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Defensible Methods for Pre- and Post-Development Assessment of Fish Habitat in the Great Lakes. I.

A Prototype Methodology for Headlands and Offshore Structures

C.K. Minns, J.D. Meisner, J.E. Moore, L.A. Greig, and R.G. Randall

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1995

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2328

Fisheries and Oceans / Pêches et Océans

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

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Cat. No. Fs 97-4/2328 ISSN 0706-6473

Correct citation for this publication:

Minns, C.K., J.D. Meisner, J.E. Moore, L.A. Greig, and R.G. Randall. 1995. Defensible methods for pre- and post-development assessment of fish habitat in the Great Lakes. I. A prototype methodology for headlands and offshore structures. Can. MS Rep. Fish. Aquat. Sci. 2328: xiii + 65 p.

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ABSTRACT

Minns, C.K., J.D. Meisner, J.E. Moore, L.A. Greig, and R.G. Randall. 1995. Defensible methods for pre- and post-development assessment of fish habitat in the Great Lakes. I. A prototype methodology for headlands and offshore structures. Can. MS Rep. Fish. Aquat. Sci. 2328: xiii + 65 p.

A prototype, defensible methodology was developed for use in the Great Lakes for pre- and post- development assessment of inshore fish habitat. The prototype methodology focuses on shoreline development projects that involve construction of headlands or offshore structures, such as islands. The purpose of the methodology is to provide a quantitative, defensible assessment protocol which proponents and fish habitat managers can use to assess compliance of shoreline development projects with the federal habitat policy of "no net loss" of fish habitat in development. The protocol combines published habitat requirements of three thermal guilds of Great Lakes fishes with GIS-based areal estimation of lost or modified inshore habitat due to placement of headlands or offshore structures in pre- and post development assessments of adult and spawning habitat of fish, and habitat for community production. In addition to estimating fish habitat area directly affected by the footprint of these structures, the methodology attempts to estimate the amount of adjacent habitat in the shadow (lee) of the structures that is indirectly affected due to changes in local wave energy and currents caused by the structures. The methodology provides the ability to integrate fish community objectives into an assessment, thereby allowing trade-offs between fish community objectives and compliance with the "no net loss" policy. The protocol provides defensible assessments because the single set of rules and algorithms that are used to assess pre-and post development fish habitat are transparent, and are meant to be updated with new knowledge of the effects of humans activity on fish habitat and fish populations.

The La Salle Marina habitat restoration project on the northern shore of Hamilton Harbour was used as a case study of the protocol. This marina development involves placement of headland and island structures. For an assemblage of coldwater, coolwater, and warmwater species that was selected based on existing fish community objectives, the assessment predicted that the headland\island development at the La Salle marina would result in a permanent loss of 2900 m^2 of sand, mud and vegetated habitat that becomes the exposed

crown of the structures, and would convert about 3184 m^2 of similar habitat to rock which becomes the armoured, submerged slope of the structures. The headland/island structures would indirectly affect an estimated 144000 m^2 of habitat due to changes to local wave exposure. The estimated reduction in wave exposure leads to a predicted increase of 43% of submerged macrophytes in the indirectly affected area. Across thermal guilds spawning and adult habitat decreased for coldwater species and increased for coolwater species. For warmwater species, non-piscivore spawning habitat decreased and adult summer habitat increased slightly while this habitat for warmwater piscivores increased substantially. The non-specific habitat for community productivity increased by about 31% due largely to the predicted increase of macrophytes in the indirectly modified area. Thus, the assessment indicated that the headland/island development at the La Salle Marina would result in a net gain in fish productivity.

The prototype methodology should provide a valuable tool with which to implement the federal habitat policy and to serve section 35 of the federal Fisheries Act. Further, the methodology should also be useful in the specification and monitoring of compensation for lost fish habitat from development. Areas of the prototype methodology that require further development are identified and discussed.

RÉSUMÉ

Minns, C.K., J.D. Meisner, J.E. Moore, L.A. Greig, and R.G. Randall. 1995. Defensible methods for pre- and post-development assessment of fish habitat in the Great Lakes. I. A prototype methodology for headlands and offshore structures. Can. MS Rep. Fish. Aquat. Sci. 2328: xiii + 65 p.

Une méthode type justifiable a été élaborée pour l'évaluation pré- et post-aménagement des habitats côtiers des poissons des Grands Lacs. Elle porte sur des projets d'aménagement du littoral comportant la construction de structures fixées à la terre ou éloignées de celle-ci, comme des îles. Cette méthode vise à fournir un protocole d'évaluation quantitative justifiable qui peut être utilisé par des promoteurs et des gestionnaires de l'habitat du poisson pour vérifier si ces projets d'aménagement respectent la politique du gouvernement fédéral «d'aucune perte nette» de l'habitat au cours de l'aménagement. Le protocole combine les exigences connues en matière d'habitat de trois guildes de poissons des Grands Lacs ayant des exigences thermiques communes avec une estimation aréale selon le système SIG, de l'habitat côtier perdu ou modifié à cause de l'implantation des structures fixées ou éloignées de la terre pour faire des évaluations avant et après l'aménagement de l'habitat des poissons adultes ou des frayères, et de l'habitat servant à la production de la communauté. En plus d'évaluer la superficie de l'habitat du poisson directement touchée par le tracé de ces structures, la méthode tente d'évaluer la superficie de l'habitat adjacent située à l'ombre (face abritée) des structures et qui est indirectement touchée par les modifications de l'hydrodynamisme et des courants engendrées par ces structures. Cette méthode permet d'intégrer les objectifs relatifs à l'ichtyofaune dans une évaluation, ce qui autorise des compromis entre les objectifs concernant l'ichtyofaune et le respect de la politique «d'aucune perte nette». Le protocole offre des évaluations défendables parce que l'ensemble de règles et d'algorithmes qui est utilisé pour évaluer l'habitat du poisson avant et après l'aménagement est transparent, et qu'elles doivent être mises à jour compte tenu des nouvelles connaissances des effets des activités humaines sur l'habitat et les populations de poisson.

Le projet de rétablissement de l'habitat du poisson dans la marina La Salle, sur la rive nord du port de Hamilton, a été utilisé comme étude de cas du protocole. L'aménagement de cette marina comprend la mise en place de structures rattachées à la terre et éloignées de

celle-ci. Dans le cas du regroupement d'espèces d'eaux froides, d'eaux tempérées et d'eaux chaudes qui a été choisi selon les objectifs de l'ichtyofaune existante, l'évaluation prévoyait que l'aménagement de structures à la marina La Salle se traduirait par une perte permanente de 2 900 m^2 de sable, de boue et d'habitat végétalisé qui deviendraient le sommet exposé des structures, et convertirait environ 3 184 m^2 d'habitat similaire en roche qui deviendrait la pente submergée et blindée structures. Les structures fixées et éloignées modifieraient indirectement 144 000 m^2 d'habitat en raison de changements à l'exposition aux vagues de la région. La réduction estimée de cette exposition entraîne une augmentation prévue de 43 % des macrophytes submergés dans la zone indirectement touchée. Entre les guildes liées par des exigences thermiques, l'habitat de fraye et des adultes a diminué pour les espèces d'eaux froides et augmenté pour les espèces d'eaux tempérées. Dans le cas des espèces d'eaux chaudes, l'habitat de reproduction des espèces non piscivores a diminué et l'habitat d'été des adultes a augmenté légèrement tandis que cet habitat pour les espèces piscivores d'eaux chaudes a considérablement augmenté. L'habitat non spécifique pour la productivité de la communauté a augmenté d'environ 31 %, en grande partie à cause de l'augmentation prévue des macrophytes dans la zone indirectement modifiée. Donc, selon l'évaluation, l'aménagement de structures fixées et éloignées à la marina de La Salle se traduirait par un gain net de la productivité du poisson.

La méthode type devrait fournir un outil valable pour mettre en oeuvre la politique fédérale en matière d'habitat et respecter l'article 35 de la *Loi sur les pêches*. En outre, la méthode devrait aussi être utile au niveau de la spécification et de la surveillance de la compensation pour la perte d'habitat du poisson à cause des aménagements. Les zones visées par la méthode type pour lesquelles il faut prévoir d'autres aménagements sont indiquées et traitées.

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FOREWORD

Since the federal policy for management of fish habitat (Department of Fisheries and Oceans 1986) was articulated in support of the federal Fisheries Act there has been an increasing realization by fish habitat managers and proponents of the need for a common, quantitative assessment protocol to assist with the implementation of the habitat policy of "no net loss" of fish habitat in development projects. The assessment process has been plagued with inconsistency due to the lack of a clear set of information requirements with which to guide proposal development, and a lack of a set of effects criteria to guide the review and decision process. The absence of a common, defensible assessment protocol has made the application process on the part of the proponent, and subsequent review by habitat managers unnecessarily difficult and time consuming. A common protocol which quantifies the effects of shoreline development proposals on Great Lakes fish habitat would expedite the assessment process and would assist implementation of the federal habitat policy.

The prototype methodology for Pre- and Post Development Assessment of Headland and Offshores Structures was developed during three workshops that were commissioned by the Department of Fisheries and Oceans, Central and Arctic Region. The initial workshop scoped the methodology in terms of purpose, project type, geographic area, and proponent and agency. At the initial workshop a summary of 127 shoreline development applications in the Great Lakes that were referred to Fisheries and Habitat Management of DFO by the Ontario Ministry of Natural Resources provided the context and insight into the range of project types that are commonly proposed for along the Great Lakes shorelines. A major requirement for a methodology for development assessments that was identified at the initial workshop was that it provide assessments that are defensible, i.e., 1) the methodology should consolidate current understanding of the effects of shoreline habitat alteration on fish populations; 2) the methodology should be transparent and easy to understand and use by proponents; and 3) the methodology should be easily updatable as new information is acquired.

Based on these initial discussions and the database of referred projects, it was decided to proceed with development of a prototype Defensible Methodology for shoreline activities involving headlands and offshore structures. Two workshops were held in December and February of 1994/95 in which the framework for the prototype defensible methodology was developed. The Defensible Methodology described herein could not have been developed without the insight and critical thinking of the following people who attended the initial scoping meeting and the subsequent two development workshops:

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The comments of Richard Strus on the initial scoping meeting report were very helpful. Special thanks to Rob Nairn for providing follow-up insight into improvements to estimation of physical habitat variables, and to Larry Halyk, Don Wismer, and the workshop participants who reviewed the draft report.

1.0 INTRODUCTION

Protection from loss or degradation of fish habitat as a result of cultural development along lakes and rivers is a major focus of federal and provincial fish habitat management strategies in Canada. The nearshore areas of lakes, such as the Great Lakes, are key areas for habitat management due to the importance of the relatively narrow band of inshore fish habitat to inshore and offshore fish populations (sensu Steedman and Regier 1987), and due to increasing development pressure that is occurring there.

Management of nearshore fish habitat in Canadian waters of the Great Lakes has formally adopted the ecosystem approach as articulated by the Great Lakes Water Quality Agreement (1985; 1978). The ecosystem approach, which recognizes the interconnectedness of the natural environment and human activity, attempts to integrate assessment of the effects of shoreline development on fish habitat and on fish populations. The ecosystem approach to fish habitat management is explicit in the federal fish habitat policy and the Strategic Plan for the Ontario Fisheries (SPOF II, 1991).

There are numerous guidelines and policies that have been developed to protect aquatic habitat of the Great Lakes from development activities. Federal and provincial habitat protection guidelines and legislation directed to fish habitat protection in Canadian waters of the Great Lakes are described by the Federal Fisheries Act, the Department of Fisheries and Oceans' (DFO) Policy for the Management of Fish Habitat (1986), the Canadian Environmental Assessment Act, the Ontario Ministry of Natural Resources' (OMNR) Interim Fisheries Guidelines for Shoreline Alterations (1991), and the Fish Habitat Protection Guidelines for Developing Areas (1994). The federal policy for management of fish habitat underlies all federal and provincial policies and guidelines. The ultimate objective of the three constituent management actions of the federal policy: 1) conservation of habitat; 2) restoration of damaged habitat; and 3) development of new habitat, is that a net gain of productive capacity of fish habitat occurs. For conservation projects the guiding principle is for a "no net loss" of productive capacity of fish habitat.

The Fisheries Act is the primary statute for the protection of fish habitat in Canada and overrides all other guidelines and policy for fish habitat protection. The sections of the Act relevant to this methodology are sections 35(1) and (2). Section 35(1) specifies that a development proposal must not cause a Harmful Alteration, Disruption, or Destruction (HADD) of fish habitat, which is broadly defined as area that supports all or any aspect of the life of a fish. Section 35(2) of the Act specifies that a HADD can be authorized only at the discretion of the federal Minister of the Department of Fisheries and Oceans.

The criteria that are used to define a HADD, and the criteria that are used to authorize a HADD have recently been distinguished by federal fish habitat managers across Canada (Greig and Meisner 1994). The current, major decision criterion for authorization of a HADD in the Fisheries Act is the existence of a compensatory measure to offset the HADD, i.e., creation of fish habitat off-site that results in the proposed project causing a "no net loss" of fish habitat. Consensus among federal fish habitat managers is that the "no net loss" criterion is the most influential determinant of an authorization of a HADD. However, while no net loss of habitat is preferred, consensus among habitat managers also is that measures to create fish habitat off-site as compensation are normally not as successful at resulting in a "no net loss" of fish habitat as on-site, mitigation measures that directly offset or decrease habitat loss or alteration that occurs due to the project.

Assessment of the "no net loss" criterion with respect to the effects of a proposed project on local fish habitat is currently difficult due to the absence of a common, quantitative protocol that can be used by both project proponents and habitat managers to conduct defensible, pre- and post development assessments of fish habitat. A defensible assessment protocol to assess compliance of development projects with the federal habitat policy, whether for the guiding principle "no net loss" of productive capacity, or for the ultimate policy objective of a "net gain" in productive capacity would increase the effectiveness of the policy, and would provide a powerful decision tool for section 35(2) of the Fisheries Act. The prototype methodology described herein is the first step toward the provision of a common assessment protocol for headlands and offshore structures for the Great Lakes.

1.1 Structure of the Report on the Prototype Methodology

The prototype defensible methodology describes the currently envisioned protocol for assessment of the effects of headland and offshore structure development on fish habitat.

Included with the description of the methodology is a case study application to the La Salle Marina development in Hamilton Harbour. Chapter 2 reviews the roles of the OMNR and DFO in the implementation of the federal habitat policy and the Fisheries Act, and identifies an ongoing impediment to the development assessment process. Chapter 3 describes the prototype methodology for headlands and offshore structures. Chapter 4 describes the case study of the methodology as applied to the La Salle Marina project in Hamilton Harbour, and chapter 5 summarizes the results of the case study, and identifies the components of the prototype methodology that require further development.

2.0 FEDERAL-PROVINCIAL PARTNERSHIP

The Ontario Ministry of Natural Resources and the Department of Fisheries and Oceans work together to protect fish habitat in Ontario from the negative effects of cultural development. The OMNR is empowered to enforce the habitat protection provisions of the Fisheries Act, and to ensure that the federal policy for fish habitat management is applied to development proposals. For development proposals on crown land the proponent normally interacts directly with DFO, whereas on private land the proponent normally interacts with OMNR. On private lands the process for evaluation and assessment of a development proposal begins with the submission of the proponent's development proposal to the municipality. The application for development is reviewed by the field offices of OMNR for compliance with provincial aquatic habitat protection guidelines, and for potential violation of the Fisheries Act. All projects are screened to determine compliance with the federal habitat policy of "no net loss" or "net gain" in productive capacity.

2.1 Referral Process

If it is judged that a HADD will not occur as a result of the proposed project, the proposal stays with OMNR and the proposed project is further screened for compliance with provincial habitat guidelines. If a proposed project is suspected of contravening Section 35(1) of the Act then the project is normally referred to DFO for final assessment. The Federal Minister of Fisheries and Oceans is responsible for the final decision for an authorization of a HADD.

Appendix A summarizes the project types that comprise 127 development proposals in the Great Lakes that were referred to DFO for final evaluation. The proposed projects were referred to DFO because the projects were evaluated as either potentially violating the Fisheries Act, were situated on crown land, or both. The most common types of development proposals were for marinas, or shoreline infilling or armourment projects. Marinas normally involve the construction of nearshore structures such as headlands and offshore structures such as islands (disconnected headlands) for buildings and parking lots, and to reduce wave energy. Islands. i.e, created littoral areas, are also being used as a compensatory measure by proponents for loss of shoreline habitat in development. The majority of project proposals summarized in Appendix A cite the development area as potentially important fish habitat but at the same time provide little information that would be needed to assess the potential effects of the project on fish habitat. However, because marina-related shoreline infilling and armourment involve the nearshore area, these projects would almost always affect fish habitat, be it spawning, nursery, feeding habitat, or seasonal migration routes.

