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A Fish Habitat Classification Model for the Upper and Middle Sections of the Bay Of Quinte, Lake Ontario

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A FISH HABITAT CLASSIFICATION MODEL FOR THE UPPER AND MIDDLE SECTIONS OF THE BAY OF QUINTE, LAKE ONTARIO

by

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ABSTRACT

A fish habitat classification model was developed and applied to the upper and middle sections of the Bay of Quinte, Lake Ontario. Available habitat inventories were assembled in a GIS database, bringing bathymetric, shoreline, substrate, and vegetation data together in a series of layers. The classification model was developed in four steps. In the first step, the Defensible Methods (DM) model developed by Minns *et al.* (2000) was used to estimate suitability values in all habitat patches for a set of nine fish groups each with three life stages. The fish groups were formed from the assemblage of fish species present in the Bay of Quinte by combining them according to thermal and vegetation preferences, and combinations of size and age-at-maturity. Different methods of combining the 27 suitability indices were examined to allow designation of each unique habitat patch to low, medium or high suitability categories for fish. The K-means clustering technique was selected for classifying habitat patches into three suitability categories, thereby exploiting natural breaks in the cumulative distributions of suitability values and maintaining consistency with underlying habitat features. In the second step, the spatially rare habitats for each fish group by life stage combination were used to identify habitat patches that are important for particular fish groups and life stages but which had been classified as medium or low suitability in the first classification step. Criteria for recognizing rarity were used to reassign habitat patches rated low or medium in step one to the high class. In the third step, local expert knowledge of important fish habitats gathered from anglers and fishers were used to develop an expert classification. This expert mapping of important fishing areas was compared with that obtained via suitability and rarity ratings and then, in step four, used to upgrade some areas from low or medium to high.

The final habitat classification model is a mixture of suitability, rarity and expert ratings. The habitat suitability class assignments obtained in step one were not changed appreciably by steps two and three. The combined suitability-rarity ratings showed good agreement with the local expert ratings. Important fishing areas either overlapped suitable areas or were close by where fisher access would be restricted by depth or vegetation density. The final habitat classification for the Bay of Quinte provides a context for both conservation and restoration efforts. Periodic updating of the classification system will be needed as conditions change, e.g., as a result of climate change or as the effects of the zebra mussel invasion on macrophytes and substrates mature, or as data on other habitat elements becomes available, e.g., seasonal and spatially thermal habitat maps. Further effort is needed to understand the procedures used by government agencies at different levels to integrate the knowledge embodied in habitat maps into on-going fisheries and fish habitat management.

RÉSUMÉ

Un modèle de classification des habitats des poissons a été élaboré et appliqué aux sections supérieure et moyenne de la baie de Quinte, dans le lac Ontario. Les inventaires existants des habitats ont été versés dans une base de données SIG, regroupant ainsi en une série de couches des données sur les propriétés bathymétriques, les littoraux, les substrats et la végétation. L'élaboration du modèle de classification s'est faite en quatre étapes. Lors de la première étape, on a fait appel au modèle des méthodes défendables de Minns *et al.* (2000) pour estimer les valeurs de convenance de toutes les parcelles

d'habitat d'un ensemble de neuf groupes de poissons, chaque groupe étant représenté par trois stades biologiques. Les groupes de poissons ont été constitués à partir de l'assemblage des espèces trouvées dans la baie de Quinte. Les espèces ont été combinées selon leurs préférences en matière de température et de végétation ainsi que selon leur taille et leur âge à la maturité. Différentes méthodes visant à combiner les 27 indices de convenance ont été examinées; on a ainsi pu attribuer à chaque parcelle d'habitat des poissons une catégorie de convenance : faible, moyenne ou élevée. La technique de regroupement à K-moyennes a été choisie pour classer les parcelles d'habitat dans les trois catégories de convenance, ce qui a permis d'exploiter les bris naturels dans les distributions cumulatives des valeurs de convenance et de conserver une constance dans les caractéristiques sous-jacentes des habitats. À la deuxième étape, on a identifié les parcelles d'habitat à caractère spatialement rare, jugées importantes pour certains groupes et stades biologiques de poissons, mais qui avaient été classées dans les catégories moyenne ou faible lors de la première étape. Les critères de reconnaissance de la rareté ont permis de promouvoir à la catégorie de convenance élevée des parcelles d'habitat désignées faibles ou moyennes lors de la première étape. À la troisième étape, les connaissances d'experts locaux sur les habitats importants des poissons, recueillies auprès de pêcheurs amateurs et professionnels, ont été utilisées pour mettre au point une classification des experts. La cartographie des zones de pêche importantes ainsi obtenue a été comparée à celle fournie par les classifications en fonction de la convenance et de la rareté, puis, à la quatrième étape, elle a servi à reclasser certaines zones, en les faisant passer des catégories faible ou moyenne à la catégorie élevée.

Le modèle final de classification des habitats est en fait fondé sur une combinaison de catégories de convenance et de rareté et du classement des experts. Les classements de convenance des habitats obtenus à la première étape n'ont pas été modifiés de manière significative par les étapes deux et trois. Les classements fondés à la fois sur la convenance et sur la rareté correspondaient bien avec les classements des experts. Les zones de pêche importantes soit chevauchaient les zones à convenance élevée, soit se trouvaient à proximité dans des endroits où l'accès des pêcheurs était limité par la profondeur de l'eau ou par la densité de la végétation. La classification finale des habitats de la baie de Quinte fournit un contexte à la fois pour les efforts de conservation et pour les efforts de restauration. Une mise à jour périodique du système de classification sera nécessaire à mesure de l'évolution des conditions (par exemple, le changement climatique et les effets des moules zébrées sur les macrophytes et les substrats) ou de l'apparition de nouvelles données sur d'autres composantes des habitats (par exemple, cartes saisonnières ou spatiales des habitats thermiques). D'autres efforts sont nécessaires pour que les organismes des divers ordres de gouvernement intègrent les connaissances contenues dans les cartes des habitats à leurs méthodes courantes de gestion des pêches et des habitats des poissons.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

In 1985, the International Joint Commission (IJC) designated the Bay of Quinte as one of 43 "Areas of Concern" across the Great Lakes basin where one or more of 14 beneficial ecosystem uses was impaired. Agencies in both Canada and the United States were charged by the IJC with developing and implementing Remedial Action Plans (RAPs) for each area. Work on the Bay of Quinte RAP began in 1985 with the formation of a federal/provincial coordination committee. That committee was able to build on the work of Project Quinte, a federal/provincial/university consortium of researchers who had been studying the Bay of Quinte ecosystem intensively since 1972 when plans for major nutrient load reductions were first established (cf Minns *et al.* 1986).

In 1993, a Stage II RAP report, Time to Act, (Bay of Quinte RAP, 1993) was released by the coordinating committee documenting 10 impaired beneficial water uses out of the list of fourteen. Many of the impairments were tied to the hyper-eutrophication that occurred in the late 1960s and early 1970s. Key impairments were those associated with the fish community and with fish and wildlife habitat. The health of fish communities, and their fisheries, is a key indicator of ecosystem health. Further, healthy fish habitats are a prerequisite for healthy fish and fisheries. The Stage II report recognized that considerable alteration, fragmentation, degradation and loss of fish habitat had occurred, and recommended, alongside a number of site-specific actions, the development of a comprehensive fish habitat management plan. As the RAP implementation process began emphasis was placed on improving and securing ecosystem health via effective management of nutrients and contaminants. There has been much progress in these areas, laying the groundwork for long-term improvements in the health of the Bay of Quinte ecosystem. Recently, the Bay of Quinte Restoration Council, the successor to the RAP coordinating committee, took on the task of developing a fish habitat management plan for the Bay of Quinte area, using the Department of Fisheries and Oceans (1986) policy document on the management of fish habitat as its starting point. The policy is exemplified by its guiding principle of "no net loss of productive capacity of fish habitats" (mirroring the policy goal of a net gain).

A key element in the development of a fish habitat management plan is information, an assessment and analysis of the supply and quality of fish habitat available to support the productivity of fish in the ecosystem (not including tributaries). The purpose of this report is to describe and document the development and implementation of a fish habitat suitability model for the upper and middle sections of the Bay of Quinte. The model draws on the considerable databases already assembled on many aspects of the Bay of Quinte ecosystem and the methodologies already applied elsewhere in the Great Lakes basin (Minns *et al.* 1999, 2001). Habitat is classified as to its relative suitability for fish although agencies managing fish habitats for productivity or species-at-risk would prefer to know which habitats are critical, essential, or important. At present, the state of the science precludes such precise designations (Rosenfeld and Hatfield 2006, Morrison *et al.* 1999). Knowledge of the fish habitats in the Bay of Quinte can guide and prioritize fish habitat conservation, restoration and enhancement efforts within the Bay proper.

Purpose and Objectives

The overall aim of this report was to generate a scientifically defensible fish habitat suitability classification scheme for the upper and middle areas of the Bay of Quinte for use as a guide for future management and conservation. The classification and assessment of the upper and middle areas of the Bay of Quinte was performed using the Defensible Methods (DM) model developed by Minns *et al.* (2001) and with a GIS database drawn from several sources detailing habitat characteristics (depth, vegetative cover, and substrate). A report by Minns *et al.* (1999), which presented a fish habitat classification model for areas of Severn Sound, in Georgian Bay, was used as a basis for the development of fish habitat suitability maps for the upper and middle areas of the Bay of Quinte. The work was limited to the upper and middle sections of the bay by the availability of mapped habitat data although the Area of Concern includes the lower Bay out to the boundaries of Adolphus Reach.

MATERIALS AND METHODS

The development of the classification model for the Bay of Quinte involves two components: 1) assembly of a GIS database describing habitat attributes and 2) implementation of an appropriate habitat classification model.

Bay of Quinte Habitat Mapping

<u>OMNR Nearshore Habitat Inventory</u>

A study to inventory and map fish and wildlife habitat in the nearshore zone of the Bay of Quinte was initiated in 1991 and completed in 1993. The results of this study included detailed mapping of substrate and aquatic vegetation that extended "from as far inland as visible from the boat" to a depth at which substrate or aquatic vegetation was not visible. Therefore the habitat information is representative of a single 'snap-shot' in time (Smith 1993). The substrate and aquatic vegetation information collected in the inventory were incorporated into the GIS habitat database used on the habitat classification model.

Shoreline and Bathymetry

The shoreline GIS layer was provided by the Ontario Ministry of Natural Resources (OMNR) at a scale of 1:10000. This scale was selected because it is consistent with the bathymetry data provided by Canadian Hydrographic Services (CHS) and is the maximum scale of the nearshore inventory data. In the GIS, the map projection data were: Universal Transverse Mercator, Zone 18, NAD83, Central Meridian -75.0.

A bathymetry map was assembled from CHS digital chart data and field sheets, corrected to International Great Lakes Datum 1985 (IGLD85). The shoreline was incorporated by converting the line to points and set to an elevation of 74.2m above sea level (Lake Ontario low-water datum IGLD85). A raster (3m cell size) representing elevation was generated then reclassified to DM depth classes (0-1, 1-2, 2-5, 5-10, 10+ metres) (Appendix Figure A1). The total area covered was 190.54 km2, distributed as follows: 0-1 m depth range had an area of 28.31 km2; 1-2 m 26.67 km2; 2-5 m 83.96 km2; 5-10 m 42.37 km2, 10+ m 9.23 km2; and 1.83 km2 as dry land above the datum.

Substrate

Two sources of substrate data were incorporated into the habitat classification model, each had a different spatial extent (nearshore and offshore) and different units. The nearshore data was extracted from the OMNR habitat inventory. The inventory maps were polygons attributed with a description of the 10 dominant and subdominant substrate types: Bedrock, Boulder, Rubble, Gravel, Sand, Silt, Clay, Muck, Detritus, and Marl (Smith 1993). The Def Meth substrate categories are bedrock, boulder, rubble, cobble, gravel, sand, silt, clay, and hard-pan clay. These types were assigned to the Defensible Methods substrate matrix where the dominant type was assigned a greater proportion than the subdominant (e.g. a polygon identified with dominant type Boulder and subdominant Gravel, was assigned 70% boulder, 30% gravel), (Appendix Table A1).

The offshore data was collected as point samples by R. Thomas of Environment Canada during the years 1972 and 1973 (R.L. Thomas, personal communication). These samples contained percent composition of sand, silt and clay. These points were used to generate Theissen polygons of substrate covering the offshore zone of the study as well as to fill in nearshore areas not mapped by the OMNR habitat inventory. The two datasets were spatially joined together, giving priority to the nearshore data, and thereby forming one substrate map (Appendix Figure A2).

Vegetation

DM requires spatial information on vegetation cover in three categories: emergent, submergent, and no cover. There were two sources of aquatic vegetation information used in the habitat suitability model: the first being the OMNR habitat inventory data, the second a submergent vegetation model developed for the Bay of Quinte (Seifried 2002) using results from repeated transect surveys conducted between 1972 and 2000. The OMNR habitat inventory data were stored as spatial polygon files with class and density attributes (Very sparse 5-20%, Sparse 20-40%, Moderate 40-60%, Dense 60-80%, and Very Dense 80-100%). Of the 6 vegetation classes only values for emergent and submergent vegetation data were used.

Emergent vegetation values were derived from the OMNR habitat inventory. There were no additional or more recent sources of emergent vegetation available. Seifried (2002) developed models to predict submerged vegetation density in the Bay of Quinte for three time periods including post-zebra mussel invasion (post 1995) using a regression tree method. The results from the post-zebra mussel period were used for the upper and middle Bay of Quinte sections to generate a 'current' representation of vegetation. In some cases, the two data sources for submergent vegetation overlapped spatially. When this occurred a hierarchical method was developed to combine the two datasets. The two sources of data were spatially joined, and then the source data for each polygon was tested and values assigned for emergent, submergent and no cover using the following logic:

EMERGENT VEGETATION:

- If data exists in Inventory Then use Emergent density mid-point
- If data does not exist in Inventory Then assume no Emergent cover

SUBMERGENT VEGETATION:

- If data exists in both Inventory and Seifried model Then use mid-point of Seifried model
- If data does not exist in Seifried model Then use inventory Submergent density mid-point
- If data does NOT exist in Inventory or no Seifried model Then No Cover = 100

NO COVER:

- 100 – (Emergent + Submergent) = No Cover

Examples of vegetation assignments are shown in Appendix Table A2.

Unique Habitat Features

A topological overlay of depth, vegetation and substrate map layers resulted in a new layer that preserved the features of all the input layers and represents a combination of all the habitat characteristics associated with each place (Appendix Figure A4). The area of each unique habitat combination was summed and resulting polygon attribute records were used in the input data table for the Defensible Methods software. Sample records for input to Defensible Methods software are shown for the zoomed in area highlighted in Appendix Figure A4 are shown along with input header records in Appendix Table A3.

Habitat Classification Approach

The approach employed here is the same as that reported in Minns *et al.* (1999) for the Severn Sound on Georgian Bay, Lake Huron. There are four steps in the approach:

- Step One: a combined habitat suitability assessment of all habitat patches for a target set of fish groups by life stage;
- Step Two: an assessment and classification of rare habitat types by fish group and life stage to ensure that step one does not misclassify habitat patches important to one or few fish groups;
- Step Three: assessment and classification of areas using local fisher expert knowledge of important fishing areas; and

- Step Four: implementation of a combined classification model drawing on results obtained in the first three steps.

Step One: Fish Habitat Suitability Assessment

The fish habitat suitabilities of the upper and middle areas of the Bay of Quinte were predicted using the 'Defensible Method's software (DM) described by Minns *et al.* (1996). DM software uses an amalgamation of literature-based databases, compiled by Lane *et al.* (1996a,b,c), which detail the habitat requirements of fish during their spawning, nursery (young-of-the-year or yoy), and adult life stages. The DM software uses these life history preferences to estimate habitat suitability values for fish in defined areas of habitat.

<u>Application of Defensible Methods</u>

The determination of the habitat suitability in the Bay of Quinte involved several steps that are outlined below.

Location Species List

In the DM software the location species list determines which species habitat preference data are used to estimate suitability indices. The location species list of those fish inhabiting the Bay of Quinte was based on a list compiled by Hurley *et al.* (1986). Only species which were cited to have been found in recent collections from the bay were included in the species list (Appendix B). Sea lamprey and splake were not included in the species list for the purpose of fish habitat suitability mapping. Sea lamprey make only a brief migratory use of the Bay between spawning and larval life stages in streams and the adult/parasitic life stage in Lake Ontario proper. Splake were never stocked in any significant numbers in Lake Ontario and certainly did not to establish a population in the Bay of Quinte.

Selection of Fish Groups

The location species list was sorted into smaller groups, or guilds, of species. This is done to ensure that when determining the overall composite habitat suitability of an area, different groups of species can be weighted differently to reflect the objectives of the particular application of DM. For example, an application geared solely towards conserving commercially important species might assign a greater weighting to some species (i.e. walleye and yellow perch) that are more valuable than others (i.e. gizzard shad and common carp). It is important to note that all species within a species group are weighted equally in the estimation of habitat suitability values from species preference data. Group suitability values are then assigned a group weight to reflect their emphasis in the application. Different weights are also assigned to each life-stage to place an emphasis on a specific life-stage deemed to be of great importance, e.g., to ensure that enough habitat is available for rearing and feeding as well as for spawning.

The Bay of Quinte species list was divided into nine groups to allow matching of species with similar life history preferences (Appendix C). These groups were formed by compiling a database from Coker *et al* (2001) to compare thermal preference, reproductive guild, age and length at maturity, maximum age and length, feeding preference and vegetative cover preference (high versus low). After considering the need for consistency in habitat preferences within groups, it was determined that the formation of groups based primarily on species thermal preferences, followed by age-at-maturity and degree of vegetative cover preference, yielded groups of species with a high degree of life history similarity. Coldwater species were amalgamated into a single group based on the uniformity of the examined traits (i.e. coldwater species prefer very little, if any, vegetative cover and the majority of species present are piscivores). Much of the Bay of Quinte does not provide coldwater fish habitat, is little used by cold water fish, and hence their habitat preferences would have a minor role in determining an overall classification. There are large quantities of coldwater fish habitat in the lower Bay and in the adjacent areas of Lake Ontario.

Coolwater and warmwater species were then further divided into eight groups based on their age at maturity and their preference for vegetative cover. Coolwater species were divided into two groups, one consisting of those with an age-at-maturity of less than or equal to 2 years and another contained species with an age of maturity at greater than 2. Warmwater species were divided into two groups, one with species whose age-at-maturity was less than or equal to 3 years and another for species with age-at-maturity greater than 3. Two exceptions were made however to these warmwater groupings. Grass pickerel (*Esox americanus vermiculatus*) and largemouth bass (*Micropterus salmoides*), both with age-at-maturity of 3 years, were placed in the latter group defying the age-at-maturity rule as their overall life-styles and sizes were more consistent with others in that group. The four thermal/age-at-maturity groups were each then divided into two groups based on species having a low or high preference for vegetation cover.

A sensitivity analysis of the groupings was not performed for this study as previous work in Severn Sound (Minns *et al.* 1999) established the main patterns of sensitivity when forming fish groups to estimate suitability values. Habitat use patterns varied most between thermal groupings compared to trophic and life stage groupings. The age-at-maturity criteria used here divides species for the most part between small and large adult sizes. The differing preferences for vegetation cover represent a well-known feature in fish communities.

Selection of Weights for Fish Groups and Life Stages

To calculate habitat suitability indices using the Bay of Quinte physical habitat database, it was necessary to assign suitability weights for each species group present (Table 1). Each life stage (adult, yoy, spawning) was assigned an equal weight of 0.333; this assumes that the habitat required to complete each life stage is of equal importance to a species. This is a conservative approach as there are no clear guide-points for setting values, although Minns *et al.* (1996) showed that the absolute habitat supply requirements of adult and yoy life stages are greater than those of spawning. Lower weightings were assigned to the cold water groups in comparison to both the cool water and warm water species. The upper and middle sections of the Bay of Quinte are mainly shallow and warm in the summer, and coldwater species are a minor component of the fish assemblages present. This does not mean those sections of the Bay are unimportant for coldwater species as there may be transitory use for migration or spawning in colder periods of the year. The main fish production takes in the warmer periods and is dominated by warmwater and coolwater species.

