Fish Habitat of the Toronto Waterfront: Community Analysis and Validation of the Habitat Alteration Assessment Tool

by

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Abstract

Fish habitat mitigation and compensation requirements must take into consideration the "no net loss of productive capacity" principle of the Department of Fisheries and Ocean's Policy for the Management of Fish Habitat. "No net loss" implies the ability to quantitatively calculate productivity before and after development. Until 1995, no acceptable method was capable of that calculation. In 1995, Minns and co-workers presented the outline of a quantitative, scientifically defensible method of assessing productivity (Minns et al. 1995) that led to the later creation of the Habitat Alteration Assessment Tool (HAAT) software. Although currently in use, to date, field-testing and validation has not been completed.

The primary purpose of this study was to determine whether the HAAT provides an acceptable method for assessing fish habitat alterations using the Toronto waterfront as a test case. An extensive fish community database assembled by the Toronto and Region Conservation Authority (TRCA) also provided the opportunity for a secondary analysis, to determine whether significant changes had occurred as a result of habitat alterations on the Toronto waterfront over the past decade. In addition to the available historical fish community data, additional fish and environmental data were collected in Summer 2002, Fall 2002, Spring 2003, and Summer 2003 and waterfront physical habitat characteristics were mapped.

Simpson's reciprocal diversity index and the modified Hill's ratio evenness analyses of the historical community data produced only two significant temporal

changes, neither of which were explained by any variables included in this study. The fish community analysis further indicated that there was no evidence to suggest that significant fish community responses had occurred along the Toronto waterfront as a result of known habitat alterations.

To meet the primary objective of validating the HAAT, available fish community data were assessed on an individual site-specific, averaged site-specific (averaged across seasons) and seasonal site-specific basis. Regression analyses indicated that suitability was important for explaining the observed variation in the biomass and abundance (productivity) for warmwater groups, and in some cases, for coldwater piscivores, but was of less importance for coolwater groups and coldwater non-piscivores. Where suitability was significantly correlated with observed productivity values, the proportion of explained variability was often greater when suitability was considered in conjunction with other measured variables in this study (e.g., temperature and fetch).

Water temperature and air temperature consistently emerged as important explanatory variables, particularly for cool and coldwater species. Results also indicated that temperature was frequently a better determinant of fish productivity than suitability, suggesting that the thermal environment may prevent habitat usage, regardless of the suitability of its physical structure. Maximum effective fetch was another important variable for explaining data variability, particularly at open coast sites where exposure was the highest. Increased wave action and turbidity, and decreased macrophyte growth associated with increased fetch (Randall et al. 1996; Brind'Amour et al. 2005) was attributed as the cause of the low observed productivity.

Although this study indicated a bias towards warmwater fish and embayment habitats, our analyses used equal weightings of the fish groupings and did not consider the addition of environmental variables when testing the ability of the HAAT to predict fish biomass or abundance. Further analyses of the operational validity of the HAAT should be performed, taking full advantage of the manipulations available in the software. Continued use of the HAAT, therefore, must be done with careful contemplation of the habitat being assessed, the habitat management objectives of the area and the species composition reasonably expected to occur. Due consideration must also be given to other possible environmental influences (e.g., temperature and fetch) that are not directly considered by the HAAT. Future versions or derivatives of the HAAT should incorporate an objective method of accounting for the effects of fetch and temperature on the fish productivity of the site being developed.

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Chapter 1:
History of the Defensible Methods Approach to Fisheries Habitat Management

Protecting fish habitat and productivity from human activities is one of the most difficult and complex tasks facing fisheries managers today (Minns et al. 1996; Lewis et al. 1996; Minns 1997; Minns et al. 2001). In major urban centers, such as the City of Toronto, the effects of urban expansion on terrestrial and aquatic environments are obvious. Coupled with ecological deterioration is a rising public awareness of the need to protect the environment. Loss of suitable habitat can prevent the environment from supporting viable, self-sustaining, resident fish populations (Minns et al. 1999b). Ultimately, habitat loss can lead to species extinctions as habitats essential for rare, threatened or endangered species disappear or become uninhabitable (Minns et al. 1999b).

Preventing extirpation at the local scale requires the adoption of conservation and management plans designed to mitigate habitat degradation. Various non-profit, institutional and governmental groups are currently making efforts to mitigate habitat loss and degradation by creating and/or rehabilitating habitats, including aquatic habitats. Managing aquatic habitat, however, requires knowledge of the relationships between physical environmental variables, the functions of those variables and the ways in which plants and animals use physical habitat structures throughout their life-cycle (Imhof et al. 1996). For example, nearshore areas play an important role in at least one life-history stage of most temperate fish species (Pratt and Smokorowski 2003). In littoral zones, submerged macrophytes influence distribution, diversity and productivity of many fish species by increasing the spatial complexity of habitat, providing cover from predators, refuge for juveniles and feeding areas (Randall et al. 1996; Pratt and Smokorowski 2003). Nearshore habitat supplies are limited for inshore and offshore fish communities due to their narrow depth and spatial ranges, and have high exposure to the detrimental effects of urban expansion and development activities (Minns et al. 1995). Accordingly, nearshore areas are of particular concern for environmental resource managers (Minns et al. 1995).

Management of nearshore areas typically follows the "ecosystem approach", as detailed by the Great Lakes Water Quality Agreement (International Joint Commission United States and Canada 1994; Great Lakes Commission 2000). The central principle of the approach is the consideration and integration of environmental, social and economic factors affecting a management unit, which is defined by ecological rather than political boundaries. Minns (1995) defined the ecosystem approach more specifically with respect to fisheries as an attempt "to integrate assessment of the effects of shoreline development on fish habitat and on fish populations".

Applying the ecosystem approach is difficult due to the numerous positive and negative feedback loops inherent in the complexity of biological systems.

Ecosystems are dynamic and the patterns and relationships found in ecosystems of similar type can show wide variation. Furthermore, the interconnectivity of ecosystem components and the prevalence of cascade effects complicate the ability to understand and predict the effect of a change in a single parameter describing an ecosystem (Carpenter et al. 1987; Pace et al. 1999; Robinson and Frid 2003). Although a target of habitat alteration may be chosen, and a particular outcome expected, it is unlikely that the impact effects of the alterations will be confined to the target. Sometimes, the desired outcome may not occur. Further, the outcome may have deleterious effects on other elements of the ecosystem (Minns et al. 1996). Ideally, outcomes will be positive with unexpected additional benefits. The range of possibilities, and lack of knowledge concerning their likelihood in any given situation, makes assessing and managing ecosystems a difficult task for managers and policy makers. The difficulty suggests the need for widely accepted analytical frameworks within which the effects of proposed habitat alterations may be rationally analyzed.

In Canada, fish habitats are considered national assets (DFO 1986). Many laws, policies and guidelines governing conservation and productivity are designed to protect aquatic habitats from detrimental human influences (DFO 1986; Minns et al. 1995; DFO 1998a; DFO 1998b; Lange et al. 2001). Those intended to protect fish habitat in the Great Lakes are hierarchical. Federal regulations include: the Fisheries Act, the Department of Fisheries and Oceans Canada (DFO) Policy for the

Management of Fish Habitat, and the Canadian Environmental Assessment Agency's Canadian Environmental Assessment Act.

Prior to 1997, Provincial-level regulations included the Ontario Ministry of Natural Resources (OMNR) Interim Fisheries Guidelines for Shoreline Alterations and Fish Habitat Protection Guidelines for Developing Areas (Minns et al. 1995). However, the interim agreement between the OMNR and the DFO ended on September 18th, 1997 and responsibility for the regulation and enforcement of fish habitat protection laws (Section 35(1) of the Fisheries Act) were returned to the Federal Government (OMNR 1997; DFO 2000). At the regional level, Conservation Authorities supplement federal initiatives with have locally designed frameworks and play a strong role in the monitoring and implementation of habitat preservation, rehabilitation and restoration initiatives, under the constraint of Federal and Provincial and legislation, guidelines and policies (Koonce et al. 1996).

The primary statute for fish habitat protection is the Fisheries Act, which supersedes all other policies and guidelines, Provincial, Federal or otherwise (Minns et al. 1995; Koonce et al. 1996; Minns et al. 2001). Section 35(1) of the Fisheries Act states, "No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat". An "undertaking" can mean any activity or development, in or near the water, from the scale of a small culvert or dock installation to the scale of a hydroelectric project (DFO 1986). Fish habitats are defined in Section 34(1) as "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes”.

Preventing the “harmful alteration, disruption or destruction of fish habitat” (HADD) is not always possible for every undertaking proposed in, or near, fish habitat. In Section 35(1) of the Fisheries Act, where a HADD cannot be prevented, the Minister of Fisheries and Oceans, pursuant to Subsection 35(2) of the Fisheries Act, may issue an authorization allowing a HADD, usually conditional upon project proponents meeting mitigation or compensation requirements for the affected habitat. Coupled with the Fisheries Act is the Department of Fisheries and Oceans’ (DFO) Policy for the Management of Fish Habitat (DFO 1986). The guiding principle of the habitat management policy is “no net loss of productive capacity” of fish habitats (NNL), with the long-term objective being the “achievement of an overall net gain of the productive capacity of fish habitats”. Productive capacity is defined in the habitat management policy as “the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend”.

There are three main ways in which the habitat management policy’s objective can be met (Figure 1.1) (DFO 1986):

- Conservation: Maintain the current productive capacity of fish habitats supporting Canada's fisheries resources, such that fish suitable for human consumption may be produced.

- Restoration: Rehabilitate the productive capacity of fish habitats in selected areas where economic or social benefits can be achieved through use of the fisheries resource.
- Development: Improve and create fish habitats in selected areas where the production of fisheries resources can be increased for the social or economic benefit of Canadians.

In a critique of the habitat management policy Minns (1995, 1997) suggested that the NNL guiding principle be reworded because it protected potential productivity, not actual productivity, occurring and therefore did little to protect fish habitat. Although destroying habitat in an area results in a net loss in productive capacity of that area and creating new habitat from non-fish habitat in the area results in a net gain, altering the actual productivity of the habitat without physically changing the habitat does not necessarily result in a change in the capacity of that habitat to produce fish (Minns 1995; Jones et al. 1996; Minns 1997). For example, if a change in environmental conditions (eutrophication, temperature change etc.) in a small lake resulted in a decrease in the population of resident fish species, the productivity would decrease. However, recalling the definition of productive capacity, the maximum natural capability of the pond's habitat to produce fish would not change. Once the lake returned to more favourable conditions, the lake's fish populations could be re-established and productivity returned. Consequently, Minns (1995, 1997) proposed that the no net loss principle be revised to "no net loss of the natural productivity of fish habitats", thereby protecting the maximum potential natural productivity as well as the realized productivity of fish habitat. However, the proposed rewording has yet to be formally accepted and so management efforts will continue to operate under the current NNL principle.

There is an implicit link between the Fisheries Act and the habitat management policy. Where a HADD cannot be avoided, it is held that there will be some change in the productivity of the effected habitat (DFO 1998a; DFO 1998b; Minns et al. 2001). As a result, mitigation or compensatory measures must be taken to ensure that there will be 'no net loss' as per the habitat management policy. The DFO has guidelines to help managers analyze development proposals where a HADD will occur and has set forth a hierarchy of preferred solutions for achieving no net loss (DFO 1998b):

- Relocation or physically moving a project, or part of a project, to eliminate adverse impacts on fish habitat;
- Redesign of a project so that it no longer has negative impacts on fish habitat;
- Mitigation of impacts in cases where relocation and redesign are not possible and;
- Compensation, which involves replacing damaged habitat with newly created habitat or improving the productive capacity of some other natural habitat.

Compensation is the least preferred option and should only be considered when relocation or redesigning the project is unfeasible and mitigation cannot prevent a HADD (DFO 1998b).

To ensure that fisheries habitat managers across Canada use a consistent approach when analyzing proposals, a procedural guideline, "Decision Framework for the Determination and Authorization of Harmful Alteration, Disruption or Destruction of Fish Habitat" has been published by the DFO. It should be noted that if a manager determines that a HADD will not occur, or that if a HADD could occur and mitigation can prevent the impact on fish habitat and productivity, an authorization is not required (DFO 1998a). Difficulties arise however, in determining whether or not there will be a net loss in productivity due to a proposed development. The key question is, how does one assess the potential effects a development will have on the habitat and its associated productivity?

Until the late 1990's, there was no standardized, quantitative protocol for assessing development impacts on fish habitat. Earlier methods consisted of *ad hoc* predictive methods, considered "too qualitative and too subjective" (Minns et al. 1995). In addition, there was no well-defined information on the habitat needs of fish and quantitative decision rules for assessing the impacts of habitat loss were non-existent. As a result, project proponents and other government agencies were unable to effectively assess potential impacts and would have to submit their development proposals to the DFO for an assessment of probable habitat loss effects

(Minns et al. 1995). The lack of expertise in other government agencies concerning the possible impacts of habitat loss on aquatic communities and the sheer number of proposals created a backlog of assessment requests within the DFO. Although a quantitative method of assessing changes in fish habitat was not available, the Fisheries Act and the habitat management policy imply the ability to quantify habitat and productivity changes (Minns 1997). In the NNL guiding principle of the habitat management policy, "net" suggests the capability to calculate gains and losses in productive capacity from a reference point and the wording of the principle "implies that a quantifiable change in the productivity of fish habitat is unacceptable" (Minns 1995). Furthermore, in the HADD prohibition of the Fisheries Act, "harmful" suggests a "measurable, significant degree of effect" (Minns 1997). Ultimately managers were left with the conundrum of how to comfortably satisfy the quantitative aspects inherent in enforceable laws and policies without having readily available, reliable methods to achieve that end.

To determine whether a proposed development will impact fish habitat and/or fish productivity, information needs to be assembled about the habitat and any fishery that exists, or could potentially exist, during the pre- and post-development stages of an aquatic development project. Proponents must first assess the physical and biological attributes (e.g., substrate, vegetation, water depth, water current, water temperature etc.) of the habitat where the development is to take place. Several previously published papers including Minns (1995), W.F. Baird and

Associates (1996), DFO (1998a), Minns and Nairn (1999) Lange et al. (2001), Minns et al. (2001) and Frezza and Minns (2002) discuss the information needs for assessing habitat and the possible effects of development on habitat and habitat productivity.

There are three methods with which to measure or predict the productivity of fish habitat (Minns 1995; Minns 1997):

- Direct measurement of productivity by summing the production rates of all fish species present;
- Measurement of biological indices (biomass, catch per unit effort (CPUE), sport/commercial yields, presence-absence);
- Measurement of habitat variables for use as surrogates of productivity rates.

In most cases, measurement of fish productivity by direct means prior to development is time consuming, not feasible and/or expensive. Using biological indices requires a substantial amount of pre-existing data before reliable predictions can be made. If new data are to be collected and used, proposal development costs rise significantly, sometimes beyond budgetary restrictions, with the net effect that the number of developments becomes limited. Although limiting developments reduces concerns about habitat loss, development limitation does not adequately recognize concerns about the derived social and economic benefits of responsible development (Minns et al. 2001). For post-development scenarios, using direct methods of assessing the impacts on fish productivity and finding a loss (contrary to the habitat management policy's guiding principle) would be redundant since rejecting a development after it has occurred is illogical (Minns and Nairn, 1999; Minns et al. 2001). As a result, managers and scientists must predict what effects habitat change may have on the fish community and productivity using the scientific evidence available (Minns et al. 1995; Håkanson 1996; Hayes et al. 1996; Minns and Nairn, 1999; Minns, 1997; Coker et al. 2001; Minns et al. 2001). The third method predicts productivity based on the habitat variables present and measured at the site and is considered the preferable method because of its quantitative and site specificity attributes (Minns 1995; Minns et al. 1995; Minns et al. 1996; Minns, 1997; Minns and Nairn, 1999; Minns et al. 2001). Although obtaining the data necessary to create a predictive model can initially be expensive and time-consuming, model development provides an assessment framework that is much less expensive and time-consuming when applied to further studies.

Minns (1995) initially generated a series of equations and proposed a mathematical framework to calculate the net change in productivity, which was further refined in Minns (1997). Equation 1.1 shows how net change is calculated. The development of the equations demonstrates that a scientifically defensible method for habitat analysis is possible.

$$\Delta P = [p_{MOD} - p_{NOW}] \cdot A_{MOD} - p_{MAX} \cdot A_{LOSS} + [p_{COM} - p_{NOW}] \cdot A_{COM} \qquad \text{Equation 1.1}$$

Where,

ΔP = Net change of natural productivity of fish habitat

A_{LOSS} = Area of habitat lost due to development activity

A_{MOD} = Area modified, directly and indirectly, as a result of the development activity

A_{COM} = Area created or modified elsewhere to compensate for development activity

p_{MAX} = Maximum potential unit area productivity rate (or productive capacity)

p_{NOW} = Present unit area productivity rate

p_{MOD} = Modified unit area productivity rate in affected areas

p_{COM} = Compensation unit area productivity rate in affected areas

The unit area productivity rates are determined by relating habitat attributes (e.g., substrate, vegetation, water quality and depth etc.) to the habitat requirements of fish species found in the study area and certain habitat variables or requirements may be given heavier emphasis depending on the management goals of the site (Minns 1997). For example, a small shallow embayment would not be suitable habitat for coldwater non-piscivores therefore more emphasis would be placed on habitat attributes required by warmwater fish species. More in-depth discussion regarding the creation and application of the equations can be found in Minns (1995, 1997) and Minns et al. (2001).

Following the development of the net change in productivity framework, several scientists, including Dr. Minns, began work on a quantitative prototype methodology aimed at the creation of a consistent, scientifically defensible assessment protocol which could be used by development proponents and other governmental organizations to evaluate development impacts on fish habitat.

Other quantitative methods of assessing development impacts using surrogate measures for productivity had been developed and are still in use in some regions today. The most widely used method is the Habitat Evaluation Procedure (HEP), and its associated Habitat Suitability Index (HSI) developed and used by the U.S. Fish and Wildlife Service (USFWS 1980; USFWS 1981; Terrell et al. 1982). The HEP is an evaluation technique that focuses on the habitat requirements of fish and wildlife species and highlights the quantitative relationships between key environmental variables and habitat suitability. The HSI is a value indicating the ability of key environmental variables to provide the habitat requirements of targeted species, that is multiplied by available habitat area to obtain a weighted suitability value (USFWS 1980; Terrell et al. 1982; Minns and Nairn 1999). Use of the HEP provides information for two possible comparisons: the relative value of different areas at the same point in time and the relative value of those same areas at future points in time (USFWS 1980; Terrell et al. 1982). Use of both comparisons allows quantitative prediction of the impacts a proposed development will have on habitat. The Instream Flow Incremental Method (IFIM) and PHABSIM are among several other quantitative habitat/productive capacity methods in current use. The methods are mainly driven by hydraulic descriptions of the site (Jowett 1997; Lamouroux et al. 1998; Minns and Nairn 1999). Consequently their use is generally restricted to stream habitat evaluations and will not be discussed in further detail here. Nevertheless, hydraulic-based methods have contributed much to the development of the quantitative methods currently used by the DFO's habitat management section (Minns and Nairn, 1999; Bradbury et al. 2001).

Habitat suitability assessment is generally completed using scientific literature detailing the habitat preferences of fish species based on their life histories (Hayes et al., 1996; Minns and Bakelaar, 1999; Coker et al., 2001). Every fish species has a preferred habitat based on the type and amount of vegetation cover, substrate type (e.g., boulder, cobble, gravel, sand), water depth and water temperature typically associated with its location in the environment. Habitat preferences may, and often do, vary between species' life-stages (e.g., young of the year, spawning, adult) and there is a substantial literature detailing species-specific and life-stage specific preferential habitat characteristics available for use in quantitative modelling (e.g., Lane et al. 1996; Coker et al. 2001; Cudmore-Vokey and Minns 2002).

Minns et al. (1995) incorporated habitat requirement data and the net productivity change equations implicit in Equation 1.1 into the prototype methodology for quantitatively assessing the impacts of development on fish habitats. The completed framework was formalized in a software application called "Defensible Methods of Assessing Fish Habitat". The habitat suitability matrix (HSM), now called the Habitat Alteration Assessment Tool, HAAT, is a refined version of the prototype and is currently used by the DFO when assessing freshwater fish habitat and deciding whether to issue a HADD authorization. Initially developed for the Great Lakes, and other large inland lakes in the Great Lakes basin, the HAAT is applicable to other lakes in Ontario provided that the fish species assemblages considered by the tool are adjusted to reflect realistic communities and differences in landscape morphology are taken into account. For instance, one would not expect American eels in an inland lake in Northern Ontario and so the species should be removed from the list of species' requirements being considered. The HAAT can also be used for lacustrine habitat assessments in Newfoundland and Labrador, where databases similar to those available for the Great Lakes exist (Bradbury et al. 1999; Bradbury et al. 2001). However, HAAT cannot yet be used for stream and river habitats (Minns et al. 2001).

The HAAT method is similar to previously developed habitat assessment methods in that it assigns, to distinct habitats, a value based on their relative suitability to fish species and calculates a weighted suitable area (WSA) from which net changes in habitat suitability can be assessed (Minns 1995; Minns 1997; Minns and Nairn, 1999). The HAAT differs from earlier methods in that it considers all fish species expected to occur at the development site, although all species may not be given equal weighting in the WSA calculation. In contrast, the HEP/HSI approaches rely mainly on single, keystone species suitability models that may not adequately describe impacts on all fish species (Forbes and Calow 1999; Minns and Nairn 1999). The HAAT method also allows for the assessment of small portions of the lake (i.e., the development site) as opposed to the "whole ecosystem" approach used in the HEP/HSI (Minns and Nairn 1999).

As with any modeling-based approach, the HAAT makes some key assumptions (Minns et al. 2001): 1) habitat suitability is an appropriate surrogate for productivity with a one-to-one relationship between habitat suitability and fish productivity, which has yet to be empirically validated; and 2) habitat suitability for resident fish species may be described by three key variables: substrate, depth and macrophyte cover. Note that non-physical habitat variables (e.g., water quality, wind and water currents etc.) affecting the actual or realized productivity at a location may be accounted for in the computation of habitat suitability indices by including a Condition Index (CI) value ranging between zero and one. The CI value is intended to reflect habitat conditions at a site that are not directly affected by alterations to the habitat as a result of development (e.g., thermal regime, fetch, proximity to industrial discharge etc.).

The HAAT is comprised of two modules and a habitat preference reference database. The habitat supply and habitat suitability modules were initially described in detail by Minns et al. (1995) and further updated in Minns et al. (2001). Brief descriptions of each of the HAAT components, however, follow.

The habitat preference reference database provides habitat requirements for all fish species within the geographic scope of the prototype methodology (Minns et al. 1995; Minns et al. 2001). Adult, spawning and nursery (or young-of-the-year (YOY)) habitats, for three thermal guilds of fish (warm, cool, coldwater), grouped by their feeding trophy (piscivore or non-piscivore), are defined by substrate and depth.

Substrate is divided into ten types: bedrock, boulder, cobble, rubble, gravel, sand, silt, clay, hardpan clay, and pelagic, and inventoried by depth zone. The depth zones considered are 0-1 metre, 1-2 metres, 2-5 metres, 5-10 metres and 10+ metres. Consideration of depth is truncated at 10 metres as the HAAT deals primarily with littoral habitats, which are generally considered less than 10 metres deep. Details of depth, cover and substrate preferences for each species are given in Lane et al. (1996) and define the groupings used in the HAAT. Similarly, thermal guild and feeding trophy details are given in Coker et al. (2001) and define the relevant groupings used in the HAAT.

The habitat supply module is used to estimate suitable fish habitat area before and after development (Minns et al. 1995; Minns et al. 2001). The development proponent identifies the area that will be affected directly and indirectly as a result of development and a community productivity index is generated using information about the physical habitat variables (i.e., vegetation, substrate type, and depth).

The habitat suitability module is used to determine the suitability of a given habitat for adult, spawning and young-of-the-year (YOY) fish, and for fish community productivity before and after a development project (Minns et al. 1995; Minns et al. 2001). Pre- and post-development habitat supplies estimated from the habitat supply module are evaluated for their suitability, based on the preferential habitat characteristics of fish species obtained from the habitat reference database. Within this module weightings among species assemblages and/or among habitat types may be changed based on the fisheries objectives and management plans for the site. For example, preference could be given to habitat suitable for warmwater non-piscivores if required by the fish community objective developed for the area being assessed. The ability to vary weightings among species assemblages and/or habitat types facilitates scenario development and "what if" experimentation, allowing project proponents and HAAT analysts to optimize project design with respect to its impact on local fish communities.

A comprehensive description of how the HAAT works, including examples and step-by-step details of using the software, is given in Minns et al. (2001). For the purpose of this chapter, only the major highlights of the HAAT are addressed (Figure 1.2). The first step in using the HAAT involves assessing the data provided by the proponent. An inventory of the physical habitat attributes, substrate, depth (as outlined previously in the habitat requirements module) and percent macrophyte cover must be assessed at the site of the proposed development. The amount of each habitat attribute currently available at the site is calculated as a proportion of the development area. Proponents must designate area types to the habitat, indicating the areas where change will and will not occur (Table 1.1). The provided data represents the pre-development state of the site. Modelling and simulation of the proposed habitat changes and resulting new area types (Table 1.1) is completed to produce a description representative of the likely post-development state of the site. Combining the pre- and post habitat data generates physical habitat assessment scenarios which are uploaded into the HAAT software.

The HAAT analyst can then select weightings for given fish species, group or life-stage depending on the ecosystem type and/or fishery objectives for the area. The HAAT analysis then compares the habitat information from the assessment scenarios with the habitat requirements of the selected/expected fish species and, after adjusting for the fish group weightings defined by the user, generates habitat suitability and WSA values. The calculated suitabilities thus allow for a prediction of net productivity changes at that site. The final result of the HAAT is a paired pre- and post-development comparison model of the likely effects development will have on the fish community and productivity at the proposed site. If the post-development WSA values are greater than the WSA values from the pre-development scenario, a net gain in productivity is predicted and the HADD approval would then be further considered. If the WSA values show a net loss in productivity, a HADD approval may be granted on the condition that the proponent develop further post-development scenarios that will meet the NNL principle.

Nonetheless, it is important to note that extensive empirical testing of whether the HAAT predictions correspond to actual fish productivity has not been completed. To meet scientific defensibility requirements, and to increase user confidence in the HAAT, appropriate empirical testing must be performed (Minns et al. 2001). Testing of the HAAT should include correlation analysis of suitability and fish community and habitat surveys, from a variety of lakes and habitat types, or replicated experimental studies of pre- and post-development fish productivity to determine whether actual productivity levels results are consistent with those predicted by the HAAT (Minns et al. 2001).