2.2 An Inherent Difficulty with the Implementation of Federal Habitat Policy

The federal fish habitat policy is difficult to administer in the Great Lakes (and elsewhere) because of the lack of an assessment protocol that would allow proponents and government agencies to conduct consistent, quantitative assessments of the effects of proposed projects on fish habitat. Current assessment is too qualitative and subjective because of the absence of clearly defined information needs on fish habitat, and quantitative decision rules. The absence of a common, assessment methodology for use by proponents and government agencies has resulted in indecisive development assessments, the large number of annual proposal referrals received by DFO, and the high variability in information content in submitted development proposals.

A major reason for the current shortcomings of development assessment is the inability to overcome and embrace the current uncertainty of the effects of development projects on fish habitat, and the resultant effects of habitat change on fish populations. There is a reluctance to try to quantify the effects of a shoreline development proposal on fish habitat and supporting fish populations because of the inability to predict effects with a high level of accuracy (and comfort). The biophysical mechanisms that form the causal linkages between shoreline alterations and the effects on fish habitat and fish populations are not as well understood as the direct physical linkages between shoreline construction activities and physical habitat. The resultant, more qualitative approach to the assessment of a project, which does not embrace the inherent uncertainty of the effects of human activity on fish habitat, often results in assessments stalling early or finishing unsatisfactorily because of the inability of the parties to agree upon appropriate assessment metrics, and what constitutes a significant change in habitat.

Quantitative estimates of the effects of development on fish habitat based on empiric understanding can offset incomplete understanding of the mechanisms of effects of development by increasing the precision of assessment. Application of empiric relationships between fish species and habitat needs, and between habitat supply and fish productivity in both pre- and post development assessments can permit consistent assessment. Empiric relationships can range from species-specific regression relations to broader community indices. These empiric tools are transparent and can be improved as understanding of the effects of habitat change on fish populations increases. By applying a single set of empiric rules to assess the pre- and post development habitat condition, the focus of the assessment becomes the potential change to fish habitat, i.e., an estimate of the effect of development, not an accurate description of the pre- and post development condition. In this way the assessment moves to completion easily and does not get bogged down with issues of the state of knowledge. The tradeoff of accuracy for precision with consistently applied quantitative rules allows an assessment to be defensible because it is based on a single set of agreed upon rules and criteria that are updated as new information is obtained. An assessment methodology common to proponents and habitat managers would increase confidence on the part of proponents because as practitioners, they would be integrally involved in the assessments of their own projects.

2.3 Integration of Federal Habitat Policy and Fish Community Objectives

The implementation of the federal habitat policy is conducted in view of existing provincial or federal fish community objectives that are in place for different areas or waterbodies. Fish community objectives can influence the definition of habitat loss or gain in the context of the "no net loss" policy in development assessments if pre-development habitat, on which the assessment is based, is different from habitat, which supports the objective fish community. While it is important to integrate community objectives with the implementation of the "no net loss" policy in development assessment, the two fish habitat goals could come into conflict. An incongruity between the two habitat goals could become apparent if a development proposal that would alter inshore fish habitat is used as an opportunity to create post-development fish habitat that supports an objective fish community that is different from the pre-development community. As an extreme example, a post-development, community of coldwater exotics that was created in support of community objectives could appear to be at odds with the pre-development community of endemic warmwater species.

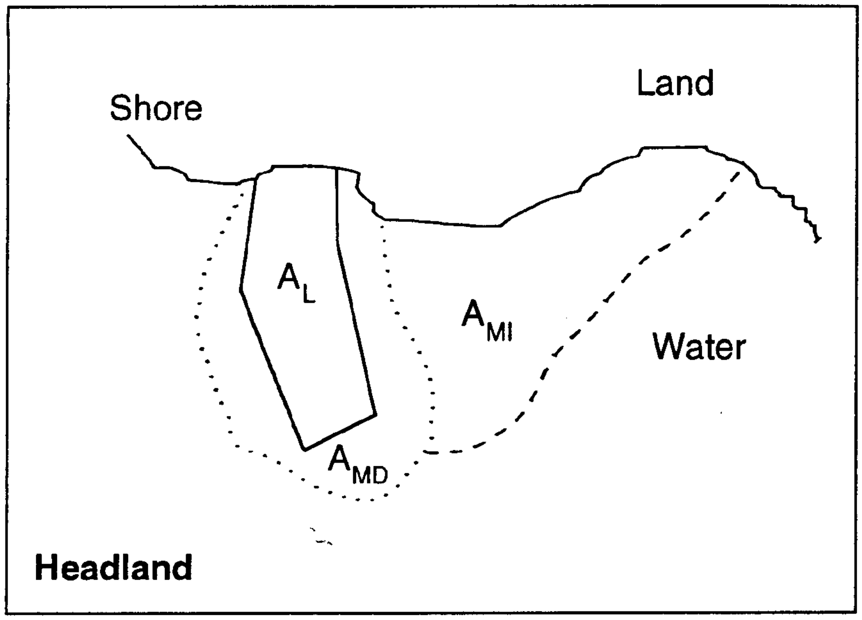
Habitat management for fish community objectives and for compliance with the habitat policy are based on the same ecologic criteria. Assessment of the habitat requirements for an objective fish community and for a "no net loss" of fish habitat, therefore, can use the same decision rules. The potential conflict between the two fish habitat management goals in the context of a development assessment is in part due to the absence of a common assessment protocol to address both management goals. A common assessment protocol can simultaneously assess the effects of a shoreline development proposal on desired fish habitat and assess compliance with the federal habitat policy. The attributes of the objective, post-development fish community can be traded-off with an acceptable level of "no net loss" of pre-development habitat.

3.0 PROTOTYPE METHODOLOGY FOR HEADLANDS AND OFFSHORE STRUCTURES

3.1 Overview and Definitions

A headland is defined as a man-made projection of lake shoreline arising either as an extension to natural shoreline or as an addition to an existing headland (Figure 3.1). An offshore structure, such as an island or breakwater, is also man-made but is not connected to the shoreline. Both structures are constructed with fill and normally have a crown that extends above the high water elevation of the lake. The structures may be bounded by sloped sides of different materials ranging from sand and gravel to armour stone, or may be defined by vertical walls of manmade material such as sheet piling. Headlands and offshore structures are common features of a wide variety of shoreline development projects in the Great Lakes. These structures form major components of marina developments, intake and discharge installations, and commercial and industrial developments.

The prototype, defensible methodology was developed for headlands and offshore structures because of the prevalence of these structures in shoreline developments, and because of the importance of inshore fish habitat to Great Lakes fish populations. Four generic shoreline types were adopted for purposes of developing the prototype assessment methodology (Waterfront Regeneration Trust 1994). These include: 1) inshore shelves of cobble, boulder, and erodible bedrock; 2) relatively steep slopes of sand over till; 3) the sand beach; and 4) slopes of non-erodible bedrock. Fish habitat is defined by substrate ranging from silt to rock including macrophyte cover, depth, temperature, and wave energy expressed as effective fetch. These variables are used to assess suitability of inshore fish habitat for fish species and for community productivity. The defensible methodology is comprised of the following three main components: 1) habitat reference database; 2) habitat supply module; and 3) habitat suitability module. The major components and steps in the prototype methodology are summarized below (Figure 3.2, Table 3.1), followed by detailed descriptions.



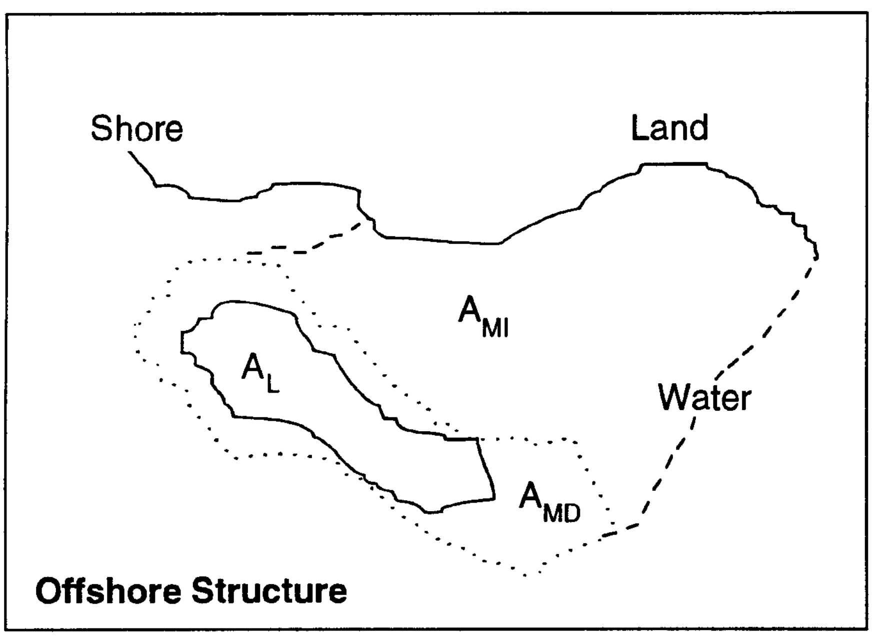


Figure 3.1 Schematic of a headland and offshore structure. A_L represents the exposed crown of the headland/structure and is fish habitat that is permanently lost; A_{MD} is habitat modified directly by the submerged slope of the headland/structure; A_{MI} is habitat that is indirectly affected by changes to local wave energy and currents due placement of the headland/structure (see text).

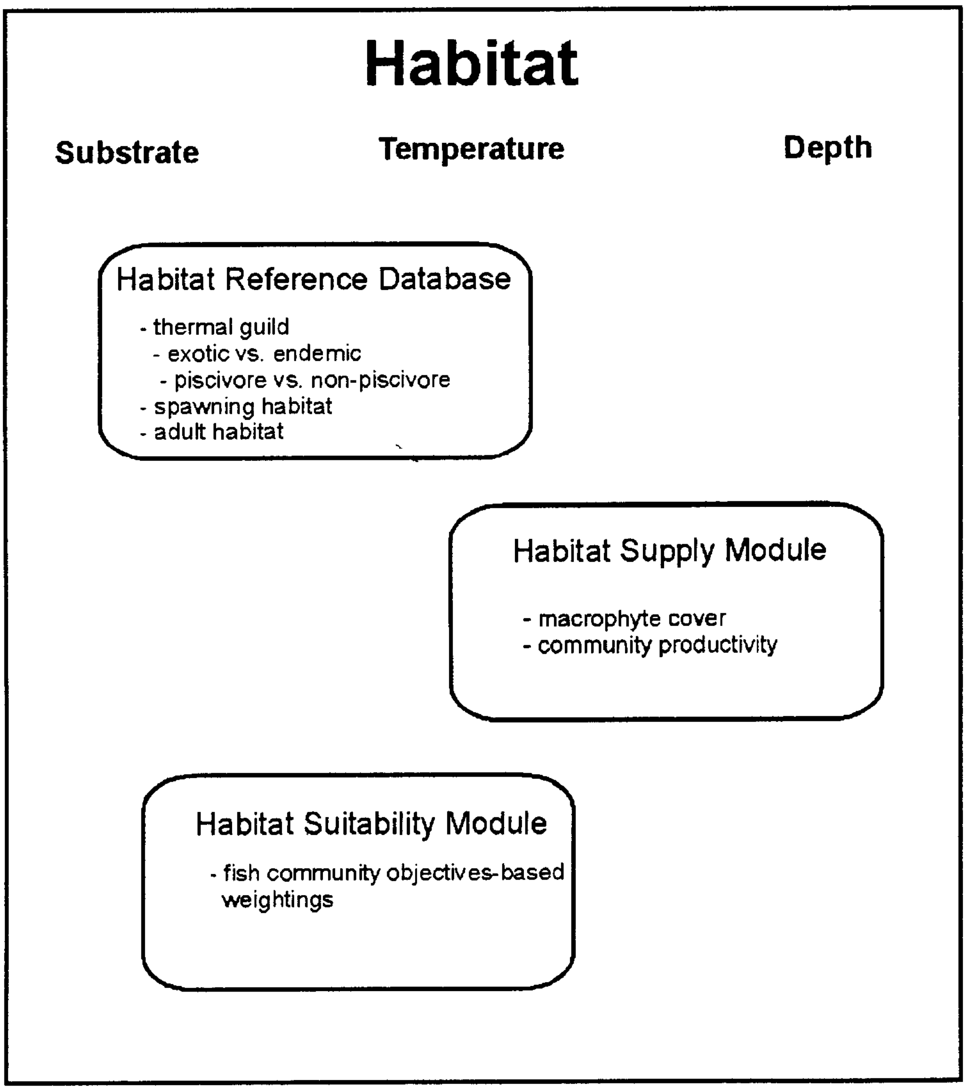


Figure 3.2 Major Components of the Defensible Methodology

3.1.1 Habitat Reference Database

The habitat reference database provides habitat requirements for all fish species within the geographic scope of the prototype methodology. For this prototype methodology, the database contains key spawning and adult habitat requirements, feeding trophy, and the origin of three thermal guilds of fish species that occupy Lake Ontario. Ultimately the reference database would be expanded for each of the Great Lakes. The habitat information in the database provides the common, ecological basis for all major components of the Defensible Methodology (Figure 3.2).

3.1.2. Habitat Supply Module

The habitat supply module is used to estimate fish habitat area before and after development. The habitat supply module houses the causal linkages between the engineering design of a shoreline project and affected fish habitat. Macrophyte cover and fish community productivity area (productive capacity) are estimated with variables of substrate type, depth, and wave action (effective fetch).

3.1.3 Habitat Suitability Module

The habitat suitability module is used to determine the suitability of habitat for adult and spawning stages of fish and for community productivity before and after a development project. Central to the habitat suitability module is the provision to assign preference weightings among species assemblages and among habitat types, based on existing fish community objectives. In a development assessment the preferred species assemblages that are identified with the habitat suitability module are combined with pre- and post development supplies of fish habitat provided by the habitat supply module to assess the effects of a proposed project on suitable fish habitat for different fish assemblages, and on the area for community production. Both modules use the same fish habitat information provided by the habitat reference database.

3.2 Habitat Reference Database

The reference database contains the habitat requirements for Lake Ontario fish species. For three thermal guilds of fishes (sensu Hokansen 1977; see below) spawning and adult habitat is defined by substrate type, and depth. Substrate is defined in six categories ranging from mud to rock and includes discrete categories for macrophyte cover and the pelagic zone. Depth is classified incrementally from 0 to 20+ metres. The reference database also specifies

Table 3.1 Sequence of the major steps in the prototype methodology for pre- and post-development assessments of the effects of headlands and offshore structures on fish habitat in the Great Lakes.

1. Estimate the total habitat area (A_L, A_{MD}, A_{MI}) that will be affected by the placement of the headland and/or offshore structure using the engineering specifications of the project, and the physical modeling tools contained in the Habitat Supply Module.
2. Estimate pre-and post-development macrophyte area and fish community productivity area using Habitat Supply Module.
3. Using the Habitat Suitability Module, determine the preferences or weightings[1] that must be assigned to the attributes of the species groupings (i.e., thermal guild, feeding trophy) in the assessment, based on fish community objectives. Similarly, assign preference weights to spawning habitat, adult habitat, or productivity habitat.
4. Using the Habitat Suitability Module, estimate weighted suitable habitat area for the preferred species groupings (e.g., adult habitat for coldwater piscivore, or spawning habitat for warmwater non-piscivore) before and after development using the pre- and post development supplies of habitat estimated in 1, and the requirements for substrate and depth of the different species groupings, as defined by the Habitat Reference Database.
5. After aggregating spawning and adult habitat across all preferred species assemblages, estimate the weighted suitable areas for spawning habitat, adult habitat, and community productivity habitat using the preference weights from 3 and the community productivity area estimated in 2.
6. Compare the community productivity habitat area (productive capacity) before and after development.

[1] Preference weights can be set equal to unity for all attributes of species groupings in order to remove the influence of fish community objectives from a development assessment.

the origin (endemic or exotic), and feeding trophy (piscivorous or non-piscivorous) of each fish species.

The reference database for fish habitat was compiled from Christie's (1982) and Mandrak and Crossman's (1992) species lists for Ontario. Each species was designated as native or exotic using information in Mandrak and Crossman along with the current status (presence or absence in Ontario). Christie's (1982) distributional data was updated with records assembled by Kelso and Minns (1996) for the Great Lakes. The trophic status (piscivore or non-piscivore) was assigned to each species based on information compiled by Christie (1982), Scott & Crossman (1973), Portt *et al.* (1988), and Minns *et al.* (1993). The trophic status was assigned on the basis of what would be expected for each species in a Great Lake. Again using Christie (1982) supplemented with evidence from Crossman and Scott (1973), each species use of lakes for adult summer or spawning habitat was recorded. At present, the data records are most complete for fish species occurring in Lake Ontario but could be expanded for the other Great Lakes, and to rivers and inland lakes if required. These data for Lake Ontario fish species are reported in Appendix B.