Linking Fish Habitat Categories to Species' Requirements

The habitat categories obtained when the inventory is assembled in a GIS are not necessarily the same as those specified for inputs to the DM software. However each habitat patch created by the overlay of depth, substrate, and vegetation cover can be described as a vector, or array, of percentages (0 to 100):

- Depth: %0-1, %1-2, %2-5, %5-10, %10+ metres.

- Substrate: %Bedrock, %Boulder, %Cobble, %Rubble, % Gravel, %Sand, %Silt, %Clay, %Hard-pan clay, %Pelagic.
- Vegetation: %No cover, %Emergents, %Submergents.

The three habitat features are treated orthogonally in DM such that suitabilities are computed for unique combinations of elements drawn singly from each feature (Minns *et al* 2001). Then the weighted sum of suitabilities is computed based on the proportions. Hence suitability for the combination 0-1 m depth by cobble by no cover is computed and its weighted contribution is %0-1 times %cobble times %no cover. These calculations are repeated for all unique habitat patches in the inventory and for each fish group and life stage combination.

Computation of Habitat Suitabilities

The fish habitat suitabilities for the upper and middle areas of the Bay of Quinte were computed as in Minns *et al.* (1999a) and, Minns and Bakelaar (1999). In this study, 27 basic DM suitabilities (i.e. 9 groups by 3 life stages), as well as one composite suitability, were calculated for each of the 3609 unique habitat characteristic combinations found in the mapped polygons. Excluded from the analysis were map polygons belonging to the lower bay and those lacking data for one of the three thematic layers.

Habitat Suitability Classification

Two classification schemes based on DM habitat suitability values were assessed. In a Severn Sound habitat classification study, Minns *et al* (1999a) used a composite DM suitability index based on a weighted sum of the constituent fish group by life stage suitability indices. Classification and regression trees (CART) were used to identify suitable cut-offs for dividing the suitability range into three categories; low, medium and high. Here, a simplified 'natural breaks' version of the Severn Sound approach was compared with a K-means clustering approach whereby patches were classified into limited numbers of sets using the raw fish group by life stage suitabilities as inputs.

The aim of suitability classification was to divide each of the 27 indices, as well as the composite index, into three different habitat suitability classes; high, medium and low. It was important that the cut-offs for these classes be assigned in a deliberate and non-random fashion, thus ensuring the safeguarding of innate groupings among the data sets. With this factor in mind, the ESRI's ArcView GIS® was employed to determine the natural break-points of the suitability data. Using the legend type 'Graduated Color' and using a classification scheme that seeks and divides the given data by its 'natural breaks' into three groups, the suitability classes were formed.

The second form of analysis was performed on the DM suitability values to gain an additional perspective of the overall fish habitat suitability (in addition to the composite index). This was done by amalgamating all 27 of the individual indices suitability rankings for each unique patch. Once the Arc-View software had determined the natural breaks for each of the 27 indices, each unique patch was ranked as either a low, medium, or high suitability (1, 2 and 3 respectively). Thus, each unique patch had been ranked a total of 27 different times. A K-means cluster analysis (Systat 10 ®) was performed in an attempt to divide each unique patch into six classes based on these 27 individual rankings. Assignment of each cluster to a low, medium of high suitability cluster was done by examining the means of the 27 suitability indices of habitat patches included in the cluster. For example, in cluster number one, the mean suitability ranking of the habitat within all of the clustered polygons for cold water fish was 1.00. These individual means for each index were then tallied and an overall mean was determined. This overall mean was the main determining factor as to how the overall cluster was ranked.

Step Two: Fish Habitat Rarity Assessment

Where composite weighted indices are used to assess habitat suitabilities there is a concern that uncommon habitat patches classified as extremely high in suitability for one of the 27 individual indices will be classified as either medium or low with respect to the overall habitat suitability as classified by either composite and cluster analysis. If conservation efforts are solely focused upon those patches considered to be high by composite and clustered suitabilities, vital habitat for one of the 27 combinations may be overlooked and possibly destroyed. The rarity assessment pinpoints and highlights those potentially 'overlooked' patches.

The identification of the 'rare' habitat patches among the individual 27 guild life stages was performed via the construction of Lorenz curves depicting percent cumulative area and percent weighted suitable area (WSA) versus habitat suitability for each of the individual indices (Appendix G). WSA is the product of area and suitability. Habitat was classified as rare if it fell into the upper 25th percentile of cumulative area, possessed a suitability of 0.75 or greater, and if the cumulative WSA curves enters the box from the left rather than from below. These patches were easily identified by use of the constructed curves. The general shape of the cumulative curves themselves reveals information regarding the nature and the quality of the overall habitat with respect to the needs and preferences of the fish species belonging to each guild and life stage. If the curve has an overall concave shape, the cumulative line will then pass into the rarity quadrant from below. In this situation, a larger amount of the habitat is of higher suitability and hence there is no rareness present (Appendix G, 3 warmwater, age-at-maturity <=3, and high vegetation preference). An overall convex shape results in the cumulative line passing into the rarity box from the left hand side, indicating that in general, very little of the habitat is of high suitability (Appendix G, 2 coolwater, age-at-maturity >2 and low vegetation preference). In instances where the cumulative line fails to enter the rarity box, none of the habitat is highly suitable (Appendix G, 3 warmwater, age-at-maturity >3 and low vegetation preference). Thus, an area in the top right corner of each curve had been classified as rare, highly suitable habitat (Appendix G). Those patches falling within this area were then cross-referenced to the composite suitability index. If a 'rare' patch fell into the low or medium composite or cluster ranking, then it was classified as a rare patch. If the 'rare' patch fell within the high composite or cluster classification it was not reclassified as rare since it was already considered an important patch to conserve.

Step Three: Local Expert Knowledge Assessment

Data Collection

The local expert knowledge database was based on interviews conducted with local fishers, recreational and commercial, by one of the co-authors of this report, M. Ewaschuk. Contacts with fishers were initially made via the Lower Trent Conservation Authority (for recreational fishers), and via the Lake Ontario Management Unit of the Ontario Ministry of Natural Resources and the Commercial Fishing Association (for commercial fishers), and then by individual referral thereafter. In addition, local bait and tackle operators were contacted. Only fishers with at least 15 years experience on the Bay of Quinte were interviewed to identify important fish catch locations with corresponding habitat descriptions.

Each fisher was interviewed alone. They were asked to indicate on maps significant fishing locations and to describe the sites where particular species were most likely to be captured or with specific habitat features, e.g., spawning areas. The location information was digitized into the same GIS used for mapping habitat suitability. The fishing locations were assigned to the unique habitat polygons derived from the combination of depth, substrate and vegetation data for the initial suitability mapping. The fishing information was analyzed to assess the spatial relationships of important fish habitats from a fisher perspective.

Fish Habitat Suitability Index Validation

While suitability mapping of habitat is an important step towards conservation of essential habitat, comparison of the constructed suitability maps with site-specific fish sampling data or expert knowledge can help validate the proposed classification. In the earlier Severn Sound study, Minns *et al.* (1999a) compared the *a priori* habitat suitabilities with fish catches and composition at a series of nearshore electro-fishing sites. This analysis showed suitability values were positively correlated with catch-per-unit-effort of numbers, biomass and species richness, especially for warm-water and cool-water fish groups in the YOY and adult life stages. Significant correlations were not expected for coldwater species and the spawning life stages as the sample data were unsuitable measures of those features of the fish community.

The fisher expert knowledge provides some basis for validation of habitat suitability although the method is limited by the subjectivity of the observations. Fishers mainly report sites where fishing success is greater. It cannot be automatically assumed fishers are able to identify essential fish habitat; essential fish habitat and good fishing locations are not necessarily the same. More suitable fish habitat may be less accessible to fishers, for example, in areas where the water is too shallow or the vegetation is impenetrable. However, it might be expected that successful fishing sites will be at, or close to, preferred or more frequently used habitat. The agreement between fish habitat class assignments and the occurrence of fishing sites was assessed by determining the proportions of fisher locations by habitat class.

Step Four: Overall Rule-Based Classification

In the final classification model, the low and medium class assignments obtained for habitat suitability, either by DM composite suitability or K-means clustering, were replaced by high values as identified by the rarity and local expert knowledge steps. This ensured balanced use of available information by incorporating DM suitability, rarity and fishing importance.

RESULTS

Habitat Suitability using Defensible Methods:

Much insight into the habitat preferences of the species within this study can be learned by plotting the mean habitat suitability index values versus substrate and depth for each type of vegetation class (emergent, submergent, and no cover). This was done for each species group over all of the three life stages (Appendix F). General habitat preference trends were found among the species groups, reinforcing the premise that the species had been properly grouped by life history preferences (Appendix C). After examination of the graphs in Appendix F, several general statements can be made regarding the habitat preferences among groups.

Coldwater species over the three life stages preferred a lack of cover over all depths of water. While the cold water adults preferred pelagic areas, the spawners and YOY preferred shallow depths with a gravel-sand substrate combination. Coolwater species were divided into four species groups but general statements could be made regarding habitat associations. The two groups preferring low vegetative (LV) cover obviously displayed high suitability towards areas lacking cover, while the coolwater high vegetative (HV) preference groups generally preferred areas with both submergent and emergent cover. Among both LV and HV coolwater groups, a higher preference was assigned to rubble-gravel-sand-silt substrate combinations.

Warmwater HV groups as expected showed strong preference for areas with high submergent and emergent vegetation along with gravel-sand-silt substrate combinations over all life stages. Warmwater LV groups generally showed a strong preference for areas lacking cover but some partiality for both submergent and emergent vegetation was found among a few of the spawning and YOY life stages. A wider variety of substrate preferences existed among the LV group compared to the HV groups but some inclination towards gravel-sand-silt combinations was evident.

A correlation analysis was performed on suitability values for the 27 indices obtained using a matrix of all unique combinations of depth, substrate and vegetation categories as inputs for DM.

Habitat Suitability Classification Methods

The 'natural break' classification of habitat suitability proceeded as follows. After examining the break points assigned by the Arc View GIS, all of the classes were adopted for use in this report, save one, the Adult Coldwater suitability. The highest habitat suitability for this index did not exceed 0.04, thus, as a result of its extremely low overall suitability, all the habitat was classified as low suitability. For all of the remaining 26 indices examined, the cut-off points for each of the classes fell within the following ranges: the low-medium suitability cut-off ranged from 0.17 to 0.34; and the medium-high suitability cut-off ranged from 0.42 to 0.62. The classifications obtained for individual indices are shown in two examples for adult, coolwater fishes with age-at-maturity <= 2 and a low vegetation preference (Figure 2) and for the spawning of warmwater fishes with age-at-maturity <= 3 and a high vegetation preference (Figure 3). Habitat for adult coolwater fishes occurs in deeper areas, often away from vegetation (Figure 2) while habitat for spawning warmwater fishes is concentrated in shallower, vegetated areas (Figure 3).

The composite suitability index ranged from 0-0.53 and the low-medium and medium-high cut-offs were 0.22 and 0.37 respectively. The percent area of habitat assigned to each composite suitability class (low, medium, and high) for each individual index was calculated (Table 2). The percentages varied considerably showing the Composite ranks were unable to parallel the rankings assigned for individual indices. DM composite suitability classifications derived with the weights reported in Table 1 showed 45.9% percent of fish habitat was classified as low, 28.8% as medium, and 25.4% as high suitability fish habitat (Figure 4).

The K-means clustering was limited to 6 clusters which were assigned in pairs to Low, Medium and High rankings (Figure 5). The 6 cluster result had non-trivial numbers of members in each cluster and clustering with larger numbers of clusters generally resulted in single or small groups of patches forming new isolated clusters. The clusters can be interpreted both in terms of the dominant habitat characteristics in each cluster and in their representation of the individual DM suitability indices. The mean percentage vegetation and substrate compositions of the clusters highlight the habitat differences among the clusters (Table 3). The two low clusters both have predominately silt and clay substrate: one little vegetation cover and some boulders (Low 3) and one with mostly submergent and emergent vegetation cover. The first medium cluster (Med. 1) was mostly silt and clay with a high percentage of submergent vegetation cover while the other (Med. 4) had a wide mix of substrates from boulders to silt and little vegetation cover. One high cluster (High 2) was dominated by sand and gravel with little vegetation cover while the other (High 5) was dominated by sand, silt and gravel with high emergent and submergent vegetation cover. The percentage of area in the three ranks based on clustering fish habitat suitability indices are 47.7% , 27.4%, and 24.9% for low, medium, and high respectively.

To examine the agreement between the individual DM suitability indices and the clustered groups, we computed the mean suitability for each DM index in each cluster (Table 4). When the means are ranked into three levels for each index, a general pattern of agreement emerges with low clusters having predominantly low and medium means, high clusters having predominantly high means, and medium clusters having intermediate numbers of all three mean groups. The groupings also show how the pairs of clusters in the three ranks capture much of the differences between low and high vegetation preferences. High-5 is dominated by indices with high vegetation preferences and High-2 with low vegetation preferences. The pattern is similar for Medium-1 and Medium-4 clusters respectively. Thus the cluster groupings appear to perform better than the composite rankings at retaining the information content of the individual suitability indices. Both the composite and clustered rankings were carried forward in the developing of the final classification.

Habitat Rarity

Polygons were ranked as rare if they had both a suitability value of >=0.75 and were in the upper 25th percentile of cumulative percent area (Appendix G) for one or more of the 27 individual suitability indices (Figure 6). Many of the polygons identified as rare were already classified as high by the composite or cluster rankings. Few polygons were reassigned from low or medium for either ranking scheme (Figures 7 and 8). With the composite rankings, a breakout of the areas assigned rare shows how little low and medium area was changed to high when rarity was factored into the classification (Table 2). Similarly with the cluster rankings, very little area was reassigned from low or medium to high when rarity was added (Table 5).

Local Expert Knowledge

Fishing success information was obtained from 30 individuals who referenced 742 specific locations in the upper and middle Bay of Quinte. The locations either referred to specific points or areas. The locations were assigned to corresponding polygons obtained when the depth, substrate, and vegetation maps layers were overlaid. A local expert knowledge map was constructed to depict those polygons containing at least one confirmed observation of a fishing site (Figure 9). The expert fishing polygons accounted for 6.9, 5.0, and 5.1 percent of the low, medium and high composite rank areas respectively (Table 6). Within the clustered rank areas, the respective percentages were 7.0, 5.1, and 4.9. Fishing areas do not strongly coincide with areas ranked as having high habitat suitability. However, the expert patches that did not correspond with high areas were usually adjacent to high or medium areas.

Combined Ranking Maps

When the suitability, rarity and fisher expert assignments are combined for composite and cluster rankings similar classification maps are obtained (Figures 10 and 11). The agreement between the two maps and the effects of combining suitability ranks with rarity and expert assignments can be assessed using cross-tabulations of area and percentage of area (Table 6). The agreement between the maps suggests the two approaches taken to suitability classification by and large produce similar results. There was a 92.3% overlap between the low-medium-high rankings for the composite and cluster schemes. Rarity accounted for 23.2% of the area though much was assigned to a high rank before the rarity criteria was applied. In the composite ranking scheme, 45.8% of the area was ranked low with 28.8% and 25.3% assigned to medium and high respectively. In the clustered scheme, the percentages were 47.7, 27.4, and 24.9 respectively. Given the ability of the cluster rankings to retain more of the individual index information the final classification based on clusters, rarity and expert assignments was preferred for an overall habitat suitability rating of the upper and middle areas of the Bay of Quinte (Figure 11).

DISCUSSION

Bay of Quinte Habitat Inventory and GIS Database

In Canada, Ontario and the Great Lakes region the information infrastructure for assembling GIS databases of aquatic habitats is still being developed. The geographic database assembled for the upper and middle Bay sections of the Bay of Quinte has some of the problems that were evident in the previous study in Severn Sound (Minns *et al.* 1999) but there were also some advances made. These problems and advances are outlined below.

The development of fish habitat GIS databases in the Bay of Quinte was hampered by the lack of seamless, fine resolution elevation models especially in the zone between the 100-year high water mark and approximately 2 metres below the navigation chart datum. The Canadian Hydrographic Survey does not sample in depths less than 2m for safety reasons therefore these areas are poorly mapped. Unfortunately, these poorly mapped areas are in the nearshore zone which contains very important fish habitat. Further, nearshore areas with extensive vegetation are extremely difficult to map by conventional methods. Again, coastal wetland areas are poorly mapped despite their importance for fish.

The substrate maps used in this study were derived from a combination of near-shore visual mapping and extrapolation of low density, offshore grid sampling. Continued advancements in substrate and vegetation mapping using combinations of electro-acoustic and remote sensing technologies are improving the mapped representations of these data but such methods are far from routine.

Vegetation mapping is especially difficult to complete in habitat mapping as cover, density and composition are continually changing both within seasons and across years. In the Bay of Quinte much of the site level vegetation mapping predated the invasion of zebra mussels, which triggered a large-scale expansion of macrophyte coverage. Further, on-going changes in the water level regime impact the location and extent of wetland vegetation types. In this study, the results of a macrophyte modelling study in the Bay of Quinte (Seifried 2002) were used to predict macrophyte spatial cover for the post-zebra mussel regime. It was judged more important to show the situation more as it is now rather than as it was in the early 1990s when most field surveys were done.

Mapped coverage information was limited to the upper and middle Bay areas as there were no nearshore inventory survey data or offshore substrate mapping for the lower Bay area. Despite these limitations the habitat GIS database provided an acceptable basis for assessing habitats and classifying fish habitats on a broad scale in the Bay of Quinte. Extension of fish habitat mapping up into the tributaries will require additional surveys of instream and riparian habitat features, barriers and other obstacles to connectivity, and the fish communities present.

The main advance in the Bay of Quinte over the Severn Sound study was the extension of the study area to the offshore zone. In the Severn Sound study, the habitat mapping was limited to a corridor along the shoreline with depths less than 1.5 metres. In this study, onshore and offshore datasets were combined with available depth maps to create complete coverage for the upper and middle Bay areas. Complete coverage is essential as fish species make use of many habitat areas through their life cycle and throughout the year. Limiting coverage to inshore areas can create false impressions about the importance of various habitat features to particular fish guilds and/or life stages.

Habitat Classification Model

The classification model used built upon the approach presented for Severn Sound (Minns *et al.* 1999) and several additions or improvements were made. The number of fish groups considered in Quinte was greater than in the Severn Sound study. First, this reflected the greater number of fish species present overall in the Bay of Quinte. Second, there was recognition from the earlier study that more attention needed to be given to the life histories and habitat preferences of the species present if useful habitat classifications were to be developed. A habitat classification scheme has to be practical from a management viewpoint, implying fewer rather than more habitat classes. At the same time, every effort must be made to accommodate the specific needs of all fish species present. Increasing the number of fish groups ensured that more specialized habitat needs were considered in the overall classification as both suitability and rarity were assessed.

More extensive use of local expert knowledge was made in this study than in the Severn Sound case. Minns *et al.* (1999) provided for an expert information layer but the database was insufficient to implement it in Severn Sound. In the Bay of Quinte, the fisher interview activities produced a useful assessment of fish habitats from a fishing success perspective. Additional efforts to validate the suitability maps through systematic fish communities surveys, such as existing electro-fishing, seining, trawling, and commercial catch data, and through further gathering of fishers' knowledge will increase the acceptance of habitat maps and enhance their utility for agencies and fishers

Finally, the repertoire of methods for developing habitat classifications and assigning habitat patches to classes was further expanded. In the Severn Sound study, efforts were focused on the use of CART regressions to build overall groupings with regard to the underlying data on bathymetry, substrate and vegetation. Here, two additional approaches were explored in parallel: a) natural breaks in frequency distributions as analyzed in Arc-View GIS software and b) K-means cluster analysis of the fish groups by life stage suitability values. Both methods showed they could produce acceptable classifications. The K-means cluster analysis results were preferred as they appear to better capture the distributional discontinuities in the underlying datasets, both habitat characteristics and suitability indices. This is an important consideration as observers are able to identify most habitat discontinuities in the field (e.g. changes in substrate composition and vegetation coverage). Arbitrary classifications that lumped features would have less acceptance operationally. The typical substrate and cover compositions of the six cluster groupings (Table 3) are readily recognizable with modest levels of training.