Figures

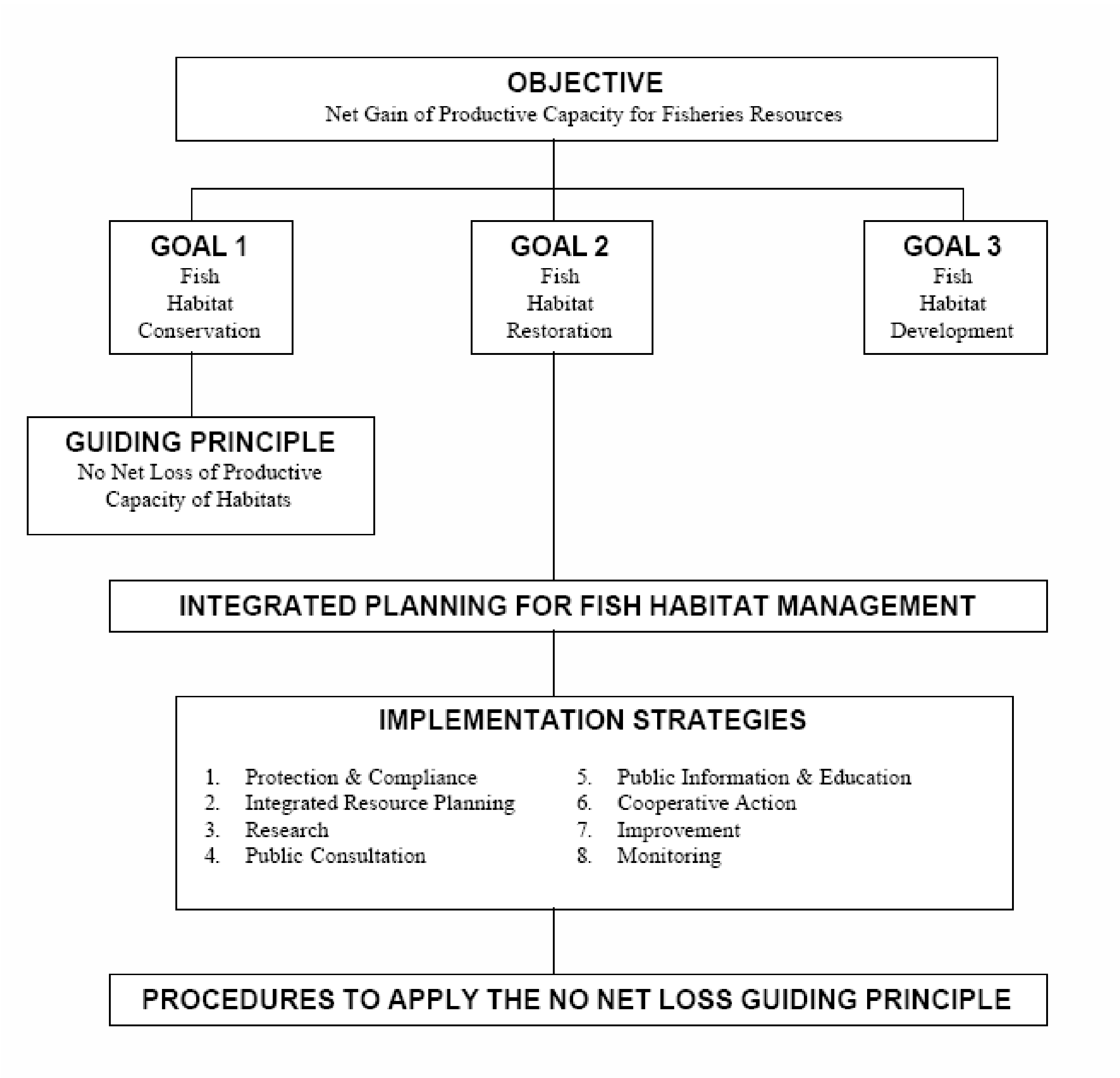

Figure 1.1 Policy Framework for Fish Habitat Management (adapted from The Department of Fisheries and Oceans Policy for the Management of Fish Habitat 1986).

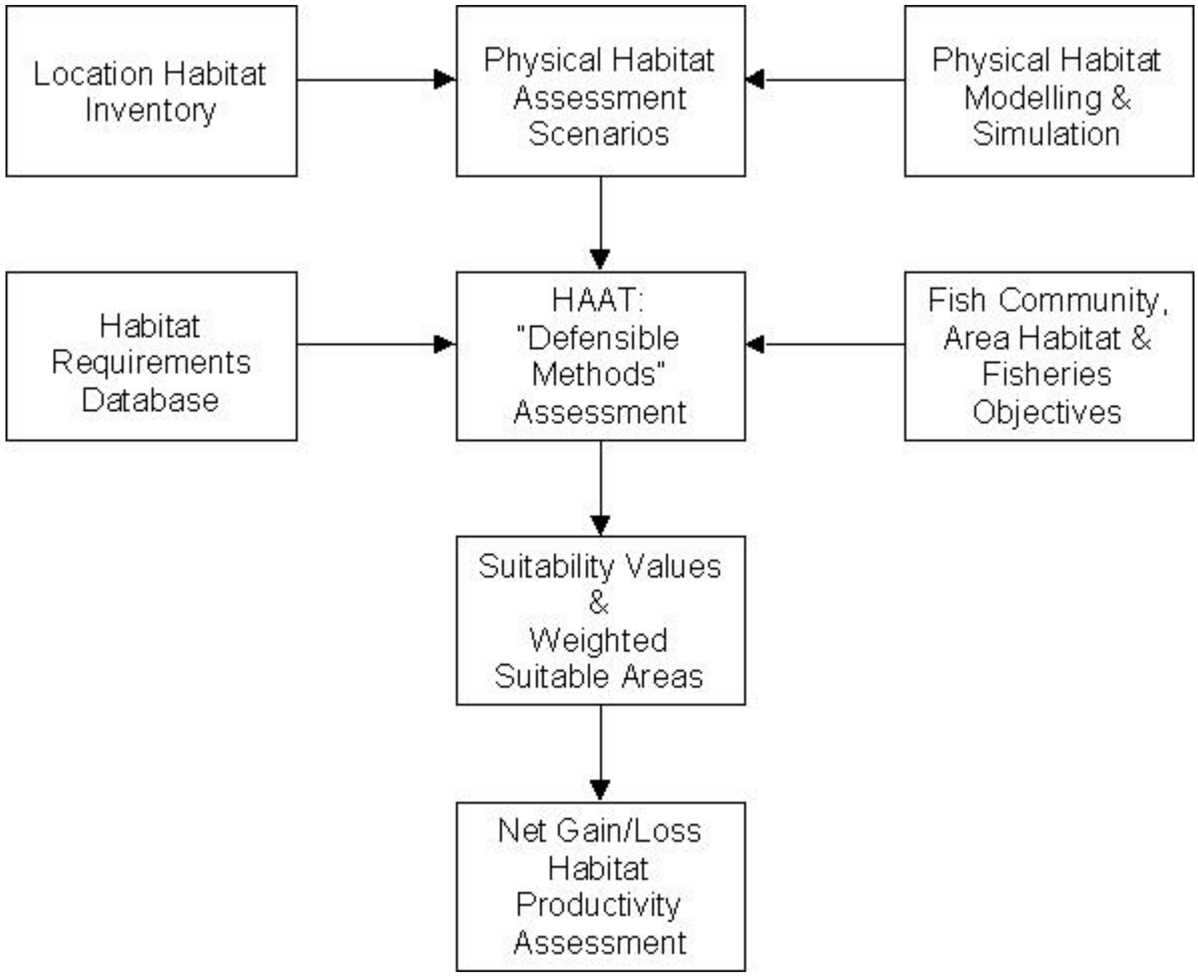

Figure 1.2 Conceptual framework for Defensible Methods/HAAT showing the key steps in the collection and use of information for assessing the possible gains and losses resulting from habitat alterations (modified from Minns and Nairn 1999).

Tables

Table 1.1 Area type categories for assessing net productivity changes when applying the HAAT (modified from Minns et al. 2001). Proponents must designate area types to all affected habitats when assessing possible habitat alteration effects.

Area Type (Code)	Name	Description
LOSS	Loss	Destruction of habitat caused by the development.
MODD	Modified-Directly	Habitat directly modified by the development
MODI	Modified-Indirectly	Habitat indirectly modified by the development e.g., the development creates a barrier altering sediment retention and wind/wave exposure of the site
COMM	Compensation-Modified	Existing habitat outside the actual development site deliberately modified to compensate for productivity loss at the site
COMC	Compensation-Created	New habitat created where none existed to compensate for productivity loss at the site
UNCH	Unchanged	Habitat not altered by the development

Chapter 2:
Community Analysis and Validation of the Habitat Alteration Assessment Tool

2.1 Introduction

Many detrimental ecological and anthropogenic changes affecting aquatic habitat have occurred in the Great Lakes over the past 200 years (Kelso et al. 1996; Minns 1997; Mills et al. 2003). Shoreline development will unquestionably continue, especially in urban areas, and with that development comes an increasing need to protect aquatic resources. In Canada, fish habitat is protected by The Fisheries Act and "harmful alteration, disruption or destruction of fish habitat" (HADD) is prohibited by Section 35(1) of the Fisheries Act (Minns et al. 1995; Koonce et al. 1996; Minns et al. 2001). However, since it may not always be possible to avoid a HADD, the Minister of Fisheries has the authority to allow a HADD provided that conditions regarding mitigation and compensation of the proposed development site are met. An additional issue managers must consider in fishery assessments is the Policy for the Management of Fish Habitat (DFO 1986) which has a guiding principle of "no net loss of productive capacity" of fish habitats (NNL) and an ultimate objective of an overall gain in the net productive capacity of fish habitat.

"No net loss of productive capacity" suggests the ability to calculate productivity before and after a development occurs (Jones et al. 1996; Minns 1997). To that end, Minns et al. (1995; 2001) developed a method to predict productivity by use of a surrogate habitat measure. The result was the Defensible Methods approach and the subsequent development of the Habitat Alteration Assessment Tool (Minns et al. 2001). Using suitability as a surrogate for productivity, Minns et al. (1995; 2001) reduced the subjectivity of the previous methods of assessing NNL and produced a quantitative and defensible method for predicting productivity impacts. Details of the methodology and instructions for its use are provided in Minns et al. (1995; 2001) as well as in Chapter 1 of this thesis. Minns et al. (2001) recognized that the methodology made certain assumptions about habitat suitability and recommended that empirical studies be performed to verify that the actual results corresponded to those predicted, thus validating the model.

Proving that a model is true under all possible sets of conditions is generally not feasible due to monetary, time or other resource constraints (Naylor and Finger 1967; Sargent 1982). It is possible, however, to test sets of conditions, or "experimental frames", to determine whether a model replicates a physical system well (Sargent 1982). If there is agreement, the model is considered valid for a given experimental frame (Sargent 1982). Increasing the number of tests with agreement between the experimental frame and the physical system increases confidence in the model (Naylor and Finger 1967; Sargent 1982). Accordingly, while validation does not prove a model to be true, it can increase user confidence that the model produces acceptable and accurate results (Naylor and Finger 1967; Sargent 1982;

Power 1993; Rykiel 1996). Ultimate acceptance of a policy based on an un-validated model may be more difficult if people are not convinced the model works.

The Toronto and Region Conservation Authority (TRCA) has collected approximately 14 years of data, which have been incorporated into a fish community database for use in the completion of environmental and fish habitat assessments. The availability of this data provided a unique opportunity to assess and test the Defensible Methods model as a means of assessing fish habitat change.

Accordingly, the primary objective of this study was to determine whether the Defensible Methods approach provided a reasonable basis for assessing fish habitat alterations on Toronto waterfront shores in terms of the accuracy and biases of its predictions. A secondary objective of this study was to determine if there was evidence of fish community response to known habitat alterations along the Toronto waterfront over the last decades.

2.2 Materials and Methods

2.2.1 Sample Site Selection

Sites were selected for study based on the availability of long-term fish community and habitat data in the TRCA database and by habitat type (sheltered embayments vs. open coasts). To facilitate comparisons, three main area were selected for analysis based on the similarity of habitat type: Tommy Thompson Park (Leslie Street Spit), the Toronto Islands and Humber Bay Park East. These areas were further separated into individual sample sites (Figure 2.1), chosen for inclusion on the basis of the following criteria: 1) extent of data coverage (multiple years of fish community data; species, length, weight etc.); 2) habitat type (sheltered embayments vs. open coasts); and 3) habitat alteration history.

Most of the sites were sheltered embayments having broadly similar habitat characteristics (e.g., water depth, macrophyte cover, substrate etc.) and environmental influences (e.g., wind, temperature and precipitation). In the case of Humber Bay, some of the sites did not have a long time series of data available because the habitats were only recently constructed or altered (e.g., the wetland area and habitat islands were created in 1996/97 and sampling of these sites began in 1997/98).

Through analysis of the TRCA database, it was determined that in relation to embayment sites, open coast habitats had been proportionately under-sampled and attempts were made through additional sampling to include representative examples of these habitat types within each of the major study site groupings. Open coast habitats may be less productive than sheltered embayments as a result of intense wave action producing harsher habitat conditions dominated by low macrophyte growth and shelter availability (Randall et al. 1996; Brind'Amour 2005). Accordingly, it was expected that the data from open coast habitats would show the lowest possible levels of fish production among the considered sites and their inclusion, increased the range of studied habitat types.

2.2.2 Study Sites

Tommy Thompson Park

The TRCA has undertaken a substantial amount of habitat change along the Lake Ontario shoreline of Toronto, particularly at Tommy Thompson Park. Filling to create the Leslie Street Spit (Tommy Thompson Park) was initiated by the Toronto Harbour Commission (now the Toronto Port Authority (TPA)) in 1959 and has continued to the present. Millions of tones of concrete, brick, earth and sand were used to create an approximate 250-hectare peninsula that stretches five kilometers into Lake Ontario (TRCA 2000). While originally designed as a port facility, in the early 1970's the TRCA was granted ownership and planning rights for the creation of a park at the site (TRCA 1989; TRCA 2000). Today the land and waters contained by the park are owned and maintained by the TRCA, while those areas still under construction (i.e., receiving fill) are owned by the Ontario Ministry of Natural Resources (MNR) and leased to the TPA (TRCA 1989; TRCA 2000).

Six sites were selected for analysis at Tommy Thompson Park (Figure 2.2) including: three dredgeate disposal cells (Cells 1, 2 and 3); Embayments A and C, and a new open coast site along the south-western most point of the park, called Lighthouse Point. Cell 1 and Cell 2 reached their dredgeate disposal capacity 1987 and 1997 respectively (TRCA personal communication). Cessation of dredgeate disposal reduced habitat disturbance, notably turbidity, thereby allowing natural fish colonization. Cell 3 continues to be used for dredgeate disposal. No rehabilitation or creation of aquatic habitat work was carried out in the cells until October 2002. Cell 1 was capped with clean fill in October 2002 and a wetland area is currently being constructed by the TRCA. As a result, no further sampling of that site was performed for this study.

Toronto Islands

Situated in the centre of Toronto Harbour, and directly across from downtown Toronto, the Toronto Islands (Islands) are home to an airport, residential area, amusement park, school, marinas and many natural areas. Access to the Islands is only possible by boat. The Islands are in the same vicinity as TTP, have a similar geographic layout as TTP and were expected to host similar fish communities. Both areas are under similar environmental stresses (temperature, winds, currents etc) and human influences. The Islands' aquatic habitats, however, have remained relatively non-anthropogenically disturbed, and have been allowed to evolve naturally in comparison to the entirely man-made constructions of TTP. Accordingly, comparative analysis of the communities at the Toronto Islands and TTP should help elucidate whether observed fish community changes at TTP have occurred in response to site-specific factors, or reflect broader environmental change trends along the waterfront as a whole (e.g., climate change). For example, if similar changes of the same magnitude exist at both sites, that may suggest naturally occurring changes unrelated to the TRCA's efforts to improve fish community metrics at TTP. If community changes differ at the two sites, results would suggest observed changes at TTP resulted principally from TRCA habitat alterations.

Six sites were selected for the Toronto Island site (Figure 2.3). Lighthouse Bay, Donut Island and Sunfish Cut were all sites sampled by the TRCA as part of the RAP for the Toronto Waterfront. Snake Island, Gibraltar Point and Ward's were added for this research project, meeting the identified need for additional open coast sites.

Humber Bay Park East

Humber Bay Park spans the waterfront between Mimico Creek and the mouth of the Humber River. This area has many of the same habitat types that exist at the Toronto Islands and TTP and it has been heavily developed by the TRCA. If fish community changes along the waterfront have occurred on a broad scale, this site will also have been affected. As Humber Bay is somewhat removed from the other study sites, site-specific factors may have influenced Humber Bay, which did not affect either the Toronto Islands or TTP. Accordingly, five sites were selected for analysis from the Humber Bay Park East site (Figure 2.4). The Wetland, Inner Habitat Isles and Outer Habitat Isles were constructed in 1996 and fish community monitoring began in 1997. Although somewhat sheltered, the Outer Habitat Isles were included in this study as an additional open coast site as was the Palace Pier site. The Fishing Pier has a substantial historical fish community data set as it continues to be a part of the TRCA's RAP monitoring and has had the least amount of alteration of all the Humber Bay Park sites.

2.2.3 Fish Community Sampling

In addition to the available historical fish community data, fish were sampled at each of the described sites for the purposes of this study. Fish were sampled using a standardized method established by the TRCA for RAP and other monitoring purposes. Unless otherwise stated, the information pertaining to what data were collected and the techniques used for collection refers to the standardized TRCA collection methods. Electrofishing surveys were conducted at each site identified in the study using a 5.5m Smith-Root electrofishing boat, the "Night Heron". Surveys were performed at night and each site was sampled once per season. Summer sampling took place from mid to late July to the first week of August, depending on the year and the site. Fall sampling took place in mid to late October. Spring data were not collected consistently for all the sites in this study, although any completed spring sampling was generally carried out in late April or early May. Current data collection dates for this study were as follows: Summer 2002 – July 22nd to August 9th; Fall 2002 – October 15th to October 24th; Spring 2003 – May 6th to May 9th; Summer 2003 – July 14th to July 23rd. The site sampling order generally depended on concurrent weather conditions. For example, extreme weather conditions made it difficult to travel to the Humber Bay sites, however, accessing the Toronto Islands or Tommy Thompson Park was less hazardous or difficult.

As per the TRCA's standardized electrofishing procedure, 1000 second transects were run at each sample site. Historical sampling generally followed the "1000 second" rule. In cases where sampling effort varied, data were corrected to standardize the effort across all years. Standardization involved multiplying the catch data by the reciprocal of the ratio of 1000 to the number of sampling seconds. Shorter electrofishing intervals may have resulted from environmental problems at the site (e.g., low water levels, bad weather) that made manoeuvring the boat impossible or dangerous, or problems with the sampling equipment itself (e.g., boat or motor concerns, problems with the electrofisher).

A five-person crew performed the sampling with one person driving and operating the electrofisher while two people netted fish and two people emptied the nets into the boat's live-well. After 500 seconds on the transect, the netters and the crew emptying the nets switched places for the remaining 500 seconds to minimize fatigue and optimize sampling effort. Once the transect was complete, the fish were transferred from the Night Heron's live-well, to bins on another boat, the Aqualab, for processing. Fish were separated by species and the following data collected: species name, total length (mm), weight (g), number of individuals (species specific), tags (if any), clips (if any), sex (if possible), presence of other marks (e.g., tumours, lamprey wounds/scars) and any other relevant comments about the fish or its condition.

For this project, where the sample size (N) ≤30, all fish were sampled and where N>30, fish were randomly selected by dipping a large net into the holding tank for that fish species until 30 had been collected. The TRCA standard procedure for sampling used a sample size of 20, not 30, however, N was increased for this research for the purposes of increasing the statistical power of comparative tests. The remaining fish were then batch sampled. The length and weight of the smallest and largest fish were recorded and then all the remaining fish were counted and weighed together to get an overall number in the sample and a batch weight.

Environmental conditions at the site and details about the electrofishing procedure used were also collected. These data included: start time of sample, electroshocking duration (seconds), amperage, voltage, water type (lake, marsh etc.), off-shore distance (m), water temperature (°C), air temperature (°C), current (visual inspection; still, slow, medium, fast), water colour (visual inspection; colourless, yellow, brown, green, blue, turbid), shoreline macrophyte coverage (visual inspection; none, sparse, moderate, dense), in-water macrophyte coverage (visual inspection; submergent/emergent; sparse, moderate, dense), substrate (visual inspection; sand, boulder, cobble, gravel etc.), and depth (m).

2.2.4 Habitat Analysis

As stated previously, the HAAT requires that specific information about the existing fish habitat be known. For this purpose, data were collected on the % macrophyte coverage, % and type of primary, secondary and tertiary substrates for the littoral zones at each site. Water depth was determined based on bathymetric data for the Toronto Waterfront as provided by the TRCA and DFO. Fetch and effective fetch data for 16 compass directions at each of the study sites were used as provided by the DFO (Carolyn Bakelaar personal communication). The highest effective fetch value at each site was considered to be the maximum effective fetch for that site.

Polygons of the macrophytes and substrates at each site were mapped in the field in August 2002 using a hand-held Garmin GPS 76 unit and ArcPad GIS (Environmental Systems Research Institute Inc. (ESRI) 2002). The GPS was interfaced with a hand-held computer with ArcPad and a base map of the Toronto waterfront installed. To map the polygon, one person drove along the edges of a macrophyte bed, while the other followed the location indicator (crosshairs) on the hand-held computer map using a stylus. All unique substrate patches were mapped in the same manner. Macrophyte and substrate data were mapped along the entire transect and up to 100 metres from shore or to a water depth of 10-metres, whichever occurred first.

ArcView GIS 3.2a (ESRI 2000) was used for analysis and graphical representation of the obtained data. Individual layers of macrophyte coverage, substrate coverage and type as well as bathymetry data were merged to produce polygons of unique vegetation, substrate and depth combinations. The data were then exported to a Microsoft Excel spreadsheet and input files for the Habitat Alteration Assessment Tool were created. The input files were then converted to a comma-separated format and uploaded to the HAAT analysis website. The habitat data were considered to be the same for Summer 2002, Fall 2002 and Summer 2003 data analyses as there was little to no observed change in the mapped variables in those seasons. However, Spring 2003 sampling took place before any macrophyte growth occurred. Although depth and substrate information remained the same as in other seasons, macrophyte coverage was set to zero in the HAAT data input file.

A custom species list was created in the Location module of the HAAT. The list comprised 57 species, including the 47 species historically found at the sample sites from the fish community database and ten other species, determined by discussions with DFO as being desirable for the area (e.g., lake sturgeon (*Acipenser fulvescens*)) or having a reasonable likelihood of being found within the study sites (Table 2.1). The rationale for decreasing the number of fish used in the HAAT weighted suitable area calculations from the default 106 Lake Ontario species was to present a "realistic scenario" for the HAAT validation.

2.2.5 Data Analysis

Fish Community Data

To assess changes in the fish community, the reciprocal form of Simpson's diversity index (D) and the modified Hill's ratio (E5), an evenness index, were used. Simpson's reciprocal index was calculated using Species Diversity and Richness version 2.65 (Pisces Conservation Ltd 2001). The Simpson's diversity index is a non-parametric test that makes no assumptions about the community from which samples are drawn (Ludwig and Reynolds 1998; Southwood and Henderson 2000). Simpson's diversity index incorporates species richness and equitability and describes the probability that a second individual chosen at random from a population will be the same as the first (Ludwig and Reynolds 1988; Southwood and Henderson 2000; Magurran and Phillip 2001; Ponce-Hernandez 2004). The reciprocal form, Simpson's D, is a measure of the very abundant species in the sample, with a higher D-value indicating higher species diversity (Ludwig and Reynolds 1988; Southwood and Henderson 2000; Magurran and Phillip 2001; Ponce-Hernandez 2004) and is given by Southwood and Henderson (2000) as:

$$D = 1/C \qquad \text{Equation 2.1}$$

where:

$$C = \Sigma p_i^2 \qquad \text{Equation 2.2}$$

and where p_i is the proportion of individuals of the i^{th} species in the sample and:

$$p_i^2 = N_i\,(N_i - 1)/\ N_T\,(N_T - 1) \qquad \text{Equation 2.3}$$

where N_i is the number of individuals of the i^{th} species and N_T is the total number of individuals in the sample.

Evenness is a measure of the equality of species abundances in a sample and is at its maximum when species abundances are equal (Ludwig and Reynolds 1988; Magurran and Phillip 2001). The modified Hill's ratio (E5) is a preferred evenness index because it is relatively unaffected by species richness in the sample. E5 increases as evenness increases, and approaches zero as a single species becomes more dominant (Ludwig and Reynolds 1988). E5 is computed as:

$$E5 = (1/\lambda) - 1/(e^{H'} - 1) = (N2 - 1)/(N1 - 1) \qquad \text{Equation 2.4}$$

where:

N2 is Hill's N2 and is equivalent to D of equation 2.1 and where:

$$N1 = e^{H'} \qquad \text{Equation 2.5}$$

where H′ is the Shannon-Wiener Index, and is computed as:

$$H' = -\sum_{i=1}^{S} p_i (\ln) p_i \qquad \text{Equation 2.6}$$

where the S is the number species and p_i is the proportion of individuals in the i^{th} species.

Temporal changes in diversity and evenness and relationships between diversity and evenness and the environmental variables (maximum effective fetch and habitat suitability values) were assessed for significance using linear regression analysis. All statistical analyses were performed using SYSTAT 10.0 (SPSS 2000) unless otherwise stated. Graphical analyses were performed using SigmaPlot Version 8.0 (SPSS 2002).

HAAT Validation

Many methods exist for testing model validity, although no single test is favoured for this purpose (Naylor and Finger 1967; Sargent 1982; Power 1993; Rykiel 1996). Selection of validation methods must take into consideration model users and purpose and resource constraints (Naylor and Finger 1967; Sargent 1982; Power 1993; Rykiel 1996). Validation of the HAAT primarily focused on operational validity, defined as determining that the pertinent characteristics of the model adequately represented the problem entity for the intended use of the model (Sargent 1982). Because the HAAT had already been developed, it was assumed that the HAAT had been face validated (Power 1993) against current biological theory and verified for possible computer coding errors. Because of the predictive nature of the HAAT, predictive validation methods were used. In predictive validation, the model is used to predict values for the real system prior to obtaining system data (Sargent 1982; Power 1993; Rykiel 1996). The resulting predictions and observed values are then statistically tested to see whether they agree (Sargent 1982; Power 1993; Rykiel 1996). Several methods exist for determining whether model and system values differ (e.g., Sargent 1982; Power 1993; Smith and Rose 1995; Rykiel 1996). Smith and Rose (1995) discuss model goodness-of-fit (GOF) methods including the regression of observed versus predicted values, as used in this study whereby HAAT predicted suitability values were regressed against observed biomass and number of individuals values from each study site to assess the degree to which suitability explained variability in biomass.

Correspondence between HAAT predicted habitat productivity as measured by suitability values and actual production as measured by captured biomass was further assessed using mean error (bias) and mean absolute percent error (MAPE) statistics (Power, 1993). HAAT suitability values were converted to biomass for each trophic grouping at each study site using the trophic grouping-specific (e.g., warmwater non-piscivores) regressions of actual biomass on suitability as discussed above. The exceptions were for coldwater piscivores (ColdP) and coldwater non-piscivores (Cold NP) for which no statistically adequate regressions were estimated. For ColdNP, HAAT predicted suitabilities were converted to biomass assuming biomass for the trophic group was proportional to the biomass in the other trophic groupings. For ColdP, where there were no HAAT predicted suitabilities, no biomass was assumed.