In temperate fisheries of North America, freshwater fish are commonly described as belonging to one of three thermal groupings: cold-, cool-, and warm-water. There were no exact criteria for these designation but in most instances fisheries biologists agreed on the assignments for most species. Attempts have been made to develop a more robust classification. At the PERCIS symposium, Hokanson (1977) produced a scheme based on four thermal life-history attributes: (I) temperature regime during gonadal growth phase, (ii) temperatures during spawning, (iii) temperature at physiological optimum, and (iv) the defined 'ultimate upper incipient lethal temperature' (UUILT). Using combinations of these criteria and set cut-offs, Hokanson defined three thermal groupings of temperate fish: steno-, meso-, and eury-therm, which are analogous to the cold-, cool-, and warm-water designations. Wichert and Lin (1995) have compiled a number of defined temperature preferences for freshwater fish (final temperature preferendum (FTP), optimum temperature for growth (OTG) which is similar to the physiological optimum, UUILT, and critical thermal maximum (CTM)), and shown that they are significantly correlated. They used the FTP to construct a thermal index for habitats as a community composition-weighted mean temperature.

Hokanson's and Wichert & Lin's compilations of thermal ecology information were supplemented with data on spawning temperatures and final preferences assembled by Portt *et al.* (1988) and Minns *et al.* (1993), and on many thermal attributes by Wismer and Christie (1987). These various types of data were used singly to predict the thermal grouping for each species. Where conflicting assignments were obtained, the raw input data were reviewed and a judgement assignment was made. The temperature cut-offs (C°) were set at 19 and 25 for FTP, 20 and 28 for OTG, and 27 and 34 for UUILT. The CTM data were not used for assessment. The cut-offs were set slightly differently from the values suggested by Hokanson as some species are widely considered to be members of certain thermal groupings and some of their ecological temperature indicators predicted erroneous group memberships if Hokanson's criteria were used. For a number of species, no thermal data were available and thermal groupings were inferred on the basis of reported habitat preferences, taxonomic similarity to other well-known species, etc. Again the thermal assignments are reported in Appendix B.

3.2.1 Spawning and Adult Summer Habitat

Spawning Habitat:

There were two main compilations of spawning habitat information for freshwater fish: (1) the data assembled by Christie (1982) for fish occurring in Ontario, and (ii) the reproductive guild schema devised by Balon (1975). Christie's data were the primary source but Balon's scheme was used in conjunction with reported evidence in Scott and Crossman (1973) to guide the assignment of substrate and depth categories where Christie had not made any assignments. Requirements were reported separately for substrate type in five categories (rock, gravel, sand, mud, and 'weeds', or vegetation) and in five depth ranges (0-5, 5-10, 10-15, 15-20, 20+ metres).

Adult Summer Habitat:

Christie (1982) provided the primary compilation of adult summer habitat requirements for freshwater fish occurring in the Great Lakes. These data were supplemented by reference to Scott and Crossman (1973) and other sources. Requirements were reported separately for substrate type in six categories (rock, gravel, sand, mud, 'weeds', and pelagic) and water body (ponds, lakes < 10m, and lakes > 10m). The latter category was re-interpreted as defining three depth ranges (0-2, 2-10, 10+ m) and some adjustment of the data was made accordingly. The Lake Ontario fish species data on locations, substrates, and depth for spawning and adult summer habitats are presented in Appendix B.

The approach taken to classify spawning and adult summer habitat requirements by substrate type and depth stemmed from the approach pioneered by Christie (1982). Christie gathered information about depth and substrate preferences for many Ontario fish species. The requirements of spawning and adult habitat for substrate type and depth can be expressed in a matrix of discrete substrate types and depth ranges. Table 3.2 shows three hypothetical examples for both spawning and summer adult habitat where the degree of habitat specificity varies as per steno-, meso-, and eury- designations. The specificity of a species for each matrix cell, i.e., a substrate/depth combination, is the inverse of the number of other suitable cells. Thus, if the preferred habitat requirements of a species are general, the suitability weights for a particular cell of substrate type and depth is low. For a particular grouping of fish species, such as coldwater piscivores or warmwater non-piscivores, the individual matrices are summed and normalized so the highest cell value was equal to 1 (Table 3.3) These suitability matrices are computed for each grouping of fish species with similar thermal and trophic characteristics. The habitat suitability matrices obtained for six groups of fish species occurring in Lake Ontario showed that some depth-substrate combinations were of no importance while others carried high weights (Table 3.4). The suitability matrices are applied in the Habitat Suitability Module (section 3.4).

3.3 Habitat Supply Module

The habitat supply module estimates physical habitat area for fish before and after a shoreline development project. It is used to identify the area within which all direct and indirect changes to fish habitat occur. Physical habitat is defined by substrate type (mud to rock), depth, temperature, and wave energy. The habitat supply module is used to estimate macrophyte cover and an index of community productivity from these physical variables.

The effect of a development project on fish habitat is bounded by the total habitat area affected by the project. The total affected area is divided into the habitat area that is

Table 3.2 Hypothetical habitat suitability matrices for individual species, representing A) 'Steno', narrow, B) 'Meso', intermediate, and C) 'Eury', broad, requirements for both spawning and adult summer habitat.

A) 'Steno' — Spawning habitat requirements

Substrate	0-5 M	5-10 M	10-15 M	15-20 M	20+ M
Rock					
Gravel	1.000				
Sand					
Mud					
Vegetation					

A) 'Steno' — Adult Summer Habitat Requirements

Substrate	0-2 M	2-10 M	10+ M
Rock		0.500	
Gravel		0.500	
Sand			
Mud			
Vegetation			
Pelagic			

B) 'Meso' — Spawning habitat requirements

Substrate	0-5 M	5-10 M	10-15 M	15-20 M	20+ M
Rock					
Gravel		0.250	0.250		
Sand		0.250	0.250		
Mud					
Vegetation					

B) 'Meso' — Adult Summer Habitat Requirements

Substrate	0-2 M	2-10 M	10+ M
Rock	0.167	0.167	
Gravel	0.167	0.167	
Sand	0.167	0.167	
Mud			
Vegetation			
Pelagic			

C) 'Eury' — Spawning habitat requirements

Substrate	0-5 M	5-10 M	10-15 M	15-20 M	20+ M
Rock					
Gravel	0.125	0.125			
Sand	0.125	0.125			
Mud	0.125	0.125			
Vegetation	0.125	0.125			

C) 'Eury' — Adult Summer Habitat Requirements

Substrate	0-2 M	2-10 M	10+ M
Rock	0.100	0.100	
Gravel	0.100	0.100	
Sand	0.100	0.100	
Mud	0.100	0.100	
Vegetation	0.100	0.100	
Pelagic			

Table 3.3 Habitat suitability matrices for a species assemblage: A) cumulative and B) normalized sum of individual suitability weights for coolwater fish species found in Lake Ontario (28 spawning, 40 adult summer).

A) Cumulative

Spawning habitat requirements — Substrate	0-5 M	5-10 M	10-15 M	15-20 M	20+ M
Rock	2.833				
Gravel	7.250				
Sand	3.417				
Mud	1.583				
Vegetation	10.917				

Adult Summer Habitat Requirements — Substrate	0-2 M	2-10 M	10+ M
Rock		1.250	0.333
Gravel	1.250	2.250	2.417
Sand	1.403	2.736	4.194
Mud	1.569	2.403	2.194
Vegetation	4.903	6.486	1.611
Pelagic	0.208	0.708	1.083

B) Normalized

Spawning habitat requirements — Substrate	0-5 M	5-10 M	10-15 M	15-20 M	20+ M
Rock	0.260				
Gravel	0.664				
Sand	0.313				
Mud	0.145				
Vegetation	1.000				

Adult Summer Habitat Requirements — Substrate	0-2 M	2-10 M	10+ M
Rock		0.193	0.051
Gravel	0.193	0.347	0.373
Sand	0.216	0.422	0.647
Mud	0.242	0.370	0.338
Vegetation	0.756	1.000	0.248
Pelagic	0.032	0.109	0.167

Table 3.4 Spawning and adult summer habitat suitability matrices for six thermal/trophic fish groups in Lake Ontario. Numbers in brackets after each group title refer to the number of species included in the suitability calculations for spawning (Sp) and summer adult (SA) habitat.

Substrate	Spawning habitat, depth ranges (m)					Summer adult habitat, depth ranges		
	0-5	5-10	10-15	15-20	20+	0-2	2-10	10+
Coldwater non-piscivores (12-Sp, 15-SA)								
Rock	1.000	0.163	0.087	0.087	0.373	-	0.049	0.049
Gravel	1.000	0.163	0.087	0.087	0.373	0.049	0.098	0.114
Sand	0.259	0.106	0.030	0.030	0.373	0.071	0.071	0.380
Mud	-	-	-	-	0.798	0.022	0.217	0.380
Vegetation	-	-	-	-	-	-	-	-
Pelagic						0.022	0.217	1.000
Coolwater non-piscivores (22-Sp, 33-SA)								
Rock	0.390	-	-	-	-	-	0.060	0.079
Gravel	1.000	-	-	-	-	0.298	0.536	0.457
Sand	0.481	-	-	-	-	0.334	0.652	1.000
Mud	0.247	-	-	-	-	0.295	0.493	0.444
Vegetation	1.000	-	-	-	-	0.930	0.831	0.265
Pelagic						0.050	0.169	0.258
Warmwater non-piscivores (14-Sp, 19-SA)								
Rock	0.440	-	-	-	-	-	0.216	-
Gravel	1.000	-	-	-	-	0.089	0.502	-
Sand	0.828	-	-	-	-	0.193	1.000	0.026
Mud	1.000	-	-	-	-	0.646	0.390	0.066
Vegetation	0.353	-	-	-	-	0.410	0.803	0.066
Pelagic						-	0.079	-

Table 3.4 Continued.

Substrate	Spawning habitat, depth ranges (m)					Summer adult habitat, depth ranges		
	0-5	5-10	10-15	15-20	20+	0-2	2-10	10+
Coldwater piscivores (4-Sp, 9-SA)								
Rock	0.226	0.097	-	-	-	-	-	0.032
Gravel	1.000	0.097	-	-	-	0.027	0.081	0.032
Sand	0.129	-	-	-	-	0.027	0.081	0.032
Mud	-	-	-	-	-	0.027	0.081	0.032
Vegetation	-	-	-	-	-	-	-	-
Pelagic						-	-	1.000
Coolwater piscivores (6-Sp, 7-SA)								
Rock	0.074	-	-	-	-	-	0.333	-
Gravel	0.185	-	-	-	-	-	-	0.167
Sand	0.074	-	-	-	-	-	-	-
Mud	-	-	-	-	-	0.111	0.111	0.111
Vegetation	1.000	-	-	-	-	0.333	1.000	0.167
Pelagic						-	-	-
Warmwater piscivores (4-Sp, 4-SA)								
Rock	0.368	-	-	-	-	-	0.133	0.133
Gravel	0.540	-	-	-	-	-	0.133	0.133
Sand	0.540	-	-	-	-	-	0.133	0.133
Mud	0.310	-	-	-	-	0.200	0.200	-
Vegetation	1.000	-	-	-	-	0.200	1.000	-
Pelagic						-	0.400	0.400

permanently lost (A_L), and by habitat that is directly and indirectly (A_{MD}, A_{MI}) affected by the proposed project (Figure 3.1). A_L is the area of the headland or offshore structure above high water mark that becomes permanent dry land. A_{MD} represents the submerged fringe of the footprint of the headland or offshore structure, which is delimited by the slope of the structure from the high water mark to the base of the structure. A_{MI} is the area adjacent to the footprint that experiences changes in substrate, wave energy, depth, and temperature as a result of modified currents and wave action caused by the presence of the structure. The affected areas (A_L , A_{MD}, A_{MI}) define the pre-development habitat area that must be considered in a development assessment. The outer edge of the total affected area defines a line at which depth, substrate, and other habitat changes are deemed to be zero.

A_{MD} can be further divided into $A_{MD,\ upper}$ and $A_{MD,\ lower}$, which are demarcated by the area between the high and low water mark. This area can be substantial if the annual range in lake level and the slope of A_{MD} are large.

3.3.1 Estimation of Affected Areas

A_L and A_{MD} are estimated directly from the engineering specifications for the headland or offshore structure. The area of dry land (A_L), is normally an explicit design specification of a headland or offshore structure, and determined simply by overlaying the construction specifications over the existing habitat. A_{MD}, i.e., the area of the slope of the structure, is normally not a design specification and, therefore, has to be estimated from the expected slope (fall:run) of the structure and the expected depth contours that will be traversed by the base of the structure. Currently A_{MI} is estimated with two methods:

1) Using the shadows of the headland or offshore structure to prevailing wind direction(s), or to the direction from which the dominant ('excess') wave weights come from.

2) Using changes in effective fetch values. Using a fine-scale grid, fetch is computed in 16 directions from the centroid of each grid square using both the pre- and post-development shorelines. An index of change (IC) can be computed as a pseudo-variance by calculating the sum of squares of fetch differences:

   a) All sixteen points are included in the IC calculation
   $IC = \sum[FPRE_i - FPOST_i]^2$, for I = 1 to 16;

b) All points within a 45° angle of the prevailing wind direction (θ), weighted by $\cos\theta$

$IC = (\sum[FPRE_i - FPOST_i]^2.\cos\theta)/(\sum\cos\theta)$, for I = where $\theta \leq 45°$; or

c) All points within a 45° angle of the 'big wave' direction (θ), weighted by $\cos\theta$

$IC = (\sum[FPRE_i - FPOST_i]^2.\cos\theta)/(\sum\cos\theta)$, for I = where $\theta \leq 45°$.

In each case, a threshold value needs to be established. Sampling of grid points over a larger area should reveal a base level of variability which rises sharply in the vicinity of the development. Another possibility (d) could use a weighted combination of (b) and (c) within a combined threshold.

Within A_{MI}, the habitats are divided into a mosaic of patches defined by depth, substrate, vegetation, and fetch. A current difficulty is identification of the mosaic of patches within A_{MI} after it is delimited. The relative magnitude of the pseudo-variances might be used to scale depth and substrate changes starting from zero at the boundary. Given each fetch grid cell has a defined depth and substrate, the pseudo-variances could be used to predict depth changes and substrate class transitions. The revised grid values could be contoured and the resulting depth-substrate values laid in over the old values within the modified-indirect zone.

The following information for physical habitat is required for the habitat supply module:

1. Pre-development shoreline and depth contour map. This can be a combination of Ontario Base Map (OBM) shoreline data and Canadian Hydrographic Service (CHS) depth soundings, if available.
2. Pre-development sediment map classified using Folk's (1954) classification. This scheme classifies sediment by relative clay, sand, mud, or silt content. The geotechnical data can be entered as the mid-points of the named Folk classes and then included in contouring. Percent sand and clay-silt ratio variables are contoured separately and then overlaid with Folk's classification boundaries. The overlay is then reclassified according to the named categories.

3. The post-development footprint (A_{MD}) of the structure developed as an overlay on a pre-development map.

3.3.2 Submerged Macrophyte Cover

Macrophyte cover, the sixth type of substrate for spawning and adult habitat, is estimated from the aforementioned physical variables. A simple first-order model predicting macrophyte cover greater than or less than 50 percent was developed for the prototype methodology based on the data from Minns et al. (1993). High percentage plant cover is usually associated with finer sediments. Minimum and maximum depths for macrophytes have been identified elsewhere. Minimum depth is a function of fetch, or more specifically the wave-mixing depth. Chambers (1987) defined a relationship between wave-mixing depth (Z_W) and minimum depth (Z_{MIN}) as:

$$Z_W = 1.10.Z_{MIN} - 9.31.$$

The regression slope was not different from 1 and the intercept was not different from 0. The data of Minns et al. (1993) indicated that up to the 1.5 metre depth contour, abundance of macrophytes greater than 50 percent cover were not present if effective fetch was > 2.0 km, but at > 1.5 m macrophytes could occur. In the model used here, we assumed that plants could grow in shallow waters but that plants were absent if effective fetch > 2.0 km. The maximum depth of plant coverage is a function of water clarity. Chambers and Kalff (1985) for inland lakes defined a relationship between Secchi depth (D) and maximum depth of macrophytes (Z_C) as:

$$(Z_C)^{0.5} = 1.33.\log_e(D) + 1.40.$$

The littoral slope must be less than 15 percent for macrophyte growth (Duarte and Kalff 1986, 1990) (100 percent slope = 45°). However a slope less than 15 percent does not guarantee high plant cover.