Implications of Results in the Bay of Quinte

The resulting habitat maps and the analyses of area by habitat class show that there is much good fish habitat in the upper and middle Bay areas of the Bay of Quinte and that there is good overall agreement between maps of habitat suitability and maps of fishing success. The Bay of Quinte is a highly productive part of the larger Lake Ontario ecosystem and contains considerable high quality habitat resources as reflected in the extensive macrophyte cover and emergent wetlands. The Bay of Quinte has not had excessive development that has degraded other areas elsewhere on Lake Ontario, (such as

Hamilton Harbour and Toronto Harbour). However, regulation of water levels for the St. Lawrence Seaway have greatly reduced the diversity of the wetlands and shoreline modifications have been extensive. Given the efforts that have gone into restoring water quality in the Bay of Quinte, local communities are well-placed to ensure that future developments in and around the adjacent urban centres (such as Trenton, Belleville, Napanee and Picton) do not further destroy or degrade important fish habitats. Of course, those communities need to be provided with technically-sound assessments of their fish habitat as illustrated in this habitat suitability mapping project and encouraged through proactive area fish habitat management plans to support enforcement of the federal fisheries act provisions for the protection of fish habitats.

Next Steps

There are several steps that should be pursued to build on the habitat classification model developed here for the Bay of Quinte:

- The information assembled in this study and the resultant analyses and maps should be made available for use by agency (DFO, CAs) and the public via suitable media (There are current efforts under way with DFO-Fish Habitat Management – Ontario Great Lakes Area to make this material accessible to DFO via a website).
- The Bay of Quinte habitat inventory and GIS database should be updated with further surveys to improve the elevation model and to provide more up-to-date mapping of substrate and vegetation conditions. Surveys should be extended to include the lower Bay area. The habitat inventories should also be extended further into the tributaries, above major barriers to fish movement to evaluate the potential benefits of barrier removal/mitigation and to prioritize rehabilitation efforts.
- Several conservation authorities with joint responsibility for the Bay of Quinte habitats should develop the infrastructure for supporting and/or using the habitat mapping and classification model on a watershed basis for future development and use in planning by local and regional government agencies. Habitat and suitability mapping tools should become part of a suite of decision-making tools used by DFO Fish Habitat Management and their partners.
- The classification scheme and its resulting maps should be integrated with fish habitat and fisheries management plans to combine opportunities to conserve, restore and

enhance fish habitats in support of fishery objectives for the Bay of Quinte and beyond.

- The local expert knowledge database could be expanded by increasing the numbers of fishers interviewed, by examining particular species in greater detail, and by combining fisher observations with a variety of standardized fish sampling datasets gathered by government agencies and university groups.
- The mapping of habitat features can be extended to consider spatial and temporal patterns in thermal conditions given that temperature is a primary determinant of fish distribution and productivity in aquatic ecosystems. Additional analysis work with existing fisheries survey datasets can be undertaken to provide local validation and refinement of the suitability maps.
- Integrated fish habitat assessments, such as the one developed here, for parts of the Bay of Quinte, can be used to ensure that high quality habitats are given maximum protection from the inroads of development and that other fish habitats are properly assessed when developments are proposed. A first step in the Bay of Quinte would be to make certain that none of the shorelines adjoining high quality fish habitat are developed without adequate provision for habitat compensation in adjacent areas, either through the creation of new habitat or by the restoration of previously degraded habitats elsewhere in the Bay of Quinte. A further step requires implementation of a Bay of Quinte area fish habitat management plan with all agencies assuming responsibility for ensuring no net loss in the future and, wherever possible, securing net gains through habitat creation and compensation to redress past losses.

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Table 1 List of weighting applied to the nine fish groups for computing a composite suitability in the DM's estimation of fish habitat suitabilities. (Life stages were assigned equal weights of 0.3333).

Species Group	Weightings
Cold water	0.0588
Cool water / Age of Maturity <= 2 / Low Vegetation	0.1176
Cool water / Age of Maturity <=2 / High Vegetation	0.1176
Cool water / Age of Maturity > 2 / Low Vegetation	0.1176
Cool water / Age of Maturity > 2 / High Vegetation	0.1176
Warm water / Age of Maturity <=3 / Low Vegetation	0.1176
Warm water / Age of Maturity <=3 / High Vegetation	0.1176
Warm water / Age of Maturity > 3 / Low Vegetation	0.1176
Warm water / Age of Maturity > 3 / High Vegetation	0.1176
Total	1.0000

Table 2 Percentages of habitat area in the Bay of Quinte ranked low, medium or high using the composite index alone, and then with the areas assigned as rare reassigned to high, separated out for each of the 27 individual habitat suitability indices and the composite index.

Habitat suitability groupings				% Area by composite only			% Area by composite and rarity			
Life stage	Thermal preference	Age at maturity	Vegetation preference	Low	Medium	High	Low	Medium	High	Rare
Adult	Cold	-	-	100.00	0.00	0.00	100	0.00	0.00	0.00
Adult	Cool	<= 2	Low	62.03	26.21	11.76	62.03	26.21	6.10	5.66
Adult	Cool	<= 2	High	57.74	24.86	17.40	57.74	24.86	7.89	9.51
Adult	Cool	> 2	Low	85.38	5.44	9.18	85.38	5.44	3.61	5.57
Adult	Cool	> 2	High	58.31	28.24	13.45	58.31	28.24	12.65	0.80
Adult	Warm	<= 3	Low	39.50	51.45	9.05	39.49	51.45	8.71	0.34
Adult	Warm	<= 3	High	58.76	22.83	18.41	58.75	22.83	7.72	10.69
Adult	Warm	> 3	Low	89.53	10.45	0.02	89.53	10.45	0.02	0.00
Adult	Warm	> 3	High	58.99	27.71	13.30	58.99	27.71	13.27	0.02
Spawning	Cold	-	-	84.76	9.12	6.12	84.76	9.12	4.84	1.28
Spawning	Cool	<= 2	Low	68.39	21.51	10.10	68.39	21.51	4.25	5.85
Spawning	Cool	<= 2	High	58.01	23.58	18.41	58.01	23.58	6.33	12.07
Spawning	Cool	> 2	Low	99.10	0.59	0.31	99.10	0.60	0.16	0.15
Spawning	Cool	> 2	High	24.17	63.36	12.47	24.17	63.37	5.82	6.65
Spawning	Warm	<= 3	Low	76.13	13.44	10.43	76.12	13.44	10.37	0.07
Spawning	Warm	<= 3	High	54.73	10.13	35.14	54.73	10.13	26.47	8.87
Spawning	Warm	> 3	Low	1.00	63.38	35.62	1.01	63.38	22.38	13.24
Spawning	Warm	> 3	High	39.84	23.73	36.43	39.84	23.73	36.06	0.37
YOY	Cold	-	-	84.61	7.61	7.78	84.61	7.61	7.77	0.01
YOY	Cool	<= 2	Low	38.68	28.04	33.28	38.68	28.04	32.02	1.26
YOY	Cool	<= 2	High	57.13	20.88	21.99	57.13	20.89	21.58	0.41
YOY	Cool	> 2	Low	72.99	15.62	11.39	72.99	15.62	5.32	6.07
YOY	Cool	> 2	High	56.20	19.84	23.96	56.20	19.84	23.16	0.80
YOY	Warm	<= 3	Low	58.44	18.55	23.01	58.44	18.55	7.49	15.52
YOY	Warm	<= 3	High	58.00	24.78	17.22	58.00	24.78	7.28	9.95
YOY	Warm	> 3	Low	94.19	5.81	0.00	94.19	5.81	0.00	0.00
YOY	Warm	> 3	High	58.47	35.03	6.50	58.47	35.03	6.09	0.41
Composite	-	-	-	45.85	28.79	25.36	45.85	28.79	25.36	0.00

Table 3 Average percentage composition of the three habitat characteristics for each of the six K-means clusters (The cluster numbers referred to their order in the K-means clustering).

Habitat Characteristic	Cluster Rank (number)					
	Low (3)	Low (6)	Med (1)	Med (4)	High (2)	High (5)
Depth						
0-1m	36.0	57.0	43.0	50.0	38.0	6.0
1-2m	14.1	18.9	26.5	20.2	17.5	23.6
2-5	25.2	23.5	29.1	19.8	26.9	9.7
5-10m	14.8	0.9	1.6	8.7	15.2	0.8
10+m	3.7	0.0	0.0	1.6	2.3	0.0
Vegetation						
Emergent	8.9	22.1	8.3	7.7	2.7	22.9
Submergent	21.2	35.2	74.4	21.1	11.7	56.1
No Cover	69.9	42.7	17.3	71.2	85.6	21.0
Substrate						
Bedrock	3.6	0.4	0.1	0.2	0.0	0.0
Boulder	11.0	1.0	0.1	8.3	0.8	0.6
Cobble	5.6	3.5	0.4	14.4	2.4	0.9
Rubble	5.6	3.5	0.4	14.4	2.4	0.9
Gravel	1.9	3.9	0.1	18.4	20.2	11.9
Sand	4.8	8.2	8.0	21.4	62.4	64.1
Silt	30.9	41.8	53.0	13.0	7.3	15.4
Clay	34.8	37.7	37.8	9.8	4.6	6.2
Hardpan	0.0	0.0	0.0	0.0	0.0	0.0

Table 4 Mean habitat suitability value in each K-means cluster group for all 27 DM indices and the numbers of indices having the lowest pair of means (*italics*), the middle pair (underlined) and the highest two pair (**bold**).

Habitat Suitability Groupings				Mean suitability value by cluster rank(#)					
Life Stage	**Thermal Pref.**	**Age Mat.**	**Vegtn. Pref.**	**Low (3)**	**Low (6)**	**Med. (1)**	**Med. (4)**	**High (2)**	**High (5)**
Adult	Cold	-	-	*0.007*	*0.012*	0.018	0.013	**0.020**	**0.026**
Adult	Cool	<=2	Low	0.239	*0.217*	*0.168*	**0.522**	**0.756**	0.419
Adult	Cool	<=2	High	*0.109*	0.256	**0.430**	*0.239*	0.278	**0.610**
Adult	Cool	>2	Low	0.158	*0.115*	*0.055*	**0.386**	**0.741**	0.195
Adult	Cool	>2	High	*0.092*	0.281	**0.493**	*0.176*	0.211	**0.508**
Adult	Warm	<=3	Low	0.315	*0.271*	*0.208*	**0.483**	**0.673**	0.278
Adult	Warm	<=3	High	*0.058*	0.292	**0.503**	0.167	*0.124*	**0.700**
Adult	Warm	>3	Low	0.049	*0.034*	*0.011*	**0.247**	**0.439**	0.119
Adult	Warm	>3	High	0.054	0.248	**0.463**	*0.114*	0.117	**0.521**
Spawning	Cold	-	-	0.206	*0.194*	*0.175*	**0.490**	**0.677**	0.318
Spawning	Cool	<=2	Low	*0.094*	*0.200*	0.292	0.515	**0.746**	**0.549**
Spawning	Cool	<=2	High	*0.193*	*0.299*	0.324	0.441	**0.604**	**0.758**
Spawning	Cool	>2	Low	0.034	*0.013*	*0.003*	**0.252**	**0.256**	0.041
Spawning	Cool	>2	High	*0.392*	0.435	*0.306*	0.449	**0.717**	**0.595**
Spawning	Warm	<=3	Low	*0.064*	0.072	*0.059*	**0.304**	**0.599**	0.219
Spawning	Warm	<=3	High	*0.064*	0.289	**0.459**	0.152	*0.120*	**0.665**
Spawning	Warm	>3	Low	*0.360*	0.425	*0.380*	0.632	**0.762**	**0.706**
Spawning	Warm	>3	High	*0.121*	0.347	**0.495**	*0.142*	0.162	**0.548**
YOY	Cold	-	-	0.098	*0.089*	*0.059*	**0.255**	**0.502**	0.159
YOY	Cool	<=2	Low	*0.173*	0.322	0.496	*0.301*	**0.416**	**0.557**
YOY	Cool	<=2	High	*0.136*	0.287	**0.490**	*0.170*	0.198	**0.445**
YOY	Cool	>2	Low	*0.152*	0.226	*0.176*	0.315	**0.723**	**0.435**
YOY	Cool	>2	High	*0.123*	0.244	**0.471**	*0.125*	0.185	**0.392**
YOY	Warm	<=3	Low	*0.108*	*0.173*	0.218	0.379	**0.773**	**0.587**
YOY	Warm	<=3	High	*0.040*	0.250	**0.482**	0.097	*0.096*	**0.626**
YOY	Warm	>3	Low	0.094	*0.050*	*0.020*	**0.223**	**0.254**	0.057
YOY	Warm	>3	High	*0.128*	0.269	**0.485**	*0.109*	0.156	**0.337**
			# lows	18	12	12	8	3	0
			# meds	9	15	5	10	7	9
			# highs	0	0	10	9	17	18

Table 5 Percentages of habitat area within each classification (low, medium, or high) of the clustered index that either passes (rare) or fails (-) the rarity threshold for each of the 27 suitability indices. Shaded percentages are those areas reclassified as high when the rarity threshold is applied.

Habitat Suitability Groupings				Percent Area of Habitat in each suitability cluster											
				Low (3)		Low (6)		Medium (1)		Medium (4)		High (2)		High (5)	
Stage	Temp	Mat.	Veg	-	Rare	-	Rare	-	Rare	-	Rare	0	Rare	-	Rare
Adult	Cold			na	na	na	na	na	na	na	na	na	na	na	na
Adult	Cool	<=2	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	3.86	5.66	15.42	0.00
Adu<	Cool	<=2	High	43.24	0.00	4.45	0.00	24.82	0.13	2.43	0.00	9.52	0.00	6.04	9.38
Adu<	Cool	>2	Low	43.24	0.00	4.45	0.00	24.82	0.00	2.43	0.00	3.95	5.57	15.42	0.00
Adu<	Cool	>2	High	43.24	0.00	4.45	0.00	24.82	0.00	2.43	0.00	9.52	0.00	14.75	0.67
Adu<	Warm	<=3	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.36	0.07	9.24	0.28	15.42	0.00
Adu<	Warm	<=3	High	43.24	0.00	4.45	0.00	23.94	1.01	2.43	0.00	9.52	0.00	5.73	9.69
Adu<	Warm	>3	Low	na	na	na	na	na	na	na	na	na	na	na	na
Adu<	Warm	>3	High	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	9.52	0.00	15.40	0.02
Spawning	Cold			43.24	0.00	4.45	0.00	24.95	0.00	2.35	0.07	8.31	1.21	15.42	0.00
Spawning	Cool	<=2	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.28	0.15	3.82	5.70	15.42	0.00
Spawning	Cool	<=2	High	43.24	0.00	4.45	0.00	24.95	0.00	2.43	*0.00	9.45	0.70	3.42	12.00
Spawning	Cool	>2	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	9.37	0.15	15.42	0.00
Spawning	Cool	>2	High	43.24	0.00	4.45	0.00	24.95	0.00	2.43	*0.00	2.89	6.63	11.05	4.37
Spawning	Warm	<=3	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	9.45	0.07	15.42	0.00
Spawning	Warm	<=3	High	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	9.52	0.00	6.74	8.68
Spawning	Warm	>3	Low	43.20	0.04	3.97	0.48	24.94	0.00	2.09	0.34	4.77	4.75	7.79	7.63
Spawning	Warm	>3	High	43.24	0.00	4.45	*0.00	24.65	0.30	2.43	0.00	9.52	0.00	15.35	0.07
YOY	Cold			43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	9.51	0.01	15.42	0.00
YOY	Cool	<=2	Low	43.24	0.00	4.45	0.00	24.82	0.13	2.43	0.00	9.50	0.02	14.32	1.10
YOY	Cool	<=2	High	43.24	0.00	4.45	0.00	24.82	0.13	2.43	0.00	9.52	0.00	15.14	0.28
YOY	Cool	>2	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	3.45	6.07	15.42	*0.00
YOY	Cool	>2	High	43.24	0.00	4.45	0.00	24.95	*0.00	2.43	0.00	9.52	0.00	14.85	0.67
YOY	Warm	<=3	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	2.80	6.72	6.61	8.81
YOY	Warm	<=3	High	43.24	0.00	4.45	0.00	24.52	0.40	2.43	0.00	9.52	0.00	5.85	9.57
YOY	Warm	>3	Low	43.24	0.00	4.45	0.00	24.95	0.00	2.43	0.00	9.52	0.00	15.42	*0.00
YOY	Warm	>3	High	43.24	0.00	4.45	0.00	24.82	0.13	2.43	*0.00	9.52	0.00	15.14	0.28

*indicates a percentage that is less than two decimal places, na indicates an index with no rare habitat. Indicated.

Table 6 Cross-tabulations of unique polygons by area and percentage of total area by the composite ranks (columns) and by cluster ranks and numbers (rows), and also with rarity and fish expert classifications. (The upper half provides weight suitable hectares and the lower half percentages).

Cluster Rank	No.	Rare	Comp= Expt=	Low No	Low Yes	Med. No	Med. Yes	High No	High Yes	Sum No	Sum Yes	Sum Sum
Area ha												
Low	3	No		7068.0	1206.5	2.9	23.6	-	-	7070.9	1230.1	8300.9
	3	Yes		2.9	5.6	-	-	-	-	2.9	5.6	8.5
	6	No		346.7	93.9	297.9	24.2	-	-	644.7	118.0	762.7
	6	Yes		37.1	-	54.4	0.3	-	-	91.5	0.3	91.8
	Sum	Sum		7454.7	1305.9	355.3	48.0	-	-	7810.0	1354.0	9163.9
Med.	1	No		4.0	-	3334.9	887.1	272.2	47.5	3611.1	934.6	4545.7
	1	Yes		-	-	50.9	3.9	188.2	5.0	239.1	8.9	248.0
	4	No		21.0	23.6	306.2	-	36.9	1.1	364.0	24.7	388.7
	4	Yes		0.3	0.0	65.7	11.1	0.1	-	66.2	11.1	77.2
	Sum	Sum		25.3	23.6	3757.7	902.1	497.4	53.7	4280.4	979.3	5259.7
High.	2	No		-	-	282.1	16.7	56.4	-	338.4	16.7	355.1
	2	Yes		-	-	125.9	0.1	1295.5	51.8	1421.4	51.9	1473.3
	5	No		-	-	10.0	-	366.6	28.3	376.5	28.3	404.8
	5	Yes		-	-	35.0	-	1673.1	850.6	1708.1	850.6	2558.7
	Sum	Sum		-	-	452.9	16.7	3391.5	930.7	3844.4	947.4	4791.9
Sum	Sum	No		7439.7	1323.9	4234.0	951.5	732.0	76.9	12405.7	2352.3	14758.0
Sum	Sum	Yes		40.3	5.6	331.9	15.3	3156.9	907.5	3529.1	928.4	4457.5
	Sum	Sum		7480.0	1329.5	4565.9	966.8	3888.9	984.4	15934.8	3280.7	19215.5
Percent												
Low	3	No		36.8	6.3	t	0.1	-	-	36.8	6.4	43.2
	3	Yes		t	t	-	-	-	-	t	t	t
	6	No		1.8	0.5	1.6	0.1	-	-	3.4	0.6	4.0
	6	Yes		0.2	-	0.3	t	-	-	0.5	t	0.5
	Sum	Sum		38.8	6.8	1.8	0.2	-	-	40.6	7.0	47.7
Med.	1	No		t	-	17.4	4.6	1.4	0.2	18.8	4.9	23.7
	1	Yes		-	-	0.3	t	1.0	t	1.2	t	1.3
	4	No		0.1	0.1	1.6	-	0.2	t	1.9	0.1	2.0
	4	Yes		t	-	0.3	0.1	t	-	0.3	0.1	0.4
	Sum	Sum		0.1	0.1	19.6	4.7	2.6	0.3	22.3	5.1	27.4
High.	2	No		-	-	1.5	0.1	0.3	-	1.8	0.1	1.8
	2	Yes		-	-	0.7	t	6.7	0.3	7.4	0.3	7.7
	5	No		-	-	0.1	-	1.9	0.1	2.0	0.1	2.1
	5	Yes		-	-	0.2	-	8.7	4.4	8.9	4.4	13.3
	Sum	Sum		-	-	2.4	0.1	17.6	4.8	20.0	4.9	24.9
Sum	Sum	No		38.7	6.9	22.0	5.0	3.8	0.4	64.6	12.2	76.8
Sum	Sum	Yes		0.2	t	1.7	0.1	16.4	4.7	18.4	4.8	23.2
Sum	Sum	Sum		38.9	6.9	23.8	5.0	20.2	5.1	82.9	17.1	100.0

t is trace <0.1%; - is zero

Figure 1 A map of the Bay of Quinte, Lake Ontario, showing the study area, the upper and middle bay sections.