Predictive errors for each trophic grouping and site combination were computed as predicted biomass minus actual biomass. Mean predictive error (bias) was then computed as the mean of the predictive errors of: 1) common trophic groupings (e.g., ColdNP) at all sites (n=17); and 2) all trophic groupings for which regression-based prediction of biomass could be made at a common site (e.g., Cell A for coolwater piscivores (CoolP), coolwater non-piscivores (CoolNP), warmwater piscivores (WarmP) and warmwater non-piscivores (WarmNP)). The statistical significance of the bias for each site was assessed using the W statistic as described in Power (1993):

$$W = \frac{\sqrt{m}\,\bar{e}}{s} \qquad \text{Equation 2.7}$$

where, m is the number of samples in the predicted data, $\bar{e}$ is the mean error of the predicted and actual data, and s is the standard deviation of the actual data. Results were then assessed for significance with absolute values of the test statistic exceeding 1.96 indicating significant bias at the 0.05 level of significance (Power, 1993). MAPE was computed following Power (1993) as:

$$\text{MAPE} = \frac{100}{m}\sum_{t=1}^{m}\frac{|e_{n+1}|}{|S_{n+1}|} \qquad \text{Equation 2.8}$$

Where m is the number of samples in the predicted data, e_{n+1} is the predictive error and S_{n+1} is the actual biomass.

Observed productivity in this study was considered in two forms: biomass and number of individuals. Standardized (1000 seconds) biomass and number of individuals (abundance) data were grouped by trophic level and thermal preference (e.g., coolwater piscivore, warmwater non-piscivore etc.) and transformed to normalize the data as follows:

$$\ln(x+1) \qquad \text{Equation 2.9}$$

where x was the total biomass or number of individuals. The transformation $\ln(x+1)$ thus eliminates zero values from the data.

Data underwent three different data treatments and analyses: individual site-specific, averaged site-specific and seasonal site-specific. The individual site-specific analyses assessed all the sample data as independent samples; by fish group (cold, cool, warm and piscivore, non-piscivore) and by study site, for each sample season. Thus there were four biomass and four number of individuals values computed for each fish group at each study site for each of the four sample seasons where data were available.

For the averaged site-specific analyses, Summer 2002, Fall 2002 and Summer 2003 biomass and number of individuals data were averaged (after transformation) for each site. Thus there was one biomass and one number of individuals value for each fish group at each study site. Spring 2003 was not included in the averaged data analyses because the data differed markedly from observations collected in the summer and fall sampling periods, with biomass and numbers of individuals being notably lower. Finally, the data were separated by fish group, by study site, and by season to assess seasonal differences in the analyses.

Using regression analyses, the HAAT's predicted productivity (suitability) and observed productivity (biomass and number of individuals) for a given site were compared to determine whether the HAAT yielded unbiased and accurate predictions. Only suitability values for adult fish were assessed in this study due to sampling limitations. Discrimination between adult, spawning and YOY fish could not be carried out without lethal sampling.

Additional regression analyses were performed on water, and air temperature, and maximum effective fetch data to assess the relationships between these variables and the observed biomass and/or number of individuals. Backward stepwise multiple regressions were used to determine the best multivariate model for explaining the variability in the productivity data. Univariate and multiple regressions were performed on embayments-only and open coasts- only in addition to all-sites in the individual site-specific and averaged site-specific analyses to determine if significant relationships were associated with habitat type.

For the individual site-specific and seasonal data, the regression analyses included individual water temperatures from the date of sampling and mean 30-day air temperatures. Mean 30-day air temperatures were calculated by averaging the air temperature for 30 days prior to, and including, the date of sampling. Air temperatures were obtained online from the Climate Data Online website maintained by Environment Canada (Environment Canada 2005). For the averaged site-specific analyses, water and mean 30-day air temperatures were averaged from Summer 2002, Fall 2002 and Summer 2003 data at each study site. An additional variable, seasonal trend (trend) was included only in the individual site-specific analysis where temporal trends resulting from localized habitat degradation or improvement were possible as a result of non-measured physical changes or habitat interventions. Accordingly, the trend variable was intended to represent the effect of included variables on habitat over time.

2.3 Results

2.3.1 Site Habitat Assessment

Site habitat assessment results are summarized for Tommy Thompson Park, Toronto Islands and Humber Bay Park in Tables 2.2–2.4. Comprehensive details of the vegetation coverage, substrate type and water depth are given in Appendices A and B for select sites. Data are provided in figure format in Appendix A, and in HAAT input file format in Appendix B. The appendices show how a site was divided into individual polygons of unique depth, substrate and vegetation combinations, as required for input into the HAAT.

The dominant substrates at all sites were sand and silt, with varying amounts of boulder, cobble, rubble, gravel and clay (Tables 2.2– 2.4). Open coast sites generally had higher percentages of coarser substrates (bedrock, boulder, cobble and rubble) than sheltered embayment sites, but were still dominated by sandy substrate. The exception was Lighthouse Point at Tommy Thompson Park where boulder and rubble dominated (95%). This site also had the greatest percentage of water ≥5 metres deep (69.27%) (Table 2.2).

Submergent macrophyte cover varied greatly among sites. The open coast sites had greater proportions of no vegetation cover, particularly Gibraltar Point (99.44%, Table 2.3), Wards Island (95.35%, Table 2.3) and Lighthouse Point (95%, Table 2.2). These open coast sites also had the highest maximum effective fetch of all study sites (Table 2.5). Areas of submergent vegetation were significantly and positively correlated with the 1-2 metre depth zone (P=0.02, r^2= 0.30) and negatively correlated with fetch (P=0.01, r^2= 0.35).

Water temperatures varied between sampling periods as was expected given the different sample dates. Summer 2002 water temperatures ranged from 17.0 - 22.3°C whereas Summer 2003 water temperatures were only 13.0 - 19.0°C (5.2°C difference in means). Fall 2002 and Spring 2003 water temperatures were similar, ranging from

4.2 - 14.7°C and 6.2 - 14.2°C, respectively. The mean 30-day air temperature (air temperature) for Summer 2002 ranged from 22.4 - 22.7°C, and like water temperature was lower for Summer 2003 (19.1 - 19.3°C). In Fall 2002 and Spring 2003, air temperature ranged from 12.2 – 16.0°C and from 6.7 - 7.9 °C, respectively.

2.3.2 Fish Community Assessment

Diversity

Diversity of the sample sites was assessed using Simpson's Reciprocal Index (D). The Gibraltar Point open coast site was removed from the analysis because only one fish was captured at the site on any of the sample dates. Site diversity in each sample season was ranked in order of ascending Simpson's value (D) to illustrate how diversity changed by season (Figure 2.5).

The results show that the ordering of site diversity differed each season and diversity of open coasts and sheltered embayments appeared to be randomly mixed, with no group more or less diverse than the other. The exception was for Summer 2003 when all five open coast sites were within the bottom eight rankings. Lighthouse Point was the most consistent in the rankings, exhibiting the lowest diversity of all the sites, in all seasons, except in Fall 2002 where it had the fourth lowest diversity score. Figure 2.6 provides a more striking contrast of the differences in diversity across the sample seasons at each site. Summer 2002 diversity was less than or equal to that of Summer 2003 in all but three sites

(Humber Bay Inner and Outer Habitat Isles and Wards Island) and was also less than Fall 2002 diversity in all but three sites (Cell 1, Wards Island and Palace Pier).

Regression analysis indicated that suitability was significantly and positively correlated with Summer 2003 diversity (r^2=0.26, 1-tail P=0.027) but not correlated with Summer 2002 diversity ($P>0.05$). As individual explanatory variables, suitability and water temperature were positively correlated with Spring 2003 diversity (r^2=0.236, 1-tail P=0.033; r^2=0.360, P=0.018, respectively) and fetch was negatively correlated (r^2=0.266, P=0.049). Backward stepwise regression analyses of the Spring 2003 data produced a multivariate model comprised of suitability and water temperature (r^2=0.514), with water temperature being more important for explaining variability in the data than suitability as measured by the standardized regression coefficients, 0.534 and 0.397, respectively. No other significant correlations were found between diversity or evenness and the variables measured in this study.

Fish Community Response

Lighthouse Point, Snake Island, Wards Island and Palace Pier were not included in analysis of fish community response because of a limited number of sample years were available ($N \leq 3$). Plots of diversity and evenness over time are provided for the remaining Tommy Thompson Park, Toronto Island and Humber Bay sites in Figures 2.7-2.9. Temporal diversity and evenness were weakly correlated (r^2=0.299) across the study period (1992-2003). Although an increase or decrease in diversity between years was usually mirrored by the same response in evenness at a site, in some cases, an increase in diversity was associated with a decrease in evenness and vice-versa. Species diversity and evenness did not significantly change in 11 of the 12 sites over the time-period studied. Diversity significantly increased for Lighthouse Bay between 1992 and 2003 (r^2=0.551, P=0.013) while evenness significantly decreased at the Humber Bay Inner Islands site (r^2=0.709, P=0.017).

2.3.3 Habitat Alteration Assessment Tool Validation

Input files created from the site habitat assessments were uploaded into the Habitat Alteration Assessment Tool (HAAT) and weighted suitable area (WSA) values were generated. Table 2.6 provides an example of a WSA output file from the HAAT. The data shown represent WSA values for Donut Island, using summer and fall habitat data. Site suitability values (WSA/total area) for every sample site and for each trophic group based on summer/fall and spring habitat assessments are shown in Tables 2.7 and 2.8, respectively. Suitability values are given for adult fish only, for reasons previously discussed in the Methods section.

Univariate Linear Regression Analyses

Detailed results of the univariate linear regression analyses are provided in Appendix C (Table C1- C6). Regression analyses showed significant correlations for some, but not all, variables and were dependent on the data treatment (e.g., individual site specific data, averaged site specific data or seasonal data), site groupings (all-sites, embayments-only, open coasts-only) and which dependent variables were included in the model (biomass data or number of individuals). No ColdNP species were caught in the course of the research and results for this trophic grouping are not reported here. Additionally, suitability for coldwater piscivores (ColdP) was calculated to be zero. Therefore, regression analyses of suitability on biomass and number of individuals could not be performed. Regression analyses, however, were possible for ColdP biomass and number of individuals and the other variables (e.g. fetch, temperature) measured in this study.

As a single explanatory variable, suitability was positively and significantly correlated to biomass and number of individuals productivity measures with r^2 ranging from 0.140 (P=0.008) (Table C3) to 0.702 (P=0.019) (Table C1).

Seasonal trend, assessed only in the individual site-specific analyses, explained only a small proportion of the variability in CoolNP biomass and number of individuals data in the all-sites and embayments-only analyses (r^2=0.099, P=0.012 to r^2=0.175, P=0.007) (Tables C4 and C3, respectively).

Water temperature was significantly correlated with biomass and number of individuals with r^2 varying from a low of 0.272 (P=0.046) (Table C5) to a high of 0.762 (P=0.023) (Table C2) in the averaged site-specific and seasonal data. Where correlations existed with water temperature, the relationship was positive except for CoolNP biomass (r^2=0.288, P=0.026) (Table C5) and number of individuals (r^2=0.367, P=0.010,) (Table C6) in the Summer 2002 cases. No correlations were found between the productivity data measures and water temperature in the individual site-specific data analyses.

When maximum effective fetch was used as a single explanatory variable, models estimated using averaged site-specific, individual site-specific or seasonal data commonly indicated a significant negative influence on biomass and number of individuals in all fish groups except ColdP. Fetch had a greater effect on the warmwater fish groups in the different data treatments (r^2=0.127, *P*=0.022 to r^2=0.891, *P*=0.005) (Tables C4 and C1, respectively) than on the coolwater fish groups (r^2=0.085, *P*=0.027 to r^2=0.408, *P*=0.001) (Table C3).

Mean 30-day air temperature (air temperature) was a better explanatory variable for the seasonal data than for the other data treatments. Positive correlations were found mainly in Summer 2002 and Summer 2003 analyses, with r^2 ranging from a low of 0.319 (*P*=0.018) (Table C6) to a high of r^2=0.707 (P<0.001) (Table C5). In Fall 2002, air temperature was able to explain 33.9% of the variability in the number of CoolP individuals (Table C6). A single correlation with air temperature was found for WarmP biomass in the averaged site-specific analysis of the all-sites data (r^2=0.277, *P*=0.030) (Table C1). Air temperature, however, was not significantly correlated with any of the individual site-specific data sets.

Multiple Regression Analyses

In addition to simple linear regressions, backward stepwise multiple regressions were used to determine the best multivariate model for explaining the variability in the observed productivity data. Results of the stepwise regression analyses are summarized in Tables 2.9 – 2.18. Altering the analysis by running forward stepwise regressions or lowering the F-to enter and exit values did not include or exclude additional explanatory variables, and verified the robustness of the models (Draper and Smith 1981). Results indicated that multiple variable models were often better able to explain variability in the productivity data than single variable models. Where no multivariate statistically adequate models were estimated, the best univariate model was used. In some cases, no model was able to adequately explain (regression F-statistic $P>0.05$) the observed variability in data for a given trophic group. In such cases, no results are reported. Graphical representations of r^2 values and the constituent explanatory variables from the all-sites analyses are provided in Figure 2.10 for the biomass data and Figure 2.11 for the number of individuals data.

Overall, very few relationships were found between the productivity data for ColdPs and study measured physico-chemical variables. The relationship of fetch to the productivity data was always negative and seasonal trend emerged as a significant explanatory variable only for the CoolNP grouping.

Averaged Site Specific Data

In the analysis of all-sites, only two multivariate statistically adequate models were found (Table 2.9). For WarmPs, suitability and mean water temperature together accounted for 69.1% of the variability in the number of individuals, with mean water temperature being the more important of the two as determined by computed standardized regression coefficients. In addition to suitability and mean water temperature, maximum effective fetch and mean 30-day air temperature were required to adequately explain WarmNP number of individuals (r^2=0.916). Suitability and mean water temperature were positively correlated with the number of individuals, while fetch and air temperature were negatively correlated. Suitability was the most important of the explanatory variables, although only marginally more important than fetch. A plot of the observed (actual) versus predicted number of warmwater non-piscivore individuals from the model is shown in Figure 2.12.

Assessment of embayment sites produced only a single multivariate model (Table 2.10). For WarmNP number of individuals, the positive correlation of suitability and the negative correlation of air temperature were equally important for explaining variability in the data. The positive correlation with mean water temperature, however, was the most important determinant of variation in the number of WarmNP individuals. A plot of the observed versus predicted number of individuals from the model is shown in Figure 2.13.

In the open coasts analyses, the models (univariate and multivariate) explained large amounts of the observed variation (r^2 = 0.877- 0.996) for both biomass and number of individuals (Table 2.11). The CoolNP number of individuals model was dominated by a positive correlation with mean water temperature that was more than twice as important than suitability for explaining variability in the data as measured by the computed standardized regression coefficients. Fetch was the most important determinant of WarmP biomass and WarmP and WarmNP number of individuals. Variations in WarmP biomass and WarmNP number of individuals were also related to mean water temperature, with suitability entering as a significant explanatory variable only in the WarmNP model.

Individual Site-Specific Data

For the all-sites analyses, multivariate models were estimated for biomass and number of individuals data for all trophic groups except for coldwater piscivores (Table 2.12). Only a small proportion of the variability in the coolwater fish data was explained by the measured variables considered in this study ($r^2 \leq 0.250$). Suitability, fetch and air temperature were all related to CoolP biomass and number of individuals with suitability having the least, and only positive influence on the observed variation in the data. Fetch was the most important variable for explaining variability in the biomass data, whereas air temperature was most important for explaining variability in the number of individuals.

Seasonal trend and fetch contributed to the observed variation for CoolNP biomass, while seasonal trend and air temperature contributed to the variation in the number of CoolNP individuals. Unlike CoolPs, the air temperature relationship with CoolNP number of individuals was positive. For both biomass and number of individuals analyses, seasonal trend was the most important explanatory variable in the multivariate model. Variability in biomass and the number of individuals in both warmwater fish groups was associated with suitability and fetch, with suitability being the more important of the two explanatory variables as measured by the computed standardized regression coefficients.

Embayments-only analyses (Table 2.13) also indicated that little of the variability in the biomass or number of individuals data was explained by the measured variables of suitability, temperature or fetch. The exceptions were WarmP biomass and number of individuals where suitability and biomass combined to explain, respectively, 45.8% and 54.2% of the variability in the data. In both cases, suitability was positively correlated with the data and was the more important of the explanatory variables. In the CoolP models, air temperature was more important for explaining data variability than suitability. For CoolNP biomass data, variability was explained more by the seasonal trend regressor than by the fetch regressor.

Analyses of the open coast sites yielded statistically adequate multivariate models for CoolNPs and WarmNPs only (Table 2.14). Fetch was more important for explaining CoolNP biomass data variability than suitability. For CoolNP number of individuals, fetch was less important than either seasonal trend or air temperature for explaining variability in the data. Suitability and fetch produced the best model for all WarmNP analyses, with suitability being most important for explaining biomass and fetch most important for explaining the number of individuals. A plot of the observed versus predicted biomass from the coolwater non-piscivore model is shown in Figure 2.14.

Seasonal Data

Only two multivariate models were found in analyses of the Summer 2002 data, both for WarmPs (Table 2.15). Suitability and water temperature were able to explain 52.2% of the variability in biomass, although water temperature was marginally more important. 52.8% of the variation in the number of individuals was driven by variations in water temperature and fetch, with the relationship with water temperature being dominant. Air temperature explained a portion of the variability in both ColdP analyses (≈0.47) and the cool non-piscivore biomass (r^2=0.328). For the CoolNP number of individuals, data variability was best explained by water temperature (r^2=0.367). Suitability was the only significant variable for explaining variability in the number of CoolP individuals (r^2=0.183), WarmNP biomass (r^2=0.315) and WarmNP number of individuals (r^2=0.445).

No significant multivariate models were found for Fall 2002 data and only three trophic groups were in any way significantly related to the measured variables used in this study (Table 2.16). Biomass and number of individuals of WarmPs and WarmNPs were negatively related to fetch, with r^2 values ranging from 0.369 to 0.785. CoolP number of individuals were positively related to measured water temperature, which explained 36.8% of the observed variability. In Spring 2003, CoolP biomass and number of individuals were positively correlated with water temperature (Table 2.17), but negatively correlated with air temperature. Together the variables explained 54% and 56%, respectively, of the variability in biomass and number of individuals data, with water temperature being the more important of the two variables as determined by standardized regression coefficients.

The model for CoolP biomass included water temperature and air temperature and was the only statistically adequate multivariate model to be estimated using the Summer 2003 data (Table 2.18). Air and water temperature were positively correlated with the biomass data, with air temperature being the more important of the explanatory variables. Suitability was the only significant explanatory variable related to CoolNP biomass, WarmNP biomass and WarmNP number of individuals and explained >52.8% of the variation in the WarmNP data (Table 2.18). Air temperature was the only significant explanatory variable for the CoolP number of individuals and WarmP biomass and number of individuals, explaining between 34.3% and 43.9% of the observed variability in the data.

Bias Assessment

Bias and accuracy analyses in the form of mean error (bias), bias significance and mean absolute percent error (accuracy) are provided in Table 2.19 for site-specific analyses and in Table 2.20 for trophic group-specific analyses. ColdP and Cold NP trophic groupings showed significant predictive bias ($P<0.05$) as a result of the prediction of no suitability (e.g., ColdP) or the non-observance of fish within that trophic grouping at each site (e.g., ColdNP). For the remaining trophic groupings, HAAT bias was statistically insignificant across sites. On a site-specific basis, the HAAT model significantly over-predicted fish productivity at Lighthouse Point

($P<0.05$) and under-predicted fish productivity at Cell 3, Lighthouse Bay and the Fishing Pier.

Mean absolute percent error (MAPE) values were quite large, ranging from a low of 10.84% at Embayment C to a high of 134.92% at Cell 1. Sites with the highest MAPE values (28.15% - 134.92%) also had observed ColdP productivity, the exceptions being Gibraltar Point (112.25%) and Lighthouse Bay (51.21%), where no ColdP species were captured. Lower MAPE values (≤ 27.76%) were associated with sites dominated by warmwater fish species in embayments with one open coast exception (Snake Island MAPE = 25.02%). Only four sites (Bay C, Donut Island, Lighthouse Bay and Sunfish Cut) had MAPE values < 25.0 % and no sites had MAPE values < 10.0%.

2.4 Discussion

2.4.1 Diversity and Fish Community Response

Having over 12 years of standardized fish community data available on multiple sites provided a rare opportunity to assess the fish communities of the Toronto waterfront. One objective of this research was to determine whether there was any evidence of a fish community response to the habitat alterations that have occurred along the Toronto waterfront over the last decade. Diversity and evenness analyses indicated that no significant changes were discernable at 11 of the 12 sites included in the diversity study, regardless of whether the sites had been subjected to habitat alterations or had been allowed to evolve naturally. Consequently, there were no detectable responses to known habitat alterations. Since physical habitat was the only variable manipulated, and neither the naturally evolving nor the altered sites showed a response, it can be inferred that physical habitat was not the driving force determining fish distributions in any of the study sites. Given that Lighthouse Bay alone demonstrated a significant change in diversity, and there was no correlation with the measured study variables, it can be presumed that the increase in diversity at Lighthouse Bay was the result of an unknown factor. Considering that Lighthouse Bay was not the only site that was allowed to progress naturally, if broad-scale changes such as increases in air and water temperature had been responsible for the observed diversity changes, similar increases in diversity should have been observed in the other natural sites as well. The decrease in evenness seen at the Humber Bay Inner Islands site similarly appears to be a result of an unknown factor. However, since the site itself was only created in 1997, too few observations (N=7) exist to draw clear conclusions.

It is important to note that species diversity analyses are not infallible methods of assessing communities in their entirety. Increases in water temperatures similar to those proposed by various climate change prediction models, but not monitored in routine sampling, may already be occurring. Increased temperatures, therefore, may have resulted in shifts in the dominant thermal guilds by creating conditions favouring warmwater species facilitating increased colonization, abundance and productivity trends (Hill and Magnuson 1990; Magnuson et al. 1990; Magnuson et al. 1997; Chu et al. 2005). Conversely, under warming conditions, cool and coldwater fish species may be displaced by higher than optimal water temperatures, causing them to seek other habitats having thermal properties closer to their preferred temperature range and/or growth optimum (Hill and Magnuson 1990; Magnuson et al. 1990; Magnuson et al. 1997; Chu et al. 2005). For example, increased water temperature might facilitate colonization by warmwater piscivorous species such as smallmouth bass (*Micropterus dolomieu*) and walleye (*Sander vitreus*) (Magnuson et al. 1997; Chu et al. 2005), but displace northern pike (*Esox lucius*), a coolwater piscivore (Chu et al. 2005). Therefore, one trophic group may replace another, resulting in similar diversity values but very different trophic compositions and community interactions.

Species' substitutions demonstrate one of the major weaknesses of diversity measures. The data used in computation are aggregated and simplified to the extent that important details within the aggregate may be lost. For example, in the analysis of Summer 2002 diversity, Wards Island had the highest diversity (D=7.0). The raw data suggests that while it does support a diverse community, it does not support an abundant community. Only five species were caught at Ward's Island, with seven individuals in total. Commonly used measures such as Simpson's reciprocal index are strongly influenced by a few very abundant species and tend to ignore rare species (Ludwig and Reynolds 1988; Southwood and Henderson, 2000), implying that a species' abundance is proportionately related to its importance to diversity

(Ponce-Hernandez, 2004). At several of the study sites, a few very abundant species dominated several species with low abundances, thereby contributing to low diversity values.

Nonetheless, analysis of site diversity did demonstrate one very important point; results from comparison of the diversity data between the 2002 and 2003 sampling periods emphasized the importance of sampling more than one season when monitoring fish communities. The suitability values used in the regression analyses were the same for both summer samples, but a significant relationship was found only for Summer 2003. Mean water temperature in Summer 2002 was 5.2°C higher than Summer 2003 and diversity was ≤ Summer 2003 in all but three sites (Humber Bay Inner and Outer Habitat Isles and Wards Island). Although temperature and diversity were not statistically correlated, the shift in temperature suggests the importance of thermal suitability in structuring fish community composition (Magnuson et al. 1979; Hill and Magnuson 1990; Magnuson et al. 1990; Magnuson et al. 1997; Attrill and Power 2004; Chu et al. 2005), and may have had an effect on the calculated diversity values for the different sample seasons. The summer comparison in particular indicates that community structure and interactions cannot be accurately estimated from a single season sample.

2.4.2 HAAT Validation

The primary objective of the study was to determine whether the Defensible Methods model provided a reasonable basis for assessing fish habitat alterations on Toronto waterfront shores in terms of the accuracy and biases of its predictions.

The implicit hypothesis being tested was that the structural suitability of a habitat is fundamental to determining fish distributions (Minns et al. 1995; Randall et al. 1996; Jackson et al. 2001; Minns et al. 2001; Pratt and Smokorowski 2003) and that fish have preferential combinations of macrophyte cover, substrates and water depths required for hunting, spawning and shelter behaviours (Hill and Magnuson 1990; Minns et al. 1995; Coker et al. 2001; Jackson et al. 2001; Minns et al. 2001; Cudmore-Vokey and Minns 2002; Chu et al. 2005) and would, therefore, have biomass and abundance indices consistently correlated with suitability. However, results of this study showed that while suitability was significantly correlated to biomass and numbers of individuals on a fairly consistent basis for warmwater species, the amount of variability explained by suitability alone was not always large. Variability in biomass or number of individuals was often better explained by suitability in conjunction with the other measured variables in this study. Accordingly, the determination of site habitat suitability for a given group of fish does not unequivocally determine its occupancy by those species. Habitat suitability better predicts warmwater fish species and overall occupancy of sheltered embayment habitats. This is possibly because factors affecting site suitability (e.g., temperature and fetch), that are not included in the habitat assessment required for the HAAT are important for the distribution of cool and coldwater fish species.

Of most interest in the suitability analyses are those for the coldwater fish groups. WSA values generated by the HAAT for coldwater non-piscivores indicated the presence of suitable habitat in each of the study sites. However, a search of the entire fish community database (including historical data) showed that at no time were any coldwater non-piscivore fish species caught at the studied sample sites. This is not necessarily surprising given the list of coldwater non-piscivores considered (Table 2.1), the sites types that were sampled and/or the location of the electrofishing transects. For some species, suitable habitat may be present but not be accessible. For example, while much of Cell 3 deep (>5m) contained suitable habitat for coolwater non-piscivores like lake sturgeon and lake whitefish (*Coregonus clupeaformis*), the isolated location of Cell 3 within the confines of Tommy Thompson Park and lack of connectivity to other similarly suitable habitat may have precluded the area from being actively used by deepwater benthic fishes. However, it is also possible that coldwater non-piscivore species utilized the available habitat, but were not present at the time of sampling. Brown et al. (2000) suggest that fish species may sporadically utilize suitable habitat and may be missed by non-coincident sampling or excluded by temporally adverse environmental conditions during sampling. Capture rates of species may also be affected by their overall abundance in an area, with capture rates tending to be less than proportionate to the quality and quantity of available suitable habitat if overall abundances are lower than the species carrying capacity (Brown et al. 2000). This may be particularly true for lake sturgeon whose populations are estimated to be low in the Great Lakes and, as a consequence, have been designated as a species of "Special Concern" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (COSEWIC 2005).

Fish species may have been present at the time of sampling but missed in the electrofishing survey. Due to the effective depth range of the electrofishing gear, survey transects were run relatively close to the shoreline to improve sampling efficiency. The range of the electric field generated by the electrofisher was approximately 3-5m and was dependant on water temperature, turbidity and conductivity conditions of the water (Straszynski and Carl 2003). Fish below the effective electric field depth would not have been affected by the electrofisher. Additionally, fish within that depth range may have been able to detect and avoid the current, or may simply have been out of reach of the netters.