The model of the presence of submerged vegetation cover greater than 50 percent was based on a combination of substrate type, depth, and effective fetch relative to the prevailing wind is described below:

If substrate is sand or finer and,
If depth is less than twice the Secchi depth and,
If effective fetch is less than 2.0 kilometres and,
If maximum slope is less than 15 percent,
Then vegetation is present, i.e., cover greater than 50 percent,
Else vegetation is absent, i.e. cover less than 50 percent.

(This model was only constructed for demonstration purposes in the case study presented in Chapter 4. Further development of the model is proceeding.) The model conditions for greater than 50% macrophyte coverage are based on empiric generalizations. Obviously much less macrophyte coverage can exist with the same conditions due to the effects of environmental factors not included in the model. The macrophyte model, however, provides the basis to estimate the change to macrophyte coverage due to placement of a headland or offshore structure. If GIS data are available for the study area, this model should be implemented with GIS software, such as SPANS. GIS-based maps of effective fetch, substrate type, and depth could be constructed for this purpose.

3.3.3 Productive Capacity - Community Production Area

The primary purpose of the defensible methodology is to provide a tool with which to improve assessment of the effects of development on productive capacity of fish habitat as stated in the federal habitat policy. Productive capacity of fish habitat, however, is not explicitly defined in the federal habitat policy. In the prototype methodology productive capacity is defined by an index of community production (CP), which is a composite measure of fish species richness, biomass and production at the community level. The policy requirement for a "no net loss" of fish productive capacity (community production) in shoreline development projects is assessed with the following general model (adapted from Minns 1995):

$$\text{Net change in CP} = (P_{post} - P_{pre}).A_{post} - P_{pre}.A_L$$

where,	P_{pre}	=	Calculated pre-development index of community productivity;
	P_{post}	=	Calculated post-development index of community productivity;
	A_L	=	Fish habitat area (m^2) that is permanently lost due to the headland or offshore structure. (Figure 3.1); and
	A_{post}	=	Fish habitat area directly and indirectly affected by development headland or offshore structure(A_{MD}, and A_{MI}). A_{post} combined with A_L delimit the pre-development area of the assessment.

There are many factors known to affect fish growth and production, including temperature, macrophyte presence and abundance, other forms of structural cover, substrate, depth, nutrient levels, fetch and exposure, and allochthonous detritus. In the prototype methodology temperature and nutrients effects are assumed negligible. The principal physical variables are depth and substrate in the directly modified area (A_{MD}) and vegetation cover in the indirectly modified area (A_{MI}). Because fetch is already included in the model that predicts vegetation, the decision was made to formulate a fish productivity model based on depth and vegetation. Similar to macrophyte cover, a first-order, empric model for fish productivity at the community level was developed for the prototype methodology.

Data relating littoral fish abundance to habitat features has been collected from a variety of nearshore habitats in three Areas of Concern, including Hamilton Harbour (Randall et al. 1993). Randall et al. (1996) showed that fish density, biomass, and a derived index of productivity (PI) were correlated with habitat features along the 1.5 metre contour. The analyses showed that the PI was related to vegetation cover, phosphorus levels, and bottom slope. More limited substrate data indicated that cover and slope are linked to substrate type. Vegetated sites have higher PI values than unvegetated sites, and finer substrates generally have higher PI values because of the prevalence of vegetation.

Keast et al. (1977) showed in an inland lake that fish biomass per unit area was significantly related to water depth. Biomass in May dropped off quickly from about 40 $kg.ha^{-1}$ at 1.2 metres to 0.3 $kg.ha^{-1}$ or less at depths greater than 5 metres. Biomass of fish in the nearshore zone (0.75 - 1.6 metres) depended on the habitat, and ranged between 43.5 $kg.ha^{-1}$ in exposed clay areas to 272 $kg.ha^{-1}$ in vegetated areas. The relationship between biomass (B) and depth (Z) significantly fitted the regression model: $\log B = a + b Z$, with slopes ranging from -0.84 in vegetated areas to -0.72 in exposed clay areas. Biomass changed with depth in a similar fashion in June, August, and September.

Using these observations and results a simple fish productivity model was formulated. Because the presence of greater than 50 percent vegetation cover was linked to the presence of fine substrates, two levels of littoral fish productivity were specified with the maximum being assigned a maximum value of 1: vegetated areas were assigned a value of 1 and unvegetated areas with coarser substrates were given value of 0.33. These values were assumed to apply in the 0 to 2 metre depth range, corresponding to the zone sampled in littoral fish sampling. For depths greater than 2 metres, Keast et al.'s result was assumed to apply with the substrate-assigned P values being divided by $Depth^{0.84}$. The fish productivity model used in the prototype methodology is as follows:

First, the nominal productivity is assigned (P'),

If substrate is sand or finer and vegetation is present, then P' = 1.00

If substrate is coarser than sand then P' = 0.33.

Second, the actual productivity (P) is a function of P' and depth,

If depth is less than or equal to 2 m then P = P'

If depth is greater than 2 m the $P = P'/(Depth^{0.84})$

Within the range of depth specified for spawning and adult habitat, community productivity habitat area is calculated as the sum of the products of the two nominal productivities (P') and the respective areas, as modified by depth. The relative importance of productivity habitat compared to spawning and adult habitat can be weighted in the assessment based on fish community objectives for the affected area. (see Habitat Suitability Module below).

3.4 Habitat Suitability Module

The habitat suitability module is used to estimate the change in the area of suitable habitat for pre-determined groupings of fish as a result of the placement of the headland or offshore structure. For this purpose the pre- and post development supplies of fish habitat that are estimated with the habitat supply module are evaluated with respect to suitability for spawning and adult habitat of the two feeding trophic levels (piscivorous & non-piscivorous) of exotic vs endemic species for each of the three thermal guilds of fish in Lake Ontario.

Habitat suitability can be based solely on habitat supply and the habitat requirements of the above groupings of fish species, or habitat suitability can include preference weightings based on fish community management objectives for the area. Unweighted and weighted habitat suitability are based on the same ecologic criteria, however, the weighted habitat suitability is influenced by management plans. The preference weightings act to limit habitat area of specified species groupings (e.g., coldwater piscivores) that is included in the pre- and post development assessments. Because of the importance of fish community objectives in the management of fish habitat in the Great Lakes, weighted habitat suitability is the focus of the prototype methodology.

3.4.1 Preferred Fish Communities

Before the pre- and post-development suitable habitat areas can be estimated certain decisions are necessary, which can be expressed in the following series of questions:

1. Are there fish community objectives for the area being assessed?

The three groupings of fish considered are the coldwater, coolwater, and warmwater guilds. Because particular fish habitats normally cannot provide equal potential for all three groups simultaneously, a statement of preference, or weight, can be assigned to three thermal habitats. Because the methodology computes net change for all fish, the management agencies can weight the analysis by assigning proportions to the three community types. For example, in a shallow, sheltered, highly vegetated bay, a warmwater community may be the most appropriate community and the weights can be assigned (Cold=0, Cool=0, Warm=100). In an open exposed area on Lake Ontario subject to frequent upwellings where the development will not greatly alter exposure, a mixture of cool and cold communities may be the target (Cold=70, Cool=30, Warm=0). The weights must sum to 100.

The setting of fish community objectives is not intended to provide a mechanism for building 'designer ecosystems'. The natural and/or historical potential of the habitat area will play the governing role in the choice of weights due to the ecologic basis of the methodology as provided by the habitat reference database. All selected preference weights are applied to both the pre- and post-development habitat assessments.

2. By fish community type (coldwater, coolwater & warmwater), should non-indigenous (exotic) species be included in the habitat assessment?

Non-indigenous fish species, a mixture of introductions and invaders, now play a major role in the dynamics of most Great Lakes fish communities and fisheries. Both common carp and coho salmon were deliberately introduced. The former is considered a nuisance while the latter supports a very important fishery. Some habitat alterations may enhance conditions for undesirable fish species and thereby may imperil preferred native species. Generally, preferred exotics are coldwater forms while undesirable ones are cool- or, most often, warmwater forms. The agency must clearly state, by fish community type, a preference for the inclusion or exclusion of non-indigenous species as a group. The procedure will provide results for all species groups but not all will be included in the final analyses.

3. Should the needs of top predators, piscivorous, be given added weight in the habitat assessments?

It is generally recognized that top predators play an important structuring and stabilizing role in the self-regulating dynamics of freshwater ecosystems. However, there are fewer species which are top predators compared to other trophic roles. The managing agency provides weights for each thermal grouping of fish species which express the degree to which top predators will contribute to the final assessment. An equal weighting would be: Piscivorous = 50, Non-piscivorous = 50. To weight all species equally within a thermal grouping, the trophic distinction is ignored and single assessment is generated for each thermal group instead of two.

4. Are spawning habitat, adult habitat, and productivity habitat (productive capacity) equally important or should one be weighted more heavily than the others?

The assessment procedure provides three habitat assessment results based on spawning habitat requirements, adult summer habitat requirements, and potential fish productivity based on habitat. The community productivity habitat that is calculated with the Habitat Supply Module (section 3.3) is used here. The managing agency assigns the weights to all three. An equal weighting would be: Spawning = 33.3, Adult = 33.3, and Community Productivity = 33.3.

3.4.2 Calculation of Suitable Habitat

The next step is the calculation of the suitability of habitat for the spawning and adult stages of piscivorous and non piscivorous species groupings of the three thermal guilds. For spawning habitat and adult habitat of two feeding trophy across three thermal guild there are 12 species groupings (e.g., adult, coldwater piscivores). As indicated in Section 3.2.1 (Table 3.2), habitat suitability for each species grouping is scored with two matrices of substrate type versus depth; one matrix for spawning habitat and the other matrix for adult habitat. The cells of either matrix reflect a substrate type and depth requirement of an individual species of a group. The numerical score assigned to a particular cell of a matrix reflects the degree of specificity of the particular species for the substrate type and depth range combination comprising the cell. The score of a cell, say for the spawning matrix, is the inverse of the number of cells (substrate/depth combination) that describe suitable spawning habitat for the species. The scores for a particular grouping of fish species, such as spawning, warmwater non- piscivores are summed and normalized so that the highest cell score is equal to 1. To estimate pre- and post-development suitable spawning and adult habitat (SA) for the species groupings, the summed and normalized habitat suitability scores for substrate type and depth derived with the matrices are multiplied by the respective pre- and post development areas (m^2).

3.4.3 Identification of Preference Weights

The suitable habitat areas that are calculated for the different species groupings must be weighted according to fish communities objectives for the waterbody. The weightings act to limit the amount of habitat of a particular species grouping that is included in an assessment.

3.4.3.1 Spawning and Adult Habitat

The amount of suitable habitat for spawning and adult stages (SA) is calculated for two feeding trophic levels (piscivore & non-piscovore) across three thermal guilds. Suitable spawning habitat and adult habitat are calculated separately and later compared with productivity habitat (see below). Inclusion or exclusion of exotic species in each thermal guild is decided upon first, which acts to finalize the species list in the assessment. The following generic equations describe suitable spawning and adult habitat, as weighted by the different attributes of the species groupings.

$SA_{habitat}$	=	Suitable habitat area (m^2) for spawning or adult stages for all thermal guilds (calculated separately);
	=	$SA_{cold} + SA_{cool} + SA_{warm}$.
$TW_{thermal}$	=	Thermal guild weights;
1	=	$TW_{cold} + TW_{cool} + TW_{warm}$.
$WSA_{thermal}$	=	Suitable spawning or adult habitat weighted by thermal guild;
	=	$SA_{cold}.TW_{cold} + SA_{cool}.TW_{cool} + SA_{warm}.TW_{warm}$.

Within each thermal guild, preference weights determine the proportion of suitable habitat areas which are included for piscivorous (PW) and non-piscivorous (1 - PW) species:

$PW_{thermal}$	=	Piscivore weights for each thermal guild;
1	=	$PW_{thermal} + (1 - PW_{thermal})$.
$WSA_{thermal,trophic}$	=	Suitable spawning or adult habitat weighted by thermal guild and feeding trophy;
	=	$[(SA_{cold,piscivore} \cdot PW_{cold} + SA_{cold,non\text{-}piscivore} \cdot (1 - PW_{cold})] \cdot TW_{cold} +$ $[(SA_{cool,piscivore} \cdot PW_{cool} + SA_{cool,\ non\text{-}piscivore} \cdot (1 - PW_{cool})] \cdot TW_{cool} +$ $[(SA_{warm,piscivore} \cdot PW_{warm} + SA_{warm,non\text{-}piscivore} \cdot (1 - PW_{warm})] \cdot TW_{warm}$.

3.4.3.2 Spawning, Adult, and Productivity Habitat

Weightings can be applied to indicate preferences among spawning habitat, adult habitat, and community productivity habitat. Community productivity is derived with the habitat supply module (Section 3.3.2) and represents productivity across all species groupings.

$HWT_{habitat}$	=	Preference weights for spawning, adult, or productivity habitat:
1	=	$HW_{spawn} + HW_{adult} + HW_{prod.}$
WSA_{total}	=	Total weighted habitat area;
	=	$WSA_{spawning} \cdot HW_{spawn} + WSA_{adult} \cdot HW_{adult} + WSA_{productivity.} \cdot HW_{prod.}$

4.0 CASE STUDY La SALLE PARK MARINA, HAMILTON HARBOUR, LAKE ONTARIO

To ensure that 1) the technical aspects of the defensible methods implementation remained realistic, and 2) the working level problems of information collection and synthesis were met, the initial implementation was conducted using a real-world situation, the La Salle Park Marina in Hamilton Harbour. Hamilton Harbour lies at the western end of Lake Ontario. It consists of an outer bay of 2150 hectares with a mean depth of 13 metres connected to the lake via a ship canal and, on the west side, an inner shallow-water marsh of 250 hectares with a mean depth less than a metre called Cootes Paradise. Hamilton Harbour is one of 43 degraded Areas of Concern (AOCs) around the Great Lakes based on the 14 beneficial use impairment criteria identified by the International Joint Commission under the terms of the Great Lakes Water Quality Agreement.

The Harbour ecosystem has been greatly altered by urban and industrial development. The fisheries have been degraded as a result of habitat loss and degradation, over-exploitation, and species introductions. Development has caused most of the marsh and littoral habitat in the outer harbour to be land-filled. In the past, substantial contaminant loads degraded sediment and water quality. Most of sewage from Hamilton, Burlington, and surrounding areas enters the Harbour while drinking water supplies are drawn from Lake Ontario. Much of the Harbour's hypolimnion is anoxic in the summer. Increased sediment loads from the watershed and combined storm-sewer overflows reduce water clarity, limiting the development of submerged macrophytes. In Cootes Paradise, land use, the regulated water level regime of Lake Ontario, nutrient and sediment inputs, and disturbance due to large carp populations, have reduced the extent and diversity of marsh vegetation. As a result of all these perturbations and changes, the fish community composition and abundance is degraded. Piscivores are rare, and large omnivores like carp and bullheads dominate the community. Some fish species exhibit health problems due to contaminant exposures, particularly to organics and metals in surface sediments. Through the immense efforts of many government agencies and other organizations, a Remedial Action Plan (RAP) has been developed for Hamilton Harbour and various measures are at different stages of implementation. A key element in the RAP is the Fish and Wildlife Habitat Restoration Plan.

4.1 Study Area and Project Description

La Salle Park Marina is one of the habitat restoration sites in the Harbour (Fig. 4.1A). In recent years, a small dock used historically for local cargo and passenger trade has provided the basis for a small marina operation. Floating used-tire barriers and floating docks linked to the old dock provide berths and shelter for sail- and motor-boats. The floating barriers have been deteriorating and are infested with newly invading zebra mussels which cause the barriers to sink and become less effective. The presence of the marina facilities has promoted the expansion of a healthy submerged macrophyte habitat in the vicinity of the marina and thereby enhanced the fish community diversity and abundance. A joint restoration plan to provide additional fish habitat and fishing opportunities along with more permanent protection for the marina was developed. The principal features of the plan are the construction of a connected island/headland extension to the old dock, the addition of numerous reef and habitat modules in the sheltered areas, and the removal of shoreline armouring in the sheltered areas to create more shallow littoral habitats for young and smaller fish. As the construction is in progress, the final engineering specifications for the La Salle project were taken as the basis for estimating the direct habitat changes.

For the purposes of this defensible methods case study, we chose to focus the assessment exclusively on the addition of the headland/island breakwater to the existing dock ignoring (i) the pre-development affects of two floating wave barriers which have been present during the sailing season for several years and (ii) all other restoration activities at and around the marina. A fuller assessment of the whole restoration project will be conducted later and the results reported elsewhere.