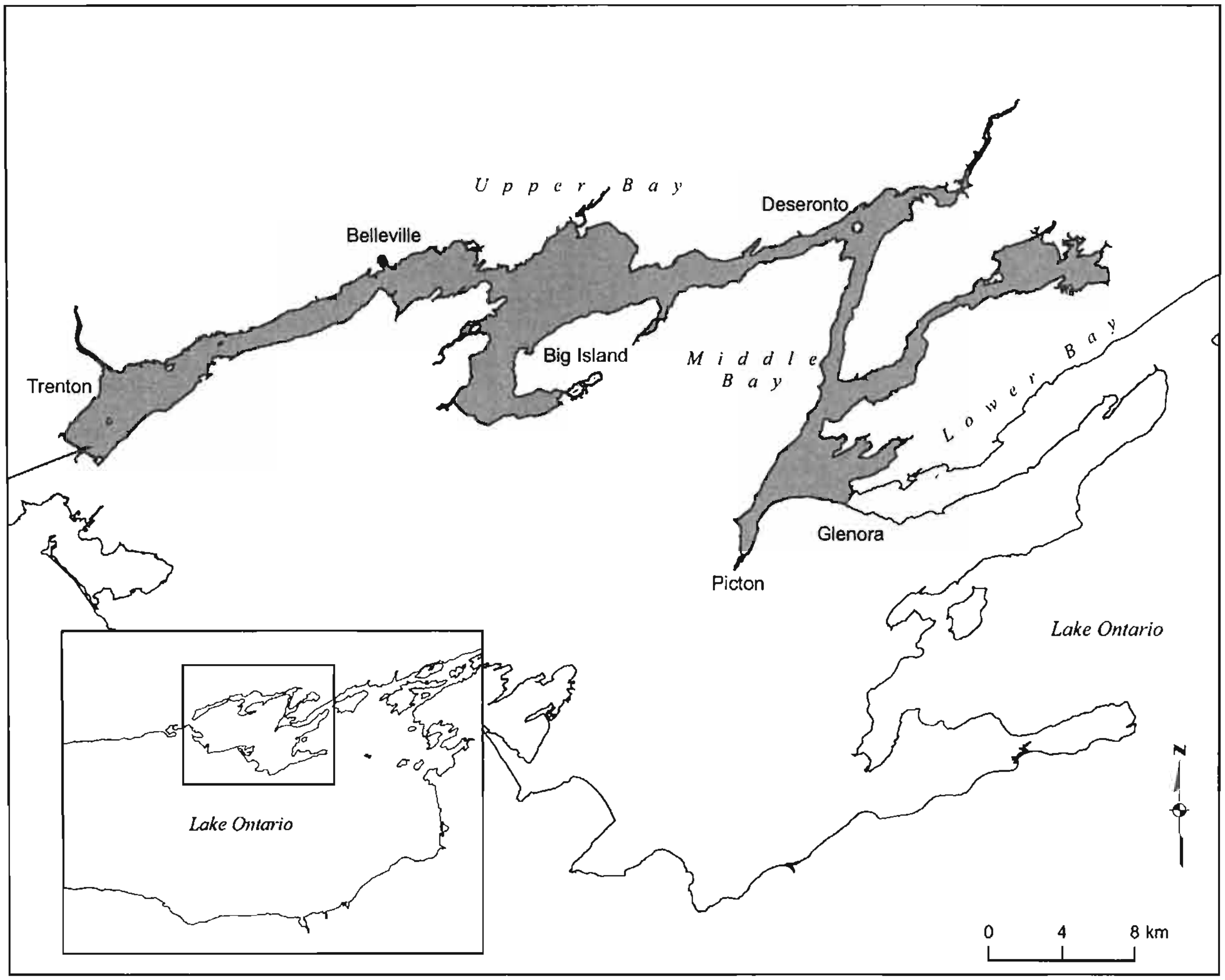


Figure 2 Areas in the Bay of Quinte classified as low, medium, and high suitability for the group of adult, cool-water fishes with age-at-maturity <= 2 years and a low vegetation preference.

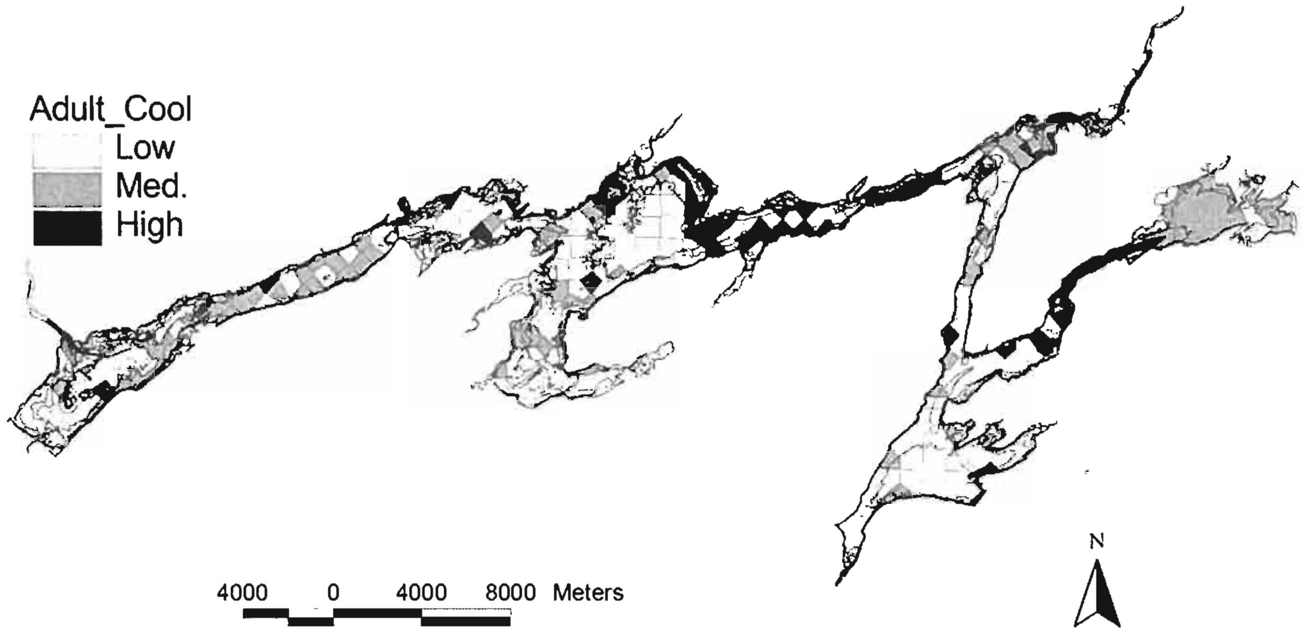


Figure 3 Areas in the Bay of Quinte classified as low, medium, and high suitability for the group of spawning, warm-water fishes with age-at-maturity <= 3 years and a high vegetation preference.

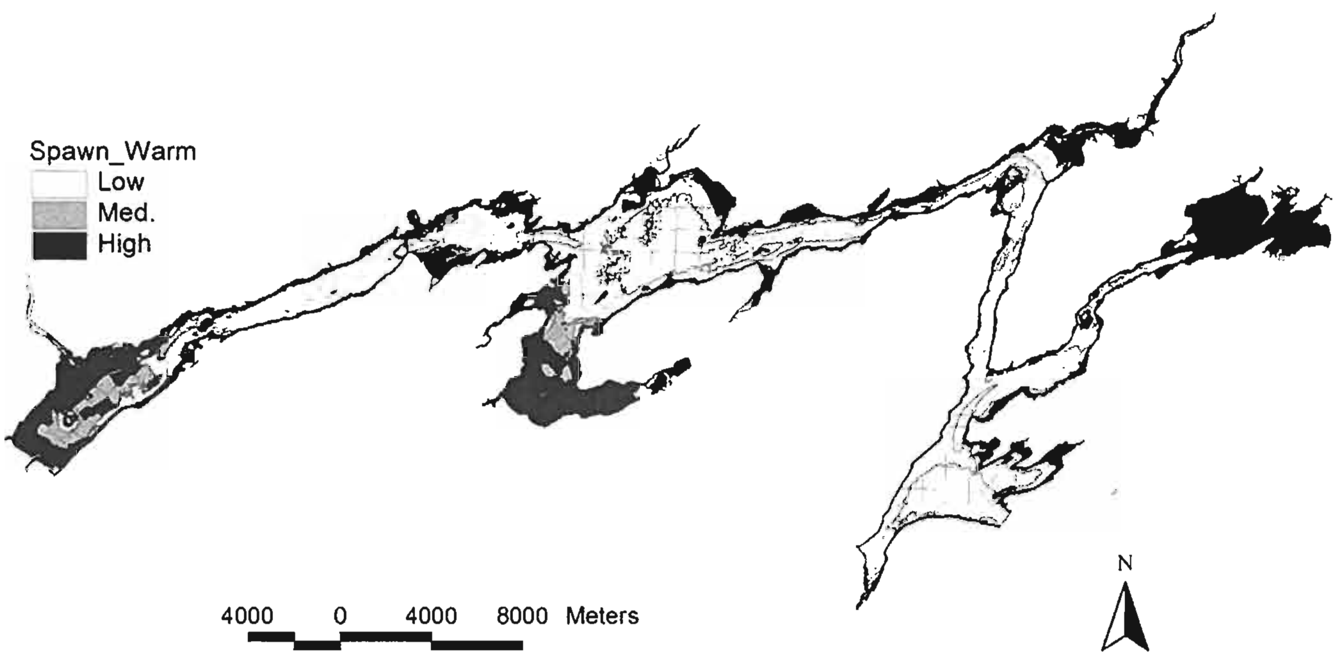


Figure 4 Areas in the Bay of Quinte classified as low, medium and high using the composite habitat suitability index obtained using DM.

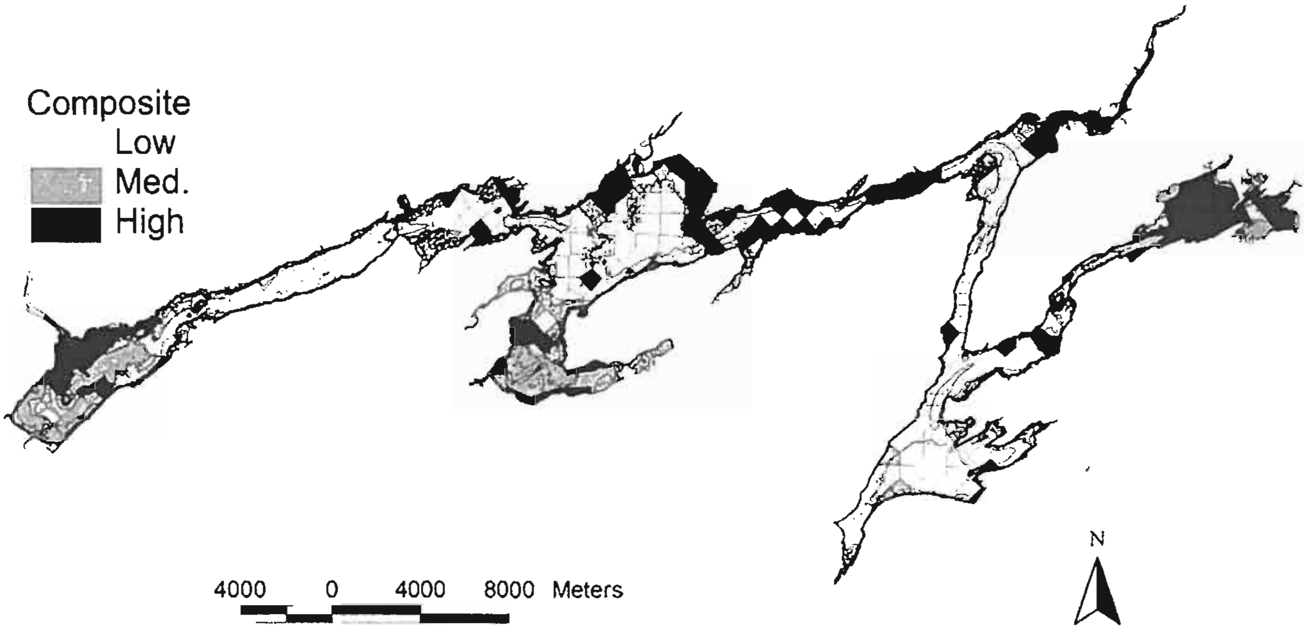


Figure 5 Areas in the Bay of Quinte classified as low, medium and high using the K-means cluster analysis of all suitability indices.

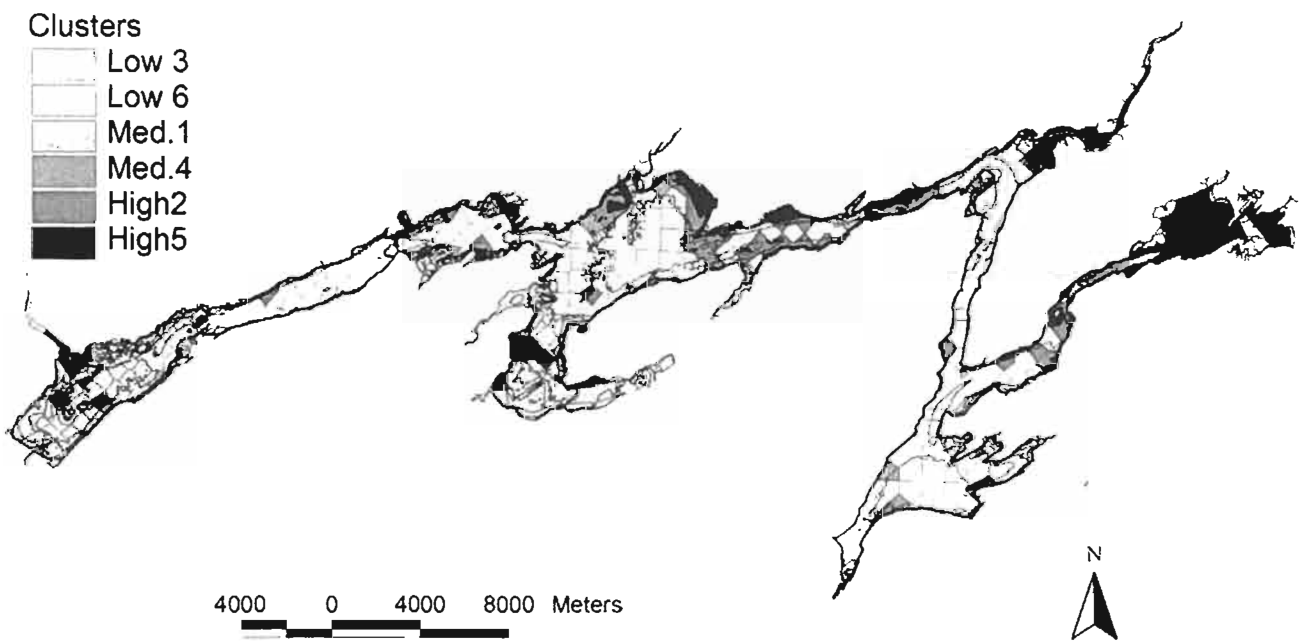


Figure 6 Habitat polygons in the Bay of Quinte ranked as "rare" at least once for any of the 27 individual fish group*life stage habitat suitability indices.

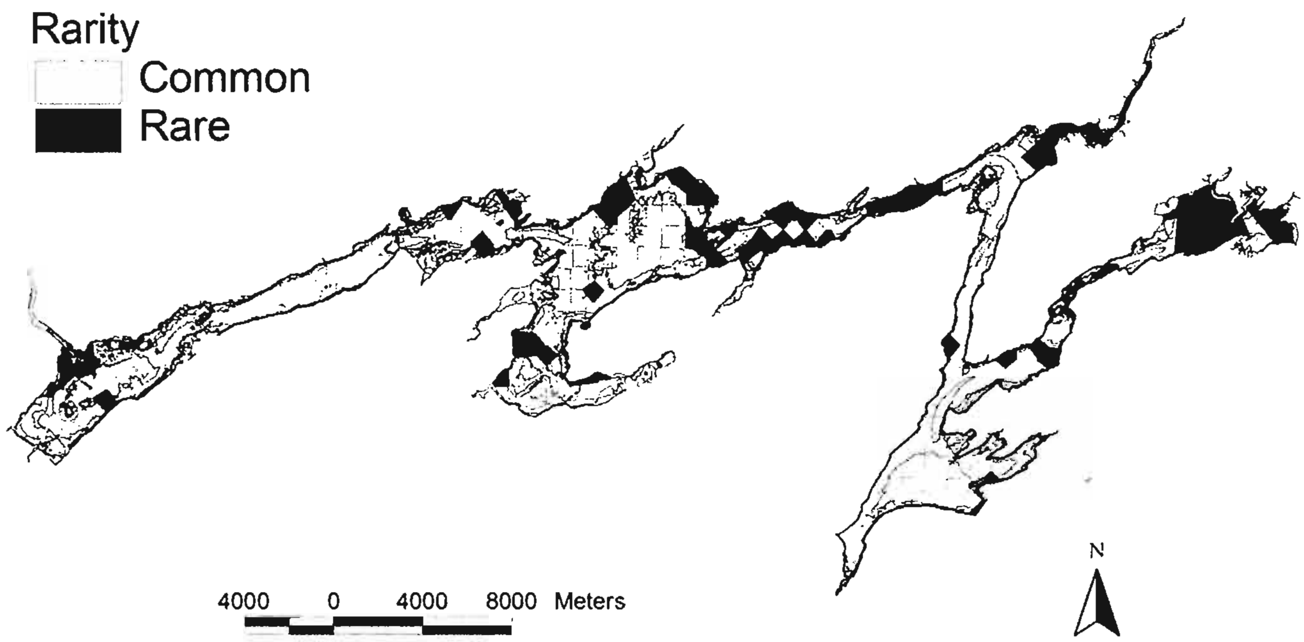


Figure 7 Habitat polygons in the Bay of Quinte classified as rare when cross-referenced with the DM composite suitability class assignments of low and medium.

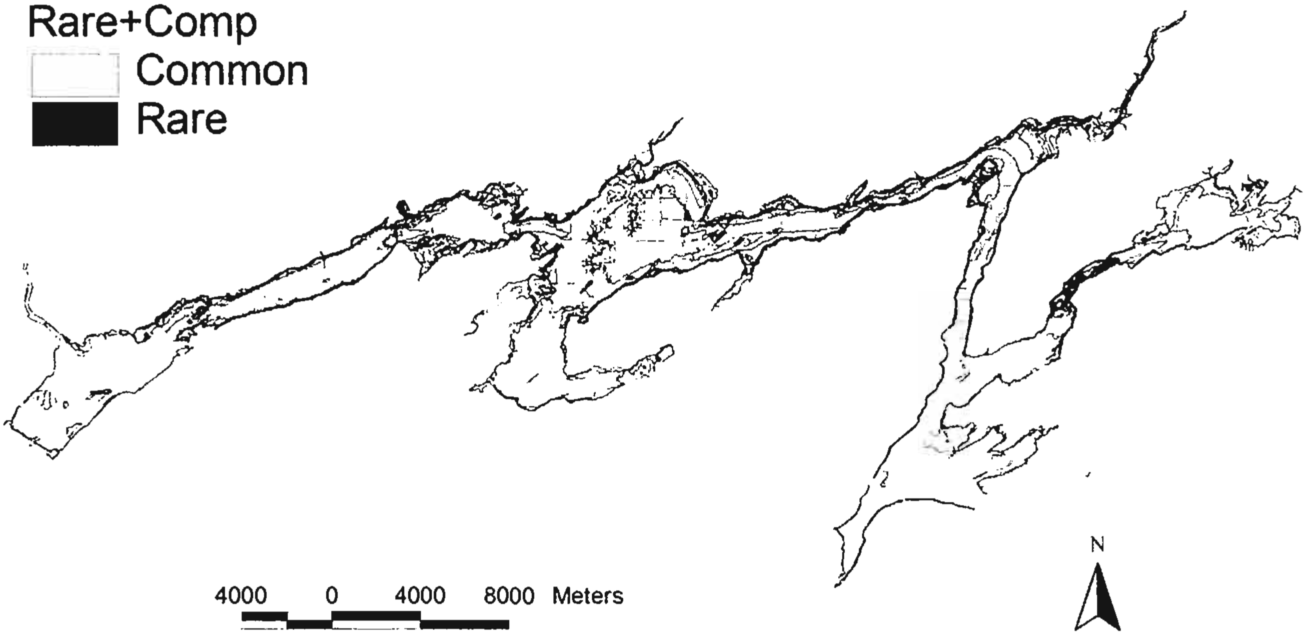


Figure 8 Habitat polygons in the Bay of Quinte classified as rare when cross-referenced to the K-means clusters assigned low and medium.