Consideration of WSA as a correlate for fish productivity yielded other anomalous results. For example, WSA and suitability values for ColdPs for all-sites were calculated to be 0, indicating that there was no suitable habitat for this group of fish. The HAAT exactly predicted an absence of ColdP productivity for 9 of the 17 sites, which encompassed sheltered embayment and open coast sites. Nevertheless, the fish community database records indicate that brown trout (*Salmo trutta*) and chinook salmon (*Oncorhynchus tshawytscha*) were present at eight sites and thus the

HAAT prediction was completely incorrect for those sites. Although a habitat may not be considered "suitable" for a given fish species, suitability does not necessarily preclude the species from sometimes being present in that habitat. This suggests that additional factors such as intra- and inter-specific competition and community dynamics, which were not analyzed in this study, are also important in determining fish productivity (Lane et al. 1996; Minns et al. 1996; Bradbury et al. 1999; Brown et al. 2000; Bradbury et al. 2001; Magurran and Phillip 2001; Brind'Amour et al. 2005; Chu et al. 2005). For example, habitat of low or no suitability to a species may be colonized due to inter-specific interactions and competition (Lane et al. 1996; Bradbury et al. 1999; Bradbury et al. 2001), or when species abundances are high (Brown et al. 2000). Alternatively, species may be captured during transient or opportunistic use of a habitat as a result of movement between suitable habitat patches or as a result of foraging activity in habitat suitable for prey species (Jones et al. 1996; Lane et al. 1996; Bradbury et al. 1999; Bradbury et al. 2001).

Temperature, measured as current water temperature or mean 30-day air temperature, and maximum effective fetch were important predictors of fish biomass or number of individuals (i.e., productivity) and often were better predictors than suitability alone, particularly for the coolwater and coldwater groups. Water temperature is an important environmental factor and may be better described as an "ecological resource" (Magnuson et al. 1979) affecting fish metabolism, behaviour, growth and distribution (Magnuson et al. 1979; Hill and

Magnuson 1990; Magnuson et al. 1990; Magnuson et al. 1997; Chu et al. 2005). Furthermore, fish are mobile and have a range of thermal preferences that they will actively seek (Magnuson et al. 1979; Magnuson et al. 1997). Accordingly, while habitat may be suitable in terms of substrate, depth and vegetative cover, a thermal regime not suited to the physiological function of a particular species will often preclude use of the habitat if more suitable thermal options are available. In addition, competitive interactions between species may lead to niche compression (Magnuson 1979) as has been observed among juvenile fish assemblages in estuarine and nearshore marine environments (Attrill and Power 2004) or when abundances are high (Brown et al. 2000).

Where correlations were found with fetch, productivity was negatively affected in all but one analysis, with relationships being particularly strong at open coast sites. It has been suggested that intermediate fetch may have a positive effect on fish productivity by increasing macrophyte growth and, therefore, fish densities (Randall et al. 1996; Brind'Amour et al. 2005). Fetch may also disperse and suspend sediments, which in turn may increase the available benthic food supply (Brind'Amour et al. 2005).

Fetch determines the amount of mechanical energy exerted on the site in the form of wind and wave action, which in turn, can affect macrophyte distribution, turbidity and substrates (Randall et al. 1996; Brind'Amour 2005). Although a moderate fetch may positively affect macrophyte growth and fish productivity, the energy resulting from a higher effective fetch can prevent or disturb macrophyte growth by increasing turbidity, damaging macrophyte beds and altering the substrates in which macrophytes would grow, such that fetch has a negative effect on productivity (Randall et al. 1996). Fetch may also have a similar direct effect on fish by preventing fish habitat usage and colonization in areas of very high wind and wave energy (Randall et al. 1996). The open coasts in this study were subject to high effective fetch, and had low or no macrophyte growth and low fish biomass and abundance data. Results would appear to support ideas set forth by Randall et al. (1996) indicating that mechanical energy can influence the distribution of the fish more than the structural suitability of the habitat itself.

It is important to note that fetch was also important in the all-sites and embayments-only analyses. Results in the all-sites analyses were likely a result of the influence of the open coast sites on the resulting correlations with biomass and number of individuals. Some of the embayment study sites were subject to relatively high effective fetch that while not affecting the macrophyte coverage to the extent seen in the open coasts, may have increased turbidity and lowered productivity. Although in the WarmP embayments-only analyses suitability emerged as a more important explanatory variable than fetch, the influence of fetch cannot be ignored. Only two WarmP species were caught in the study (largemouth bass (*Micropterus salmoides*) and bowfin (*Amia calva*)) with the largemouth bass having a greater influence on the biomass and number of individuals data. Both species prefer highly vegetated, shallow waters (Lane et al. 1996) and are visual predators. Bowfin prefer to stalk their prey while largemouth bass pursue their prey (Coker et al. 2001). Decreased light penetration as a result of turbidity may affect feeding behaviour (Blaber and Blaber 1980) and the ability of the predator to visually locate prey. As a result, some fish may have moved out of turbid habitats to seek food elsewhere, thereby reducing the strength of the associated between suitability and productivity. Human error in sampling may also have contributed to the results, since turbidity may have prevented netters from seeing and collecting stunned fish.

The embayments-only analysis also yielded the sole positive correlation between CoolNP biomass and fetch. Most of the CoolNP species collected were cyprinids and white suckers (*Catostomus commersonii*). In addition to the increase in productivity associated with an intermediate effective fetch, increased turbidity may have provided small cyprinids with cover from predators. Increased abundance associated with turbidity is a commonly observed phenomenon in estuary environments (Blaber and Blaber 1980). In addition, white suckers and carp (*Cyprinus carpio*) are tolerant of degraded conditions. As bottom feeding species, turbid conditions may have had a smaller effect on their feeding habits and distribution (Hartig 1993; Barbour et al. 1999; Emery et al. 2003).

The single significant positive bias estimated for Lighthouse Point was not surprising given the conditions affecting the site. Lighthouse Point is a deep, open coast site with extremely high effective fetch and wave action which, as previously discussed, can have negative effects on fish productivity, regardless of the suitability of the habitat. Significant negative bias found for Cell3, Lighthouse Point and the Fishing Pier was likely related to the large proportion of fish cold and cool grouping fish biomass found at each site. Although the HAAT model over- or under-predicts actual productivity at some sites, overall the model does not provide biased results across the majority of the sites (13 of 17). Nevertheless, the model does not provide very accurate predictions as a whole. Higher MAPE values (low accuracy) were found at sites with observed ColdP because the HAAT predicted no ColdP productivity that resulted in high error values that heavily influenced site-specific MAPE computations. Conversely, the HAAT was 100% accurate for ColdPs at individual sites where no ColdP productivity was observed, when only that fish group was evaluated. The lack of predictive accuracy of the HAAT at Gibraltar Point and Lighthouse Point was not unexpected due to the high effective fetch affecting the sites, which precluded their colonization by most fish. That the HAAT had better predictive accuracy at embayment sites dominated by warmwater species supports findings from the regression analyses that similarly demonstrated the HAAT has a bias towards warmwater fish groups in embayments.

2.5 General Conclusions and Future Work

2.5.1 Fish Community

Simpson's reciprocal index is a measure of the very abundant species in a given sample and therefore may not sufficiently account for many species of low abundances (Ludwig and Reynolds 1988; Southwood and Henderson, 2000). The modified Hill's ratio is independent of sample size and variation caused by the inclusion of rare species and, therefore, it is also independent of species richness (Ludwig and Reynolds 1988). As a result, a sample may be perfectly even, but not very rich. Because of these weaknesses in diversity and evenness indices, it is important to recognize that a single measure of community diversity or evenness is not necessarily able to adequately explain community composition and/or interactions and, therefore, that more in-depth analyses of the trophic changes and interactions are necessary to gain an understanding of temporal changes in community structure. This was true of the data examined in this study. Major changes in the fish community may have occurred either naturally, or as a result of habitat alterations, but the changes were not revealed by the use diversity analyses alone. As a result, the TRCA is currently conducting a comprehensive analysis of the fish community data to determine what significant species and trophic changes occurred (if any) in Toronto waterfront communities in the last decade. Results from the analysis may ultimately detect fish responses to the known habitat alterations and may also be able to explain the significant changes noted at Lighthouse Bay and the Humber Bay Inner Islands.

2.5.2 Habitat Alteration Assessment Tool

The Habitat Alteration Assessment Tool (HAAT) provides reasonably accurate results for warmwater fish species in sheltered embayments and as such, is a relatively good surrogate for productivity in such cases. However, results here indicate that while habitat suitability may be correlated with the biomass and numbers of individuals of other fish groups, suitability was not necessarily the most important explanatory variable. Maximum effective fetch appears to be an equally good, if not better, predictor of productivity than suitability for open coast sites and for some of the less sheltered embayments. Temperature also plays a strong role in determining which fish groups contribute to the overall productivity of a site, especially in the case of the coolwater piscivores. According to climate change models, temperature may become an increasingly important determinant of productivity (Hill and Magnuson 1990; Magnuson et al. 1990; Magnuson et al. 1997; Chu et al. 2005). Increases in air and water temperature may allow warmwater species to expand their habitats and increase their biomass, with ultimate consequences for species composition and overall productivity (Hill and Magnuson 1990; Magnuson et al. 1990; Magnuson et al. 1997; Chu et al. 2005). Such predictions suggest the HAAT tool may become increasingly better at predicting the productivity consequences of habitat alterations.

When habitat suitability was significantly correlated to the productivity of the coolwater piscivores and non-piscivores, it explained only a small proportion of the variation in the productivity data, or was a much less important explanatory variable than air or water temperature. Although the HAAT was able to exactly predict the coldwater piscivore productivity at nine of the study sites, significant predictive error at the remaining sites resulted in overall significant predictive bias for the trophic grouping as a whole. Similarly, for coldwater non-piscivores, significant predictive bias was evident. Predictive biases for the coldwater trophic groupings suggest the need for inclusion of other explanatory variables in the HAAT and underscores the fact that suitability, does not adequately explain observed variability in the use of Toronto waterfront habitats by coldwater fishes. As a result, questions exist about the logic of including coldwater species habitat suitability considerations in the HAAT when factors such as inter-specific interactions may exert a much stronger influence on fish distribution or when habitats may not include adult representatives of such species. Usage and suitability relationships for YOY or spawning populations were not studied and therefore cannot be commented upon. However, that no coldwater non-piscivore species of any life history stage were recorded in the history of the TRCA's fish community database gives some cause for concern about their populations and/or habitat usage in the Toronto Harbour area. As stated previously, the apparent absence may be a function of sampling gear bias and human sampling error and data may not be representative of a true lack of habitat usage. Accordingly, further efforts to assess abundances specifically of this fish group are warranted.

The purpose of the HAAT is to predict productivity before and after a development to assess whether no net loss (NNL) of productive capacity of the habitat has been achieved. The critical point to bear in mind about the NNL principle is that it refers to "productive capacity", not realized productivity. Minns (1997) and Jones et al. (1996) discuss the difficulty of interpreting and assessing "productive capacity" and Minns (1997) argued that the NNL principle should refer to "no net loss in the natural productivity of fish habitats" as opposed to "no net loss in the productive capacity of fish habitats". Although it is likely that the HAAT model protects the productive capacity of a site, it does not necessarily take into consideration the actual or realized productivity of the site (Minns et al. 2001). However, the NNL principle is intended as a guide to assessing habitat alterations and common sense and logic must be used when trying to attain NNL (DFO 1986). It is possible that HAAT predicted net losses may be associated with actual increases in realized productivity in the post-development phase. Accordingly, unless the wording of the NNL principle is changed, development proponents will still be required to compensate for loss of productive capacity, regardless of the development's effects on realized productivity.

The use of a precautionary approach as recommended by Minns et al. (2001) is nonetheless suggested. It should be assumed that habitat alterations resulting from a development will produce a net loss in productivity, contrary to the habitat management policy. Although a species may not currently be using the habitat, or is not perceived to be using the habitat, it does not necessarily mean that they will not use the habitat in the future. This is especially true of desirable species occurring in low abundances like lake sturgeon. The fact that that there are no sturgeon present along the Toronto waterfront does not mean that development proponents and fisheries managers should not include them in their assessments. If viable populations are to return to the area, they will need suitable habitat. If such habitat does not exist, it will almost certainly hamper the population re-establishment.

Several cautionary statements regarding the HAAT are detailed in Minns et al. (2001) and must be taken seriously. The HAAT is a short step between a decision made in "almost complete ignorance" and a decision made with "complete knowledge" (Minns et al. 2001). The HAAT was not developed to replace the interaction and negotiation between the development proponent and the habitat analyst. Proponents must provide a realistic, defensible assessment of the pre- and post-development habitat conditions. Although the HAAT is meant to be an objective method of assessing fish productivity, a certain amount of subjectivity is required by the habitat analyst. Species lists, fish groupings and fish group weightings must be appropriate for the location and type of site being developed. Furthermore, that analyst must take into account all aspects and implications of the proposed development that are not considered by the HAAT, such as fisheries activities, threatened and invasive species (Minns et al. 2001).

The HAAT "is an empirical approach with no pretensions of providing an explanatory model of how fish productivity derives from the productivity potential of habitats. It is designed for its intended use as a problem-solving tool from the outset" (Minns et al. 2001). As an empirical approach, it much be tested empirically by replicated experimental habitat alteration studies that provide results consistent with the predicted HAAT results and/or by comparative surveys yielding significant relationships between the predicted suitabilities and a variety of fish community measures (Minns et al. 2001). A study in Severn Sound, Georgian Bay, Ontario (Minns et al. 1999a) tested suitability against three fish community measurements (biomass, density and species richness), and found significant correlations in 10 of 36 cases that included spawning and YOY populations. The only correlation found for warmwater adults in Severn Sound was between suitability and warmwater non-piscivores density. In addition, significant correlations were found between suitability and all three fish community measurements for coolwater non-piscivore adults. The Severn results differ from those in this study, which has shown better correlations between suitability and adult warmwater groups and fewer significant correlations between suitability and adult coolwater groups. The contrasting results between the two studies emphasize the importance of performing multiple studies before conclusions regarding the validity of the HAAT can be made.

Continued evaluation of the HAAT should be performed and more conclusive results may be obtained by increasing the number of fish samples in a season to get a better representation of site productivity. By using fewer samples, the risk of collecting bias data due to a single aberrant event is greatly increased. Furthermore, spot physico-chemical data collected coincident with sampling may not have been representative of the community for the entire season. This study only looked at suitability for adult fish because it could not differentiate adults from YOY and/or spawning fish without lethal sampling. Although time consuming and costly, future evaluations of the HAAT should endeavour to ensure adequate collection of the three life history stages for comparison with suitability values. A method of incorporating temperature should also be investigated, although it is suspected that such an attempt would be labour intensive and would require a substantial number of observations to build a representative database that could account for the necessary temperature-species interactions occurring under different environmental and habitat conditions.

The HAAT has many options and is highly flexible, but was not tested to its fullest extent of manipulability. For example, application of the Condition Index (CI) available in the HAAT modifies how the net productivity change is calculated by the HAAT (Minns et al., 2001). The CI allows the habitat analyst to account for mechanical effects impacting fish productivity at wave-exposed sites (Minns et al. 2001). Use of the CI may provide better correlative results for sites highly affected by fetch (Minns et al. 2001) than was found for this study where CI values were not included. Furthermore, with fine-tuning of the species considerations and rebalancing of group suitability weightings, a more accurate and less biased tool may ultimately be produced.

Figures

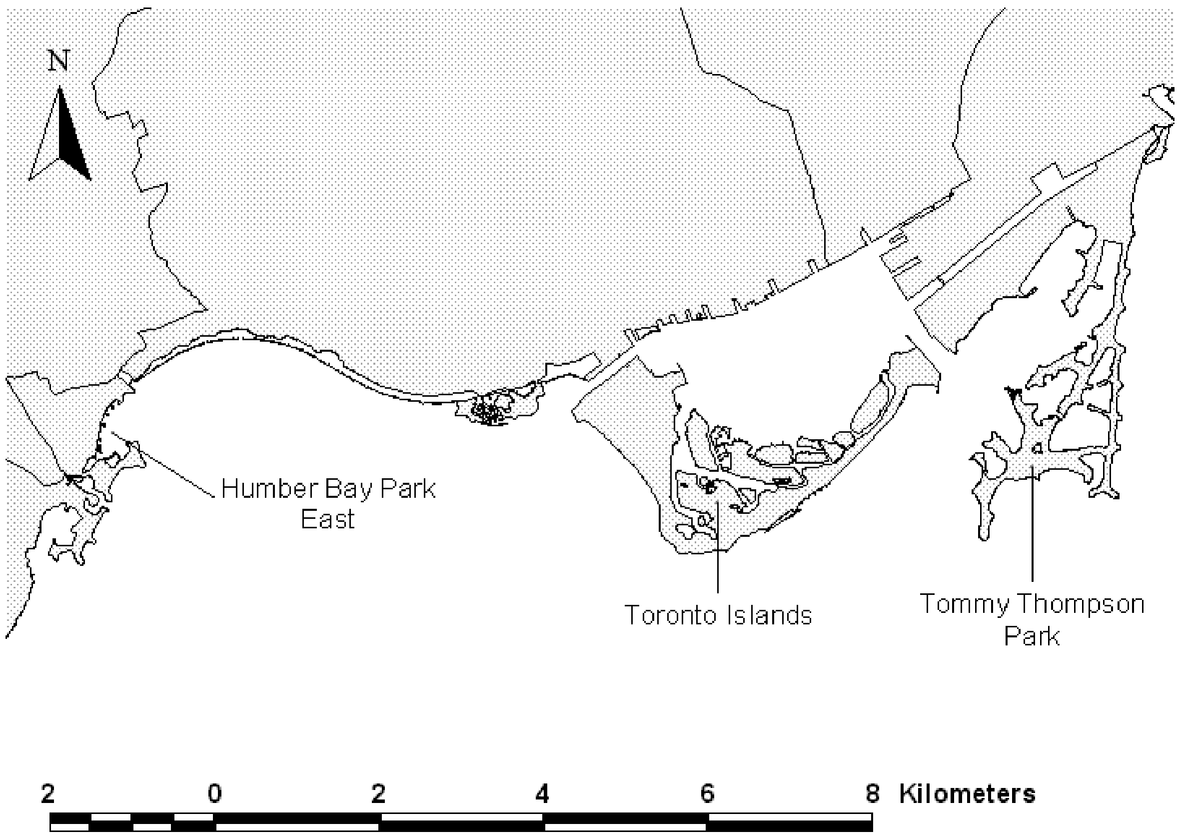

Figure 2.1 Map of the Toronto waterfront indicating the main study sites.

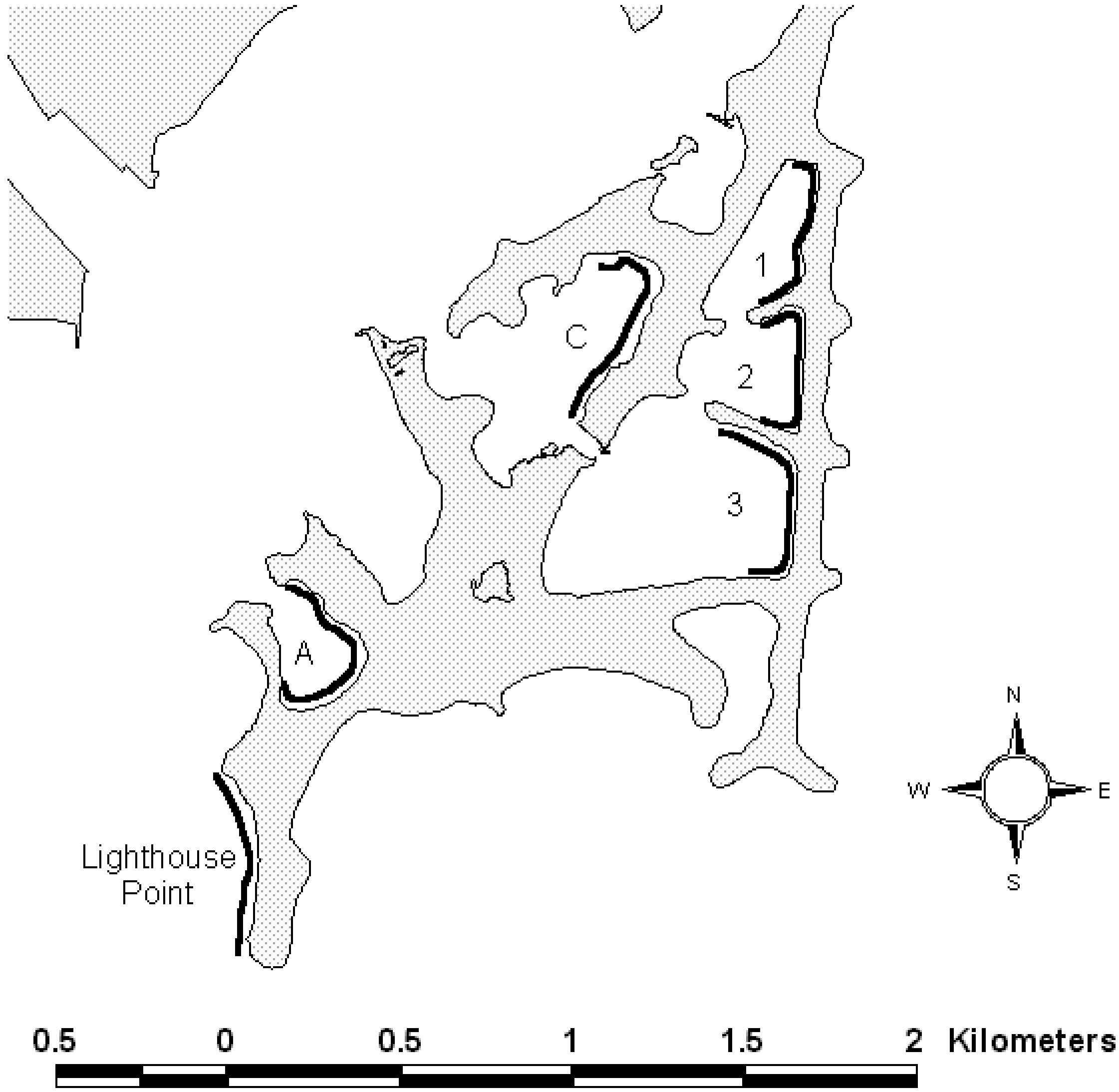

Figure 2.2 Tommy Thompson Park sites including electrofishing runs (▬) as sampled in 2002-2003. Numbers 1 to 3 denote the dredgeate disposal cells: Cell 1, Cell 2 and Cell 3. Embayments A and C, respectively, are indicated by A and C.

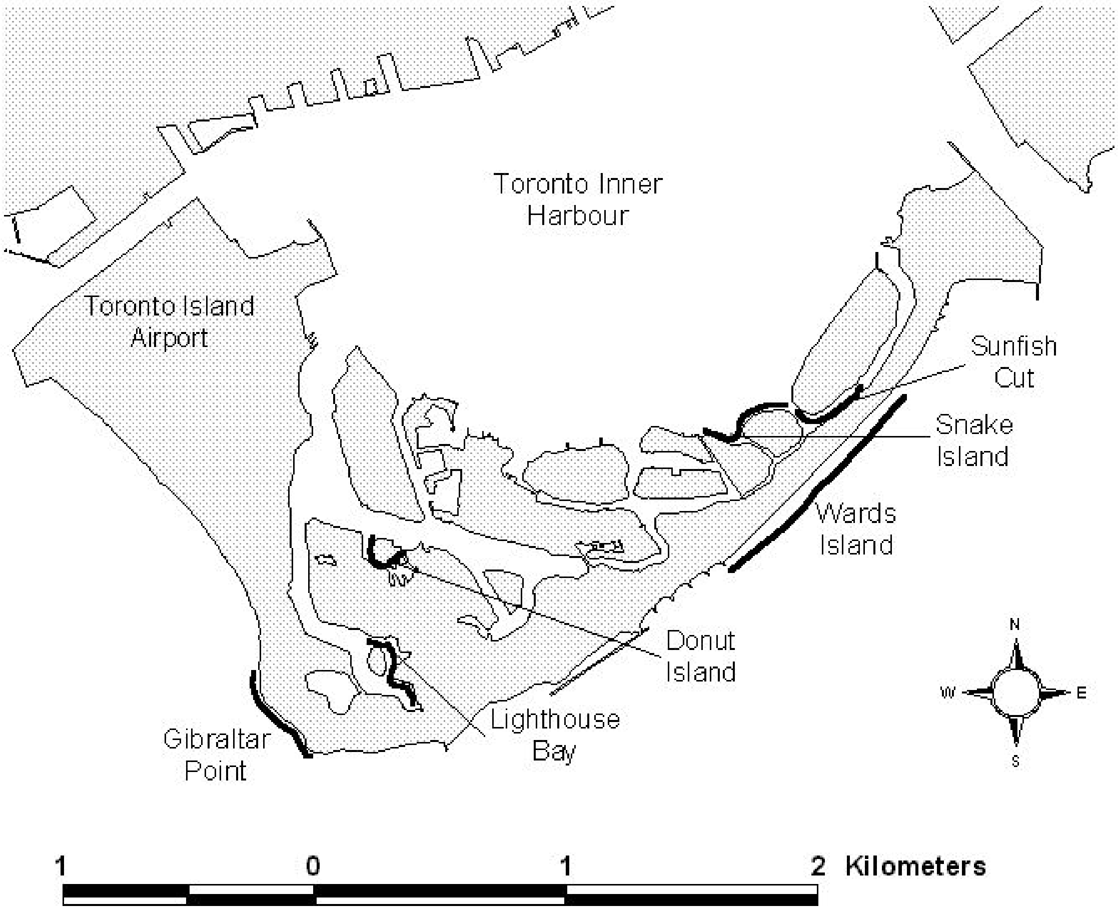

Figure 2.3 Toronto Islands sub-sites including electrofishing runs (▬) as sampled in 2002-2003.