4.2 Pre- and Post- Development Physical Habitat Assessment

Physical habitat assessment and subsequent area analyses of the marina were done using SPANS GIS software by Tydac Technologies Inc. The geographic frame of reference for this work was created using the five 1:10000 digital Ontario Base Maps (OBMs) which encompass

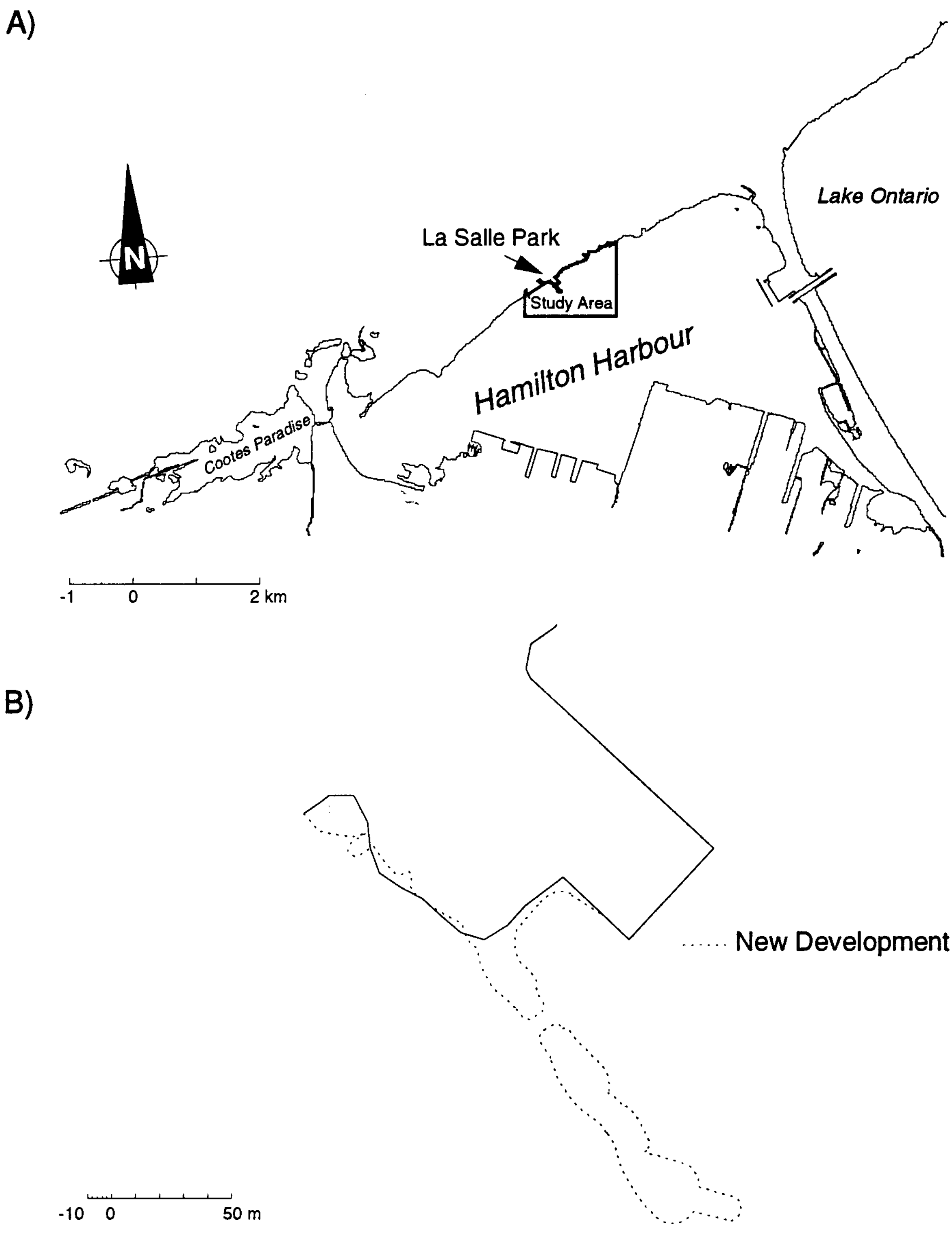


Figure 4.1 The location of La Salle Park in Hamilton Harbour (A) and the current and planned configurations at the Marina dock (B).

Hamilton Harbour and adjoining Cootes Paradise (Fig. 4.1A). The shoreline extracted from those digital map files was used to bound the pre-development areas. Its elevation was taken (from OBM paper charts) to be 74.6 metres above mean sea level (MSL). This line was in turn modified as described below to define the post-development areas, using geo-referenced engineering drawings providing details of the proposed La Salle Park breakwater (Fig. 4.1B). Lines representing various breakwater features above and below the water-line were digitized using SPANS TYDIG software. The goal was to obtain from that line-work a new shoreline and to obtain the breakwater footprint. Neither of those things was explicitly represented in the digitized drawings, but all lines had elevations defined with respect to a datum of 74.2 metres above the International Great Lakes Datum (IGLD) and all were associated with defined slopes of 1.5 horizontal:1 vertical. Thus, the drawings provided the information necessary to infer the locations of the desired entities.

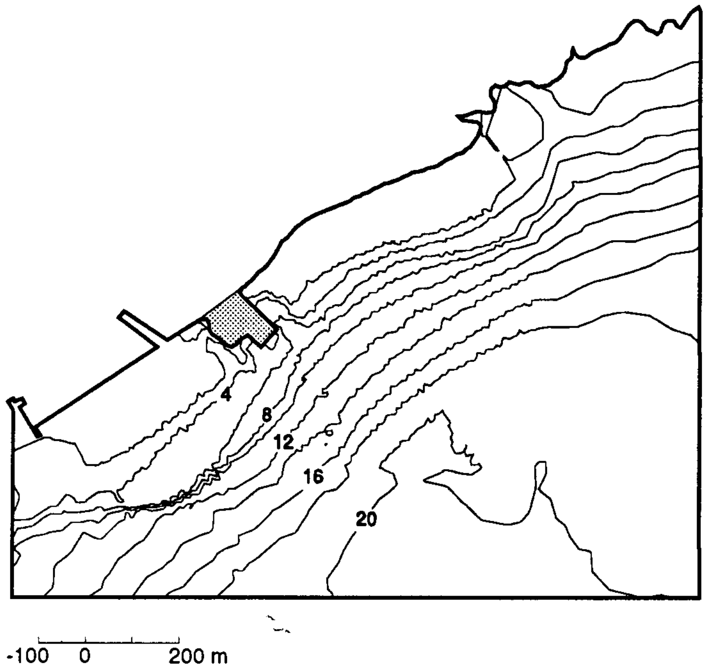
The elevations of the engineering drawing lines were converted to the OBM shoreline as follows:

$$dz = 74.6 - 0.1 - (74.2 + z)$$

where z is the line's elevation on the drawing, dz is the required elevation change, and 0.1 is an approximate correction from MSL to IGLD. Given this displacement and the defined slope, a horizontal displacement could be computed. In-house software was used to do that for all lines with negative vertical displacements, i.e., lines initially above the water-line. This involved, for example, moving the line representing the top of the breakwater down 2 metres in elevation and moving other lines representing lateral features of the development through smaller distances. The resulting patchwork of lines all had the required OBM shoreline elevation and were then assembled into a continuous line using vector editing software (SPANS VECED). The same software was then used to patch this line into the pre-development shoreline to obtain the post-development shoreline.

A pre-development bathymetry map was produced from Canadian Hydrographic Service (CHS) bathymetry data obtained for the La Salle Park area, recast as depths below the OBM shoreline elevation, and contoured in SPANS at 0.5 metre depth increments (Fig 4.2A). A post-development bathymetry map was derived from this and the new shoreline information as described in the following section (Fig. 4.2B).

A)



B)

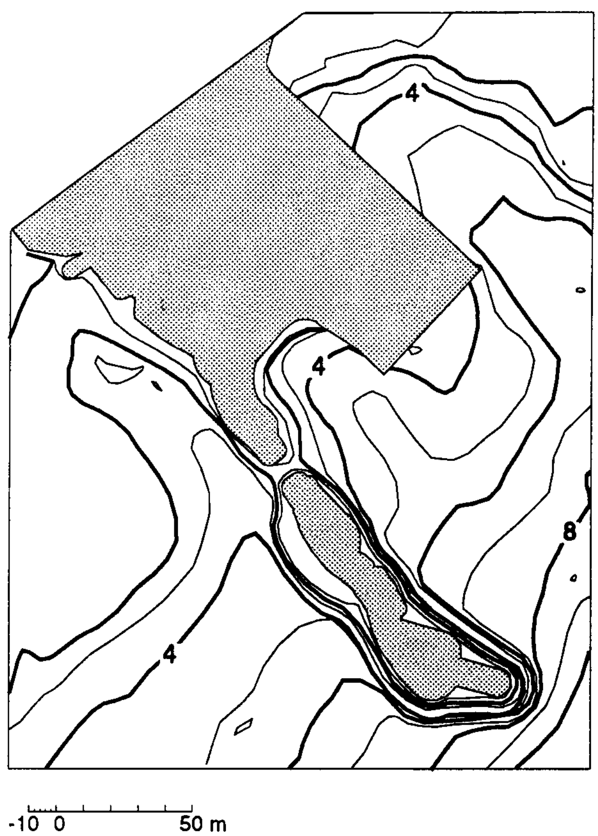


Figure 4.2 The known bathymetry of the study area prior to the new development (A), and the projected bathymetry in the immediate vicinity of the new breakwall at La Salle Park Marina (B).

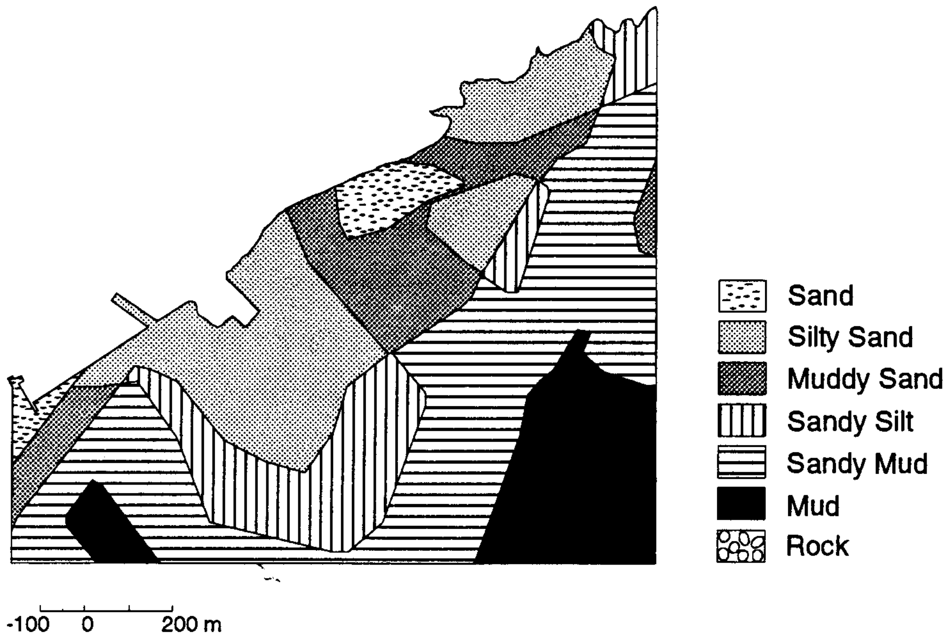
Finally, a pre-development substrate map was produced in SPANS from source data on percent sand+gravel and clay:silt ratio provided by Rukavina (Pers. Comm.) and reported by Rukavina and Versteeg (1995). Eight geotechnical survey stations from two surveys at the La Salle site were added to Rukavina's data compilation to increase coverage and to ensure that nearshore sands were better represented. These geotechnical data were entered as the mid-points of named Folk sediment classes and then included in the contouring. The percent sand and clay:silt ratio variables in the combined data set were contoured separately using Folk's (1954) class boundaries. The resulting two maps were overlaid to obtain unique combinations of all possible values of the two variables, and this overlay was then reclassified according to the named substrate categories (Figure 4.3A). From this pre-development substrate map, a post-development map was made by overlaying the development's footprint (see below) and then classifying the overlay area as rock (Figure 4.3B).

4.2.1 Areas Lost (A_L) and Modified-Direct (A_{MD})

Single class base maps were produced in SPANS for the pre- and post-development conditions from their respective shorelines. These maps represent the wet areas in the two scenarios. An overlay of the two maps revealed areas wet in the pre- map but not in the post- map. The sum of those areas was taken to be the area lost (A_L) (Figure 4.1B).

The footprint represented by the breakwater was derived from a post-development bathymetry map. To produce that map, the new shoreline created above had to be modified to reflect the influence of new structures below the water-line, in particular, a submerged shelf on the west flank of the breakwater. For that, a westward extension of the shoreline was obtained by patching-in an outline of the shelf after moving it through a *positive* displacement to the OBM shoreline elevation, creating a temporary "shoreline" to be used to infer surrounding bathymetry. To do this an intermediate map was first made in SPANS which consisted of a series of 20 parallel corridors surrounding the temporary shoreline, their width chosen to correspond to 0.5 metre depth increments. This intermediate map was then overlaid on the pre-development bathymetry map, and its depth became the new depth wherever that depth was less than the old depth. The result of this overlay operation became the post-development bathymetry map. The area modified-direct (A_{MD}) of the breakwater development was taken to

A)



B)

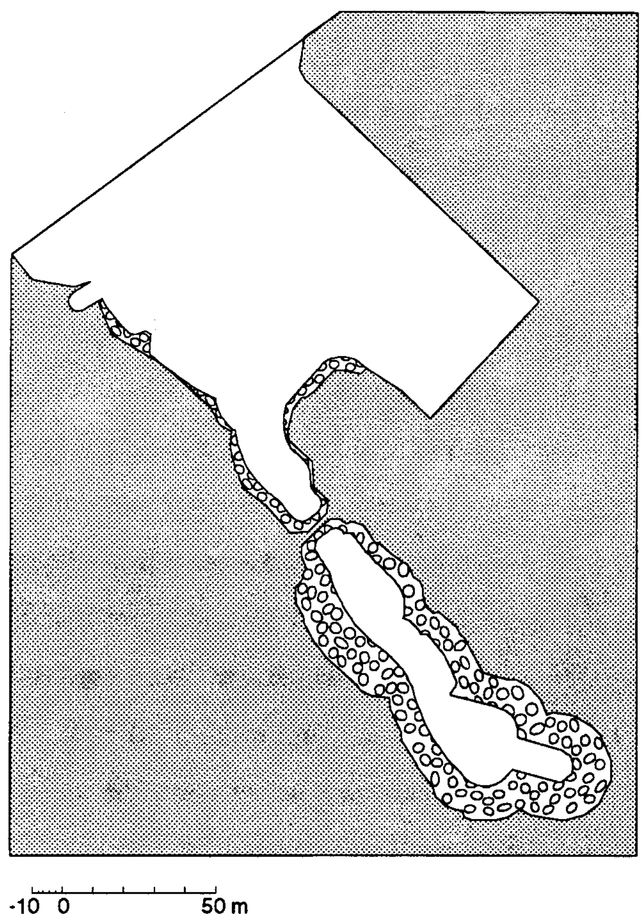


Figure 4.3 The inferred bottom substrate characteristics in the study area (A), and the substrates expected adjacent to the new breakwall at La Salle Park Marina (B).