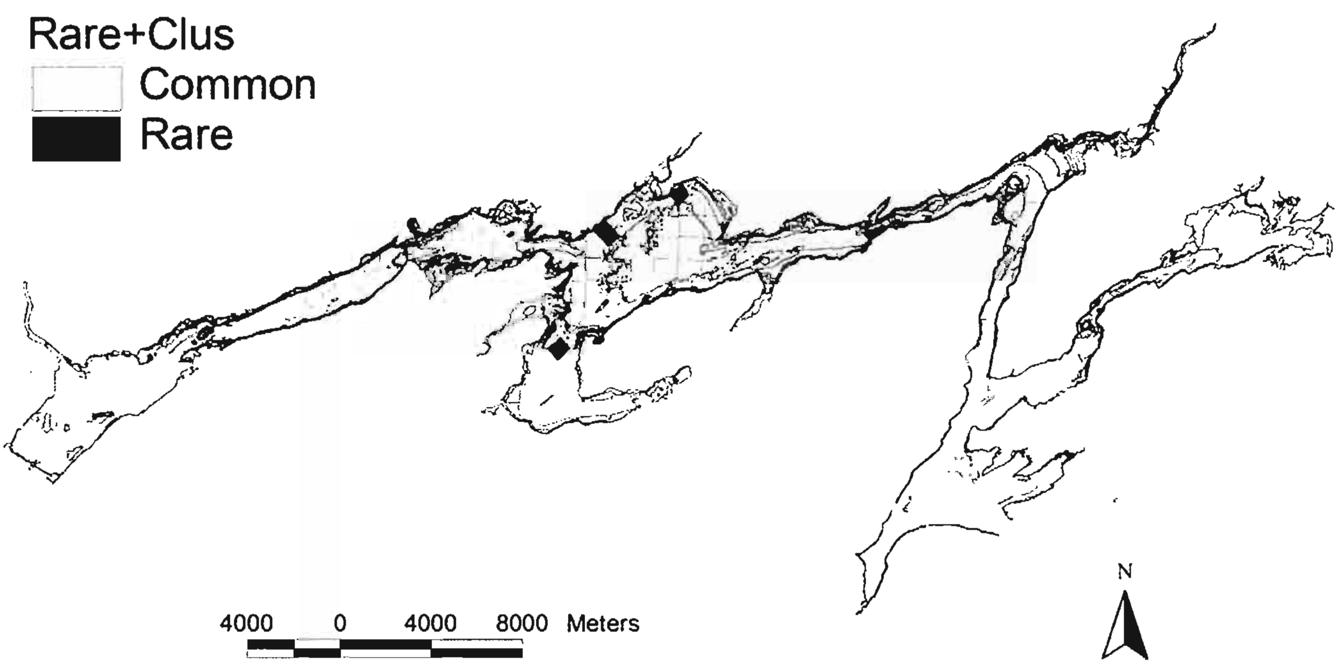


Figure 9 Habitat polygons in the Bay of Quinte containing at least one expert fisher validated fishing site.

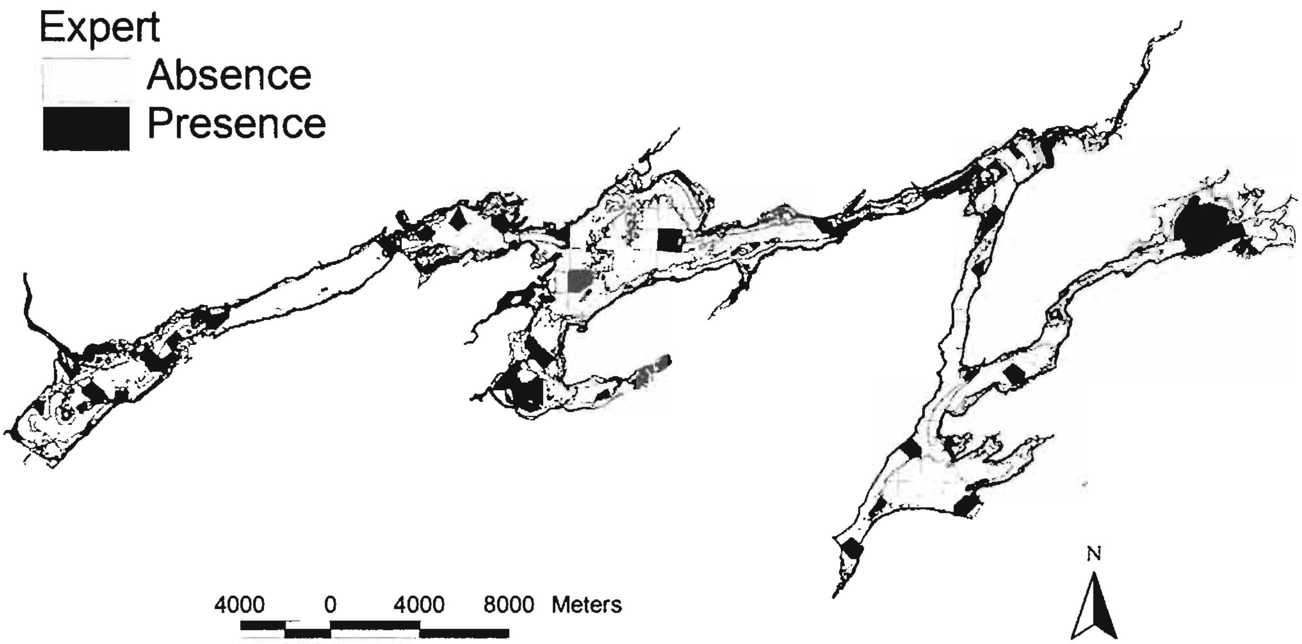


Figure 10 Map of the Bay of Quinte indicating the areas classified as low, medium, and high fish habitat suitability with respect to the DM composite index, rarity, and expert fishers.

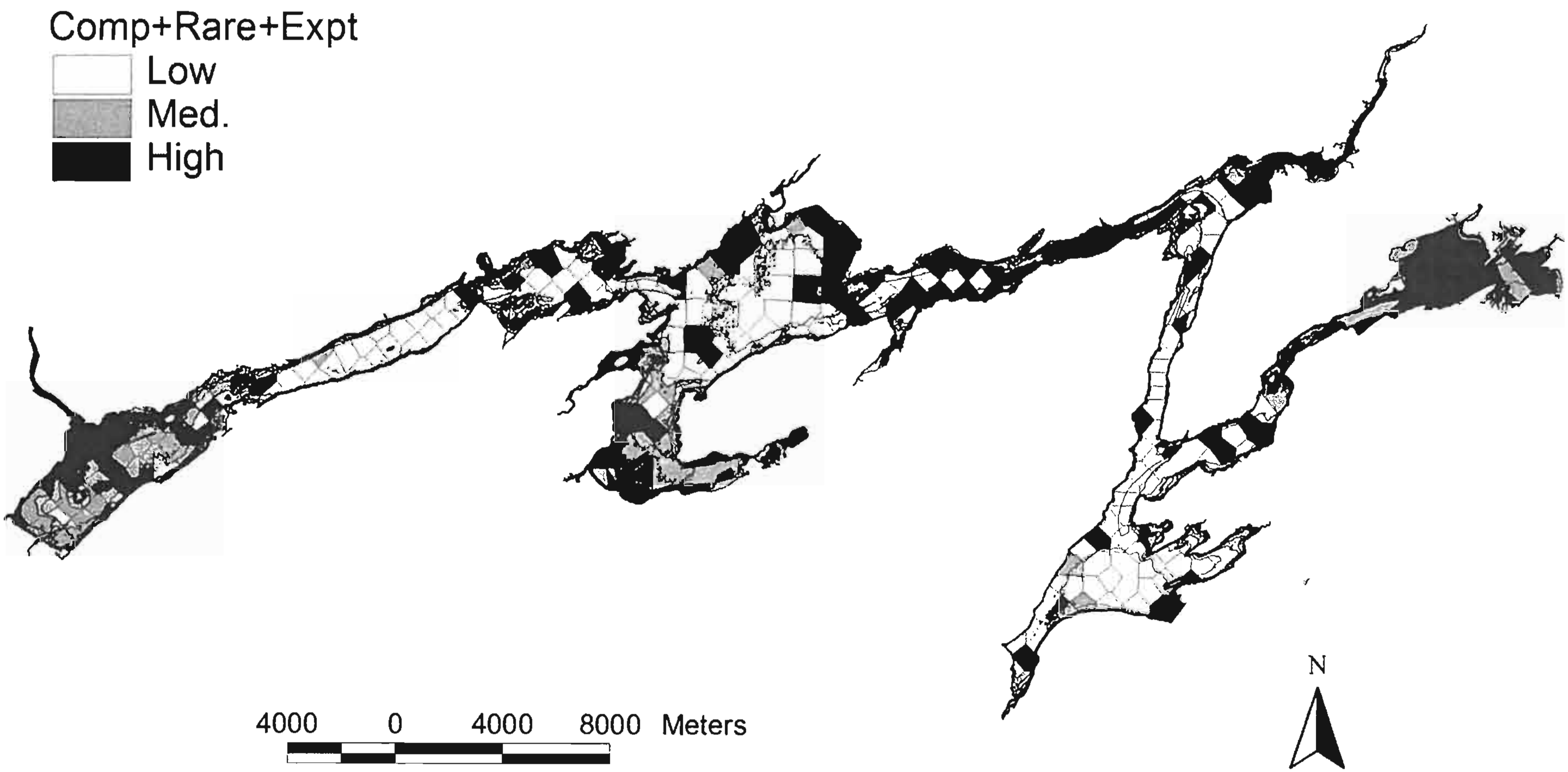
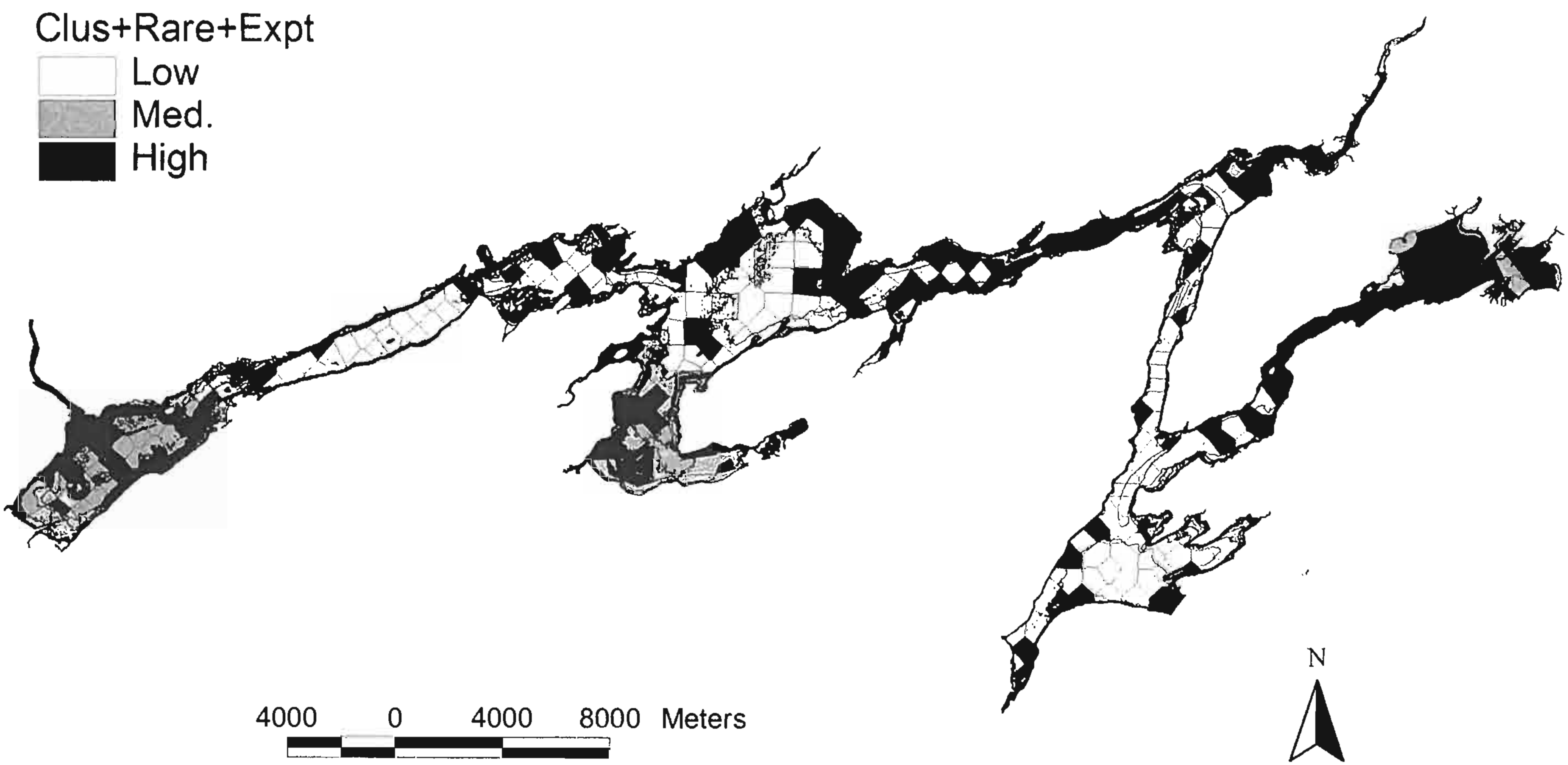


Figure 11. Map of the Bay of Quinte indicating the areas classified as low, medium and high fish habitat suitability with respect to the K-means suitability clusters, rarity, and expert fishers.



APPENDICES

Appendix A Metadata tables for the Bay of Quinte physical habitat GIS database

Appendix Table A1 Cross-table of Defensible methods substrate classes and the substrate categories used in the nearshore habitat inventory, categories, etc.

Inventory Type	Defensible Methods' Class								
	Bedrock	Boulder	Rubble	Cobble	Gravel	Sand	Silt	Clay	Hardpan Clay
Bedrock	100								
Boulder		100							
Rubble			50	50					
Gravel					100				
Sand						100			
Silt							100		
Clay								100	
Detritus						20	40	40	
Muck						20	40	40	
Marl						-99			

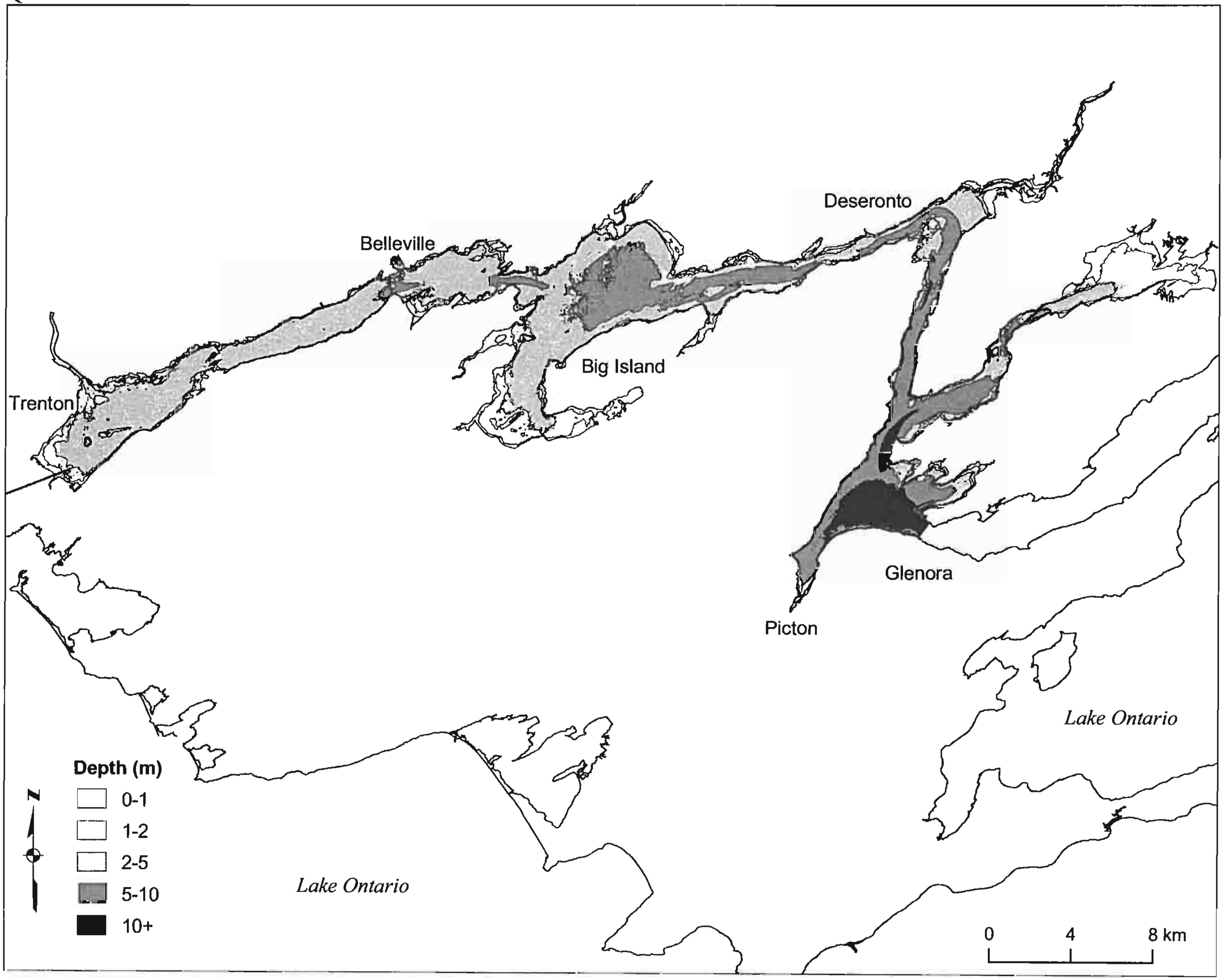
Appendix Table A2 Examples of vegetation assignments for Defensible Methods based on information available from the OMNR Inventory and predictions of Seifried's model.

