArcMap Table of Contents, right-click on *Fetch_Line* and select ***Edit Features>Start Editing***.

6. On the Snapping Toolbar, ensure that "Use Snapping" is checked in the dropdown menu and turn on Edge Snapping. 

7. Open the Create Features window and select the *Fetch_Line* template.

8. Draw a line representing fetch direction and length:

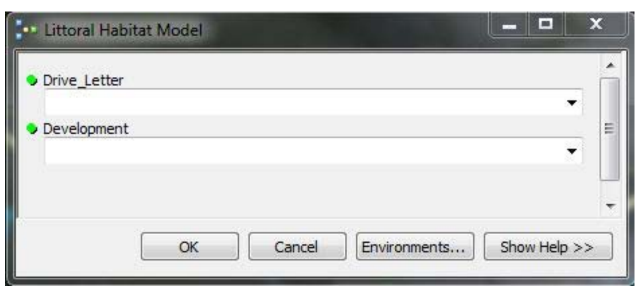
a. Click on your shoreline point of interest to create a start vertex (the vertex should "snap" to the shoreline[2]);
b. Drag the cursor to create a line that is perpendicular to the shoreline;
c. Click on the opposite shoreline to create an end vertex.

9. When both vertices are created, finish the sketch by hitting F2 (or right-click and select ***Finish Sketch***).

10. Close the editing session by clicking on ***Stop Editing*** in the dropdown menu of the Editor toolbar.

11. Open up the ArcCatalog window and open the up the Model toolbox (Model.tbx).

12. Open the Littoral Habitat Model.



13. In the **Drive_Letter** dropdown menu, select the drive letter where the model is stored.

[2] **IMPORTANT NOTE:** In some areas—particularly along the New York shoreline—the landward extent of the Depth_Points feature layer deviates greatly from the shoreline as represented in the Lake_Champlain feature class. When creating your starting point, check to make sure points in the Depth_points feature layer occur within **30 m** of the shoreline point of interest. If there are no depth points within 30 m, it is necessary to create the starting point at the edge of the Depth_Points feature layer rather than snapped to the Lake_Champlain feature class. ***If a starting point is created more than 30 m from any depth point, the model will generate an empty output.***

14. In the **Development** dropdown menu, select the appropriate development intensity (***High*** or ***Low***) by referring to the example images at the end of this section.

15. Click ***OK*** to run the model.

16. When the tool has finished running, the results table (a .dbf table located in the *Results* folder) can be added to the ArcMap Table of Contents or opened in Microsoft Excel.

To rerun the model for a different point of interest, start an editing session and delete the previous fetch line in the *Fetch_Line* Layer. Then proceed from Step 8.

Results

The results table includes the following fields of interest:

[MIN_FEET_DPTH] – Extracted from the *Depth_points* feature class and used in the littoral slope calculations.

[SLOPE_PCNT] – Modeled littoral slope %.

[SLOPE_CL] – Littoral slope category (high/low). The threshold between categories (1.9% slope) is derived from comparisons of modeled and field-measured slope values.

[SUBSTRATE] – Predicted substrate type (hard/soft) based on slope category.

[WEP] – Calculated WEP value.

[WEP_CL] – WEP category (high /low). The threshold between categories is 9.

[DEVELOPMENT] – Development category based on user input.

[MACROPHYTES] – Predicted qualitative value for macrophyte species richness. Possible values: lowest, lower, moderate, higher, highest.

[WOODY_DEBRIS] – Predicted qualitative value for woody debris habitat. Possible values: lowest, lower, moderate, higher, highest.

[BIOTA] - Predicted qualitative value for biotic richness (macroinvertebrates). Possible values: lowest, lower, moderate, higher, highest.

Future Improvements

The LHM is intended to be improved over time based on additional field research and collaborative development. Key areas for improvement include:

1. **Slope and WEP thresholds.** The LHM was developed using data from Malletts Bay and was subject to a short and limited validation study involving three other areas of Lake Champlain. A broader and more extensive examination of the model's results around Lake Champlain may help to identify model thresholds that perform better for all areas of the lake.
2. **Substrate predictions.** The LHM uses littoral slope information to predict substrate type. A more refined model incorporating additional information (e.g., soils, parent material) may improve predictive success.
3. **Development intensity.** Currently, we do not provide a specific buffer distance threshold to aid users when defining "high" and "low" development intensity. Future research may help identify

such a threshold. In addition, this is the only user-defined parameter in the model. Higher resolution land cover maps for the Lake Champlain shoreline may allow developers to automate this parameter.

Example images of "high" and "low" developed shorelines

Shorelines with **High Development** lack a vegetative buffer and consist primarily of developed land cover features, including lawns, roads, and structures.

Shorelines with **Low Development** consist primarily of natural vegetation. For the purposes of this model, developed areas that retain naturally vegetated riparian buffers are included in this category.