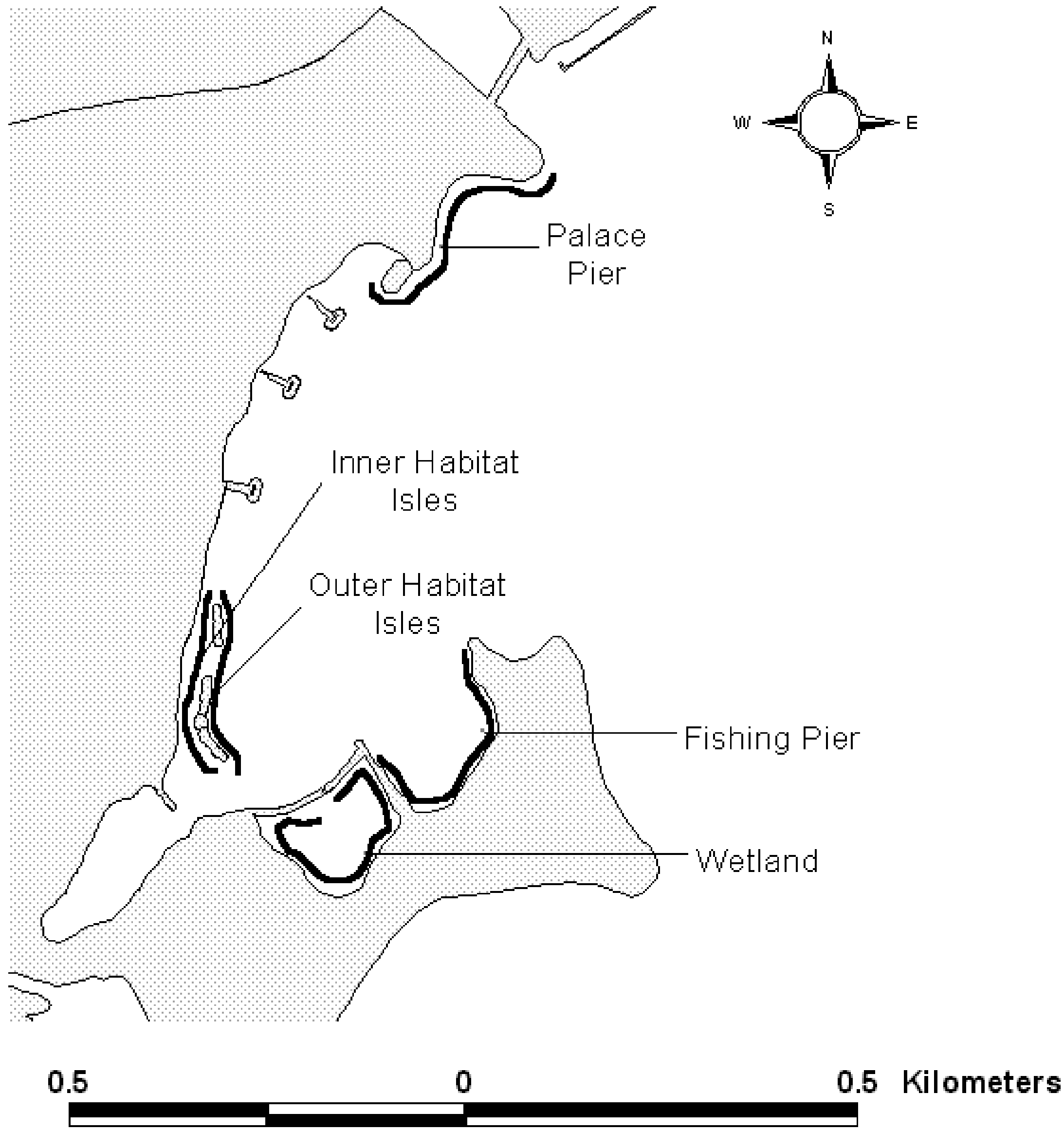

Figure 2.4 Humber Bay Park East sites including electrofishing runs (▬) as sampled in 2002-2003.

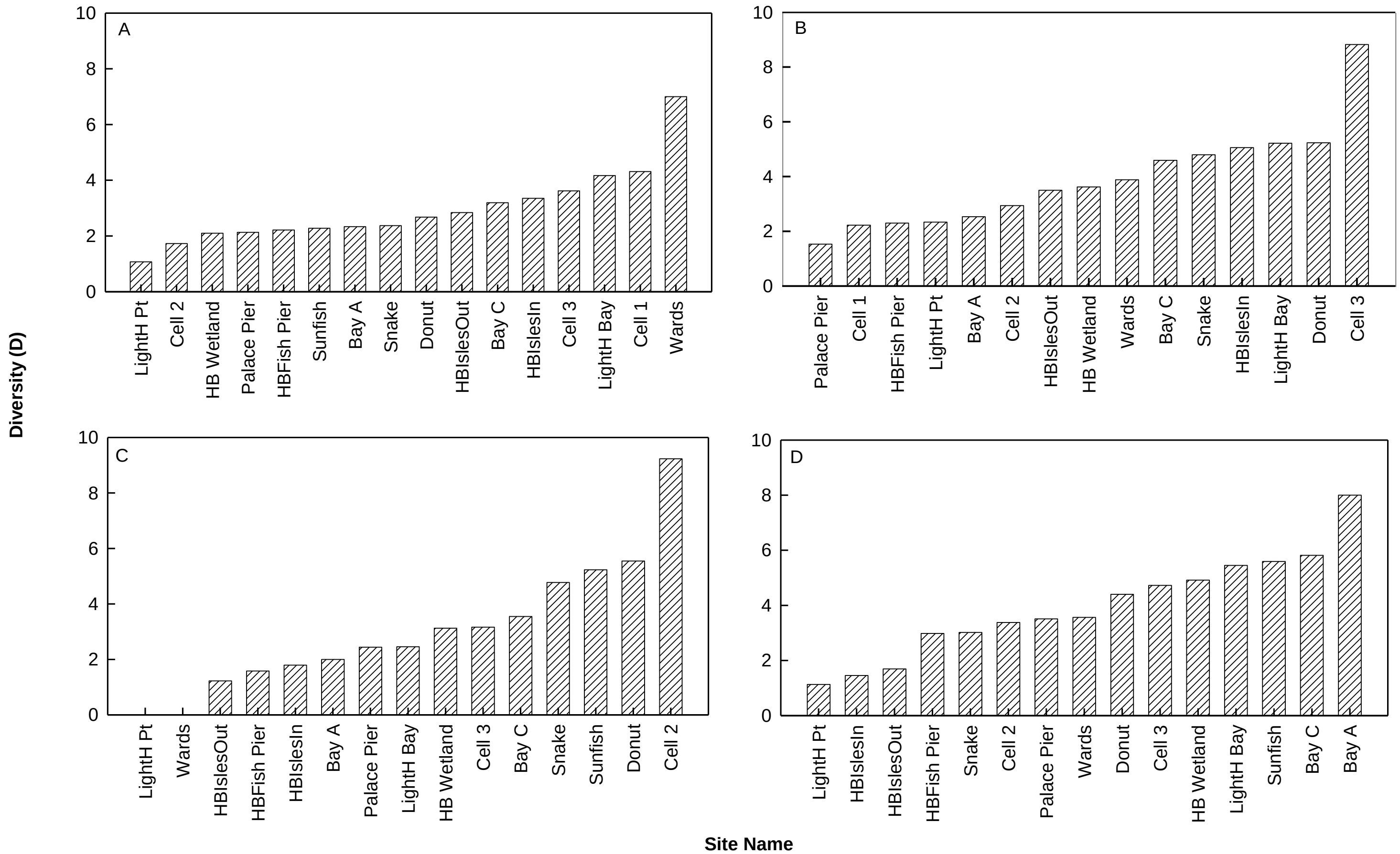

Figure 2.5 Site diversity in order of ascending Simpson's (D) value for A) Summer 2002; B) Fall 2002; C) Spring 2003; and D) Summer 2003. LightH Pt=Lighthouse Point; LightH Bay=Lighthouse Bay; Donut=Donut Island; Sunfish=Sunfish Cut; Snake=Snake Island; Wards=Wards Island; HBIslesIn=Humber Bay Inner Habitat Isles; HBIslesOut=Humber Bay Outer Habitat Isles; HBFish Pier=Humber Bay Fishing Pier; HBWetland=Humber Bay Wetland.

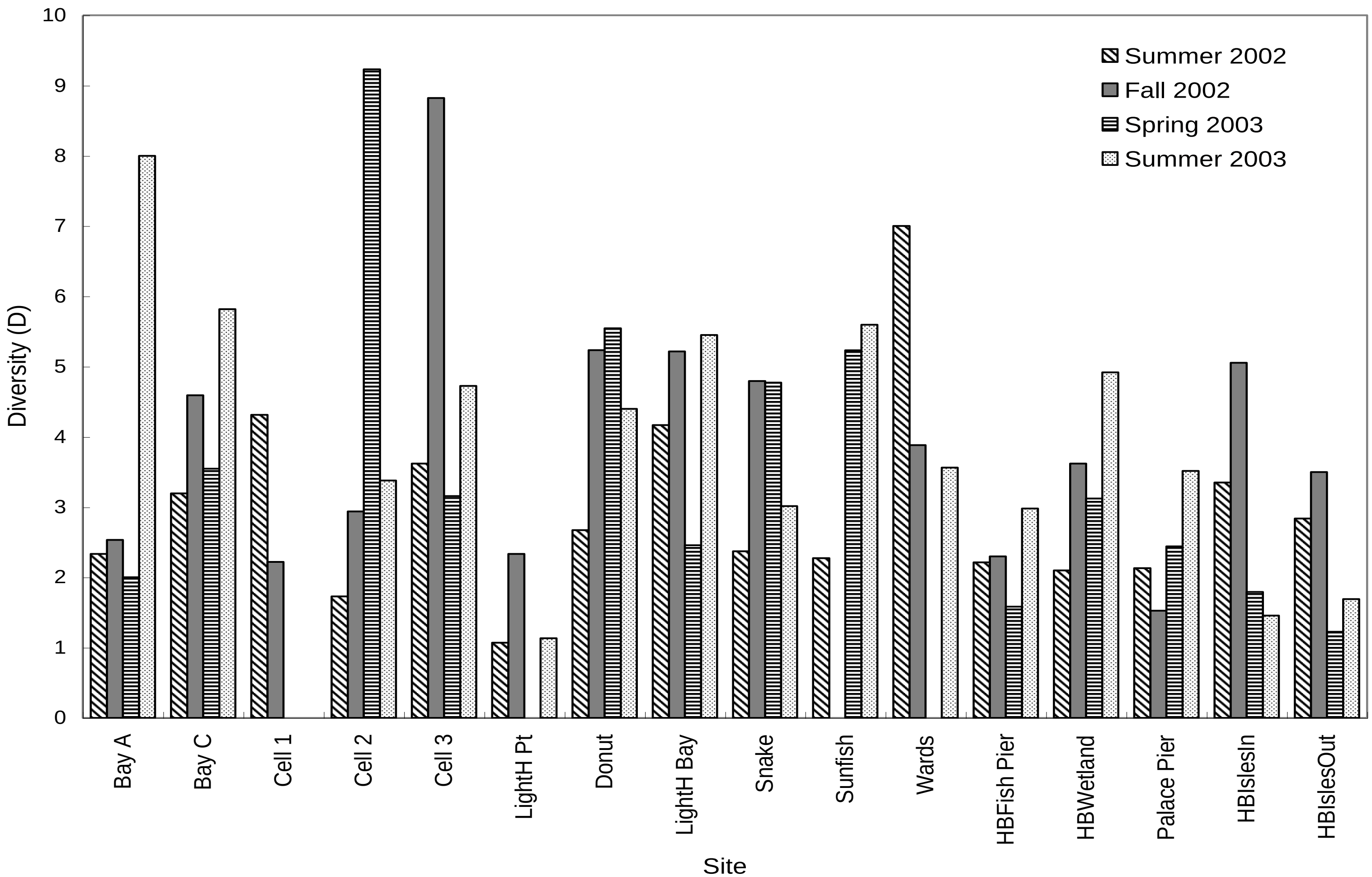

Figure 2.6 Diversity (Simpson's D) by season. LightH Pt=Lighthouse Point; Donut=Donut Island; LightH Bay=Lighthouse Bay; Snake=Snake Island; Sunfish=Sunfish Cut; Wards=Wards Island; HBFish Pier=Humber Bay Fishing Pier; HBWetland=Humber Bay Wetland; HBIslesIn=Humber Bay Inner Habitat Isles; HBIslesOut= Humber Bay Outer Habitat Isles.

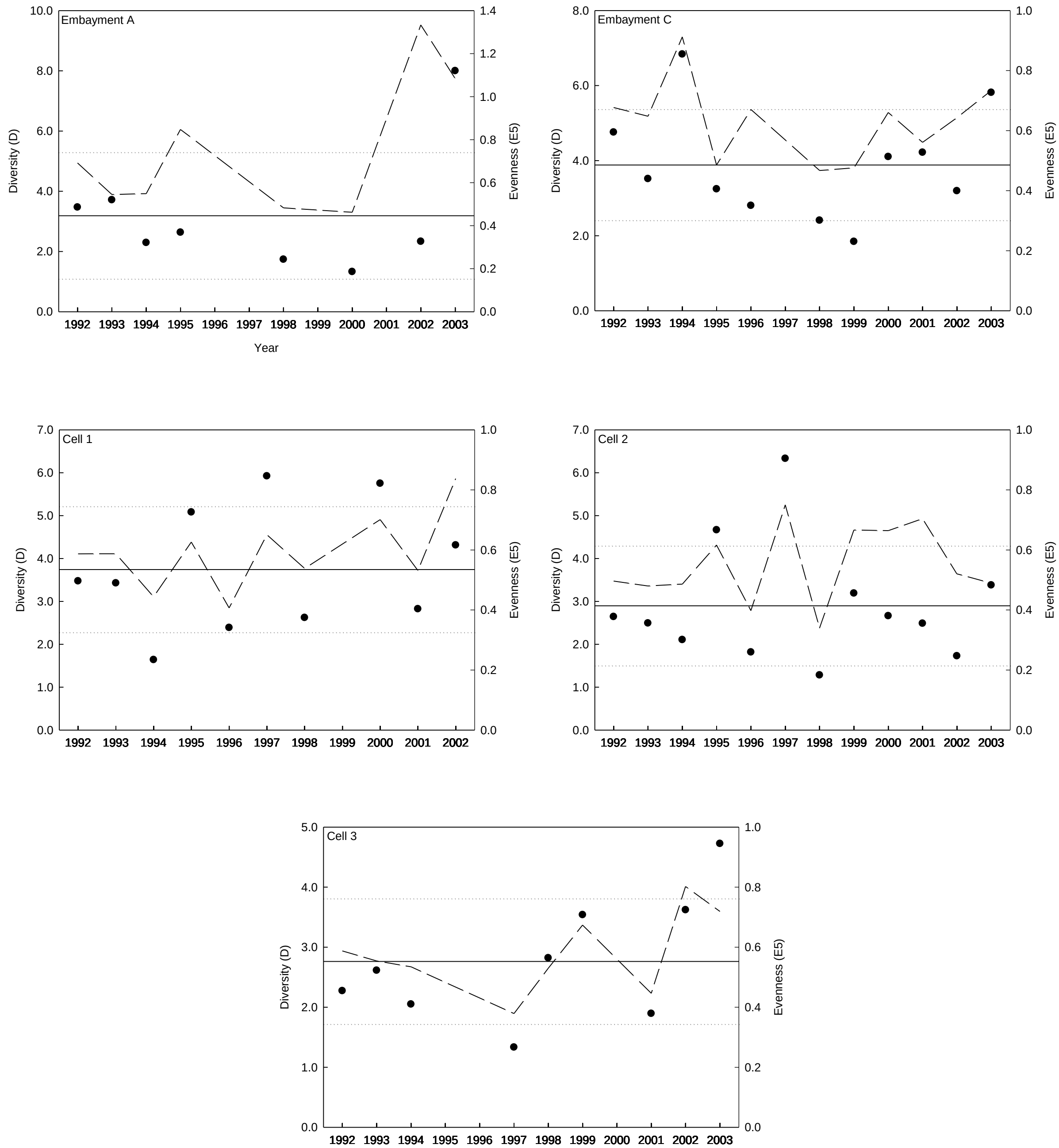

Figure 2.7 Historical changes in diversity and evenness at Tommy Thompson Park sites based on standardized sampling. ● : Simpson's diversity (D); —— :mean diversity; ······ : mean ± SD; — — —: modified Hill's ratio (E5).

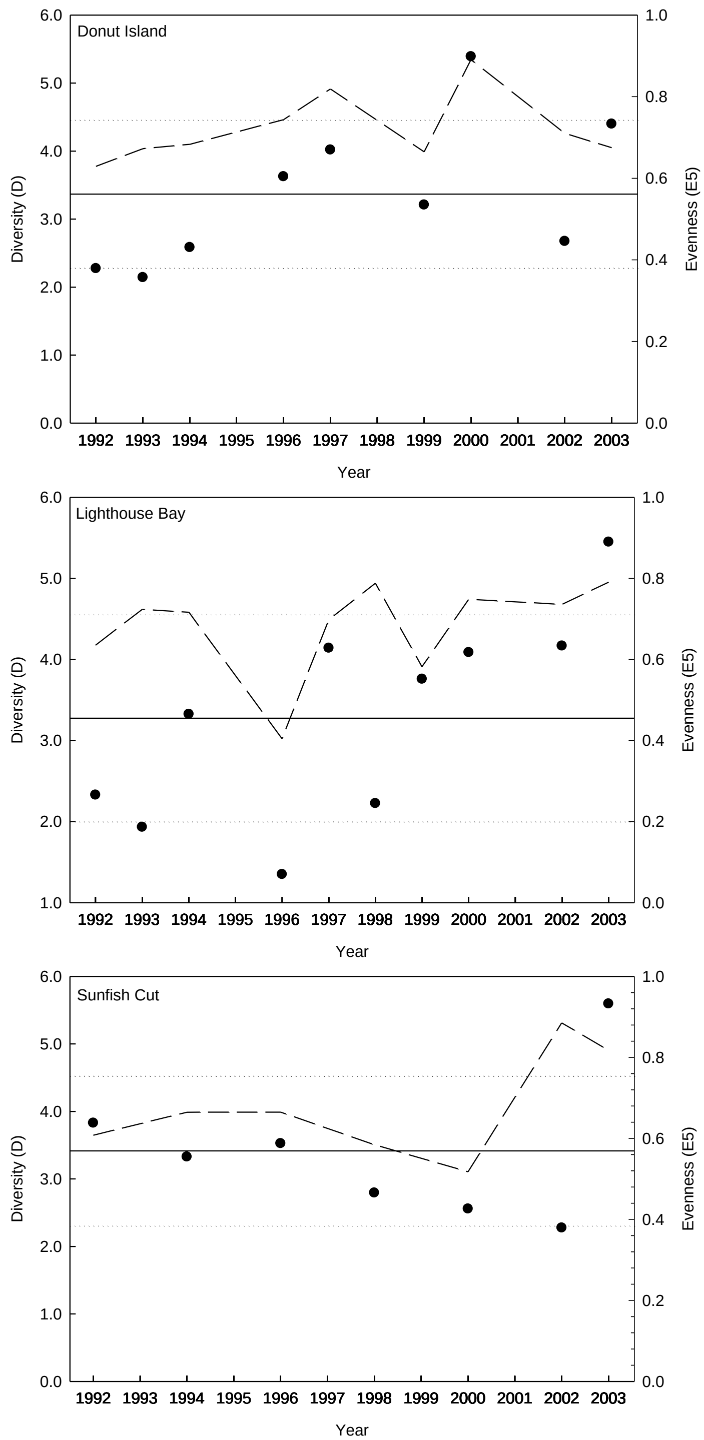

Figure 2.8 Historical changes in diversity and evenness at Tommy Thompson Park sites based on standardized sampling. ● : Simpson's diversity (D); —— :mean diversity; ······ : mean ± SD; — — —: modified Hill's ratio (E5).

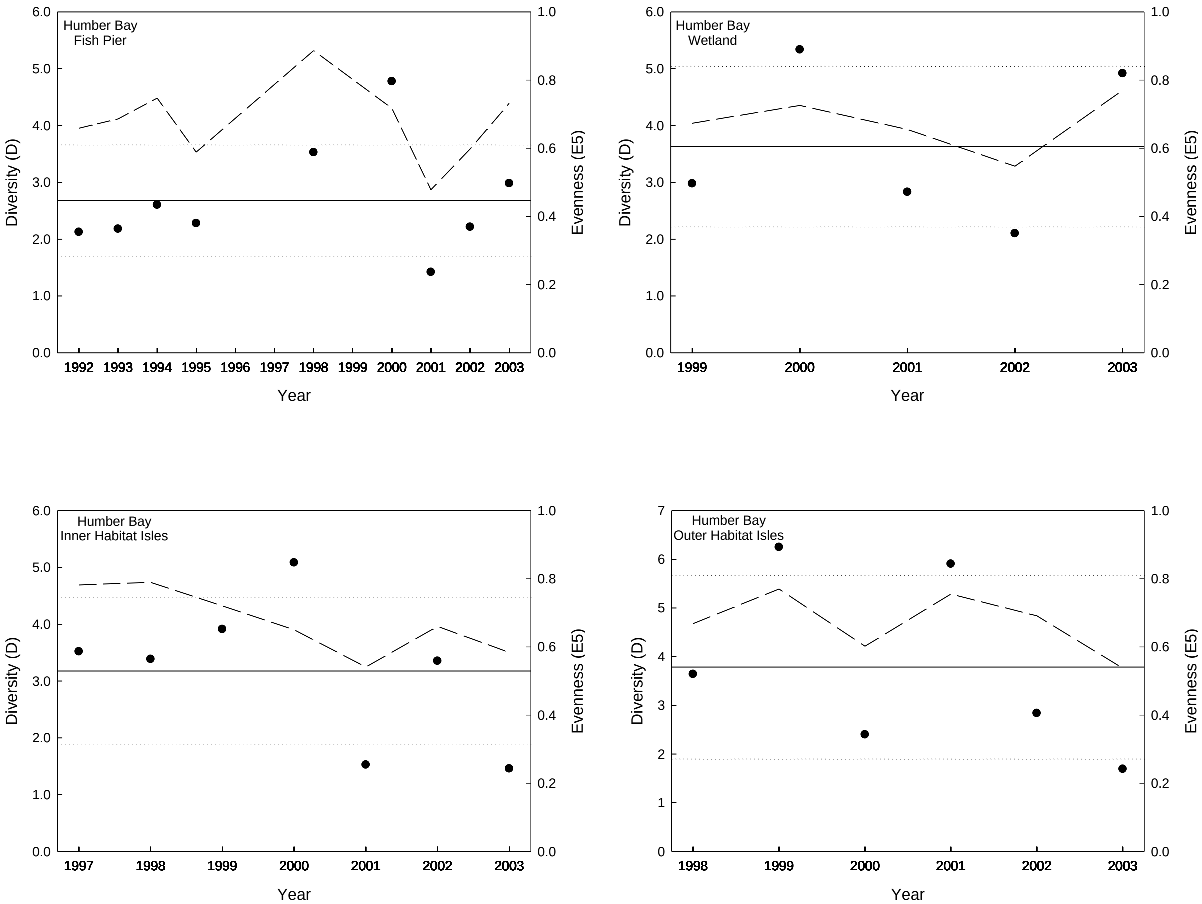

Figure 2.9 Historical changes in diversity and evenness at Tommy Thompson Park sites based on standardized sampling. ● : Simpson's diversity (D); —— :mean diversity; ······ : mean ± SD; — — —: modified Hill's ratio (E5).

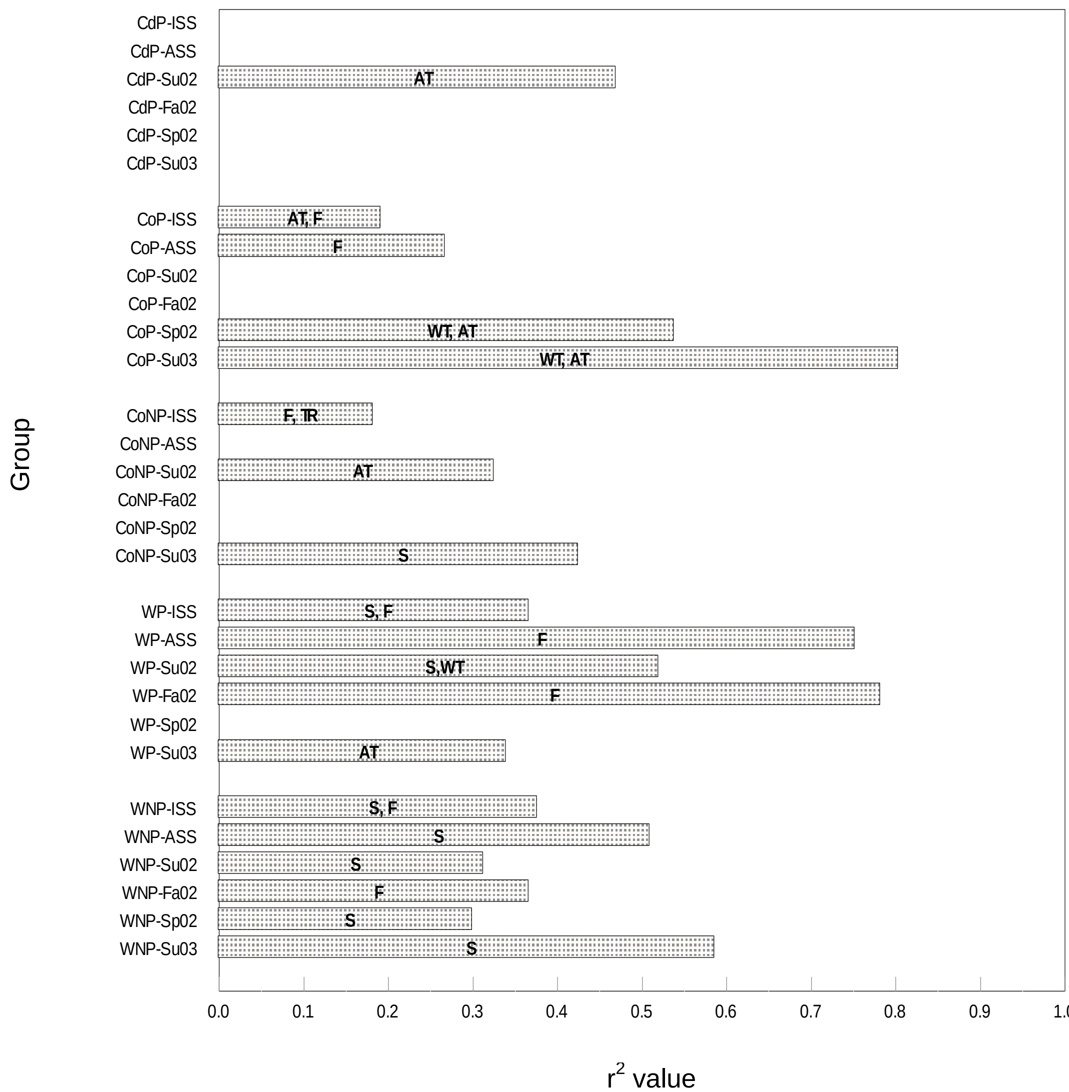

Figure 2.10 Estimated explanatory power for biomass data from the multiple regression analyses in Tables 2.9, 2.12 and 2.15-2.18.

The length of the bar indicates the r^2 value and the initials within the bar indicate the variable(s) contributing to the best model. AT=mean 30-day air temperature, F=fetch; S=suitability; TR=seasonal trend; WT=water temperature. CdP=coldwater piscivore; CoP=coolwater piscivore; CoNP=coolwater non-piscivore; WP=warmwater piscivore; WNP=warmwater non-piscivore. ISS=Individual site-specific; ASS=averaged site-specific; Su02=summer 2002; Fa02=fall 2002; Sp03=spring 2003; Su03=summer 2003.