Source Information			Defensible Methods' Values		
OMNR Inventory Description	OMNR Vegetation	Seifried Submergent Model	Emergent	Submergent	NoCover
Submergent Very Sparse (5-20%)	15	10	0	10	90
Emergent Sparse (20-40%)	30	20	30	70	0
Emergent Moderate (40-60%)	50	70	50	50	0
Submergent Dense (60-80%)	70	45	0	50	50
Emergent Very Dense (80-100%)	90	70	90	10	0
NO DATA		35	0	30	70
NO DATA		NO DATA	0	0	100

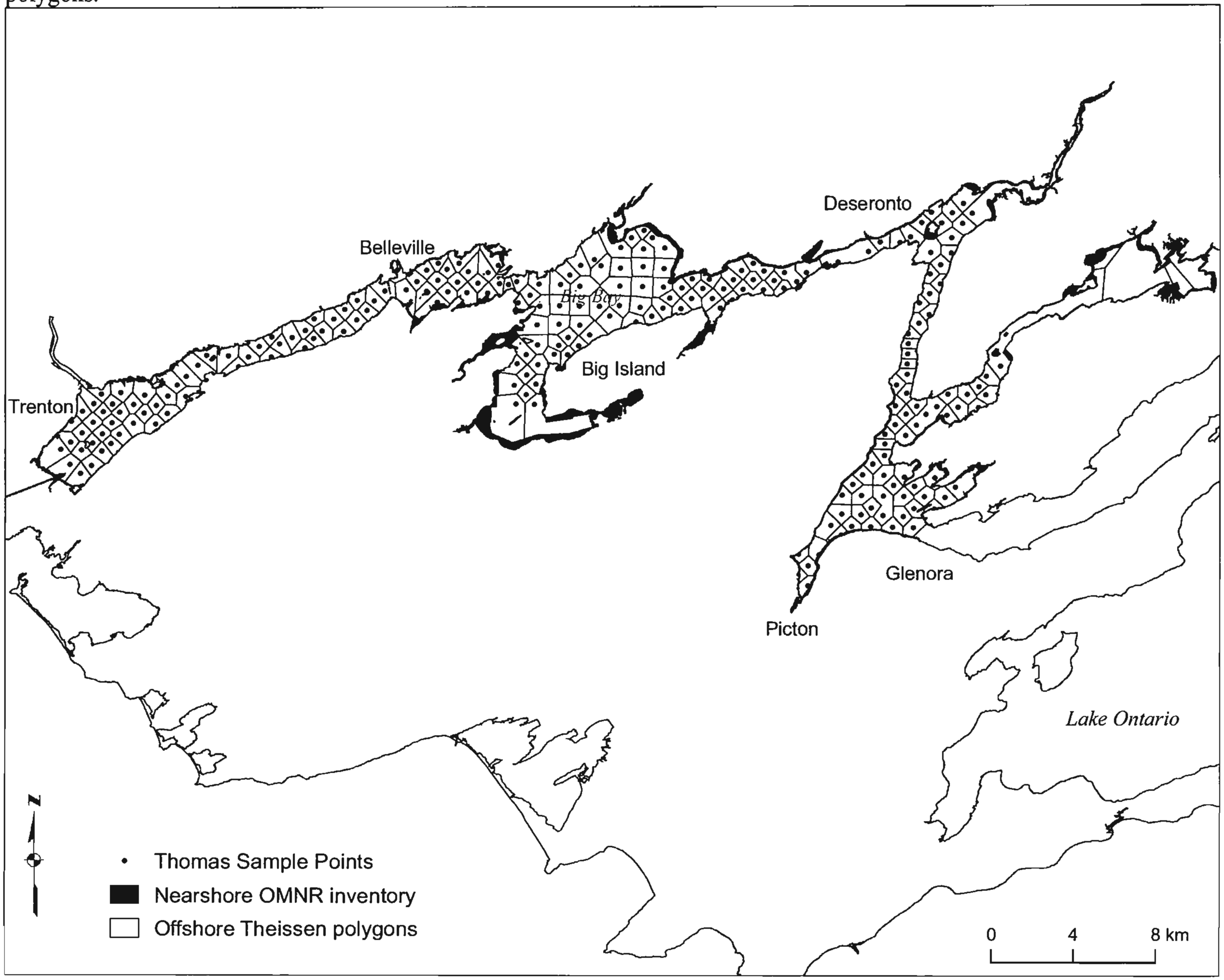
Appendix Table A3 Sample records (zoomed in area in Figure A4) from a Defensible Methods input data file.

```
; QUINTE DEF METH
; Sample of Quinte.dat

* UnitType=Area
* Units=m2

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

...
182,32356.6075,UNCH,"0,0,0,100,","0,0,0,0,6,61,33,0,0","100,0,0"
1254,398.2930,UNCH,"0,0,100,0,","0,0,15,15,70,0,0,0,0,0","40,50,10"
1255,3411.0072,UNCH,"0,0,100,0,0","0,70,15,15,0,0,0,0,0,0","40,50,10"
1256,7.5968,UNCH,"0,0,100,0,0","0,0,0,0,0,100,0,0,0,0","20,50,30"
1257,1409.7233,UNCH,"0,0,100,0,0","0,0,35,35,30,0,0,0,0,0","20,50,30"
1264,10.3698,UNCH,"0,0,100,0,0","0,100,0,0,0,0,0,0,0,0","0,50,50"
1265,7806.4303,UNCH,"0,0,100,0,0",",70,15,15,0,0,0,0,0,0","0,50,50"
1266,68.4521,UNCH,"0,0,100,0,0","0,0,0,0,0,20,40,40,0,","30,70,0"
1267,1176.4070,UNCH,"0,0,100,0,0","0,0,0,0,0,20,40,40,0,0","0,70,30"
1268,131.0483,UNCH,"0,0,100,0,0","0,0,15,15,70,0,0,0,0,0","0,70,30"
1271,129.0008,UNCH,"0,0,100,0,0","0,0,25,25,50,0,0,0,0,0","0,90,10"
1273,29.1329,UNCH,"0,100,0,0,0","0,0,0,0,0,1,32,67,0,0","100,0,0"
1275,6.5130,UNCH,"0,100,0,0,0","0,0,0,0,0,1,52,47,0,0","100,0,0"
1339,2.0000,UNCH,"0,100,0,0,0","0,0,0,0,0,3,51,46,0,0","90,0,10"
...
```

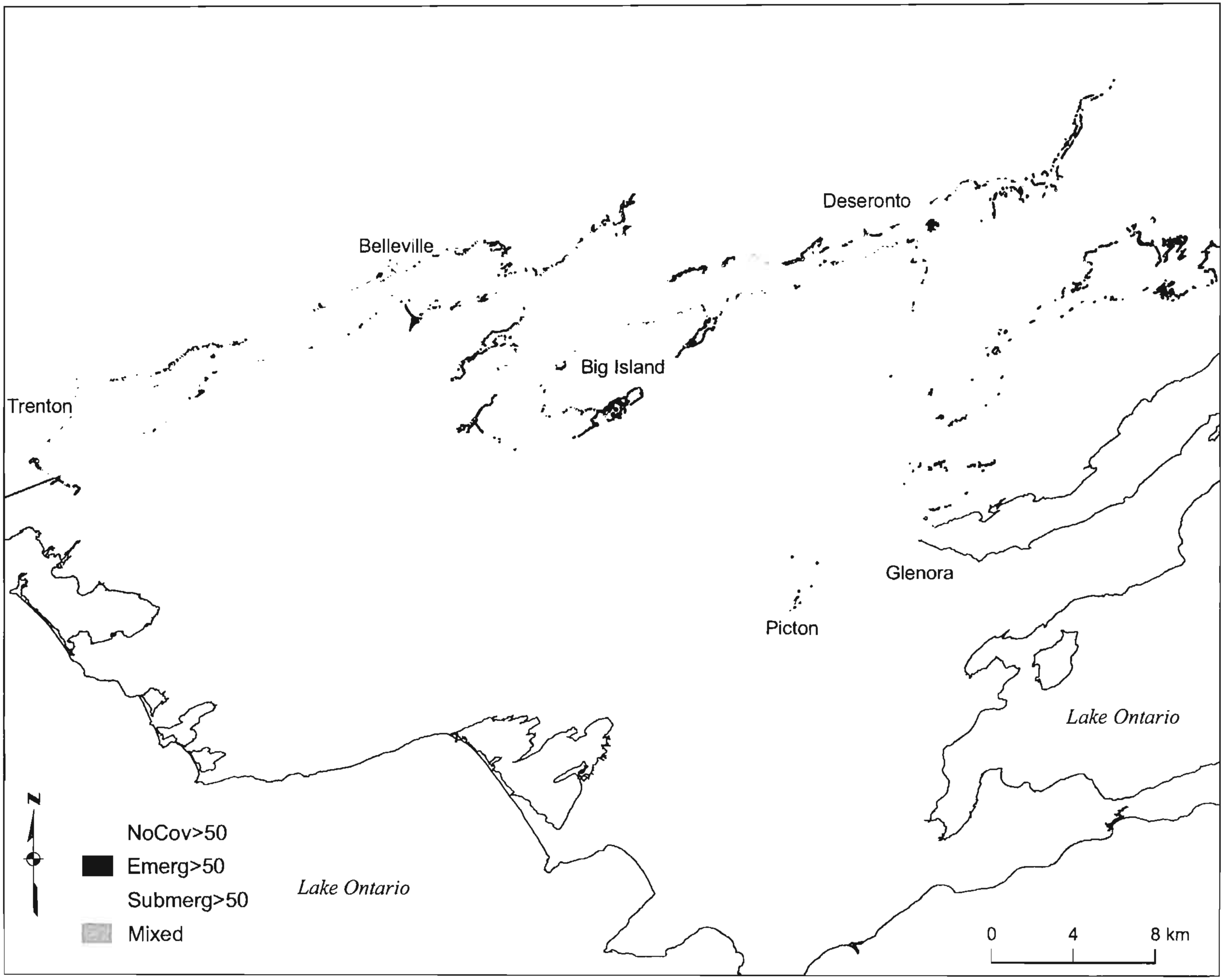
Appendix Figure A1 Ontario Base Map (OBM) 1:10000 shoreline and bathymetry in the upper and middle regions of the Bay of Quinte.



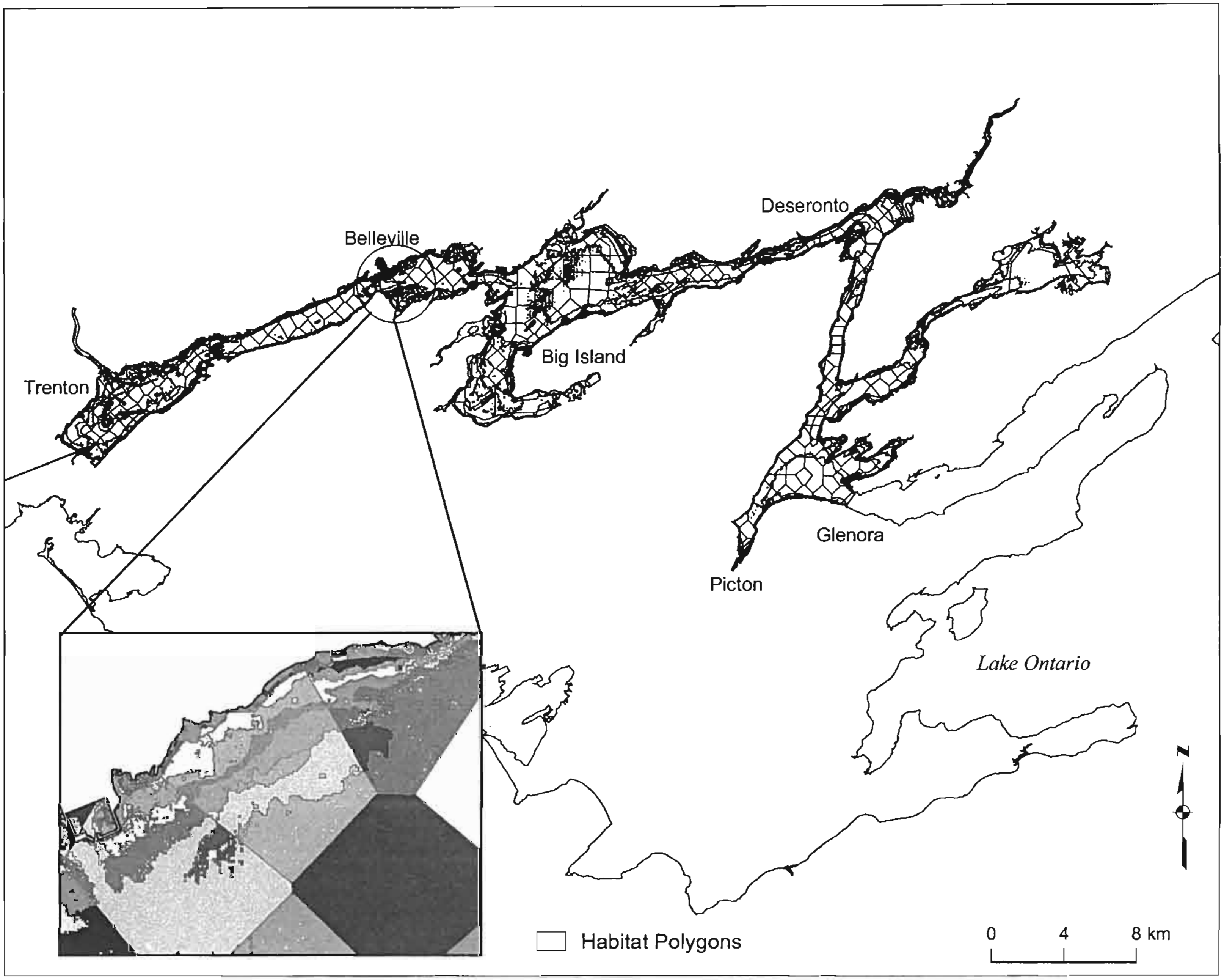
Appendix. Figure A2 Substrate polygons showing offshore sampling points, OMNR nearshore inventory and offshore Theissen polygons.



Appendix Figure A3 Observed emergent and predicted submergent vegetation in the upper and middle Bay of Quinte.



Appendix Figure A4 Habitat polygons, zoomed in area shows unique combinations of attribute data, see sample in Table A2



Appendix B

Species location list of the fish present in the Bay of Quinte compiled from Minns *et al.* (1986).

Latin name	Common name	*Latin name*	common name
Acipenser fulvescens	lake sturgeon	*Catostomus commersonii*	white sucker
Lepisosteus osseus	longnose gar	*Hypentelium nigricans*	northern hog sucker
Amia calva	bowfin	*Ictiobus cyprinellus*	bigmouth buffalo
Alosa pseudoharengus	alewife	*Moxostoma anisurum*	silver redhorse
Dorosoma cepedianum	gizzard shad	*Moxostoma macrolepidotum*	shorthead redhorse
Oncorhynchus kisutch	coho salmon	*Moxostoma valenciennesi*	greater redhorse
Oncorhynchus tshawytscha	Chinook salmon	*Ictalurus nebulosus*	brown bullhead
Onchorhynchus mykiss	rainbow trout	*Ictalurus punctatus*	channel catfish
Salmo trutta	brown trout	*Noturus flavus*	stonecat
Salvelinus namaycush	lake trout	*Anguilla rostrata*	American eel
Coregonus artedii	cisco	*Fundulus diaphanus*	banded killifish
Coregonus clupeaformis	lake whitefish	*Lota lota*	burbot
Osmerus mordax	rainbow smelt	*Labidesthes sicculus*	brook silverside
Hiodon tergisus	mooneye	*Gasterosteus aculeatus*	threespine stickleback
Esox americanus vermiculatus	grass pickerel	*Culaea inconstans*	brook stickleback
Esox lucius	northern pike	*Percopsis omiscomaycus*	trout-perch
Esox masquinongy	muskellunge	*Morone americana*	white perch
Carassius auratus	goldfish	*Morone chrysops*	white bass
Cyprinus carpio	common carp	*Ambloplites rupestris*	rock bass
Notemigonus crysoleucas	golden shiner	*Lepomis gibbosus*	pumpkinseed
Notropis atherinoides	emerald shiner	*Lepomis macrochirus*	bluegill
Luxilus chrysocephalus	striped shiner	*Micropterus dolomieui*	smallmouth bass
Notropis hudsonius	spottail shiner	*Micropterus salmoides*	largemouth bass
Cyprinella spilopterus	spotfin shiner	*Pomoxis nigromaculatus*	black crappie
Notropis heterodon	blackchin shiner	*Etheostoma nigrum*	johnny darter
Luxilus cornutus	common shiner	*Etheostoma flabellare*	fantail darter
Notropis stramineus	sand shiner	*Perca flavescens*	yellow perch
Pimephales promelas	fathead minnow	*Percina caprodes*	logperch
Pimephales notatus	bluntnose minnow	*Sander vitreum*	walleye
Semotilus corporalis	fallfish	*Aplodinotus grunniens*	freshwater drum
Rhinichthys cataractae	longnose dace	*Cottus bairdii*	mottled sculpin
Carpiodes cyprinus	quillback		

Appendix C

Listing of the 9 fish species groupings for the freshwater species, present in the Bay of Quinte, used in this study.

(1) Cold-water	Cool-water, Age-at-maturity <=2	Cool-water, Age-at-maturity >2	Warm-water, Age-at-maturity <=3	Warm-water, Age-at-maturity >3
	(2) Low vegetation cover	**(4) Low vegetation cover**	**(6) Low vegetation cover**	**(8) Low vegetation cover**
lake sturgeon cisco burbot rainbow smelt lake whitefish trout-perch alewife coho salmon rainbow trout Chinook salmon brown trout lake trout threespine stickleback mottled sculpin	emerald shiner gizzard shad longnose dace brook stickleback fantail darter	mooneye walleye silver redhorse fallfish greater redhorse	northern hogsucker shorthead redhorse spotfin shiner white perch sand shiner stonecat white bass	freshwater drum smallmouth bass channel catfish
	(3) High vegetation cover	**(5) High vegetation cover**	**(7) High vegetation cover**	**(9) High vegetation cover**
	brook silverside golden shiner blackchin shiner banded killifish spottail shiner log perch rock bass striped shiner common shiner johnny darter	American eel yellow perch white sucker northern pike black crappie quillback	bluegill pumpkinseed bluntnose minnow fathead minnow brown bullhead	bigmouth buffalo longnose gar goldfish common carp muskellunge grass pickerel* bowfin largemouth bass*

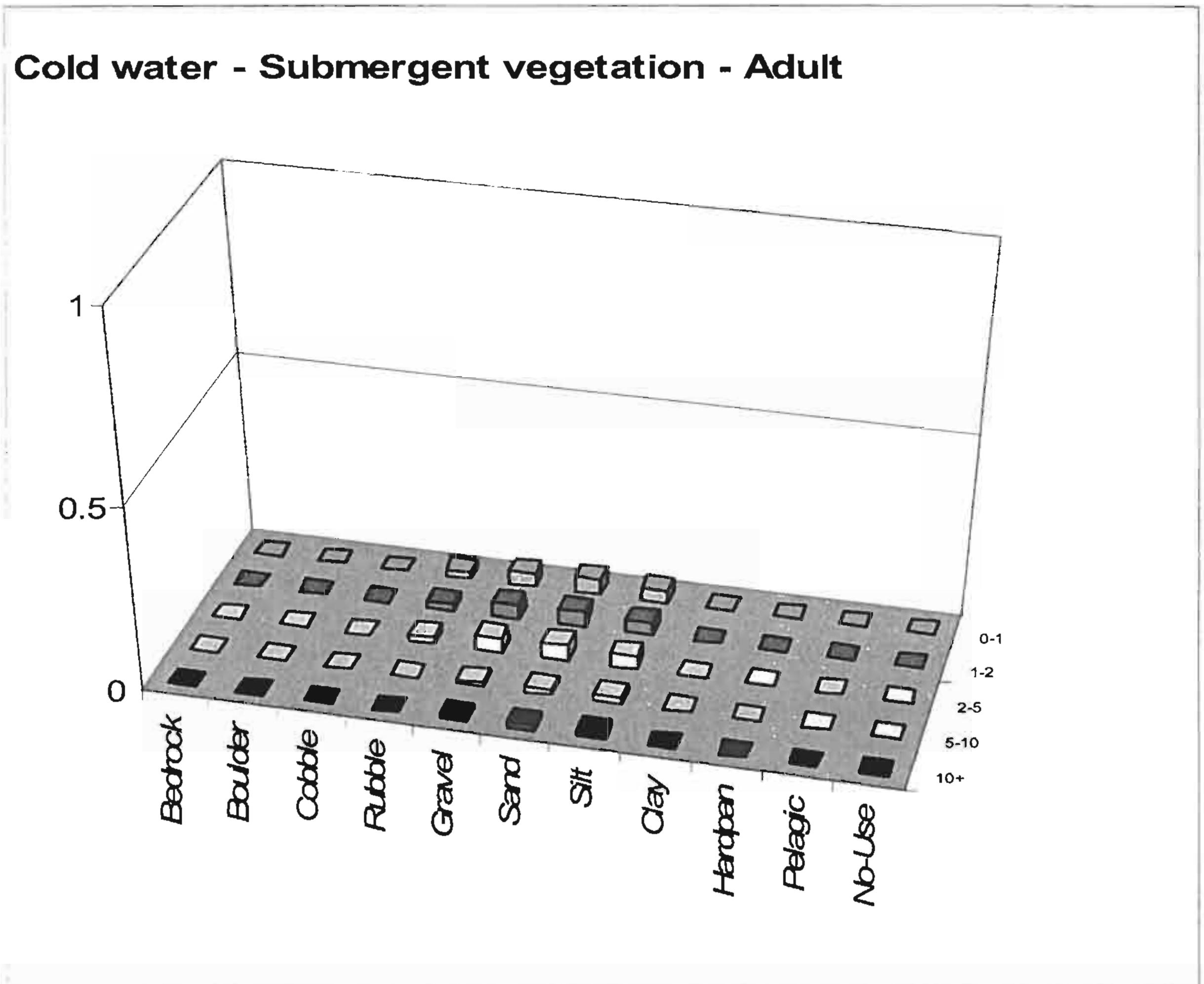
* Exceptions to age-at-maturity rule.