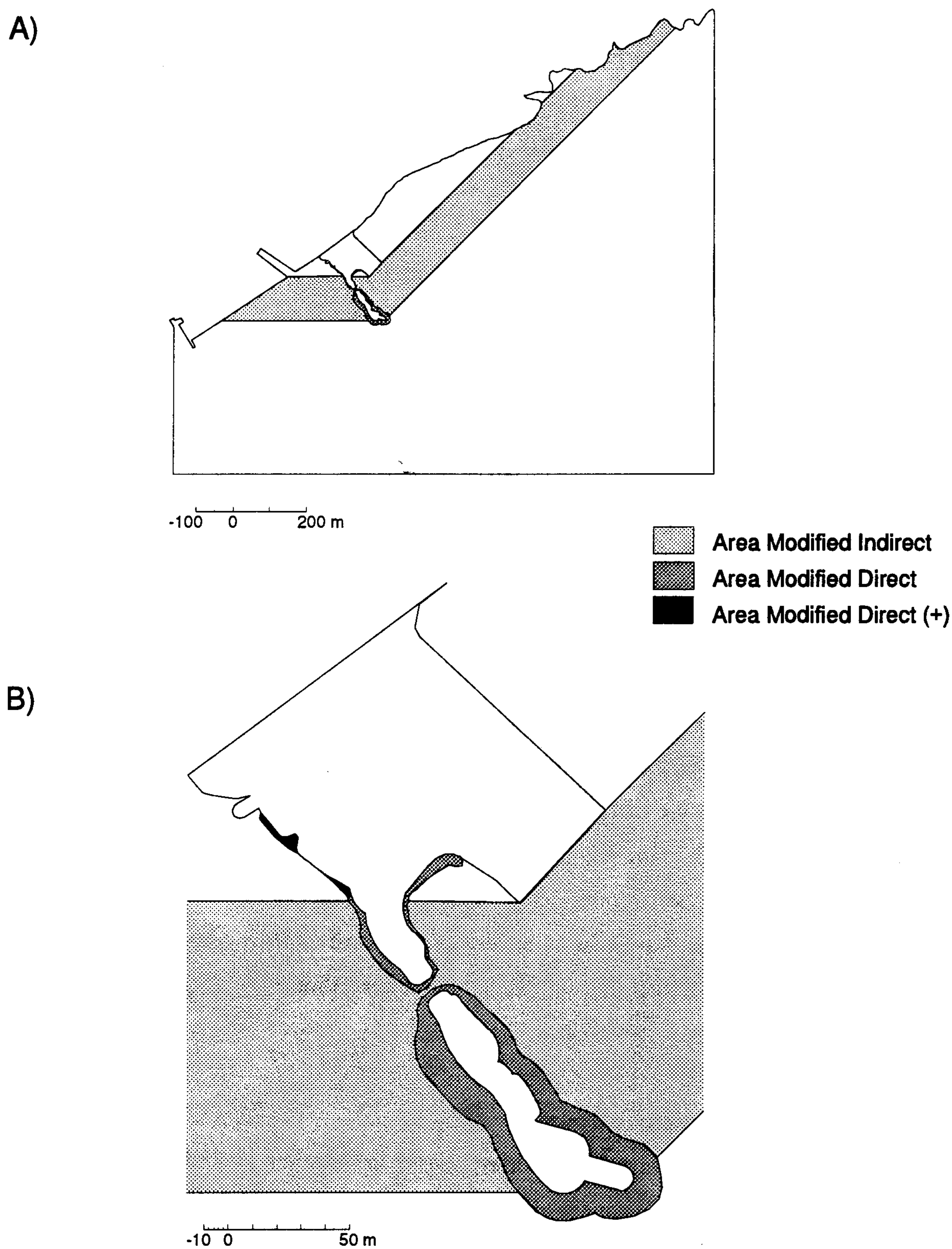


Figure 4.4 The extent of the modified habitat areas in the study area (A) and , in detail, at the dock and breakwall (B).

be the area where the pre- and post-development bathymetry maps differed, less $\mathbf{A_L}$ (Figure 4.4B). In practice, this underestimates $\mathbf{A_{MD}}$ by ten to twenty percent.

Another result of the overlay operation above which was used to measure $\mathbf{A_L}$ was to reveal a small area along the shoreline which was dry in the pre-development scenario and became wet in the post- scenario. This area was also recorded as part of $\mathbf{A_{MD}}$.

4.2.2 Area Modified-Indirect (A_{MI})

The 'shadow line' approach was used to define the indirectly modified area (A_{MI}), attempting to capture the effects of sheltering from winds from the southwest and from the east. In-house software was used to define a southwest shadow line with a southwest-northeast orientation which just touched the tip of the breakwater portion of the post-development shoreline. A shadow area was created by editing into the post-development shoreline the portion of the shadow line running northeast from an origin at the tip of the breakwater to the shoreline. A similar east shadow line was created with an east-west orientation, resulting in a shadow area to the west of the breakwater. Both types of shadow area were also created for the pre-development scenario, using intersections with the existing dock as the origins for the shadow lines.

Having spliced these shadow lines into their respective shorelines, it was possible in SPANS to create for the pre- and post- scenarios a single-class map representing the area shadowed. An overlay of the two maps revealed areas shadowed in the post- scenario but not the pre-. The sum of such areas was taken to be a first-order estimate of $\mathbf{A_{MI}}$ (Figure 4.4A,B).

No attempt was made to infer depth and substrate changes in this indirectly modified area. New structures such as the marina breakwater will undoubtedly affect the wave exposure and circulation regime with consequent effects on sediment transport, accumulation, and sorting.

4.2.3 Submerged Macrophyte Cover

Recent extensive surveys of macrophyte cover in Hamilton Harbour indicated that plants were not found in areas deeper than 3.5 metres, about twice the average secchi depth. As indicated earlier the littoral slope must be less than 15 percent for macrophyte growth

(Duarte and Kalff 1986, 1990) (100 percent slope = 45°), while a slope less than 15 percent does not guarantee high plant cover. The slope factor was not used in the La Salle application as the derivation of the necessary slope map was impractical in the time available. Because fine substrates tend to be associated with shallower slope, the deletion of slope was unlikely to affect the prediction of macrophyte cover.

As indicated earlier the model of the presence of submerged vegetation cover greater than 50 percent was based on a combination of substrate, depth, effective fetch relative to the prevailing wind, from the south-west in Hamilton Harbour, as follows:

If substrate is sand or finer and,
If depth is less than twice the Secchi depth and,
If effective fetch is less than 2.0 kilometres and,
If maximum slope is less than 15 percent,
Then vegetation is present, i.e., cover greater than 50 percent,
Else vegetation is absent, i.e. cover less than 50 percent.

To implement the model, a SPANS map was created showing areas where effective fetch in the direction of the prevailing southwest winds was less than or equal to 2 km. This variable was used in subsequent modelling steps along with depth and substrate to predict the presence of submerged vegetation. To compute effective fetch, a point grid was created which covered the whole study area at an interval of 20m. In-house software was then used to compute the distance from each of those points to the nearest shore in each of 16 directions. Effective fetch was then computed for each point by taking the mean of the distances for all directions within and including 45 degrees of southwest, weighted by the cosines of the angular differences. The resulting values were contoured and the contour map reclassified to show only the areas where the fetch was $<=$2km (Figure 4.5). In any scenario, once depth and substrate combinations have been specified using the physical model, the vegetation model was super-imposed to identify the areas where macrophytes with greater than 50 percent cover were expected.

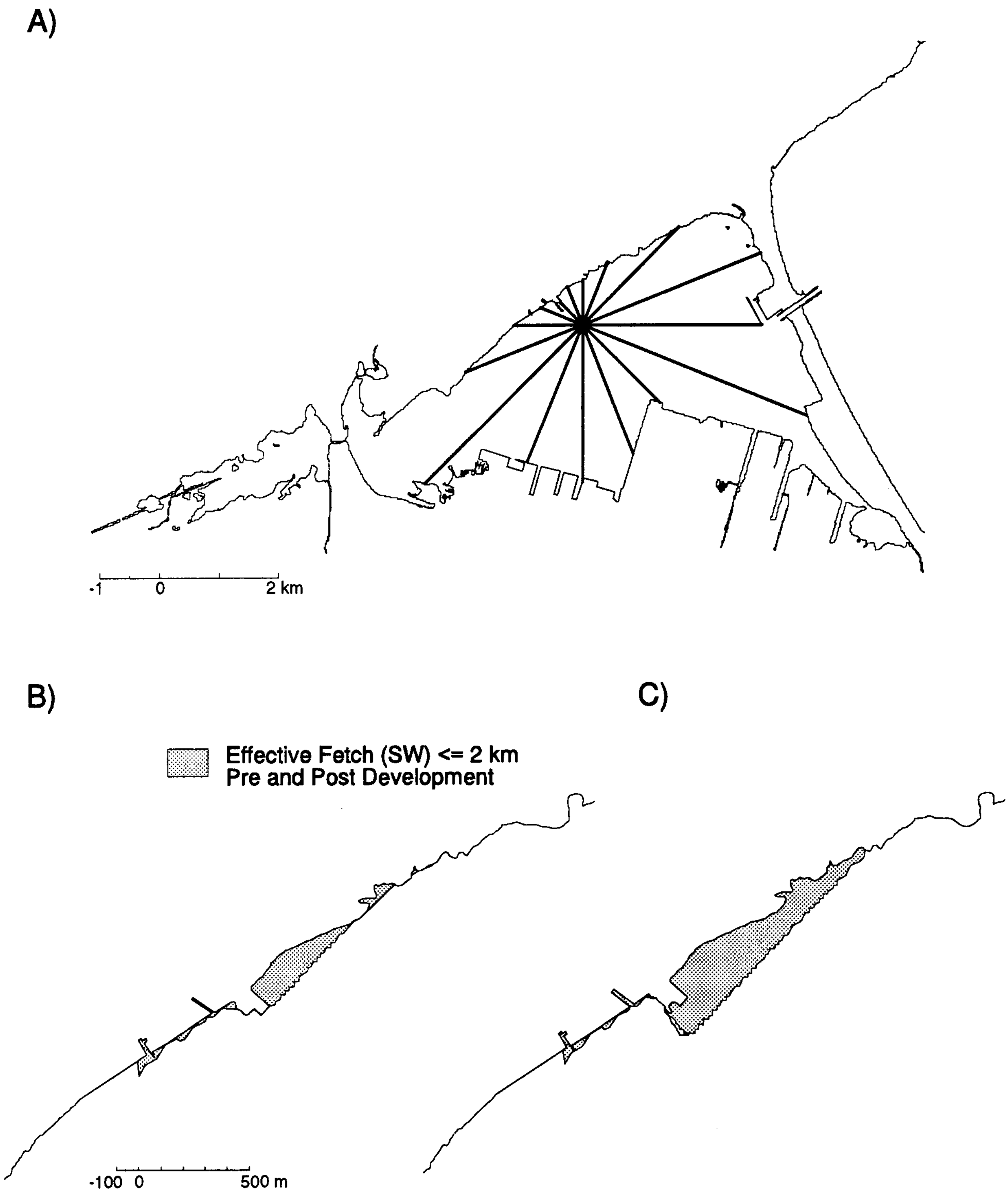


Figure 4.5 The method of determining fetch for 16 compass directions (A), and the areas where effective fetch <=2 km in the pre- (B) and post- (C) development scenarios at La Salle Park Marina.

4.2.4 Creation of Habitat Overlay Mosaics and Area Reports

The final stage of the SPANS GIS work involved the creation of a unique conditions map for the pre- and post-development scenarios obtained in each case by overlaying four maps, the first to delimit and enable an areal accounting and the others to represent essential habitat features. The first map was an affected areas map used for both scenarios showing A_L, A_{MD}, **and** A_{MI}. The remaining three maps were the scenario's bathymetry, substrate, and effective fetch maps. Any map areas outside the affected areas are excluded, by definition, from consideration in the assessment. The resulting overlay operation created a complex mosaic of small polygons each with a set of attributes. A list of areas (km^2) associated with each unique combination of features was created and exported for use in a subsequent modelling step.

In the calculation procedures used for this case study, both the pre- and post- scenarios are summarized by type of area affected, depth and substrate (after vegetation had been predicted). Habitat area reports like these can give those assessing a project a direct indication of the changes in areas of various combinations of habitat features. Also, the area lost (A_L) is measured and shown.

4.3 Fish Habitat Suitability and Productivity Assessment

Fish community management objectives were encapsulated through a series of options which lead to weightings being established. As indicated the weightings apply to the groupings of fish species based on ecological criteria. The fish species were grouped according to thermal guild (coldwater, coolwater, and warmwater) and by feeding trophic level (piscivores vs non-piscivores). The thermal groupings were weighted according to the basic capabilities of the target habitat; weighting the assessment heavily toward coldwater species makes little sense in a shallow, warmwater, partially-enclosed bay. The trophic groups can be assigned differential weights; piscivores can be assigned a weight equal to all non-piscivores, or greater or lesser weights. Within the thermal groupings, exotic species can be included or excluded. Having grouped the fish species, the relative weightings of the habitat components are assigned. Assessments of spawning and adult summer habitats, and overall habitat productivity for each fish group are combined using the weights.

At the La Salle Park Marina, the assessment was weighted towards coolwater and warmwater fishes: the percentage weights were Coldwater - 20, Coolwater - 40, and Warmwater - 40. Exotic coldwater species were included in the analysis because of the importance attached to Pacific salmonids in providing fishing opportunities. Exotic cool- and warm-water species were excluded from the analysis on the grounds that restoration of habitats is directed to enhancement of habitat for native species. Piscivores were examined separately and, although the number of species is less than for non-piscivores, they were assigned a 50 percent weighting in the assessment. The habitat components were weighed equally with 100/3 being assigned to spawning habitat, adult summer habitat, and habitat productivity.

4.3.1 Fish Community Production

The fish productivity model defined in Chapter 3 was used in the assessment as follows:

First the nominal productivity is assigned (P'),

If substrate is sand or finer and vegetation then $P' = 1.00$

If substrate is coarser than sand the $P' = 0.33$.

Second the actual productivity (P) is a function of P' and depth,

If depth less than or equal to 2 m then $P = P'$

If depth great than 2 m the $P = P'/(Depth^{0.84})$

4.4 Assessment Results

After the physical assessment was completed, the affected areas delimited, and the fish assemblages groupings and weights determined, the integrated summation of habitat supply and weighted suitable area (WSA) changes were computed. For habitat supply summaries, the area of each discrete polygon obtained in the pre- or post- scenario overlays was added to the appropriate categories of depth and substrate. For WSA summaries, summations were computed for each habitat attribute and fish species grouping. In each sub-grouping of suitabilities, the area of the discrete polygon is multiplied by the appropriate suitability and the result was added to the scenario total. Once the sub-group summations were completed, the species grouping and attribute weights were applied to arrive at weighted sums, first for habitat attributes and then for final overall values.

4.4.1 Physical Habitat Changes

The summary of habitat supply distribution and changes showed that 2900 m^2 of habitat was predicted to be lost as a result of building the headland (Table 4.1). The depth changes involved an increase in the 0-2 m range and losses in the 2-5 and 5-10 m ranges. In the area lost (A_L), substrate losses were from the sand, mud, and vegetation categories. In the modified-direct area (A_{MD}), sand and mud substrates are replaced by rock on the submerged slopes of the headland (3184 m^2). In the modified-indirect area (A_{MI}), the wave shadowing effect of the headland predicted that substantial areas of sand and mud substrates in the 0-5 depth range gain submerged vegetation (62311 m^2). Overall in the simulated La Salle Park Marina scenarios, A_L was similar in area to A_{MD} (2906 vs 3100 m^2) and both of those areas were much smaller than A_{MI} (144000 m^2). The area ratios were about 1:1:48. Habitat assessments typically focus on the direct effects but clearly, where added structures can modify wave regimes in lakes, indirect effects might be more extensive.

4.4.2 Net Changes in Productivity of Fish Habitats

Estimated fish habitat supplies, as weighted suitable areas for spawning and adult summer habitats by thermal and trophic fish groups, showed varied responses when the pre- and post- development scenarios were contrasted (Table 4.2). WSA of spawning and adult summer habitats for all coldwater fish declined as a result of the headland construction while those for coolwater species increased. For warmwater species, non-piscivore spawning habitat decreased and adult summer habitat increased slightly while those for warmwater piscivores increased substantially. As the fish community objectives were weighted toward cool- and warm- water species, the combined values of WSA showed increases. The non-specific estimate of productivity changes followed the same pattern. The final overall weighted WSA's showed an increase from 51750 to 68000 m^2 equivalents. Thus the conclusion for the headland scenario at La Salle Park Marina was that a net gain of productivity would be attained with the indirect effects contributing the most.

Table 4.1 Summary of estimated area habitat supply (m^2) by depth and substrate for the pre- and post- restoration scenarios at the La Salle Park Marina, separated by area types (lost A_L, modified-direct A_{MD} , modified-indirect A_{MI}).

Areas m^2	Substrate	Pre-development scenario, depth ranges (metres) 0 - 2	2 -5	5 - 10	10 +	Σ	Post-development scenarios, depth ranges (metres) 0 - 2	2 - 5	5 - 10	10 +	Σ	Difference
Lost	Rock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(A_L)	Gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sand	416.0	468.8	843.5	0.0	1728.3	0.0	0.0	0.0	0.0	0.0	-1728.3
	Mud	178.3	200.9	361.5	0.0	740.7	0.0	0.0	0.0	0.0	0.0	-740.7
	Vegetat'n	328.4	108.7	0.0	0.0	437.1	0.0	0.0	0.0	0.0	0.0	-437.1
	Σ	922.7	778.5	1204.9	0.0	2906.1	0.0	0.0	0.0	0.0	0.0	-2906.1
Modified-	Rock	0.0	0.0	0.0	0.0	0.0	1492.4	1141.6	550.0	0.0	3183.9	3183.9
Direct	Gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(A_{MD})	Sand	88.7	702.7	1377.7	0.0	2169.0	0.0	0.0	0.0	0.0	0.0	-2169.0
	Mud	38.0	301.1	590.4	0.0	929.6	0.0	0.0	0.0	0.0	0.0	-929.6
	Vegetat'n	0.0	3.9	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	-3.9
	Σ	126.7	1007.7	1968.1	0.0	3102.6	1492.4	1141.6	550.0	0.0	3183.9	81.3
Modified-	Rock	125.2	0.0	0.0	0.0	125.2	43.9	0.0	0.0	0.0	43.9	-81.3
Indirect	Gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(A_{MI})	Sand	58261.4	20079.3	21827.6	549.8	100718	17392.6	12032.6	21832.8	549.8	51807.8	-48910.3
	Mud	19162.2	8184.8	9354.7	235.6	36937.3	8795.7	5156.8	9356.9	235.6	23545.1	-13392.3
	Vegetat'n	3986.6	2310.3	0.0	0.0	6296.9	55231.4	13376.4	0.0	0.0	68607.8	62310.9
	Σ	81535.4	30574.4	31182.3	785.4	144077.5	81463.6	30565.9	31189.7	785.4	144004.5	-73.0
Σ		82584.8	32360.6	34355.4	785.4	150086.2	82955.9	31707.5	31739.6	785.4	147188.5	-2897.7

Table 4.2 Hierarchical summary by habitat attribute and species group of weighted suitable areas (equivalent m^2) for the pre- and post- restoration scenarios at La Salle Park Marina.