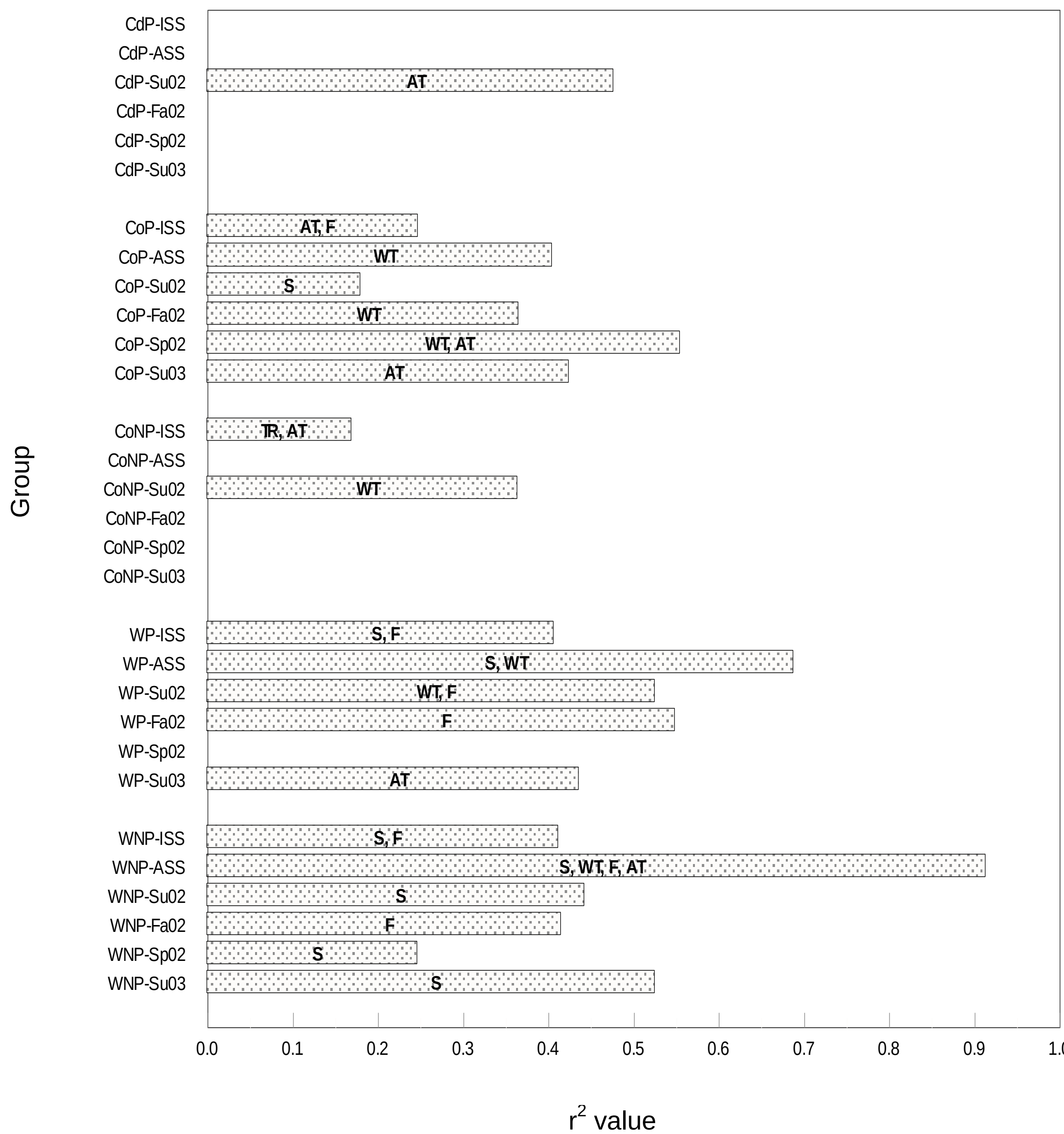

Figure 2.11 Estimated explanatory power for number of individuals data from the multiple regression analyses in Tables 2.9, 2.12 and 2.15-2.18.
The length of the bar indicates the r^2 value and the initials within the bar indicate the variable(s) contributing to the best model. AT=mean 30-day air temperature, F=fetch; S=suitability; TR=seasonal trend; WT=water temperature. CdP=coldwater piscivore; CoP=coolwater piscivore; CoNP=coolwater non-piscivore; WP=warmwater piscivore; WNP=warmwater non-piscivore. ISS=Individual site-specific; ASS=averaged site-specific; Su02=summer 2002; Fa02=fall 2002; Sp03=spring 2003; Su03=summer 2003.

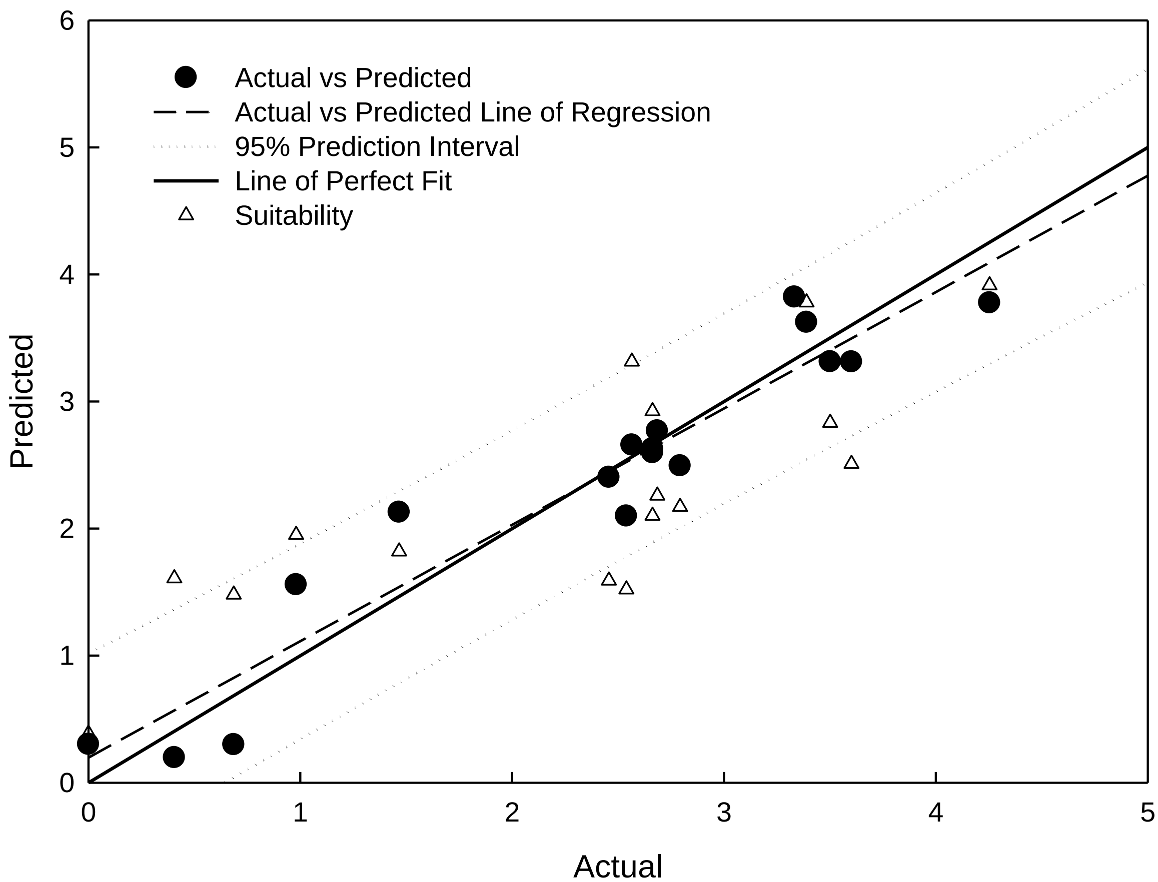

Figure 2.12 Actual vs. predicted productivity. Predictions are based on the best multivariate model from Table 2.9 for warmwater non-piscivore individuals data using suitability, mean water temperature, maximum effective fetch and mean 30-day air temperature as the explanatory variables, (●) and the univariate model using suitability as the explanatory variable (Δ).
The regression (r^2=0.92) of actual on predicted values for the multivariate model is plotted as a dashed line, with associated 95% prediction intervals given as dotted lines. The perfect fit 45° line is plotted as a solid line.

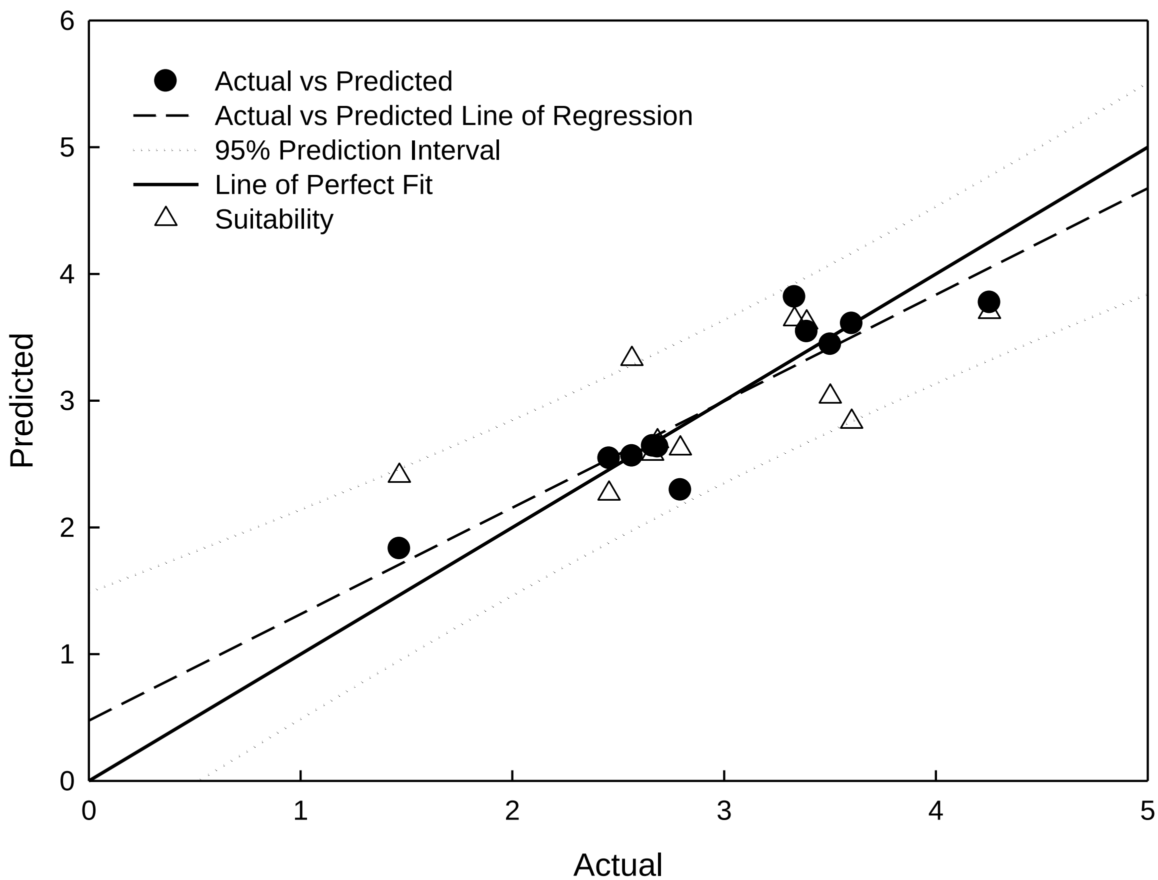

Figure 2.13 Actual vs. predicted productivity. Predictions are based on the best multivariate model from Table 2.10 for warmwater non-piscivores individuals data, embayments-only using suitability, mean water temperature and mean 30-day air temperature as the explanatory variables, (●) and the univariate model using suitability as the explanatory variable (Δ).

The regression (r^2=0.84) of actual on predicted values for the multivariate model is plotted as a dashed line, with associated 95% prediction intervals given as dotted lines. The perfect fit 45° line is plotted as a solid line.

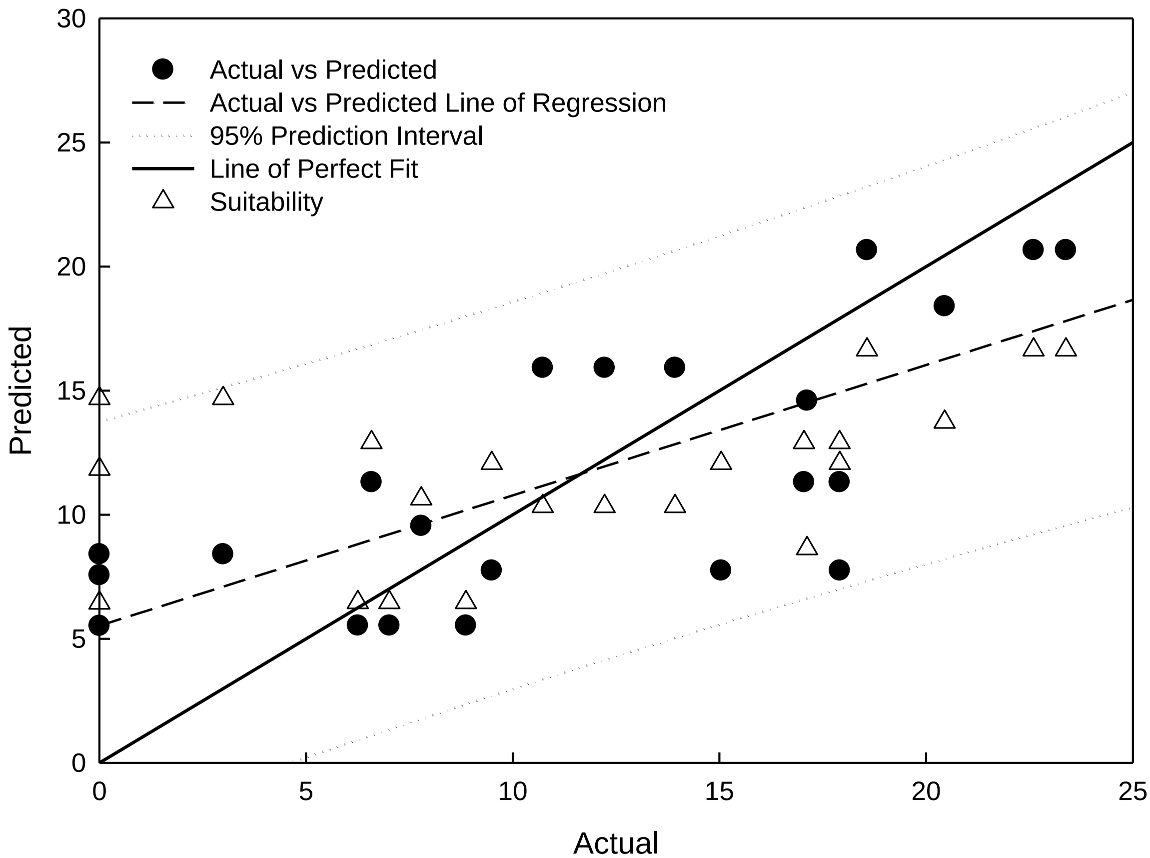

Figure 2.14 Actual vs. predicted productivity. Predictions are based on the best multivariate model from Table 2.14 for coolwater non-piscivores biomass data, open coasts-only using suitability, maximum effective fetch and mean 30-day air temperature as the explanatory variables, (●) and the univariate model using suitability as the explanatory variable (Δ).

The regression (r^2=0.53) of actual on predicted values for the multivariate model is plotted as a dashed line, with associated 95% prediction intervals given as dotted lines. The perfect fit 45° line is plotted as a solid line.

Tables

Table 2.1 Species list used in the HAAT. Each species is classified by indigenous status (native vs. exotic), thermal guild (cold, cool, warm) and trophic status (piscivore vs. non-piscivore) as given in the HAAT. An asterisk (*) denotes species used in the HAAT, but not found in Toronto waterfront samples.

Common Name	Latin	Status	Thermal	HAAT Trophy
Lake sturgeon*	*Acipenser fulvescens*	Native	Cold	Non Piscivore
Lake whitefish	*Coregonus clupeaformis*	Native	Cold	Non Piscivore
Longnose sucker*	*Catostomus catostomus*	Native	Cold	Non Piscivore
Mottled sculpin	*Cottus bairdii*	Native	Cold	Non Piscivore
Sea lamprey	*Petromyzon marinus*	Exotic	Cold	Non Piscivore
Trout-perch	*Percopsis omiscomaycus*	Native	Cold	Non Piscivore
Brown trout	*Salmo trutta*	Exotic	Cold	Piscivore
Chinook salmon	*Oncorhynchus tshawytscha*	Exotic	Cold	Piscivore
Coho salmon	*Oncorhynchus kisutch*	Exotic	Cold	Piscivore
Lake trout	*Salvelinus namaycush*	Native	Cold	Piscivore
Rainbow trout	*Oncorhynchus mykiss*	Exotic	Cold	Piscivore
Alewife	*Alosa pseudoharengus*	Exotic	Cool	Non Piscivore
Banded killifish*	*Fundulus diaphanus*	Native	Cool	Non Piscivore
Blacknose dace*	*Rhinichthys atratulus*	Native	Cool	Non Piscivore
Brook silverside	*Labidesthes sicculus*	Native	Cool	Non Piscivore
Brook stickleback	*Culaea inconstans*	Native	Cool	Non Piscivore
Common shiner	*Luxilus cornutus*	Native	Cool	Non Piscivore
Creek chub	*Semotilus atromaculatus*	Native	Cool	Non Piscivore
Emerald shiner	*Notropis atherinoides*	Native	Cool	Non Piscivore
Fantail darter*	*Etheostoma flabellare*	Native	Cool	Non Piscivore
Golden shiner	*Notemigonus crysoleucas*	Native	Cool	Non Piscivore
Iowa darter	*Etheostoma exile*	Native	Cool	Non Piscivore
Johnny darter	*Etheostoma nigrum*	Native	Cool	Non Piscivore
Lake chub	*Couesius plumbeus*	Native	Cool	Non Piscivore
Logperch*	*Percina caprodes*	Native	Cool	Non Piscivore
Longnose dace*	*Rhinichthys cataractae*	Native	Cool	Non Piscivore
Rainbow smelt	*Osmerus mordax*	Native	Cool	Non Piscivore
Spottail shiner	*Notropis hudsonius*	Native	Cool	Non Piscivore
Threespine stickleback	*Gasterosteus aculeatus*	Native	Cool	Non Piscivore
White sucker	*Catostomus commersonii*	Native	Cool	Non Piscivore
Yellow perch	*Perca flavescens*	Native	Cool	Non Piscivore
American eel	*Anguilla rostrata*	Native	Cool	Piscivore
Longnose gar	*Lepisosteus osseus*	Native	Cool	Piscivore
Northern pike	*Esox lucius*	Native	Cool	Piscivore
Spotted gar*	*Lepisosteus oculatus*	Native	Cool	Piscivore
Walleye	*Sander vitreus*	Native	Cool	Piscivore
Black crappie	*Pomoxis nigromaculatus*	Native	Warm	Non Piscivore
Bluegill	*Lepomis macrochirus*	Native	Warm	Non Piscivore
Bluntnose minnow	*Pimephales notatus*	Native	Warm	Non Piscivore
Brown bullhead	*Ameiurus nebulosus*	Native	Warm	Non Piscivore
Common carp	*Cyprinus carpio*	Exotic	Warm	Non Piscivore
Central mudminnow*	*Umbra limi*	Native	Warm	Non Piscivore
Fathead minnow	*Pimephales promelas*	Native	Warm	Non Piscivore
Freshwater drum	*Aplodinotus grunniens*	Native	Warm	Non Piscivore
Gizzard shad	*Dorosoma cepedianum*	Native	Warm	Non Piscivore
Goldfish	*Carassius auratus*	Exotic	Warm	Non Piscivore
Green sunfish*	*Lepomis cyanellus*	Native	Warm	Non Piscivore
Pumpkinseed	*Lepomis gibbosus*	Native	Warm	Non Piscivore
Rock bass	*Ambloplites rupestris*	Native	Warm	Non Piscivore
Sand shiner*	*Notropis ludibundus*	Native	Warm	Non Piscivore
Spotfin shiner	*Cyprinella spiloptera*	Native	Warm	Non Piscivore
White perch	*Morone americana*	Exotic	Warm	Non Piscivore
Yellow bullhead	*Ameiurus natalis*	Native	Warm	Non Piscivore
Bowfin	*Amia calva*	Native	Warm	Piscivore
Largemouth bass	*Micropterus salmoides*	Native	Warm	Piscivore
Smallmouth bass	*Micropterus dolomieu*	Native	Warm	Piscivore
White bass	*Morone chrysops*	Native	Warm	Piscivore

Table 2.2 Habitat supply areas for Tommy Thompson Park sample sites as measured in August 2002.

Variable	Class	% of Total Area					
		Embayment A	Embayment C	Cell 1	Cell 2	Cell 3	Lighthouse Point
Depth Zone (m)	0-1	39.35	18.52	6.39	16.62	11.21	3.13
	1-2	14.63	34.42	82.15	79.36	22.80	3.95
	2-5	43.88	47.06	11.46	4.02	16.66	23.64
	5-10	2.14	0.00	0.00	0.00	36.33	69.27
	10+	0.00	0.00	0.00	0.00	13.00	0.00
Substrate	Bedrock	0.00	0.00	0.00	0.00	0.00	0.00
	Boulder	0.00	0.00	0.00	0.00	0.00	75.00
	Cobble	0.36	0.00	0.22	1.15	0.07	0.00
	Rubble	0.00	0.20	0.00	0.00	0.03	20.00
	Gravel	0.05	0.00	0.11	1.05	1.64	0.00
	Sand	89.64	94.81	39.93	39.61	39.46	5.00
	Silt	9.95	4.99	49.78	48.49	48.99	0.00
	Clay	0.00	0.00	9.96	9.70	9.80	0.00
	Hardpan	0.00	0.00	0.00	0.00	0.00	0.00
	Pelagic	0.00	0.00	0.00	0.00	0.00	0.00
Vegetation	No Cover	83.38	35.92	24.15	27.37	83.28	95.00
	Emergent	0.00	0.00	0.00	0.00	0.00	0.00
	Submergent	16.62	64.08	75.85	72.63	16.72	5.00
Fetch		552.40	437.50	279.44	305.34	544.42	44691.61
Total Area (m^2)		50788.80	66511.60	45928.90	47768.50	58350.00	57669.00

Table 2.3 **Habitat supply areas for Toronto Island sample sites as measured in August 2002.**

		% of Total Area					
Variable	**Class**	**Donut Island**	**Gibraltar Point**	**Lighthouse Bay**	**Snake Island**	**Sunfish Cut**	**Wards Island**
Depth Zone (m)	**0-1**	53.80	98.35	62.82	29.31	11.62	16.75
	1-2	46.20	1.65	10.22	45.93	72.16	37.41
	2-5	0.00	0.00	26.96	18.97	16.23	45.85
	5-10	0.00	0.00	0.00	5.78	0.00	0.00
	10+	0.00	0.00	0.00	0.00	0.00	0.00
Substrate	**Bedrock**	0.00	0.00	0.00	0.00	4.85	0.00
	Boulder	0.00	1.45	0.00	0.00	0.00	11.38
	Cobble	0.00	5.86	4.56	0.00	0.00	0.00
	Rubble	0.00	2.27	0.22	0.00	0.00	0.00
	Gravel	0.00	0.08	1.54	0.00	0.00	0.00
	Sand	98.00	89.50	92.74	99.00	88.49	88.62
	Silt	1.00	0.84	0.93	0.50	3.81	0.00
	Clay	1.00	0.00	0.00	0.50	2.85	0.00
	Hardpan	0.00	0.00	0.00	0.00	0.00	0.00
	Pelagic	0.00	0.00	0.00	0.00	0.00	0.00
Vegetation	**No Cover**	37.80	99.44	61.55	53.54	47.49	95.35
	Emergent	3.49	0.28	0.00	0.00	0.00	0.00
	Submergent	58.70	0.28	38.45	46.46	52.51	4.65
Fetch		265.47	72120.80	161.90	2235.19	159.79	50772.40
Total Area (m^2)		18915.50	45991.30	28866.60	76414.20	19566.00	106468.50

Table 2.4 Habitat supply areas for Humber Bay Park sample sites as measured in August 2002.

Variable	Class	% of Total Area				
		Fishing Pier	Wetland	Palace Pier	Inner Habitat Isles	Outer Habitat Isles
Depth Zone (m)	0-1	15.08	35.40	22.28	58.78	7.32
	1-2	14.01	25.74	16.57	17.22	6.87
	2-5	70.91	38.86	61.15	24.01	85.81
	5-10	0.00	0.00	0.00	0.00	0.00
	10+	0.00	0.00	0.00	0.00	0.00
Substrate	Bedrock	0.00	0.00	0.00	0.00	0.00
	Boulder	0.12	0.43	2.54	1.04	0.00
	Cobble	3.76	0.00	1.69	19.68	0.00
	Rubble	1.05	1.82	12.69	0.28	0.08
	Gravel	6.38	2.14	0.00	5.37	1.43
	Sand	55.01	63.72	49.85	49.55	59.13
	Silt	33.67	31.90	33.23	0.00	0.00
	Clay	0.00	0.00	0.00	24.08	39.37
	Hardpan	0.00	0.00	0.00	0.00	0.00
	Pelagic	0.00	0.00	0.00	0.00	0.00
Vegetation	No Cover	75.05	71.48	45.76	39.41	26.85
	Emergent	0.00	5.99	0.00	0.00	0.00
	Submergent	24.95	22.52	54.24	60.59	73.15
Fetch		735.67	119.71	38335.90	1575.50	1749.41
Total Area (m^2)		19256.30	16887.90	39176.10	11732.60	34149.80

Table 2.5 Fetch values and wind direction for all sample sites (sorted highest to lowest).

Site Name	Site Type	Compass Direction	Maximum Effective Fetch
Gibraltar Point	Open Coast	SE	72120.80
Wards Island	Open Coast	SSE	50772.40
Lighthouse Point	Open Coast	S	44691.61
Palace Pier	Open Coast	SE	38335.90
Snake Island	Open Coast	NNW	2235.19
Outer Habitat Isles	Open Coast	NE	1749.41
Inner Habitat Isles	Embayment	ENE	1575.50
Fishing Pier	Embayment	N	735.67
Embayment A	Embayment	SW	552.40
Cell 3	Embayment	WSW	544.42
Embayment C	Embayment	WSW	437.50
Cell 2	Embayment	W	306.34
Cell 1	Embayment	SSW	279.44
Donut Island	Embayment	NW	265.47
Lighthouse Bay	Embayment	WSW	161.90
Sunfish Cut	Embayment	NNE	159.79
Wetland	Embayment	SW	119.71

Table 2.6 Sample HAAT output file (Donut Island) showing the format of the table.
Type refers to the life-stage of the fish considered. Group ID refers to the trophic/thermal guild selected by the HAAT analyst. Weight is the weighting for the corresponding fish group as given by the HAAT analyst and used in the calculation of weighted suitable area (WSA) and Productivity Scenario is the WSA calculated by the HAAT for the corresponding fish group.

Type	Group ID	Weight	Productivity Scenario
Adult	Coldwater Piscivores	0.17	0.0
	Coldwater Non-Piscivores	0.17	2893.2
	Coolwater Piscivores	0.17	2782.0
	Coolwater Non-Piscivores	0.17	15277.6
	Warmwater Piscivores	0.17	13066.8
	Warmwater Non-Piscivores	0.17	13520.3
Spawning	Coldwater Piscivores	0.17	609.4
	Coldwater Non-Piscivores	0.17	8381.2
	Coolwater Piscivores	0.17	3998.6
	Coolwater Non-Piscivores	0.17	10055.4
	Warmwater Piscivores	0.17	7889.0
	Warmwater Non-Piscivores	0.17	12265.1
YOY	Coldwater Piscivores	0.17	6765.4
	Coldwater Non-Piscivores	0.17	12831.5
	Coolwater Piscivores	0.17	3534.6
	Coolwater Non-Piscivores	0.17	13607.2
	Warmwater Piscivores	0.17	12912.6
	Warmwater Non-Piscivores	0.17	13272.9
Weighted Sum			
	Adult	0.33	7923.3
	Spawning	0.33	7199.8
	YOY	0.33	10487.4
Overall Sum			8536.8

Table 2.7 Summer suitability values by trophic group as calculated for adult fish by dividing WSA values (m^2) from the HAAT output by the total area of the corresponding site (m^2).