Appendix D: Correlation coefficients for the 27 habitat suitability indices which represent all of the combinations with respect to thermal, age of maturity, vegetation preference and life stage of the freshwater fish inhabiting the Bay of Quinte (note: Life stages : A = adult, S = spawning, Y = YOY).[Correlations >= 0.5 are highlighted in **bold**.]

Thermal			Coldwater			Coolwater												Warmwater											
Age at maturity						Less than or equal to 2						Greater than 2						Less than or equal to 3						Greater than 3					
	Vegetation					Low			High			Low			High			Low			High			Low			High		
		Life Stage	A	S	Y	A	S	Y	A	S	Y	A	S	Y	A	S	Y	A	S	Y	A	S	Y	A	S	Y	A	S	Y
Cold		A		-0.04	0.02	**0.51**	0.02	0.14	0.13	0.05	0.11	-0.01	-0.03	0.00	0.08	0.00	0.12	0.16	0.01	0.11	0.07	0.04	0.07	-0.04	-0.10	-0.09	0.09	0.02	0.09
		S			**0.81**	**0.74**	**0.82**	0.31	0.14	0.45	0.15	**0.86**	**0.80**	**0.52**	0.14	0.43	0.13	**0.86**	**0.85**	**0.57**	0.00	-0.05	0.04	**0.80**	0.41	**0.83**	0.04	0.02	0.10
		Y				**0.77**	0.68	0.39	0.14	0.42	0.1	**0.94**	**0.73**	**0.62**	0.05	0.49	0.06	**0.85**	**0.97**	**0.74**	-0.11	-0.13	-0.10	**0.88**	0.48	**0.51**	-0.06	-0.09	0.02
Cool <=2	Low	A					0.65	0.42	0.26	0.44	0.14	**0.73**	**0.63**	0.38	0.08	0.37	0.13	**0.83**	**0.74**	**0.65**	-0.01	-0.05	-0.05	**0.72**	0.42	**0.53**	0.00	-0.10	0.04
		S						**0.51**	0.45	**0.73**	0.45	**0.65**	**0.69**	**0.59**	0.49	**0.59**	0.37	**0.74**	**0.76**	**0.69**	0.40	0.33	0.39	**0.71**	**0.60**	**0.53**	0.40	0.35	0.31
		Y							**0.92**	**0.73**	**0.85**	0.23	0.12	0.42	**0.77**	**0.56**	**0.71**	0.35	0.35	**0.74**	**0.67**	**0.61**	**0.57**	0.18	**0.53**	-0.04	**0.73**	**0.56**	**0.67**
	High	A								-0.07	0.32	-0.01	-0.07	0.32	**0.85**	**0.54**	**0.71**	0.11	0.14	**0.66**	**0.85**	**0.77**	**0.70**	0.00	**0.53**	-0.18	**0.84**	**0.65**	**0.66**
		S									0.7	0.31	0.23	**0.59**	**0.72**	**0.83**	0.45	0.37	0.47	**0.79**	**0.76**	**0.74**	**0.63**	0.32	**0.77**	0.07	**0.69**	**0.62**	0.40
		Y										-0.01	-0.09	0.42	**0.94**	**0.58**	**0.87**	0.13	0.11	**0.52**	**0.86**	**0.77**	**0.82**	-0.07	0.33	-0.18	**0.92**	**0.80**	**0.88**
Cool >2	Low	A											0.75	**0.56**	-0.04	0.42	-0.01	**0.83**	**0.94**	**0.63**	-0.20	-0.23	-0.16	**0.93**	0.41	**0.65**	-0.16	-0.15	-0.04
		S												0.22	-0.09	0.15	-0.12	**0.78**	**0.77**	0.34	-0.20	-0.22	-0.16	**0.84**	0.40	**0.68**	-0.17	-0.20	-0.15
		Y													0.48	**0.80**	0.28	0.45	**0.65**	**0.64**	0.39	0.34	0.45	0.43	0.38	0.22	0.40	0.49	0.33
	High	A														**0.60**	**0.79**	0.04	0.10	0.45	**0.94**	**0.81**	**0.90**	-0.07	0.36	-0.19	**0.94**	**0.87**	**0.84**
		S															0.33	0.43	**0.50**	**0.66**	**0.60**	**0.56**	**0.52**	0.32	**0.62**	0.04	**0.52**	**0.60**	0.37
		Y																0.15	0.05	0.38	**0.65**	**0.54**	**0.75**	-0.09	0.12	-0.10	**0.78**	**0.63**	**0.97**
Warm <=3	Low	A																	**0.81**	**0.58**	-0.13	-0.16	-0.09	**0.78**	0.40	**0.67**	-0.05	-0.09	0.10
		S																		0.75	-0.03	-0.05	-0.03	**0.91**	**0.51**	**0.55**	0.00	-0.03	0.01
		Y																			0.15	0.05	0.38	-0.09	0.12	-0.10	**0.78**	**0.63**	**0.97**
	High	A																				0.91	**0.90**	-0.19	0.41	-0.30	**0.93**	**0.87**	0.67
		S																					**0.81**	-0.22	0.39	-0.33	**0.91**	**0.87**	**0.55**
		Y																						-0.19	0.21	-0.24	**0.93**	**0.92**	**0.78**
Warm >3	Low	A																							0.49	**0.60**	-0.19	-0.21	-0.14
		S																								0.19	0.28	0.24	0.07
		Y																									-0.26	-0.28	-0.14
	High	A																										**0.92**	**0.80**
		S																											**0.73**

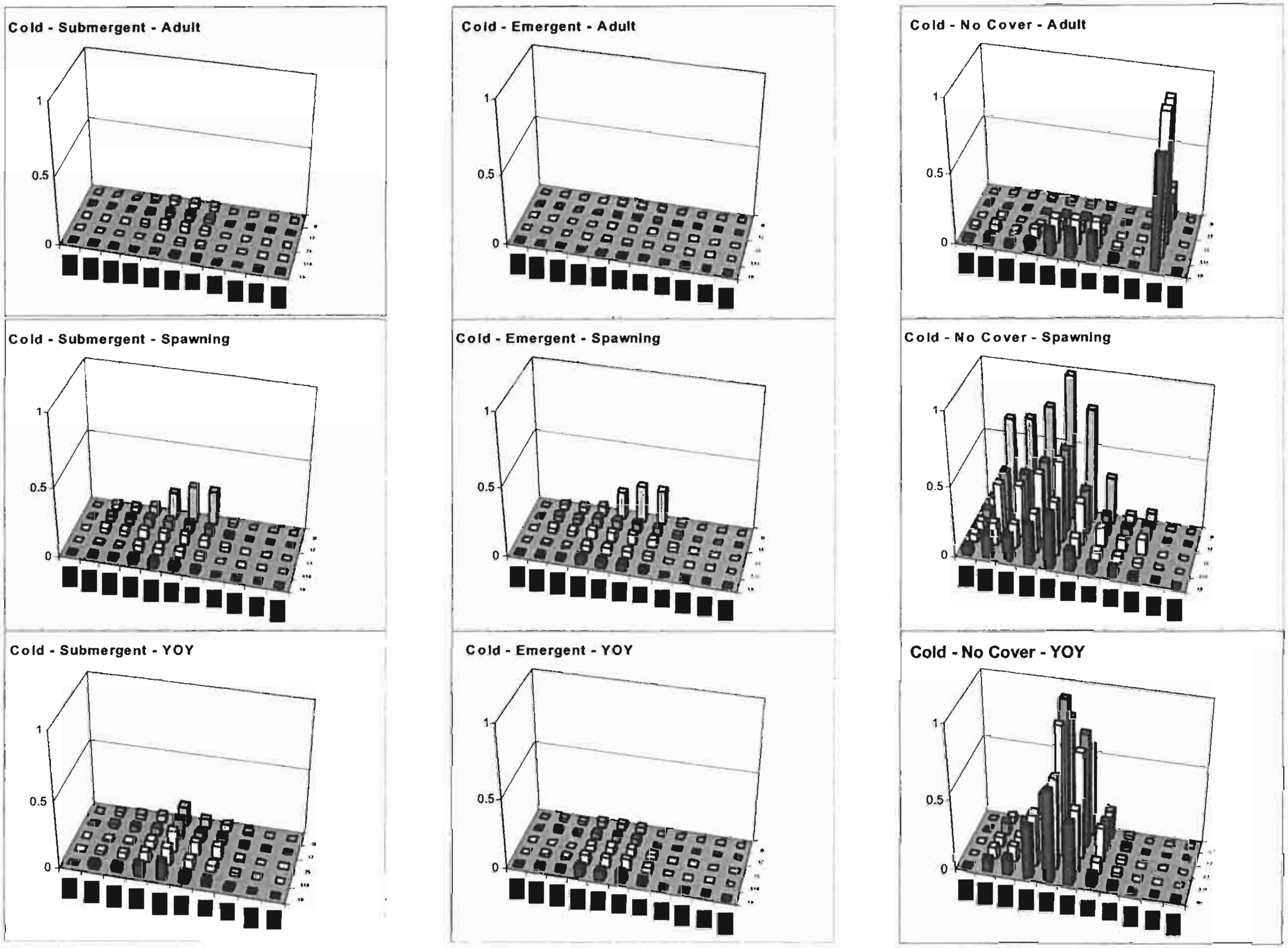
Appendix E

Sample graph of the mean habitat suitability index values (y-axis) versus depth (m) (z-axis) and substrate classes (x-axis) for adult habitat preferences in members of the cold water groups in habitats containing only submergent vegetation.

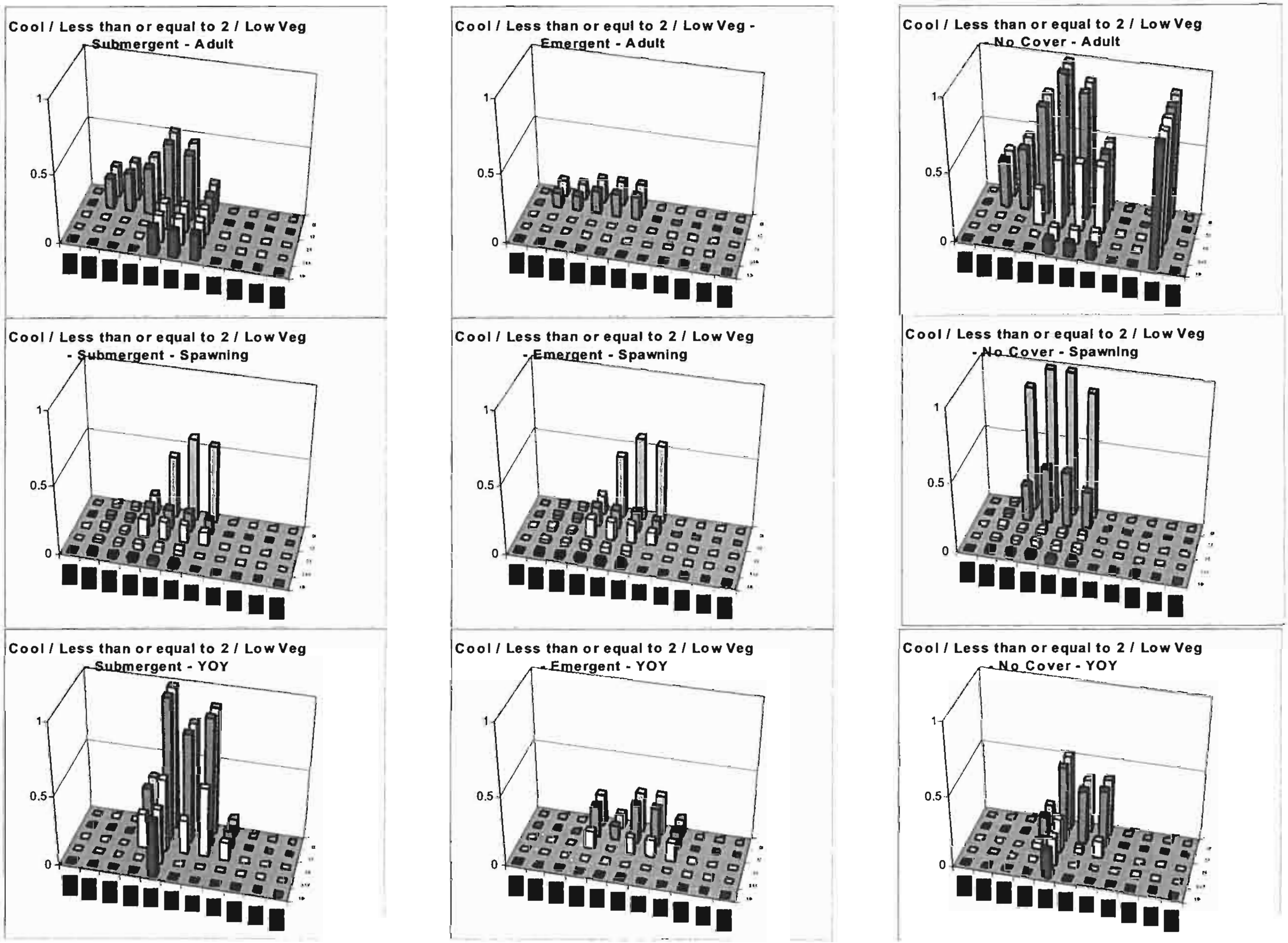


APPENDIX F: Habitat Suitability Matrices (depth vs. substrate for 9 fish groups by 3 life stages and by vegetation type)

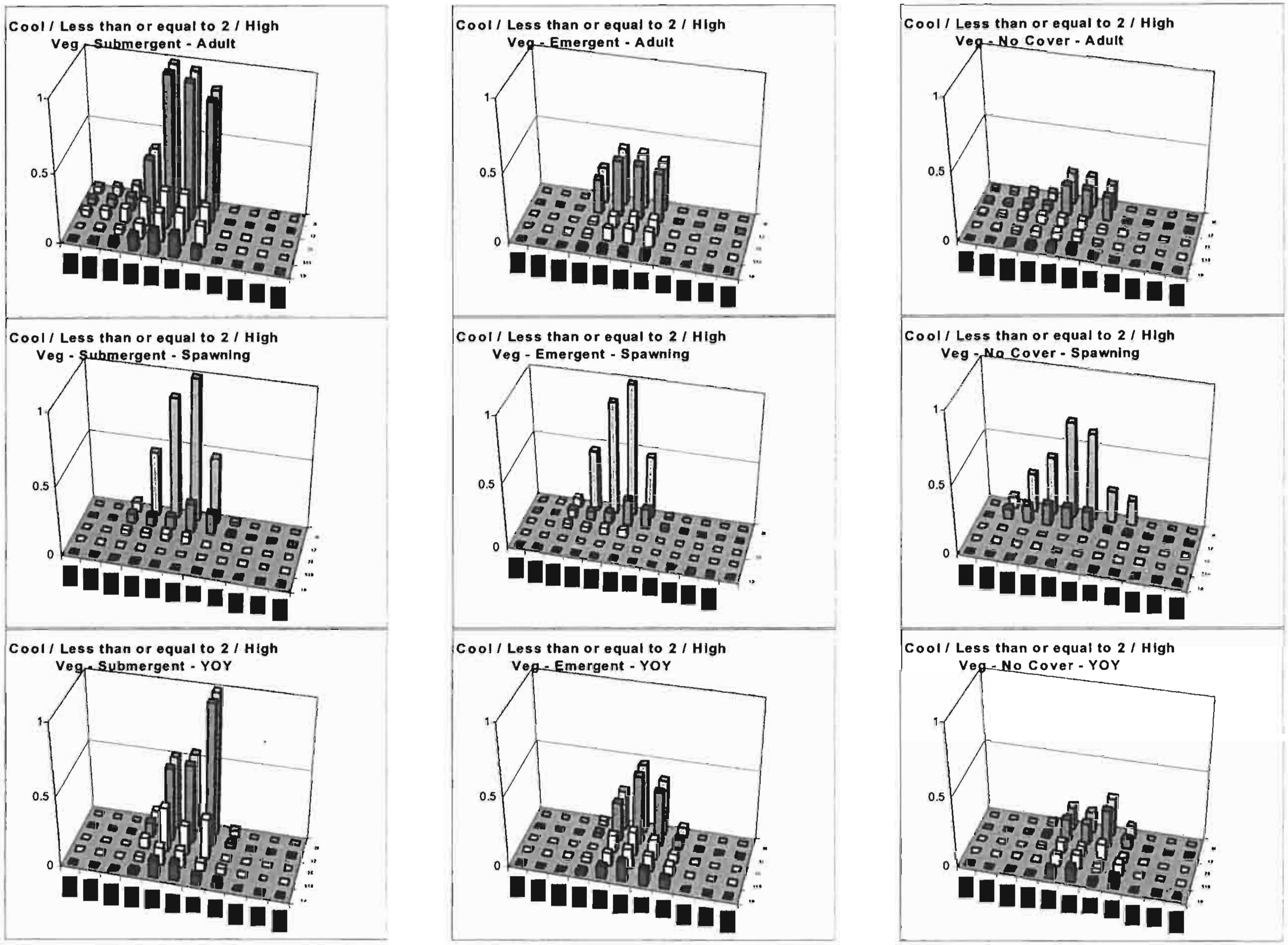
(1) Cold-water



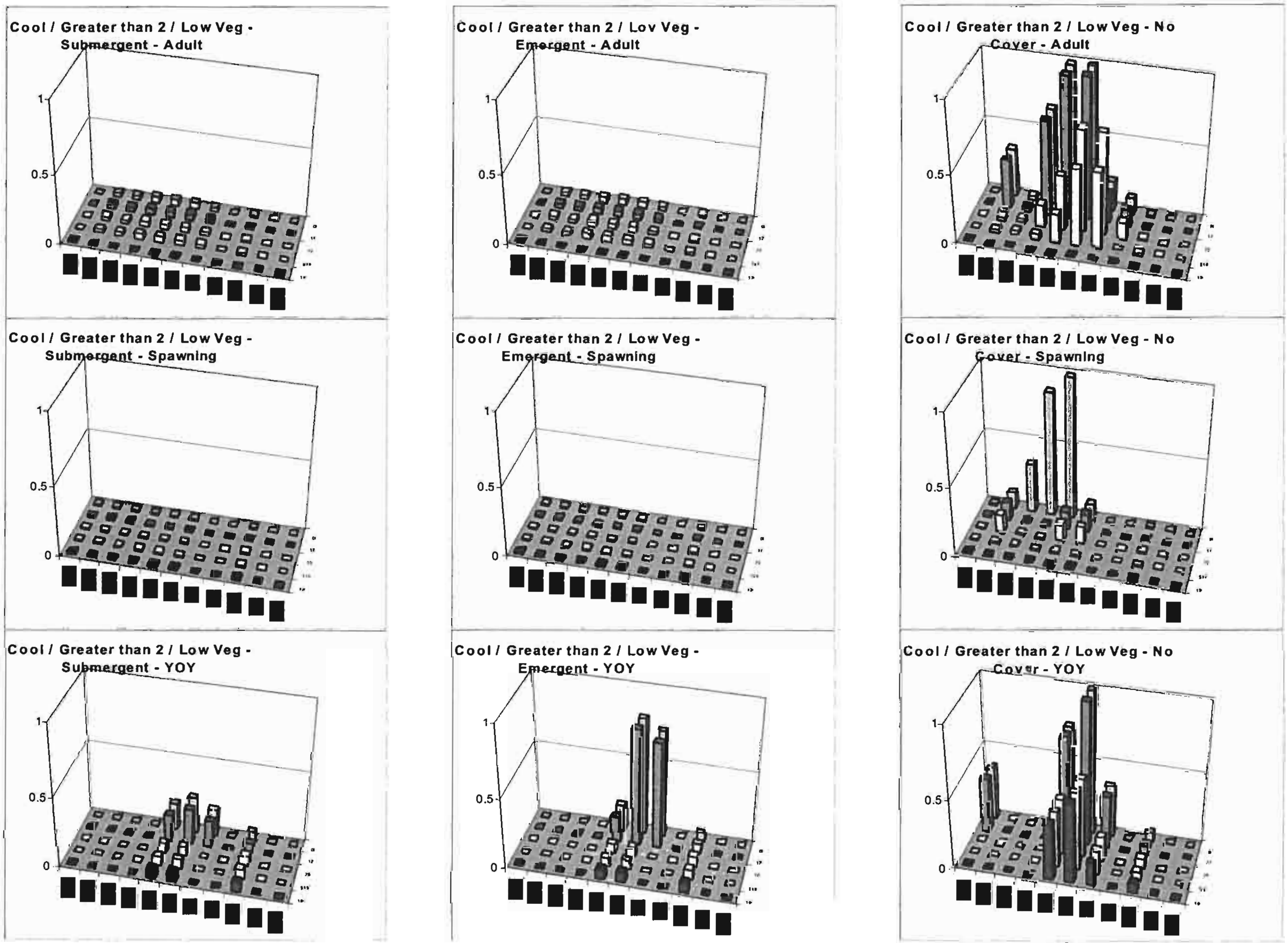
(2) Cool-water, age of maturity <= 2, low vegetation preference.