Habitat	Fish species groups				Weighted Suitable Areas			Weights		
Attributes	Thermal	Natives?	Exotics?	Trophic	Pre-	Post-	Difference	Thermal	Trophic	Attributes
Spawning	Cold	Yes	Yes	NonP	23391.1	12716.9	-10674.1	0.2	0.5	
				Pisc	10353.0	4454.7	-5898.3	0.2	0.5	
	Cool	Yes	No	NonP	52161.6	87233.4	35071.8	0.4	0.5	
				Pisc	12674.3	70985.8	58311.5	0.4	0.5	
	Warm	Yes	No	NonP	96722.8	63731.1	-32991.7	0.4	0.5	
				Pisc	58721.4	89819.3	31097.8	0.4	0.5	
Adult	Cold	Yes	Yes	NonP	12201.5	7349.4	-4852.2	0.2	0.5	
				Pisc	7310.9	4630.9	-2680.1	0.2	0.5	
	Cool	Yes	No	NonP	70968.1	100924.0	29955.9	0.4	0.5	
				Pisc	8151.0	34966.9	26815.9	0.4	0.5	
	Warm	Yes	No	NonP	80339.2	82350.5	2011.3	0.4	0.5	
				Pisc	17073.6	33898.8	16825.2	0.4	0.5	
Weighted										
Spawning					47430.5	64071.1	16640.6			0.33
Adult					37257.6	51626.1	14368.4			0.33
Productivity					70028.8	87620.9	17592.1			0.34
Overall Σ					51756.9	67971.1	16214.3			

5.0 DISCUSSION AND NEXT STEPS

The prototype methodology that has been developed for headlands and offshore structures has provided the basis for a tool with which to conduct more effective assessments of the effects of shoreline developments on Great Lakes fish habitat. The strength of the methodology centres on:

1) the common set of habitat variables and assessment rules to describe pre- and post development fish habitat; and

2) the focus on quantification of the change in fish habitat from the pre and post development condition, rather than an accurate quantification of absolute habitat before and after development.

The first quality provides the critical ecological basis of the methodology. The second quality acts to expedite completed development assessments because the change in fish habitat can be estimated with incomplete knowledge of the effects of human activity on fish habitat and fish populations. In addition, the rules used to quantify habitat effects of shoreline development are transparent and can be updated as new information is obtained. These qualities are the primary reasons why the prototype methodology can provide development assessments that are consistent and defensible.

The defensible methodology provides an operational link between the federal Fisheries Act and the federal policy for habitat management (Figure 5.1). By providing proponents and habitat managers with a common tool with which to assess the effects of a shoreline development project on productive capacity of fish habitat, the methodology serves the habitat policy for "no net loss" of fish habitat, and provides a powerful tool in authorizations of a HADD as per section 35(2) of the Fisheries Act. The methodology can be used to prescribe, and later monitor the efficacy of compensation or mitigation measures that are used to base authorizations of a HADD.

The prototype methodology for headlands and offshore structures requires further development in different areas, which are discussed below.

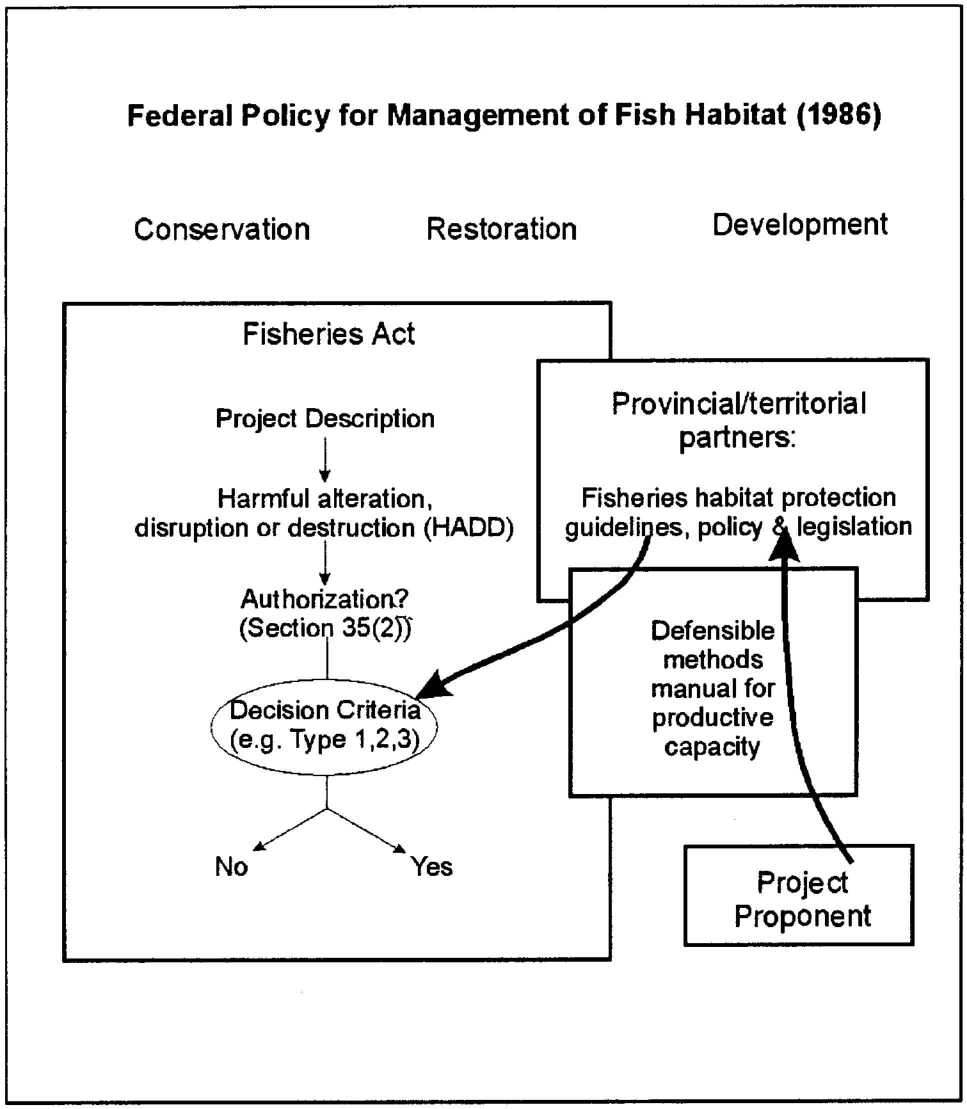


Figure 5.1 The Defensible Methodology as a tool to link the federal Fisheries Act and the federal habitat policy.

5.1 Affected Areas

The designation of the subarea of the directly modified slope of the headland or offshore structure that is bounded by high and low water marks should be explored for inclusion into the methodology. By making this area explicit in the assessment protocol, project proponents will be encouraged to compare the benefits to fish habitat between placement of low slopes of rock or vertical sheet pilings as the means to stabilize headlands or offshore structures. The potential gain of fish habitat with low slopes of rock could be substantial in water bodies that experience a wide annual range in water levels.

The current method to estimate habitat area that is indirectly (A_{MI}) affected by the shoreline structure due to changes in local currents and wave action requires further development. The current 'shadow' method overestimates the areas indirectly affected by headlands or offshore structures and could be significantly improved by including wave refraction and diffraction processes. While the indirect effects of a headland or shoreline structure on fish habitat are the most difficult to estimate, they are likely the most important due to potentially far-reaching cumulative effects. Estimation of the indirectly affected areas would also be improved with consideration of changes to wave exposure, depth, substrate and temperature.

5.2 Wave Exposure

Wave energy affects substrate type and the ability of an area to support macrophytes. Modelling of wave energy inshore of the 8-10 metre depth contour could greatly improve estimates of change to inshore fish habitat (i.e., substrate and macrophyte cover). For estimation of the effects of changes to wave energy on macrophyte cover information is needed on the growing season in order to tune information requirements to critical times. While effective fetch is currently used in the macrophyte model a more versatile and relevant parameter is total wave energy over some threshold wave height level. The threshold level would delimit possible macrophyte growth. Once again, to maximize the utility of total wave energy in assessments and ultimately improve estimation of the area indirectly affected by a headland or offshore structure, wave refraction and diffraction processess must be included in the analysis of total wave energy.

5.3 Depth and Littoral Transport

The resolution of the changes to depth that are modelled by the methodology needs to keep in view the measurable sensitivity of fish populations (i.e. will the effects a 0.5 m change in habitat on fish populations be quantifiable?) The degree of sensitivity of fish to depth will determine the required fineness of modelled changes to depth. As an example, similar to the area between high and low water marks on the submerged slope of structures are the potential effects on fish populations of habitat gained or lost from beach ("fillet" beach) updrift or downdrift respectively. Information required to assess such changes in depth is local sediment budget, which is often published, historic shoreline recession or accretion rates, which are often published, the potential or actual sediment transport rate, and the possibility of bypassing to establish the extent of any updrift accumulation and downdrift erosion for sandy shores. Cohesive shores will feature the same updrift accumulation consideration but may not feature a similar increase in downdrift erosion, as is the case with sandy shores.

5.4 Substrate

Estimation of changes in substrate in the indirectly affected areas is restricted to coarse changes among glacial sediments (i.e. till - highly consolidated and very hard), silt/clay (i.e. soft mud), sand, gravel/shingle/pebble, boulder, bedrock (highly fractured or smooth). At a minimum these changes can be determined with consideration of the combined influence of changes in wave exposure and depth leading to areas of erosion and deposition. In depositional areas, the substrate may become finer, or glacial sediments may be buried by sand and gravel. In erosional areas, sediments may become coarser (although this is a less certain outcome than the fining of sediments in depositional areas) and glacial sediments may become exposed. Other substrate types that should be included in the methodology are bedrock and glacial sediment providing they are relevant as fish habitat.

Second order substrates that provide fine habitat structure, such as tires, and tree stumps and brush should be included in the methodology, again providing that there are empiric relationships that link them to fish abundance, or diversity etc. It is judged that the effect of fine habitat structure on productivity would have to be added as a primary substrate.

5.5 Temperature

Changes to temperature will only be detectable in areas where basins with small entrances are created, i.e., areas sheltered from waves on one side of a headland will not experience a significant temperature change. Therefore, some mean temperature for the appropriate season will have to be specified to differentiate between warm, cool, and coldwater habitat. The affected area will simply be the area of the basin. The rule applied here could be a simple empirical comparison to data for other created or natural basins in the vicinity.

As alluded to above, improvements to the physical modelling requires information from the biological modelling on the required resolution and timing of physical habitat change that is meaningful to fish. It is important to have knowledge of the sensitivity of the various life stages to changes in physical habitat.

5.6 Biological

The existing spawning and adult summer habitat requirements database needs to be reviewed and updated where new or more detailed evidence is available. The macrophyte model needs to be able to distinguish submergent and emergent macrophytes, and ideally be able to predict a finer gradation of coverage between 0 and 100%. The productivity model will be refined as additional data are analyzed and new physical and chemical variables become available as part of the assessment methodology. The current model, which predicts community productivity habitat from depth and vegetation, needs to be expanded to include substrate independent of vegetation cover.

Community productivity (i.e., productive capacity) needs to be articulated in terms of species richness, biomass, and production. Community productivity indices for a range of substrate and depth, and other variables should be compared to corresponding weighted suitable areas (WSA) and species groupings to determine how well these two metrics correlate. The productivity model needs to be able to predict at the species assemblage level (e.g., thermal guild by feeding trophy). Also, absolute productivity needs to be estimated. A young-of-year (YOY) habitat requirement component should be included to complement spawning and adult habitat. Division of productivity by thermal and other ecological groupings should be considered to account for basic differences and enable equalization regardless of absolute productivities. For example coldwater production rates will always be less than warmwater ones purely because of Q_{10} effects alone (Regier et al. 1990).

The methodology reports on spawning and adult habitat of thermal guilds, and community production, as per the habitat policy. In order to be directly relevant to all other habitat management practices, strategies and policy etc., the methodology should also be able to report assessments at the species level, and report the relative dominance of species assemblages. Similarly, measures of species and habitat diversity should also be available. The methodology needs to become more transparent allowing the user access to all elements of the assessment protocol.

5.7 Chemical

Nutrient status of the waterbodies should be considered and can be built directly into the predictions of fish productivity. This is particularly important in situations where a shoreline structure may create an embayment that entraps nutrients from an outfall. Constraints on habitat use or productivity due to water chemistry need to be considered in the assessment. For example, anoxia in the hypolimnion of a lake during the summer may exclude coldwater fishes from suitable habitat. Acidity, waste plumes, etc. could produce similar considerations. The methodology also should be able to integrate independent, long-term changes to water quality in development assessments.

5.8 Recommendations

1. Develop a young-of-year (YOY) model.
2. Disaggregate productivity model by species group and develop and expand predictor variables (e.g., substrate).
3. Move toward expressing productivity in terms of species richness, biomass, and production;

4. Physical modelling of depth, substrate, wave intensity, and temperature, needs further development.

4. Apply prototype methodology to other headland/island developments that have occurred for further ground truthing of empiric models.

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Appendix A. Great Lakes Referral Summary Data Sheet and Distribution Tables

Summary of 127 shoreline projects in the Great Lakes that were referred to the Department of Fisheries and Oceans, central region.

The following is a complete text print out of the summary of our survey for 127 referrals.