Site	Cold Piscivores	Cold Non-Piscivores	Cool Non-Piscivores	Cool Piscivores	Warm Non-Piscivores	Warm Piscivores
Embayment A	0.00	0.194	0.464	0.076	0.357	0.427
Embayment C	0.00	0.216	0.589	0.159	0.501	0.722
Cell 1	0.00	0.152	0.687	0.258	0.696	0.771
Cell 2	0.00	0.144	0.689	0.244	0.688	0.742
Cell 3	0.00	0.420	0.335	0.077	0.257	0.321
Lighthouse Point	0.00	0.159	0.047	0.036	0.019	0.107
Donut Island	0.00	0.153	0.808	0.147	0.715	0.691
Gibraltar Point	0.00	0.086	0.527	0.046	0.260	0.308
Lighthouse Bay	0.00	0.163	0.580	0.102	0.438	0.526
Snake Island	0.00	0.189	0.642	0.122	0.520	0.600
Sunfish Cut	0.00	0.165	0.675	0.131	0.596	0.624
Wards Island	0.00	0.164	0.374	0.052	0.235	0.326
Fishing Pier	0.00	0.228	0.367	0.097	0.302	0.444
Wetland	0.00	0.169	0.474	0.099	0.388	0.462
Palace Pier	0.00	0.217	0.423	0.191	0.327	0.639
Inner Habitat Isles	0.00	0.119	0.463	0.094	0.371	0.535
Outer Habitat Isles	0.00	0.179	0.273	0.099	0.243	0.615

Table 2.8 Spring suitability values by trophic group as calculated for adult fish by dividing WSA values (m^2) from the HAAT output by the total area of the corresponding site (m^2). Cell 1 and Gibraltar Point were not sampled in Spring 2003 and therefore are not listed in the table.

Site	Cold Piscivores	Cold Non-Piscivores	Cool Non-Piscivores	Cool Piscivores	Warm Non-Piscivores	Warm Piscivores
Embayment A	0.000	0.177	0.390	0.045	0.243	0.326
Embayment C	0.000	0.173	0.397	0.046	0.244	0.328
Cell 2	0.000	0.079	0.350	0.035	0.248	0.283
Cell 3	0.000	0.341	0.290	0.030	0.199	0.248
Lighthouse Point	0.000	0.132	0.045	0.035	0.018	0.108
Donut Island	0.000	0.090	0.548	0.046	0.283	0.325
Lighthouse Bay	0.000	0.134	0.456	0.046	0.249	0.316
Snake Island	0.000	0.154	0.471	0.047	0.263	0.327
Sunfish Cut	0.000	0.111	0.454	0.043	0.252	0.303
Wards Island	0.000	0.161	0.360	0.045	0.216	0.299
Fishing Pier	0.000	0.215	0.292	0.041	0.196	0.308
Wetland	0.000	0.156	0.388	0.042	0.235	0.319
Palace Pier	0.000	0.195	0.291	0.041	0.178	0.296
Inner Habitat Isles	0.000	0.085	0.316	0.032	0.167	0.193
Outer Habitat Isles	0.000	0.153	0.173	0.028	0.155	0.199

Table 2.9 Multiple regression analyses for averaged site-specific data (All sites: *n*=17).
One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cool Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	**IND**	**BM**	**IND**	**BM**	**IND**
Suitability	b_j				2.127	8.612	3.023
	β_j				0.316	0.716	0.475
	P				0.039	<0.001	<0.001
Mean Water Temp (Range 12.25-18.57)	b_j		0.199		0.458		0.280
	β_j		0.638		0.642		0.395
	P		0.006		0.002		0.024
Maximum Effective Fetch	b_j	-8.593×10^{-5}		-1.513×10^{-4}			-3.098×10^{-5}
	β_j	-0.520		-0.869			-0.453
	P	0.033		<0.001			0.002
Mean 30-Day Air Temp (Range 17.57-20.92)	b_j						-0.460
	β_j						-0.300
	P						0.042
Intercept	b_j	6.866	-2.462	6.292	-6.806	4.549	5.638
	P	<0.001	0.024	<0.001	0.001	<0.001	0.075
r^2		0.270	0.407	0.755	0.691	0.512	0.916

Table 2.10 Multiple regression analyses for averaged site-specific data (Embayments only: *n*=11). One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cold Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	**IND**	**BM**	**IND**	**BM**	**IND**
Suitability	b_j			6.808		5.190	2.657
	β_j			0.693		0.728	0.596
	P			0.009		0.006	0.006
Mean Water Temp (Range 13.90-18.57)	b_j	-1.930			0.467		0.440
	β_j	-0.638			0.696		0.830
	P	0.035			0.017		0.006
Maximum Effective Fetch	b_j						
	β_j						
	P						
Mean 30-Day Air Temp (Range 18.04-20.92)	b_j						-0.537
	β_j						-0.587
	P						0.030
Intercept	b_j	35.500		2.813	-5.513	6.066	4.598
	P	0.022		0.073	0.068	<0.001	0.153
r^2		0.407		0.481	0.485	0.529	0.840

Table 2.11 Multiple regression analyses for averaged site-specific data (Open coasts only: *n*=6). One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		CoolNon-Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	**IND**	**BM**	**IND**	**BM**	**IND**
Suitability	b_j		1.131			20.118	1.639
	β_j		0.493			0.918	0.236
	P		0.006			0.001	0.026
Water Temp (Range 12.25-15.77)	b_j		0.354	-0.540			-0.262
	β_j		1.037	-0.377			-0.324
	P		0.002	0.036			0.035
Maximum Effective Fetch	b_j			-1.110×10^{-4}	-1.777×10^{-5}		-5.358×10^{-5}
	β_j			-1.175	-0.937		-1.007
	P			0.002	0.006		0.005
Mean 30-Day Air Temp (Range 17.57-19.27)	b_j					-2.858	
	β_j					-0.524	
	P					0.014	
Intercept	b_j		-2.500	12.088	0.747	54.109	6.008
	P		0.014	0.014	0.003	0.012	0.020
r^2			0.978	0.980	0.877	0.970	0.996

Table 2.12 Multiple regression analyses for individual site-specific data (All sites: *n*=63) .
One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cool Piscivores		Cool Non-Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	IND	BM	IND	BM	IND	BM	IND
Suitability	b_j	17.008	2.861			10.895	3.615	26.878	8.321
	β_j	0.255	0.251			0.474	0.519	0.396	0.433
	P	0.035	0.032			<0.001	<0.001	<0.001	<0.001
Trend	b_j			2.165	1.097				
	β_j			0.318	0.416				
	P			0.009	0.002				
Water Temp (Range 4.20-22.30)	b_j								
	β_j								
	P								
Maximum Effective Fetch	b_j	-7.349×10^{-5}	-1.417×10^{-5}	-1.276×10^{-4}		-6.137×10^{-5}	-1.750×10^{-5}	-2.458×10^{-5}	-6.795×10^{-5}
	β_j	-0.291	-0.329	-0.272		-0.233	-0.219	-0.324	-0.316
	P	0.020	0.007	0.023		0.042	0.048	0.007	0.006
Mean 30-Day Air Temp (Range 6.71-22.74)	b_j	-0.189	-0.041		0.146				
	β_j	-0.268	-0.345		0.289				
	P	0.050	0.010		0.025				
Intercept	b_j	6.461	1.174	8.298	-0.326	-1.071	-0.469	7.300	1.414
	P	<0.001	<0.001	<0.001	0.834	0.445	0.256	0.038	0.141
r^2		0.194	0.250	0.185	0.172	0.369	0.410	0.379	0.414

Table 2.13 Multiple regression analyses for individual site-specific data (Embayments only: *n*=41) . One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cool Piscivores		Cool Non-Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	IND	BM	IND	BM	IND	BM	IND
Suitability	b_j	19.620	3.867			15.506	5.230	25.650	8.681
	β_j	0.324	0.344			0.581	0.649	0.374	0.434
	P	0.041	0.029			<0.001	<0.001	0.008	0.002
Trend	b_j			2.906	0.907				
	β_j			0.416	0.320				
	P			0.005	0.041				
Water Temp (Range 8.00-22.30)	b_j								
	β_j								
	P								
Maximum Effective Fetch	b_j			7.560×10^{-3}		-3.650×10^{-3}	-1.071×10^{-3}		
	β_j			0.298		-0.250	-0.243		
	P			0.039		0.047	0.036		
Mean 30-Day Air Temp (Range 6.71-22.74)	b_j	-0.244	-0.059						
	β_j	-0.366	-0.479						
	P	0.050	0.010						
Intercept	b_j	7.478	1.430	2.785	2.664	-1.381	-0.673	7.831	1.406
	P	<0.001	<0.001	0.352	0.028	0.483	0.221	0.094	0.284
r^2		0.112	0.170	0.264	0.102	0.458	0.542	0.140	0.188

Table 2.14 Multiple regression analyses for individual site-specific data (Open Coasts only: *n*=22). One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cool Non-Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	**IND**	**BM**	**IND**	**BM**	**IND**
Suitability	b_j	13.302				30.440	5.836
	β_j	0.349				0.444	0.400
	P	0.021				0.011	0.016
Trend	b_j		0.911				
	β_j		0.419				
	P		0.040				
Water Temp (Range 4.20-21.10)	b_j						
	β_j						
	P						
Maximum Effective Fetch	b_j	-2.204×10^{-4}	-5.197×10^{-5}	-3.760×10^{-5}	-1.056×10^{-5}	-2.144×10^{-4}	-5.271×10^{-5}
	β_j	-0.578	-0.403	-0.480	-0.478	-0.403	-0.465
	P	0.002	0.036	0.024	0.025	0.034	0.015
Mean 30-Day Air Temp (Range 6.71-22.74)	b_j		0.186				
	β_j		0.452				
	P		0.028				
Intercept	b_j	12.609	0.492	1.518	0.427	5.410	1.324
	P	<0.001	0.809	0.005	0.006	0.274	0.201
r^2		0.525	0.440	0.230	0.228	0.509	0.532

Table 2.15 Multiple regression analyses for seasonal data (Summer 2002).
One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cold Piscivores		Cool Piscivores		Cool Non-Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	**IND**	**BM**	**IND**	**BM**	**IND**	**BM**	**IND**	**BM**	**IND**
Suitability	b_j				2.863			10.073		26.766	8.221
	β_j				0.427			0.410		0.562	0.667
	P				0.044			0.031		0.010	0.002
Water Temp (Range 17.00-22.30)	b_j						-1.434	1.593	0.515		
	β_j						-0.606	0.453	0.530		
	P						0.010	0.041	0.013		
Maximum Effective Fetch	b_j								-2.817×10^{-5}		
	β_j								-0.406		
	P								0.048		
Mean 30-Day Air Temp (Range 22.38-22.74)	b_j	5.321	1.624			36.638					
	β_j	0.687	0.692			0.573					
	P	0.002	0.002			0.016					
Intercept	b_j	-119.692	-36.530		-0.009	-816.947	33.698	-34.628	-9.310	3.231	0.070
	P	0.002	0.002		0.967	0.017	0.005	0.026	0.028	0.489	0.948
r^2		0.472	0.479		0.183	0.328	0.367	0.522	0.528	0.315	0.445

Table 2.16 Multiple regression analyses for seasonal data (Fall 2002).
One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cool Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	IND	BM	IND	BM	IND
Suitability	b_j						
	β_j						
	P						
Water Temp (Range 4.20-14.70)	b_j		0.133				
	β_j		0.606				
	P		0.013				
Maximum Effective Fetch	b_j			-1.522×10^{-4}	-6.129×10^{-5}	-4.856×10^{-4}	-1.337×10^{-4}
	β_j			-0.886	-0.743	-0.608	-0.646
	P			<0.001	0.001	0.013	0.007
Mean 30-Day Air Temp (Range 12.19-15.97)	b_j						
	β_j						
	P						
Intercept	b_j		-0.548	6.333	2.536	20.472	5.608
	P		0.303	<0.001	<0.001	<0.001	<0.001
r^2			0.368	0.785	0.552	0.369	0.418

Table 2.17 Multiple regression analyses for seasonal data (Spring 2003).
One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cool Piscivores		Warm Non-Piscivores	
		BM	IND	BM	IND
Suitability	b_i			99.629	28.034
	β_i			0.550	0.499
	P			0.017	0.029
Water Temp (Range 6.20-14.20)	b_i	1.451	0.283		
	β_i	0.798	0.806		
	P	0.004	0.003		
Maximum Effective Fetch	b_i				
	β_i				
	P				
Mean 30-Day Air Temp (Range 6.71-7.89)	b_i	-5.681	-1.128		
	β_i	-0.588	-0.606		
	P	0.021	0.017		
Intercept	b_i	30.596	5.993	-10.804	-3.416
	P	0.049	0.043	0.261	0.268
r^2		0.541	0.557	0.302	0.249

Table 2.18 Multiple regression analyses for seasonal data (Summer 2003).
One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed. The estimated regression coefficient is denoted by b_j and the standardized regression coefficient by β_j.

		Cool Piscivores		Cool Non-Piscivores		Warm Piscivores		Warm Non-Piscivores	
		BM	IND	BM	IND	BM	IND	BM	IND
Suitability	b_j			20.897				56.663	16.004
	β_j			0.654				0.768	0.727
	P			0.004				<0.001	0.001
Water Temp (Range 13.00-19.00)	b_j	0.964							
	β_j	0.314							
	P	0.030							
Maximum Effective Fetch	b_j								
	β_j								
	P								
Mean 30-Day Air Temp (Range 19.12-19.34)	b_j	48.919	5.764			40.269	9.744		
	β_j	0.838	0.653			0.585	0.663		
	P	<0.001	0.008			0.022	0.007		
Intercept	b_j	-950.519	-110.115	7.898		-769.918	-186.378	-3.702	-1.439
	P	<0.001	0.009	0.040		0.023	0.007	0.529	0.446
r^2		0.806	0.427	0.427		0.343	0.439	0.589	0.528

Table 2.19 Site-specific bias analyses of the HAAT model based on averaged site-specific data.
Predictive bias is measured by mean error and predictive accuracy is measured by mean absolute percent error. Lower values for bias and accuracy are preferred. *P* refers to the significance of the predictive bias and $P < 0.05$ indicates significant predictive bias.

Site Name	Mean Error	*P*	Mean Absolute % Error
Embayment A	-0.13	>0.05	25.66
Embayment C	-0.57	>0.05	10.84
Cell 1	1.94	>0.05	134.92
Cell 2	-0.51	>0.05	28.15
Cell 3	-1.79	<0.05	27.76
Lighthouse Point	3.07	<0.05	51.21
Donut Island	-0.57	>0.05	11.06
Gibraltar Point	2.60	>0.05	112.25
Lighthouse Bay	-1.73	<0.05	20.79
Snake Island	-0.50	>0.05	25.02
Sunfish Cut	0.05	>0.05	12.06
Wards Island	-0.45	>0.05	39.37
Fishing Pier	-1.60	<0.05	38.10
Wetland	-1.26	>0.05	33.65
Palace Pier	1.10	>0.05	40.42
Inner Habitat Isles	-0.59	>0.05	30.89
Outer Habitat Isles	0.96	>0.05	45.81

Table 2.20 Trophic group-specific bias analyses of the HAAT model based on averaged site-specific data.

Predictive bias is measured by mean error and predictive accuracy is measured by mean absolute percent error. Lower values for bias and accuracy are preferred. P refers to the significance of the predictive bias and P < 0.05 indicates significant predictive bias. Actual biomass for coldwater non-piscivores was zero, thus MAPE could not be calculated and is designated by n/a.

Trophic Group	Mean Error	*P*	Mean Absolute % Error
Coldwater Piscivore	-3.07	<0.01	100.00
Coldwater Non-Piscivore	5.22	<0.01	n/a
Coolwater Piscivore	1.62×10^{-8}	>0.05	21.14
Coolwater Non-Piscivore	5.21×10^{-8}	>0.05	59.71
Warmwater Piscivore	7.57×10^{-10}	>0.05	26.94
Warmwater Non-Piscivore	-6.05×10^{-8}	>0.05	11.14

Appendix A
Site Habitat Maps

The following are examples of summer site habitat maps produced in ArcView GIS 3.2a to generate the unique polygon information needed for Habitat Alteration Assessment Tool input files. Three maps are provided for each site, which illustrate the polygons of % macrophyte coverage, substrate type and depth (m). Included are: Embayment C from the sheltered embayments habitat grouping (Table A1-A3) and Lighthouse Point from the open coasts habitat grouping (Table A4-A6). The three layers were subsequently merged in ArcView GIS to produce a single layer of polygons with unique cover, substrate and depth combinations. However, due to the substantial number of possible unique polygon combinations for a site, and imaging limitations of ArcView, this final layer is not provided here.

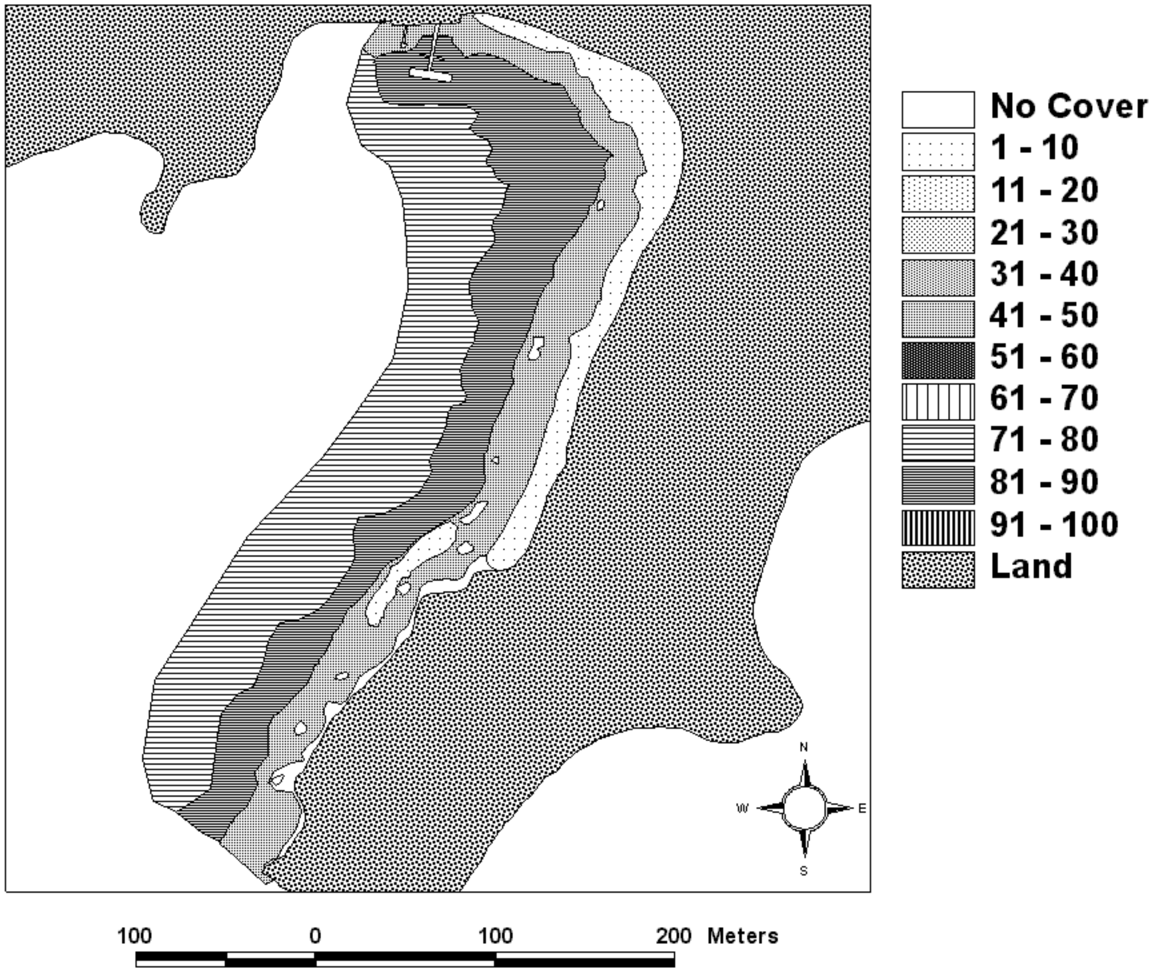

Figure A1 Embayment C: Unique macrophyte polygons layer from ArcView GIS. The percent submergent vegetation of each polygon is defined in the legend.

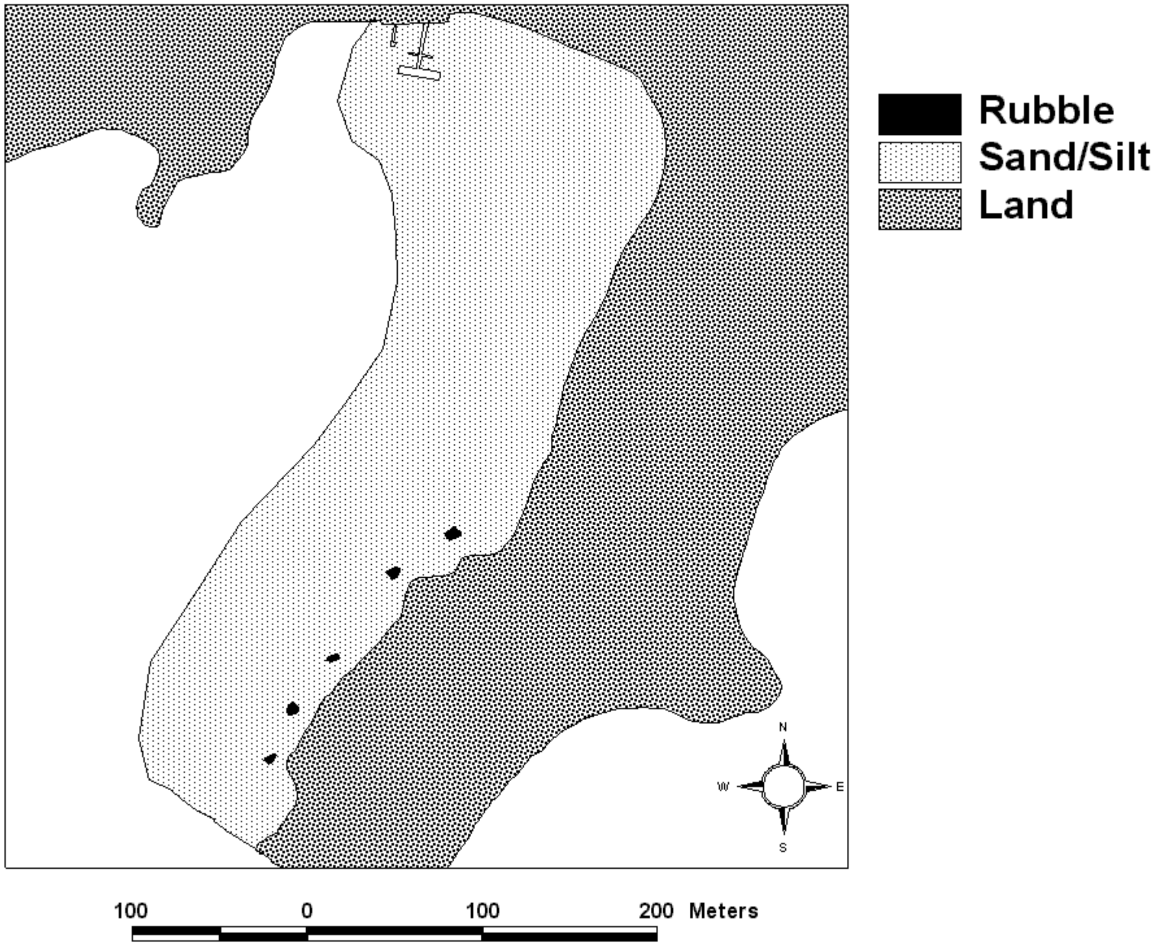

Figure A2 Embayment C: Unique substrate polygons layer from ArcView GIS. The substrate type of each polygon is defined in the legend.

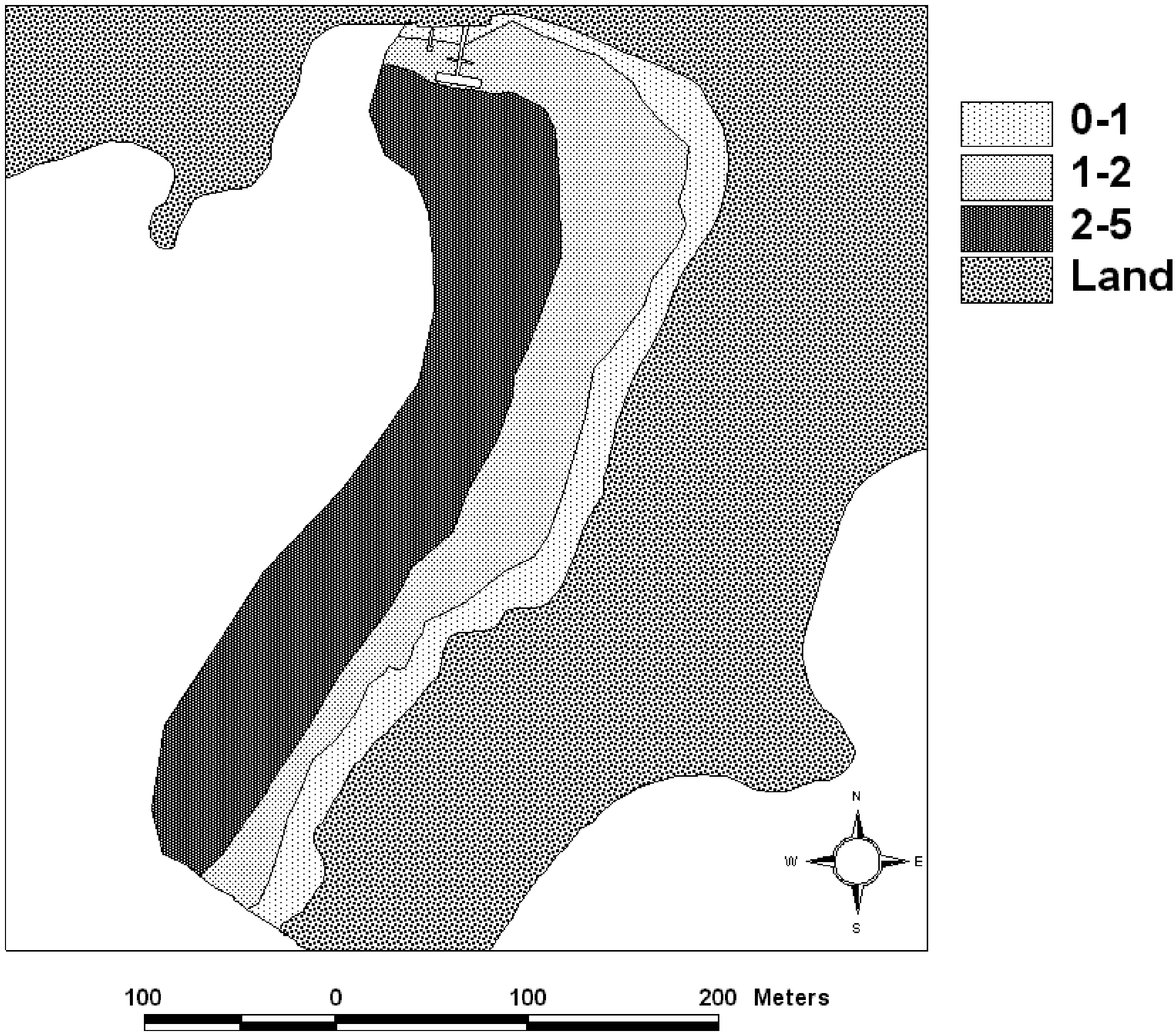

Figure A3 Tommy Thompson Park – Embayment C: Unique depth polygons layer from ArcView GIS. The depth category (metres) of each polygon is defined in the legend.

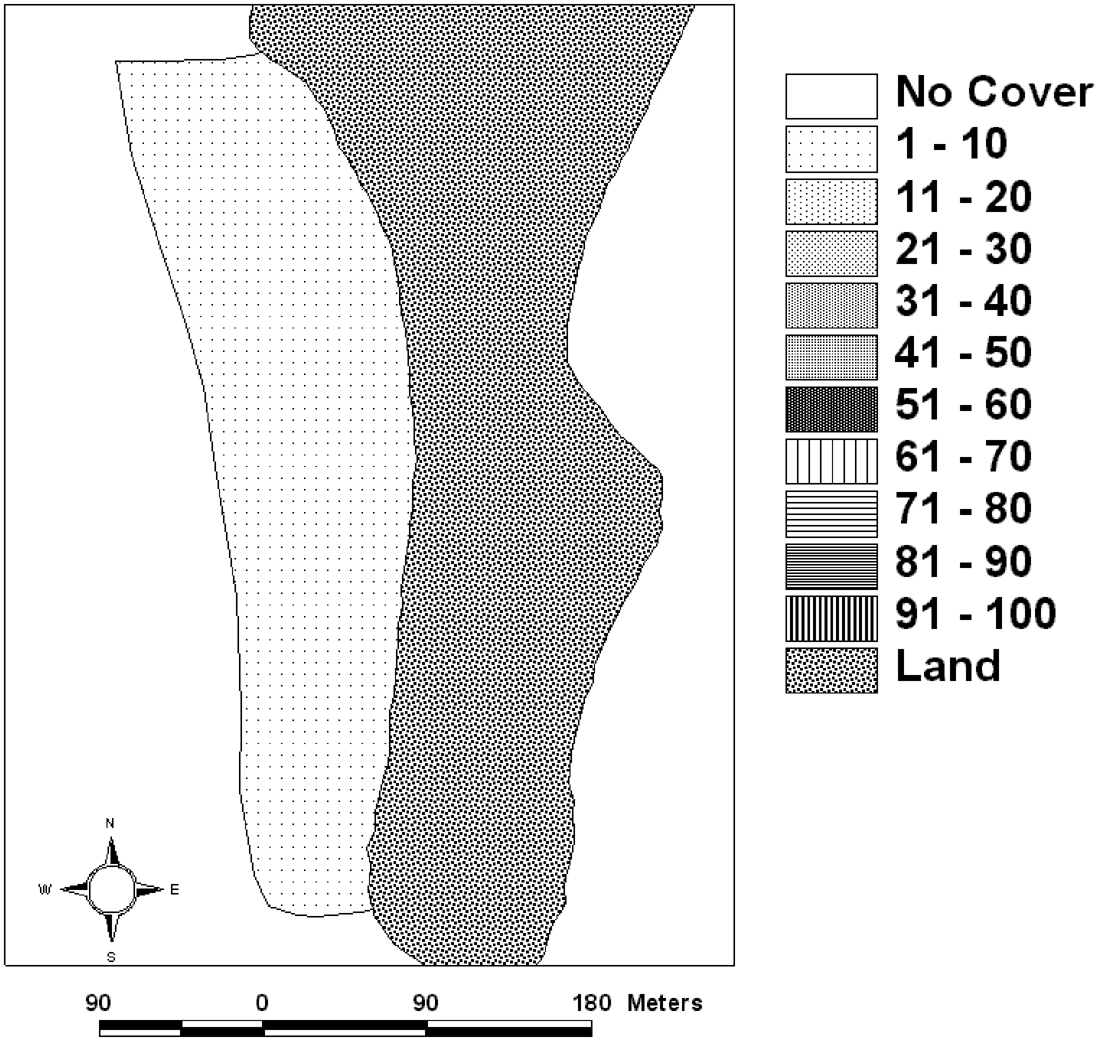

Figure A4 Tommy Thompson Park – Lighthouse Point: Unique macrophyte polygons layer from ArcView GIS. The percent submergent vegetation of each polygon is defined in the legend. Macrophyte coverage was between 1% and 10% and across the entire mapped area, thus only one macrophyte polygon was generated for this site.

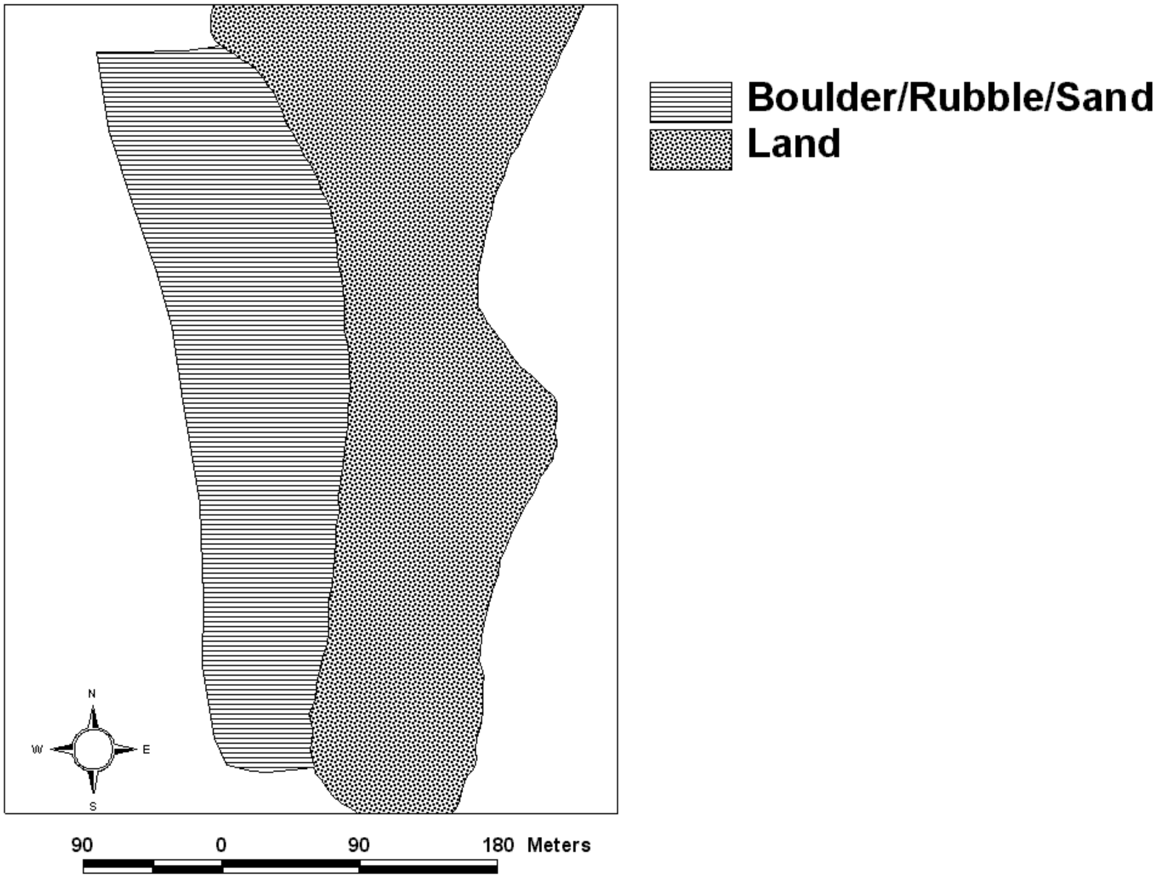

Figure A5 Tommy Thompson Park – Lighthouse Point: Unique substrate polygons layer from ArcView GIS. The substrate type of each polygon is defined in the legend. The substrate was uniform across the entire mapped area, thus only one macrophyte polygon was generated for this site.

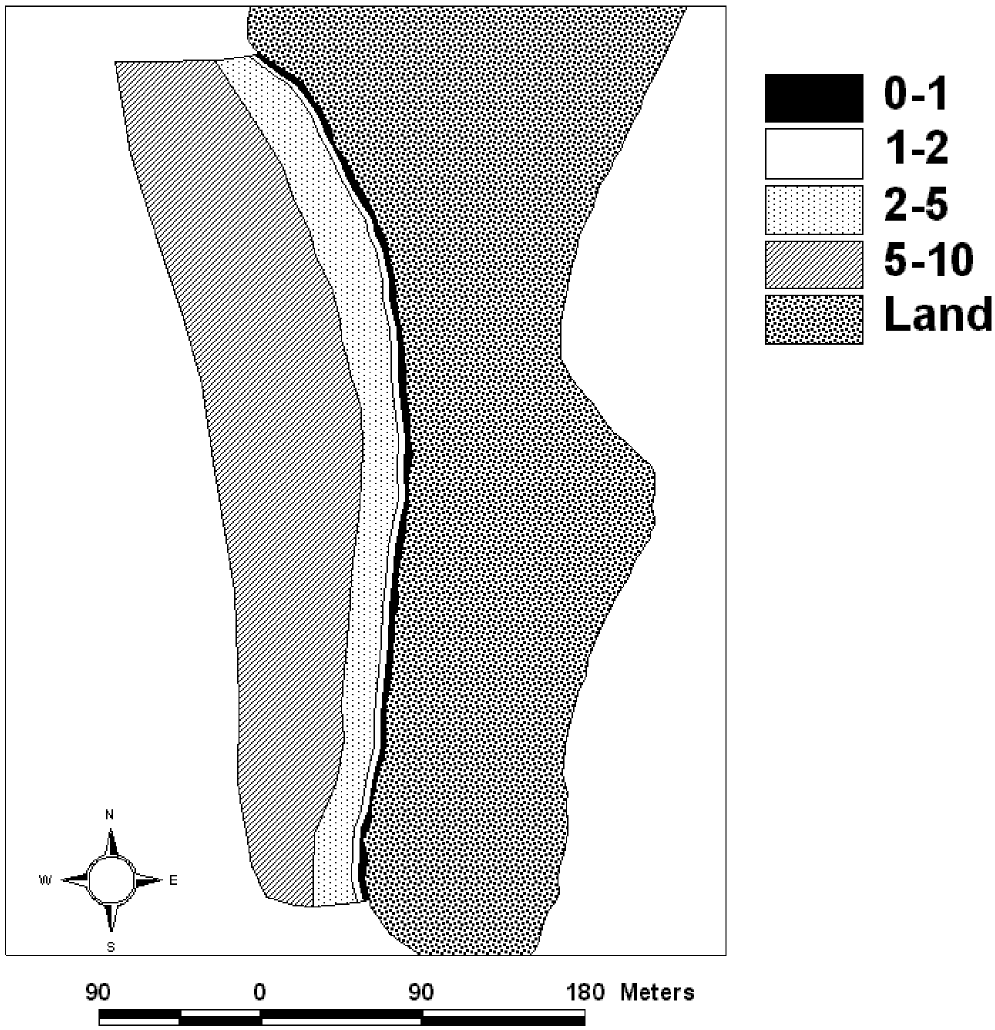

Figure A6 Tommy Thompson Park – Lighthouse Point: Unique depth polygons layer from ArcView GIS. The depth category (metres) of each polygon is defined in the legend.

Appendix B
HAAT Input Files

The following are examples of files used to input the mapped habitat data into the Habitat Alteration Assessment Tool. Included are input files based on summer habitat mapping for: Embayment C from the sheltered embayments habitat grouping (Table B1) and Lighthouse Point from the open coasts habitat grouping (Table B2). An input file based on spring habitat mapping is provided for Embayment C (Table B3). Note that Table B3 is the same as the summer input file (Table B1) except for vegetation proportion, where the proportion of no cover was set to 100 to account for sampling prior to macrophyte growth.

Table B1 HAAT input file for Embayment C at Tommy Thompson Park detailing depth, substrate and macrophyte proportions for individual, unique polygons based on summer habitat mapping.

```
; TOMMY_THOMPSON
; EmbaymentC

* UnitType=Area
* Units=m2

* Order=ID,Area,AreaType,Depth,Substrate,Vegetation
* Proportions=Depth:Z0_1,Z1_2,Z2_5,Z5_10,Z10+
* Proportions=Substrate:Bedrock,Boulder,Cobble,Rubble,Gravel,
  Sand,Silt,Clay,Hardpan,Pelagic
* Proportions=Vegetation:NoCover,Emergent,Submergent

1,24.054,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
2,28.739,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
3,36.477,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
4,37.703,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
5,45.717,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
6,0.087,UNCH,"100,,,,",",,,,,95,5,,,","95,,5"
7,0.181,UNCH,"100,,,,",",,,,,95,5,,,","50,,50"
8,1.494,UNCH,"100,,,,",",,,,,95,5,,,","50,,50"
9,34.279,UNCH,"100,,,,",",,,,,95,5,,,","10,,90"
10,1107.742,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
11,4703.015,UNCH,"100,,,,",",,,,,95,5,,,","50,,50"
12,6296.987,UNCH,"100,,,,",",,,,,95,5,,,","95,,5"
13,0.374,UNCH,",100,,,",",,,75,,25,,,,","100,,"
14,4.682,UNCH,",100,,,",",,,75,,25,,,,","100,,"
15,11.009,UNCH,",100,,,",",,,,,95,5,,,","100,,"
16,19.246,UNCH,",100,,,",",,,,,95,5,,,","100,,"
17,73.244,UNCH,",100,,,",",,,,,95,5,,,","100,,"
18,88.696,UNCH,",100,,,",",,,,,95,5,,,","95,,"
19,138.098,UNCH,",100,,,",",,,,,95,5,,,","25,,75"
20,474.251,UNCH,",100,,,",",,,,,95,5,,,","95,,5"
21,843.145,UNCH,",100,,,",",,,,,95,5,,,","95,,5"
22,9920.176,UNCH,",100,,,",",,,,,95,5,,,","50,,50"
23,11327.647,UNCH,",100,,,",",,,,,95,5,,,","10,,90"
24,7503.682,UNCH,",,100,,",",,,,,95,5,,,","10,,90"
25,23795.282,UNCH,",,100,,",",,,,,95,5,,,","25,,75"
```

Table B2 HAAT input file for Lighthouse Point at Tommy Thompson Park detailing depth, substrate and macrophyte proportions for individual, unique polygons based on summer habitat mapping.

```
; TOMMY_THOMPSON
; Lighthouse Point

* UnitType=Area
* Units=m2

* Order=ID,Area,AreaType,Depth,Substrate,Vegetation
* Proportions=Depth:Z0_1,Z1_2,Z2_5,Z5_10,Z10+
* Proportions=Substrate:Bedrock,Boulder,Cobble,Rubble,Gravel,
  Sand,Silt,Clay,Hardpan,Pelagic
* Proportions=Vegetation:NoCover,Emergent,Submergent

1,1806.826,UNCH,"100,,,,",",75,,20,,5,,,,","95,0,5"
2,2279.460,UNCH,",100,,,",",75,,20,,5,,,,","95,0,5"
3,13633.829,UNCH,",,100,,",",75,,20,,5,,,,","95,0,5"
4,39948.892,UNCH,",,,100,",",75,,20,,5,,,,","95,0,5"
```

Table B3 HAAT input file for Embayment C at Tommy Thompson Park detailing depth, substrate and macrophyte proportions for individual, unique polygons based on spring habitat mapping.

```
; TOMMY_THOMPSON
; EmbaymentC_Spring

* UnitType=Area
* Units=m2

* Order=ID,Area,AreaType,Depth,Substrate,Vegetation
* Proportions=Depth:Z0_1,Z1_2,Z2_5,Z5_10,Z10+
* Proportions=Substrate:Bedrock,Boulder,Cobble,Rubble,Gravel,
  Sand,Silt,Clay,Hardpan,Pelagic
* Proportions=Vegetation:NoCover,Emergent,Submergent

1,24.054,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
2,28.739,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
3,36.477,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
4,37.703,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
5,45.717,UNCH,"100,,,,",",,,75,,25,,,,","100,,"
6,0.087,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
7,0.181,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
8,1.494,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
9,34.279,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
10,1107.742,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
11,4703.015,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
12,6296.987,UNCH,"100,,,,",",,,,,95,5,,,","100,,"
13,0.374,UNCH,",100,,,",",,,75,,25,,,,","100,,"
14,4.682,UNCH,",100,,,",",,,75,,25,,,,","100,,"
15,11.009,UNCH,",100,,,",",,,,,95,5,,,","100,,"
16,19.246,UNCH,",100,,,",",,,,,95,5,,,","100,,"
17,73.244,UNCH,",100,,,",",,,,,95,5,,,","100,,"
18,88.696,UNCH,",100,,,",",,,,,95,5,,,","100,,"
19,138.098,UNCH,",100,,,",",,,,,95,5,,,","100,,"
20,474.251,UNCH,",100,,,",",,,,,95,5,,,","100,,"
21,843.145,UNCH,",100,,,",",,,,,95,5,,,","100,,"
22,9920.176,UNCH,",100,,,",",,,,,95,5,,,","100,,"
23,11327.647,UNCH,",100,,,",",,,,,95,5,,,","100,,"
24,7503.682,UNCH,",,100,,",",,,,,95,5,,,","100,,"
25,23795.282,UNCH,",,100,,",",,,,,95,5,,,","100,,"
```

Appendix C

Linear Regression Analyses

These results are for univariate models only. Positive significant correlations are designated by a plus (+) sign and negative correlations by a minus (-) sign. The significance of the correlation is indicated as follows: + or - = P ≤0.05; ++ or - - = P ≤0.01; +++ or - - - = P ≤0.001. Where no + or – signs follow, the correlation was statistically insignificant. For coldwater piscivores, suitability was calculated by the HAAT to be zero, therefore, “n/a” is used to indicate that no model could be produced.

One-tailed *P*-values are given for suitability based on the *a-priori* expectation that biomass and numbers of individuals are positively related to suitability. All other *P*-values are 2-tailed.

Table C1 r^2 values for averaged site-specific data using biomass as the dependent variable.

Sites	r^2	Suitability	Mean Water Temp (Range 12.25-18.57)	Maximum Effective Fetch	Mean 30-Day Air Temp (Range 17.57-20.92)
All Sites (*n*=17)	Cold Piscivores	n/a	0.082	0.005	0.153
	Cool Piscivores	0.162	0.187	0.270 -	0.098
	Cool Non-Piscivores	0.026	0.007	0.089	0.026
	Warm Piscivores	0.401 ++	0.552 +++	0.755 - - -	0.277 +
	Warm Non-Piscivores	0.512 +++	0.057	0.156	0.014
Embayments Only (*n*=11)	Cold Piscivores	n/a	0.407 -	0.074	0.326
	Cool Piscivores	0.013	0.007	0.022	0.019
	Cool Non-Piscivores	0.150	0.227	0.122	0.165
	Warm Piscivores	0.481 ++	0.436 +	0.369 -	0.235
	Warm Non-Piscivores	0.529 ++	0.518 +	0.277	0.208
Open Coasts Only (*n*=6)	Cold Piscivores	n/a	0.093	0.103	0.119
	Cool Piscivores	0.190	0.005	0.007	0.077
	Cool Non-Piscivores	0.004	0.275	0.512	0.104
	Warm Piscivores	0.388	0.119	0.891 - -	0.123
	Warm Non-Piscivores	0.702 +	0.139	0.077	0.147

Table C2 r^2 values for averaged site-specific data using number of individuals as the dependent variable.

Sites	r^2	Suitability	Mean Water Temp (Range 12.25-18.57)	Maximum Effective Fetch	Mean 30-Day Air Temp (Range 17.57-20.92)
All Sites (*n*=17)	**Cold Piscivores**	n/a	0.035	0.021	0.110
	Cool Piscivores	0.196 +	0.407 ++	0.251 -	0.112
	Cool Non-Piscivores	0.042	0.049	0.015	0.019
	Warm Piscivores	0.359 ++	0.610 +++	0.489 -	0.212
	Warm Non-Piscivores	0.634 +++	0.526 +++	0.718 - - -	0.193
Embayments Only (*n*=11)	**Cold Piscivores**	n/a	0.273	0.119	0.213
	Cool Piscivores	0.102	0.260	0.085	0.008
	Cool Non-Piscivores	0.131	0.286	0.111	0.093
	Warm Piscivores	0.369 +	0.485 +	0.286	0.071
	Warm Non-Piscivores	0.492 ++	0.493 +	0.103	0.075
Open Coasts Only (*n*=6)	**Cold Piscivores**	n/a	0.001	0.001	0.188
	Cool Piscivores	0.110	0.003	0.015	0.115
	Cool Non-Piscivores	0.022	0.762 +	0.540	0.539
	Warm Piscivores	0.379	0.144	0.877 - -	0.209
	Warm Non-Piscivores	0.501	0.088	0.845 - -	0.076

Table C3 r^2 values for individual site-specific data using biomass as the dependent variable.

Sites	r^2	Suitability	Trend	Water Temp (Range 4.20-22.30)	Maximum Effective Fetch	Mean 30-Day Air Temp (Range 6.71-22.74)
All Sites (*n*=63)	**Cold Piscivores**	n/a	0.025	0.012	0.002	0.001
	Cool Piscivores	0.042	0.022	0.001	0.126 - -	0.021
	Cool Non-Piscivores	0.008	0.112 ++	0.001	0.085 -	0.007
	Warm Piscivores	0.324 +++	0.006	0.042	0.181 - -	0.051
	Warm Non-Piscivores	0.297 +++	0.006	0.052	0.256 - - -	0.035
Embayments Only (*n*=41)	**Cold Piscivores**	n/a	0.045	0.006	0.024	0.004
	Cool Piscivores	0.016	0.054	0.009	0.041	0.037
	Cool Non-Piscivores	0.029	0.175 ++	0.033	0.091	0.001
	Warm Piscivores	0.397 +++	0.006	0.026	0.133 -	0.092
	Warm Non-Piscivores	0.140 ++	0.038	0.006	0.128 -	0.015
Open Coasts Only (*n*=22)	**Cold Piscivores**	n/a	0.001	0.039	0.036	0.012
	Cool Piscivores	0.021	0.001	0.041	0.023	0.014
	Cool Non-Piscivores	0.201 +	0.025	0.085	0.408 - -	0.054
	Warm Piscivores	0.163 +	0.072	0.002	0.230 -	0.005
	Warm Non-Piscivores	0.375 ++	0.038	0.092	0.347 - -	0.136

Table C4 r^2 values for individual site-specific data using number of individuals as the dependent variable.

Sites	r^2	Suitability	Trend	Water Temp (Range 4.20-22.30)	Maximum Effective Fetch	Mean 30-Day Air Temp (Range 6.71-22.74)
All Sites (*n*=63)	Cold Piscivores	n/a	0.006	0.001	0.001	0.005
	Cool Piscivores	0.031	0.028	0.003	0.153 - -	0.050
	Cool Non-Piscivores	0.001	0.099 +	0.001	0.044	0.020
	Warm Piscivores	0.369 +++	0.038	0.033	0.185 - - -	0.045
	Warm Non-Piscivores	0.336 +++	0.008	0.040	0.267 - - -	0.027
Embayments Only (*n*=41)	Cold Piscivores	n/a	0.020	0.005	0.051	0.004
	Cool Piscivores	0.007	0.055	0.036	0.042	0.086
	Cool Non-Piscivores	0.033	0.103 +	0.020	0.085	0.006
	Warm Piscivores	0.485 +++	0.065	0.014	0.137 -	0.081
	Warm Non-Piscivores	0.188 ++	0.036	0.005	0.127 -	0.020
Open Coasts Only (*n*=22)	Cold Piscivores	n/a	0.010	0.004	0.006	0.011
	Cool Piscivores	0.010	0.001	0.032	0.046	0.042
	Cool Non-Piscivores	0.087	0.093	0.093	0.195 -	0.089
	Warm Piscivores	0.161 +	0.076	0.004	0.228 -	0.007
	Warm Non-Piscivores	0.353 ++	0.047	0.060	0.400 - -	0.090

Table C5 r^2 values for seasonal site-specific data using biomass as the dependent variable.

Sites	r^2	Suitability	Water Temp	Maximum Effective Fetch	Mean 30-Day Air Temp
Summer 2002 (*n*=17)	Cold Piscivores	n/a	0.055	0.005	0.472 ++
	Cool Piscivores	0.094	0.102	0.019	0.007
	Cool Non-Piscivores	0.021	0.288 -	0.028	0.328 +
	Warm Piscivores	0.350 ++	0.382 ++	0.220	0.051
	Warm Non-Piscivores	0.315 ++	0.157	0.172	0.083
Fall 2002 (*n*=16)	Cold Piscivores	n/a	0.002	0.004	0.016
	Cool Piscivores	0.142	0.160	0.065	0.202
	Cool Non-Piscivores	0.053	0.023	0.061	0.058
	Warm Piscivores	0.240 +	0.353 +	0.785 - - -	0.111
	Warm Non-Piscivores	0.147	0.239	0.369 -	0.153
Spring 2003 (*n*=15)	Cold Piscivores	n/a	0.047	0.099	0.078
	Cool Piscivores	0.040	0.272 +	0.361 -	0.045
	Cool Non-Piscivores	0.023	0.243	0.261	0.082
	Warm Piscivores	0.068	0.001	0.042	0.094
	Warm Non-Piscivores	0.302 +	0.128	0.212	0.038
Summer 2003 (*n*=15)	Cold Piscivores	n/a	0.016	0.009	0.206
	Cool Piscivores	0.135	0.104	0.255	0.707 +++
	Cool Non-Piscivores	0.427 ++	0.060	0.107	0.207
	Warm Piscivores	0.291 +	0.034	0.139	0.343 +
	Warm Non-Piscivores	0.589 +++	0.027	0.372 -	0.409 ++

Table C6 r^2 values for seasonal site-specific data using number of individuals as the dependent variable.

Sites	r^2	Suitability	Water Temp	Maximum Effective Fetch	Mean 30-Day Air Temp
Summer 2002 (*n*=17)	**Cold Piscivores**	n/a	0.067	0.001	0.479 ++
	Cool Piscivores	0.183 +	0.172	0.038	0.027
	Cool Non-Piscivores	0.045	0.367 - -	0.041	0.319 +
	Warm Piscivores	0.348 ++	0.369 ++	0.257 -	0.060
	Warm Non-Piscivores	0.445 ++	0.214	0.364 - -	0.064
Fall 2002 (*n*=16)	**Cold Piscivores**	n/a	0.006	0.003	0.038
	Cool Piscivores	0.154	0.368 +	0.181	0.339 +
	Cool Non-Piscivores	0.075	0.015	0.017	0.071
	Warm Piscivores	0.325 ++	0.431 ++	0.552 - - -	0.244
	Warm Non-Piscivores	0.264 +	0.303 +	0.418 - -	0.198
Spring 2003 (*n*=15)	**Cold Piscivores**	n/a	0.027	0.046	0.085
	Cool Piscivores	0.018	0.272 +	0.287 -	0.051
	Cool Non-Piscivores	0.013	0.080	0.140	0.061
	Warm Piscivores	0.061	0.001	0.039	0.106
	Warm Non-Piscivores	0.249 +	0.044	0.133	0.090
Summer 2003 (*n*=15)	**Cold Piscivores**	n/a	0.015	0.004	0.207
	Cool Piscivores	0.159	0.162	0.222	0.427 ++
	Cool Non-Piscivores	0.114	0.023	0.019	0.038
	Warm Piscivores	0.311 +	0.089	0.153	0.439 ++
	Warm Non-Piscivores	0.528 +++	0.106	0.333 -	0.401 ++

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