Variable	Code	Count	Percent
Location			
Lake Superior	1	10	7.8
St. Mary's River	2	3	2.3
Lake Huron	3	2	1.5
Georgian Bay	4	18	14.1
North Channel	5	1	0.7
St. Clair River	6	6	4.7
Lake St. Clair	7	3	2.3
Detroit River	8	5	3.9
Lake Erie	9	10	7.8
Niagara River	10	3	2.3
Lake Ontario	11	25	19.6
St. Lawrence River	12	10	7.8
Tributary	13	31	24.4
Total		127	100
RAP area			
Yes	1	46	36.2
No	2	81	63.7
Total		127	100
RAP name			
N/A	0	81	63.7
St. Lawrence River	1	4	3.1
Bay of Quinte	2	5	3.9
Port Hope	3	0	0
Metro Toronto & Region	4	3	2.3
Hamilton Harbour	5	2	1.5
Niagara River	6	3	2.3
Wheatley Harbour	7	0	0
Detroit River	8	5	3.9
St. Clair River	9	7	5.5
St. Marys	10	3	2.3
Spanish River	11	0	0
Severn Sound	12	0	0
Collingwood Harbour	13	1	0.7
Thunder Bay	14	7	5.5
Nipigon Bay	15	5	3.9
Jackfish Bay	16	0	0
Peninsula Harbour	17	1	0.7
Total		127	100

Variable	Code	Count	Percent
Development type			
New	1	80	62.9
Repair	2	27	21.2
Expansion	3	20	15.7
Unknown	9	0	0
Total		127	100
Purpose			
Marina	1	27	21.2
Dock	2	9	7.0
Wetland Creation	3	2	1.5
Water Intake	4	3	2.3
Industrial Waste Water	5	9	7.0
Storm Sewer	6	3	2.3
Sewage Treatment	7	4	3.1
-	8	0	0
Water Course Diversion	9	3	2.3
Armourment	10	16	12.5
Restoration / Clean-up	11	5	3.9
Infilling	12	16	12.5
Road / Bridge	13	2	1.5
Dredging	14	11	8.6
Boat Launch	15	1	0.7
Other	16	15	11.8
Unknown	99	1	0.7
Total		127	100
Site			
Bay	1	30	23.6
River / Channel	2	65	51.1
Exposed	4	30	23.6
Unknown	9	2	1.5
Total		127	100
Fish detail			
None	1	76	59.8
Low	2	33	25.9
Medium	3	14	11.0
High	4	4	3.1
Total		127	100
Fish			
Potential Spawning	1	6	4.7
Potential Nursery	2	1	0.7
Pot'l Rearing / Foraging	3	2	1.5
Known Spawning	4	5	3.9
Known Nursery	5	2	1.5
Known Rearing /Foraging	6	2	1.5
1 & 2 & 3	7	2	1.5
4 & 5 & 6	8	12	9.4
Entrainment	9	5	3.9
Potential Migration Route	10	1	0.7

Variable	Code	Count	Percent
Known Migration Route	11	3	2.3
Unknown	99	86	67.7
Total		127	100
Fish concerns			
No Concerns	1	13	10.2
Forage Fish	3	2	1.5
Sport Fish	4	24	18.8
Both	5	88	69.2
Unknown	9	0	0
Total		127	100
Habitat data			
None	1	46	36.2
Low	2	56	44.0
Med	3	19	14.9
High	4	4	3.1
Unknown	9	2	1.5
Total		127	100
Habitat primary			
None	1	11	8.6
Silty	2	3	2.3
Mud / Organic	3	8	6.2
Wetland	4	10	7.8
Erosional	5	1	0.7
Sand	6	11	8.6
Cobble	7	7	5.5
Rubble	8	1	0.7
Bedrock	9	9	7.0
Gravel	10	3	2.3
Boulders	11	1	0.7
Unknown	99	62	48.8
Total		127	100
Habitat secondary			
None	1	11	8.6
Silty	2	3	2.3
Mud / Organic	3	8	6.2
Wetland	4	10	7.8
Erosional	5	1	0.7
Sand	6	11	8.6
Cobble	7	7	5.5
Rubble	8	1	0.7
Bedrock	9	9	7.0
Gravel	10	3	2.3
Boulders	11	1	0.7
Unknown	99	62	48.8
Total		127	100

Variable	Code	Count	Percent
Habitat: Man Made			
None	1	28	22.0
Armour Stone	2	0	0
Rubble	3	2	1.5
Groyne / Headland	4	2	1.5
Berm	5	3	2.3
V. Steel / Concrete	6	11	8.6
Dredged	7	18	14.1
Unknown	9	63	49.6
Total		127	100
Vegetation			
None	1	6	4.7
Cattail	2	7	5.5
Algae	3	3	2.3
Other Macrophytes	4	3	2.3
Mixture	5	11	8.6
Unknown	9	97	76.3
Total		127	100
Vegetation Cover			
None	1	6	4.7
<5% Low	2	7	5.5
5-50% Medium	3	1	0.7
>50% High	4	8	6.2
Unknown	9	105	82.6
Total		127	100
Dimensions			
Written Document	1	59	46.4
Map / Drawing	2	16	12.5
Estimate	3	28	22.0
Dimensions Stated	4	1	0.7
Unknown	9	23	18.1
Total		127	100
Shore Affected			
0	1	16	12.5
>0-10	2	9	7.0
10-100	3	29	22.8
100-1000	4	27	21.2
1000-10000	5	15	11.8
>10000	6	2	1.5
Unknown	9	29	22.8
Total		127	100
Area Affected			
0	1	10	7.8
>0-10	2	1	0.7
10-100	3	8	6.2
100-1000	4	37	29.1
1000-10000	5	20	15.7

Variable	Code	Count	Percent
>10000	6	25	19.6
Unknown	9	26	20.4
Total		127	100
Effects			
Construction	1	7	5.5
Permanent	2	13	10.2
Both	3	90	70.8
None	4	7	5.5
Unknown	9	10	7.8
Total		127	100
Work permit			
Yes	1	66	51.9
No	2	15	11.8
Most Likely Yes	3	8	6.2
Propon. Likely Gave Up	4	3	2.3
Unknown	9	35	27.5
Total		127	100
File			
Few Letters +/- Map	1	36	28.3
Detailed Prop. + Letters	2	45	35.4
Complete EARP docs	3	30	23.6
Incomplete	9	16	12.5
Total		127	100

Appendix B. Listing of data for fish species reported in Lake Ontario, by thermal and trophic group, indicating their origin and their spawning and summer habitat requirements.*

OMNR Code	Common name	Latin name	O?	Spawning Habitat ?	Spawning Habitat Sub	Spawning Habitat Dep	Adult Summer Habitat ?	Adult Summer Habitat Sub	Adult Summer Habitat Dep
	Coldwater Non-Piscivores:								
S014	Sea lamprey	Petromyzon marinus	Ex	No	na	na	Yes	_____x	__x
S214	Pearl dace	Margariscus margarita	Na	No	na	na	Yes	_xx___	xx_
S381	Mottled sculpin	Cottus bairdi	Na	No	na	na	Yes	__x___	__x
S031	Lake sturgeon	Acipenser fulvescens	Na	Yes	xx___	x____	Yes	___x__	_x_
S091	Lake whitefish	Coregonus clupeaformis	Na	Yes	xxx__	xx___	Yes	_xxx__	__x
S093	Lake herring	Coregonus artedii	Na	Yes	xxx__	xxxxx	Yes	_____x	__x
S094	Bloater	Coregonus hoyi	Na	Yes	xxxx_	____x	Yes	_____x	__x
S096	Kiyi	Coregonus kiyi	Na	Yes	_____	____x	Yes	_____x	__x
S099	Shortnose cisco	Coregonus reighardi	Na	Yes	__xx_	____x	Yes	_____x	_xx
S100	Shortjaw cisco	Coregonus zenithicus	Na	Yes	___x_	____x	Yes	_____x	_xx
S102	Round whitefish	Prosopium cylindraceum	Na	Yes	xx___	xxxx_	Yes	______	_xx
S162	Longnose sucker	Catostomus catostomus	Na	Yes	xx___	x____	Yes	__xx__	__x
S291	Trout-perch	Percopsis omiscomaycus	Na	Yes	xxx__	x____	Yes	__xx_x	xxx
S382	Slimy sculpin	Cottus cognatus	Na	Yes	xx___	x____	Yes	xx____	_xx
S384	Deepwater sculpin	Myoxocephalus thompsoni	Na	Yes	xx___	____x	Yes	___x__	__x
	Coldwater Piscivores:								
S072	Chum salmon	Oncorhynchus keta	Ex	No	na	na	Yes	_____x	__x
S073	Coho salmon	Oncorhynchus kisutch	Ex	No	na	na	Yes	_____x	__x
S075	Chinook salmon	Oncorhynchus tshawytscha	Ex	No	na	na	Yes	_____x	__x
S076	Rainbow trout	Onchorhynchus mykiss	Ex	No	na	na	Yes	xxxx_x	__x
S077	Atlantic salmon	Salmo salar	Na	No	na	na	Yes	_____x	__x
S078	Brown trout	Salmo trutta	Ex	Yes	_x___	x____	Yes	_xxx__	xx_
S080	Brook trout	Salvelinus fontinalis	Na	Yes	_x___	x____	Yes	_xxx__	_x_
S081	Lake trout	Salvelinus namaycush	Na	Yes	xx___	xx___	Yes	_____x	__x
S271	Burbot	Lota lota	Na	Yes	xxx__	x____	Yes	_____x	__x

* Meaning of information headings:
O?/Species origin? - Na = Native, Ex = Exotic
Spawning Habitat:
?/In the lake? - Yes or No.
Sub/Substrate - _ = No, x = Yes. (5 types - Rock, Gravel, Sand, Mud, Vegetation)
Dep/Depths (m) - _ = No, x = Yes. (5 ranges 0-5, 5-10, 10-15, 15-20, 20+)
Adult Summer Habitat:
?/In the lake? - Yes or No.
Sub/Substrate - _ = No, x = Yes. (6 types - Rock, Gravel, Sand, Mud, Vegetation, Pelagic)
Dep/Depths (m) - _ = No, x = Yes. (3 ranges 0-2, 2-10, 10+)

Appendix B continued.

OMNR Code	Common name	Latin name	O?	Spawning Habitat ?	Spawning Habitat Sub	Spawning Habitat Dep	Adult Summer Habitat ?	Adult Summer Habitat Sub	Adult Summer Habitat Dep
	Coolwater Non-Piscivores:								
S152	Mooneye	Hiodon tergisus	Na	No	na	na	Yes	______	xx_
S166	Bigmouth buffalo	Ictiobus cyprinellus	Ex	No	na	na	Yes	___x_x	xx_
S168	Silver redhorse	Moxostoma anisurum	Na	No	na	na	Yes	______	_x_
S172	Greater redhorse	Moxostoma valenciennesi	Na	No	na	na	Yes	xxxx__	_x_
S182	Northern redbelly dace	Phoxinus eos	Na	No	na	na	Yes	___x__	xx_
S185	Lake chub	Couesius plumbeus	Na	No	na	na	Yes	__xxxx	xxx
S194	Golden shiner	Notemigonus crysoleucas	Na	No	na	na	Yes	____x_	_x_
S197	Bridle shiner	Notropis bifrenatus	Na	No	na	na	Yes	__xxx_	x__
S211	Longnose dace	Rhinichthys cataractae	Na	No	na	na	Yes	_xx___	_x_
S212	Creek chub	Semotilus atromaculatus	Na	No	na	na	Yes	_x____	xx_
S213	Fallfish	Semotilus corporalis	Na	No	na	na	Yes	_x____	xx_
S261	Banded killifish	Fundulus diaphanus	Na	No	na	na	Yes	_xx_x_	xx_
S335	Eastern sand darter	Ammocrypta pellucida	Na	No	na	na	Yes	__x___	__x
S061	Alewife	Alosa pseudoharengus	Ex	Yes	_xx__	x____	Yes	_____x	__x
S121	Rainbow smelt	Osmerus mordax	Na	Yes	_x___	x____	Yes	_xxx_x	__x
S163	White sucker	Catostomus commersoni	Na	Yes	_x___	x____	Yes	__xxx_	_x_
S171	Shorthead redhorse	Moxostoma macrolepidotum	Na	Yes	_x___	x____	Yes	______	_x_
S189	Brassy minnow	Hybognathus hankinsoni	Na	Yes	___x_	x____	No	na	na
S190	Eastern silvery minnow	Hybognathus regius	Na	Yes	____x	x____	Yes	____x_	x__
S195	Pugnose shiner	Notropis anogenus	Na	Yes	_____	x____	Yes	__x_x_	xx_
S196	Emerald shiner	Notropis atherinoides	Na	Yes	_____	_____	Yes	_xxxx_	_xx
S198	Common shiner	Luxilus cornutus	Na	Yes	_x___	x____	Yes	__xxxx	xx_
S199	Blackchin shiner	Notropis heterodon	Na	Yes	____x	x____	Yes	____x_	xx_
S200	Blacknose shiner	Notropis heterolepis	Na	Yes	_xxxx	x____	Yes	__xxx_	_x_
S201	Spottail shiner	Notropis hudsonius	Na	Yes	_xx__	x____	Yes	_xxxx_	_xx
S281	Brook stickleback	Culaea inconstans	Na	Yes	____x	x____	Yes	____x_	x__
S282	Threespine stickleback	Gasterosteus aculeatus	Na	Yes	__x__	x____	Yes	__x_x_	xx_
S283	Ninespine stickleback	Pungitius pungitius	Na	Yes	____x	x____	Yes	__xxxx	__x
S331	Yellow perch	Perca flavescens	Na	Yes	_xx_x	x____	Yes	__xxx_	xxx
S338	Iowa darter	Etheostoma exile	Na	Yes	x___x	x____	Yes	__xxx_	__x
S340	Least darter	Etheostoma microperca	Na	Yes	____x	x____	Yes	__xx__	__x
S341	Johnny darter	Etheostoma nigrum	Na	Yes	x____	x____	Yes	_xx___	__x
S342	Logperch	Percina caprodes	Na	Yes	__x__	x____	Yes	xxx___	__x
S343	Channel darter	Percina copelandi	Na	Yes	_x___	x____	Yes	_xx___	__x
S346	Tessellated darter	Etheostoma olmstedi	Na	Yes	x____	x____	Yes	_xxxx_	xxx
S361	Brook silverside	Labidesthes sicculus	Na	Yes	_x_xx	x____	Yes	_____x	_xx
	Coolwater Piscivores:								
S251	American eel	Anguilla rostrata	Na	No	na	na	Yes	___x__	xxx
S041	Longnose gar	Lepisosteus osseus	Na	Yes	_x__x	x____	Yes	____x_	_x_
S131	Northern pike	Esox lucius	Na	Yes	____x	x____	Yes	____x_	_x_
S132	Muskellunge	Esox masquinongy	Na	Yes	____x	x____	Yes	x___x_	_x_
S133	Grass pickerel	Esox americanus vermiculatus	Na	Yes	____x	x____	Yes	____x_	x__
S136	Tiger muskellunge	Hybrid 131x132	Na	Yes	____x	x____	Yes	x___x_	_x_
S334	Walleye	Stizostedion vitreum vitreum	Na	Yes	xxx__	x____	Yes	_x__x_	__x

Appendix B continued.

OMNR Code	Common name	Latin name	O?	Spawning Habitat ?	Spawning Habitat Sub	Spawning Habitat Dep	Adult Summer Habitat ?	Adult Summer Habitat Sub	Adult Summer Habitat Dep
	Warmwater Non-Piscivores:								
S141	Central mudminnow	Umbra limi	Na	No	na	na	Yes	___x__	x__
S203	Spotfin shiner	Cyprinella spiloptera	Na	No	na	na	Yes	_xx___	_x_
S204	Sand shiner	Notropis stramineus	Na	No	na	na	Yes	__x___	_x_
S206	Mimic shiner	Notropis volucellus	Na	No	na	na	Yes	__xxx_	xx_
S208	Bluntnose minnow	Pimephales notatus	Na	No	na	na	Yes	_xx___	xx_
S232	Yellow bullhead	Ameiurus natalis	Na	No	na	na	Yes	_xxxx_	xx_
S063	Gizzard shad	Dorosoma cepedianum	Na	Yes	_xx__	x____	Yes	____x_	_x_
S161	Quillback	Carpoides cyprinus	Na	Yes	__xx_	x____	Yes	__x___	_x_
S165	Northern hog sucker	Hypentelium nigricans	Na	Yes	_x___	x____	No	na	na
S181	Goldfish	Carassius auratus	Ex	Yes	____x	x____	Yes	___xx_	xx_
S186	Carp	Cyprinus carpio	Ex	Yes	____x	x____	Yes	___xx_	xx_
S209	Fathead minnow	Pimephales promelas	Na	Yes	x____	x____	Yes	___x__	x__
S233	Brown bullhead	Ameiurus nebulosus	Na	Yes	__xxx	x____	Yes	__xxx_	xx_
S234	Channel catfish	Ictalurus punctatus	Na	Yes	_x_x_	x____	Yes	xxx___	_x_
S235	Stonecat	Noturus flavus	Na	Yes	xx___	x____	Yes	xxxx__	_x_
S236	Tadpole madtom	Noturus gyrinus	Na	Yes	___x_	x____	Yes	_x_xx_	_x_
S301	White perch	Morone americana	Ex	Yes	xxxxx	x____	Yes	_____x	_x_
S311	Rock bass	Ambloplites rupestris	Na	Yes	xxxxx	x____	Yes	xx__x_	_x_
S313	Pumpkinseed	Lepomis gibbosus	Na	Yes	_xx_x	x____	Yes	____x_	xx_
S314	Bluegill	Lepomis macrochirus	Na	Yes	_xxx_	x____	Yes	____x_	xx_
S318	White crappie	Pomoxis annularis	Na	Yes	_xxxx	x____	Yes	___xx_	xxx
S319	Black crappie	Pomoxis nigromaculatus	Na	Yes	_xxxx	x____	Yes	__xxx_	xxx
S323	Warmouth	Lepomis gulosus	Ex	Yes	xxxxx	x____	Yes	___xx_	x__
S324	Orangespotted sunfish	Lepomis humilis	Ex	Yes	xxxxx	x____	Yes	___x__	x__
S371	Freshwater drum	Aplodinotus grunniens	Na	Yes	__xx_	x____	Yes	__xx_x	_x_
S601	CarpxGoldfish	Hybrid 186x181	Ex	Yes	____x	x____	Yes	___xx_	xx_
S902	Rudd	Scardinius erythrophthalmus	Ex	Yes	____x	x____	Yes	__xxx_	xx_
	Warmwater Piscivores:								
S051	Bowfin	Amia calva	Na	Yes	____x	x____	Yes	____x_	_x_
S302	White bass	Morone chrysops	Na	Yes	xxxxx	x____	Yes	_____x	_xx
S316	Smallmouth bass	Micropterus dolomieui	Na	Yes	xxx__	x____	Yes	xxx___	_xx
S317	Largemouth bass	Micropterus salmoides	Na	Yes	_xxxx	x____	Yes	___xx_	xx_