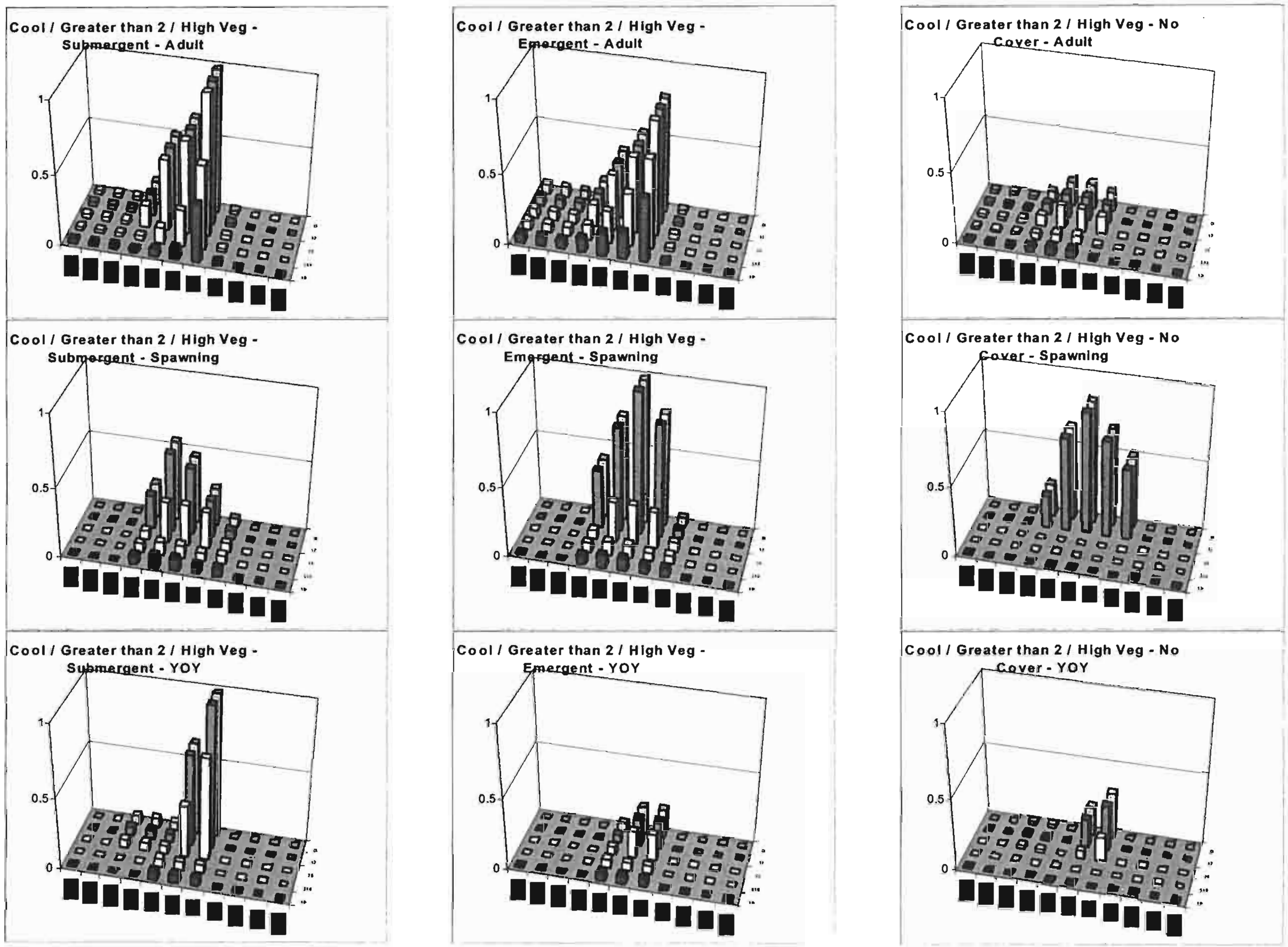
(3) Cool-water, age at maturity <= 2, high vegetation preference.



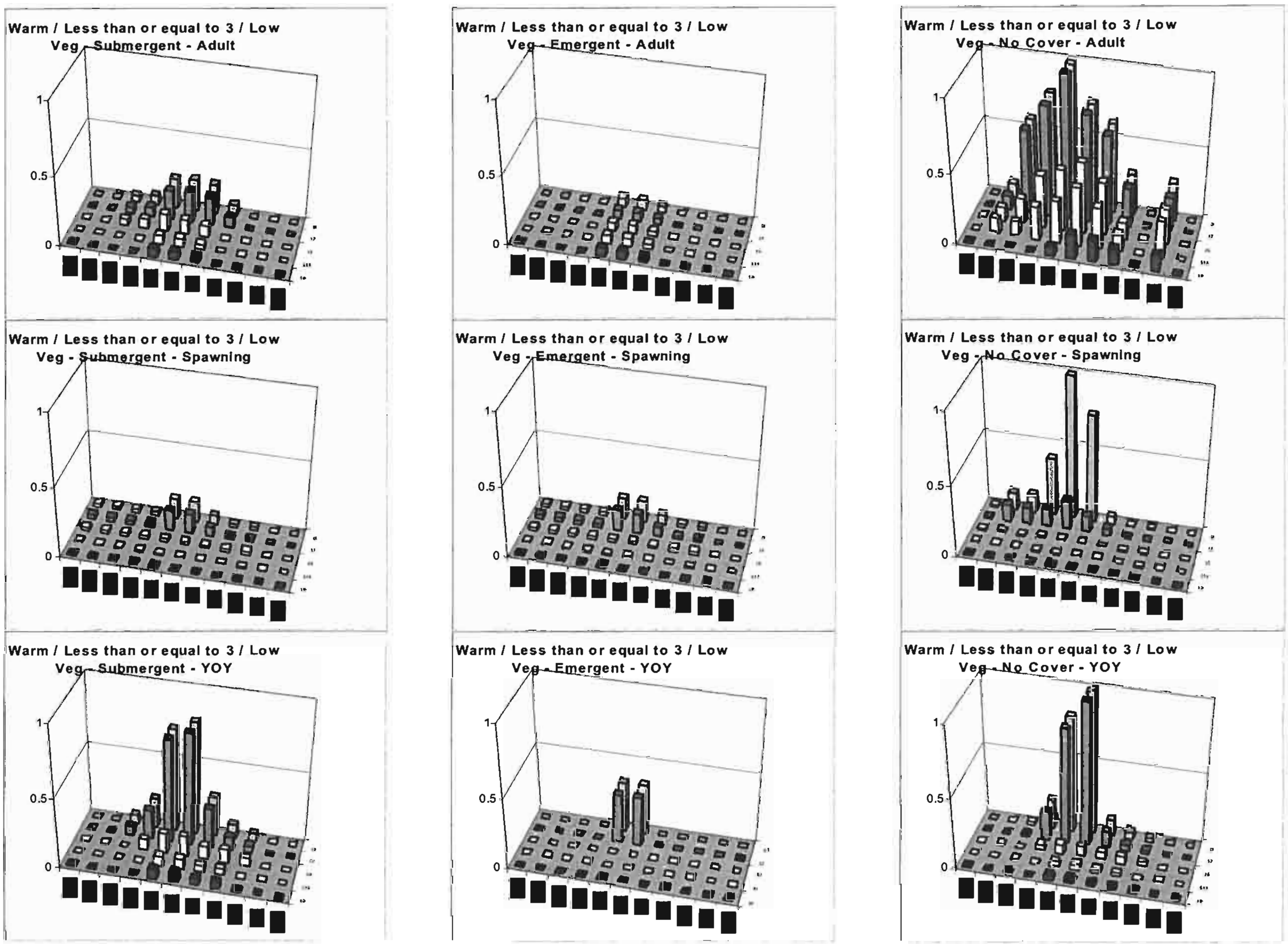
(4) Cool-water, age at maturity > 2, low vegetation preference.



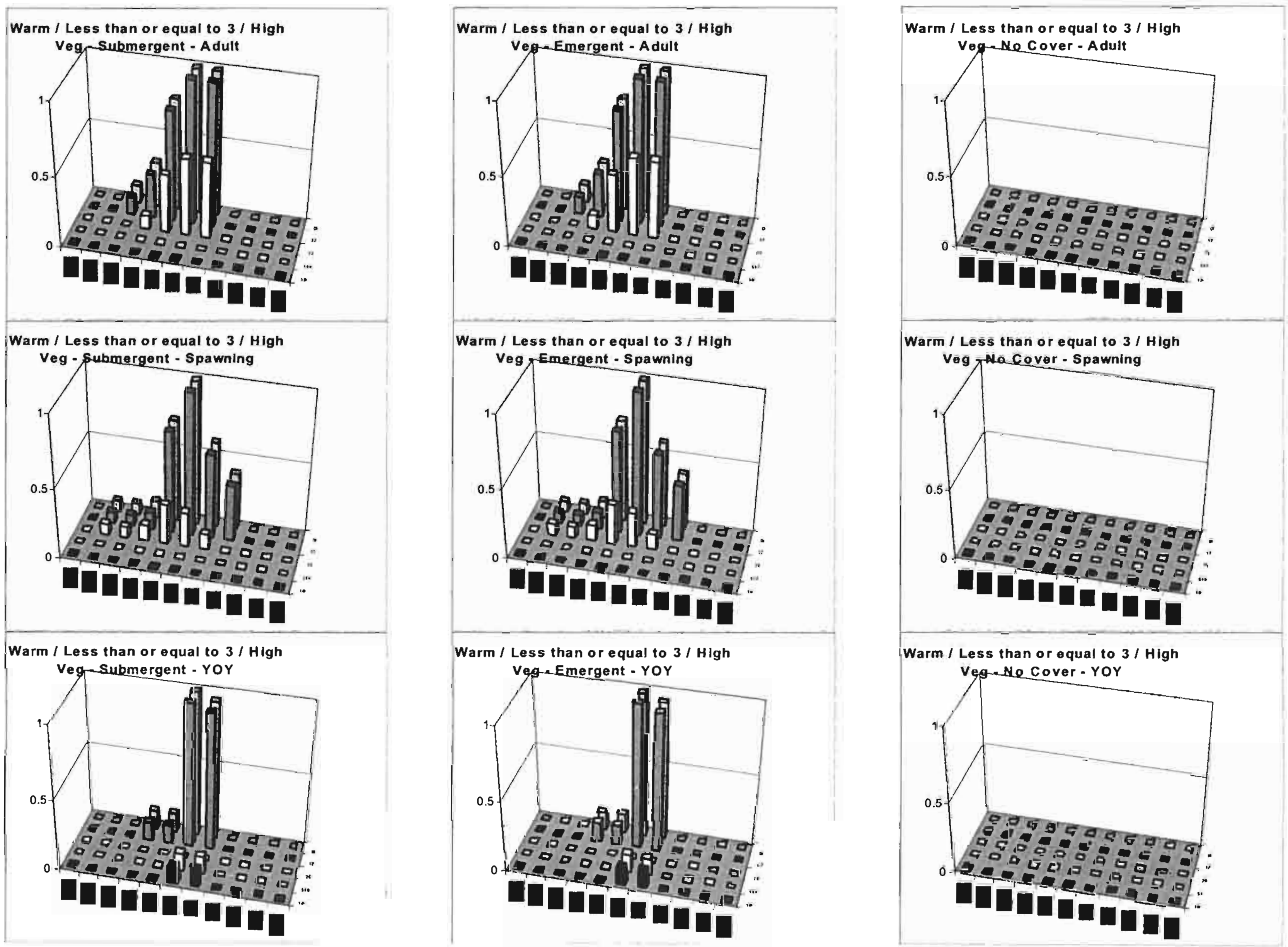
(5) Cool-water, age at maturity >2, high vegetation preference.



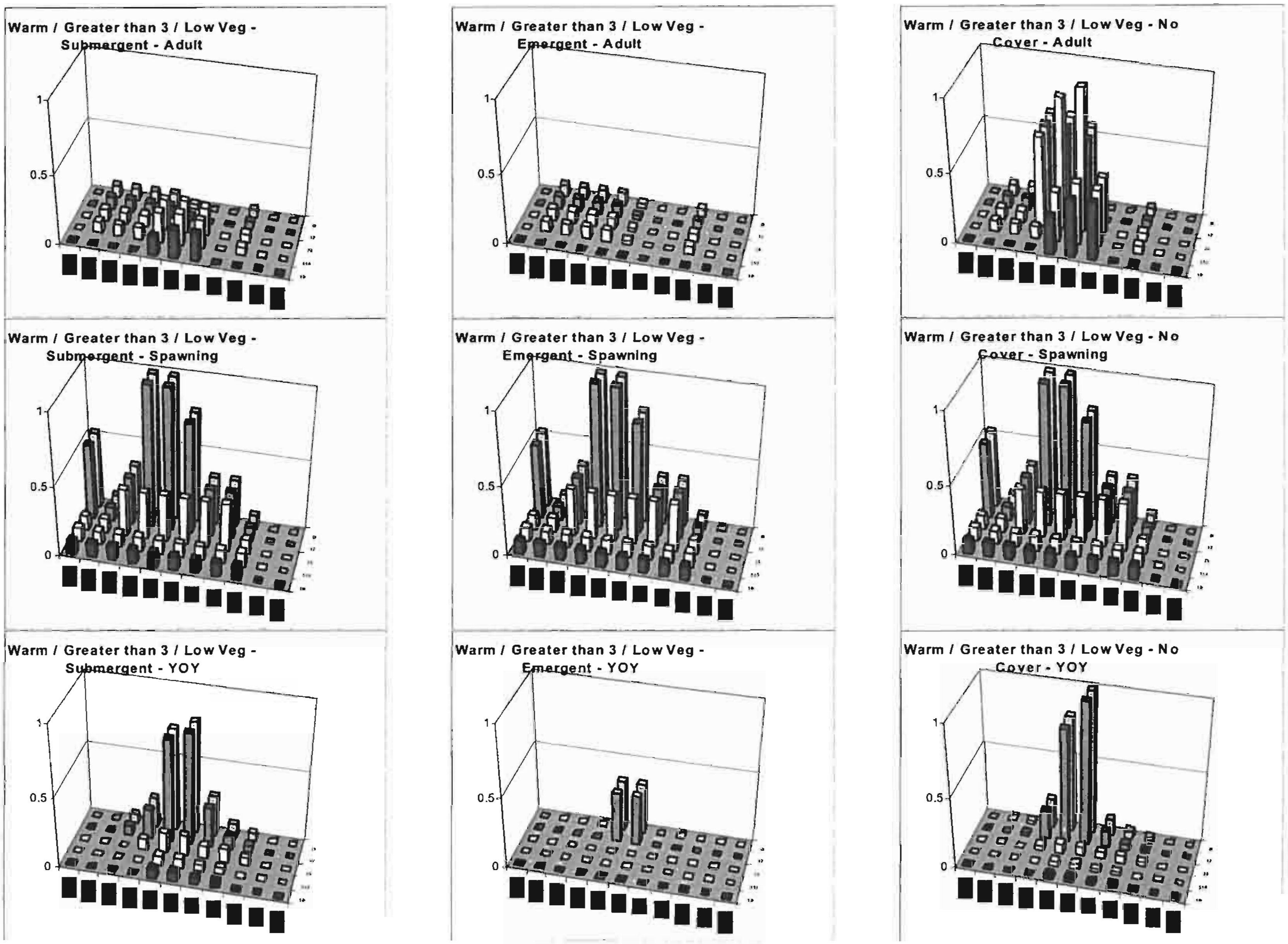
(6) Warm-water, age at maturity <=3, low vegetation preference.



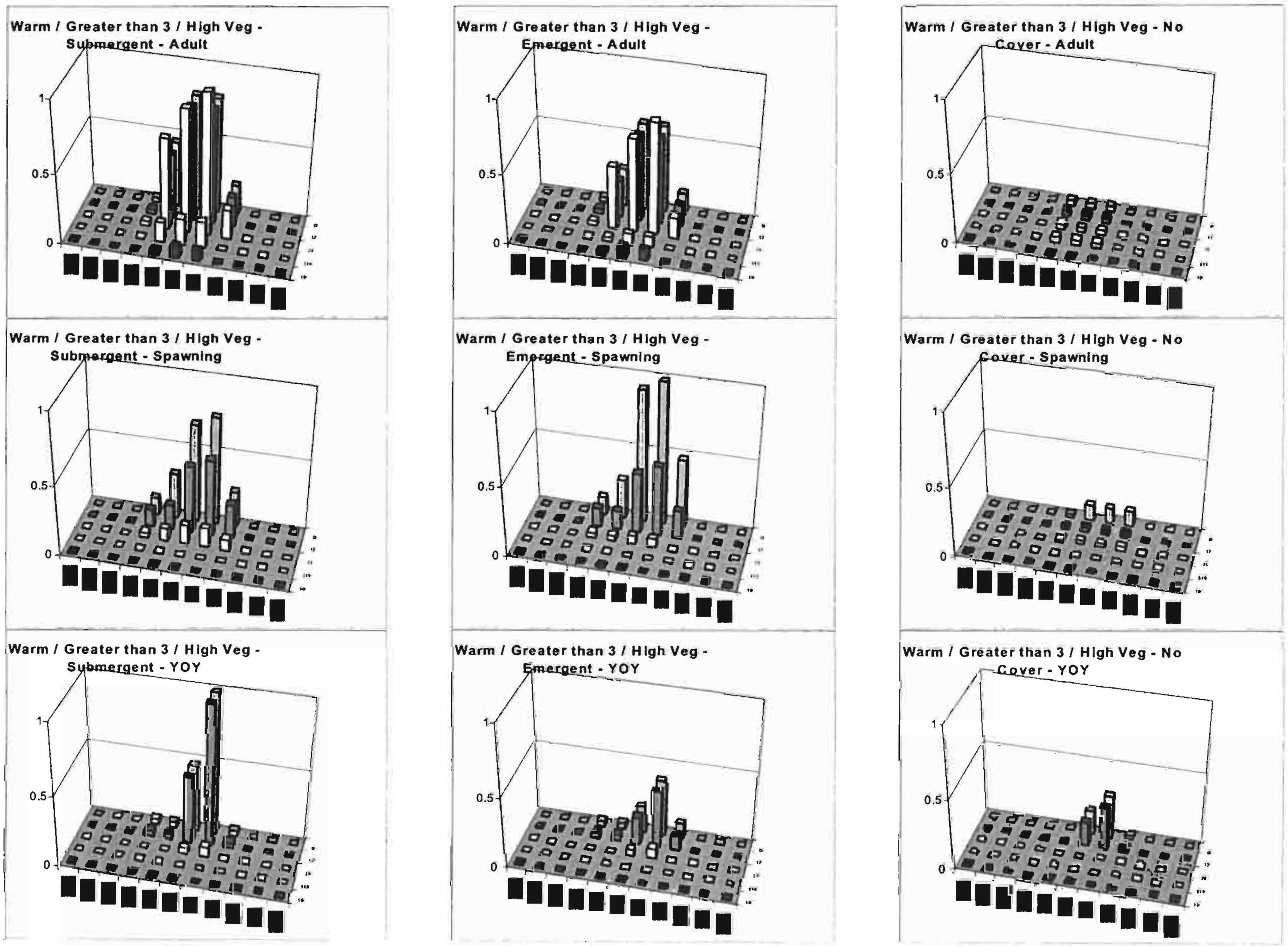
(7) Warm-water, age at maturity <= 3, high vegetation preference.



(8) Warm-water, age at maturity > 3, low vegetation preference.



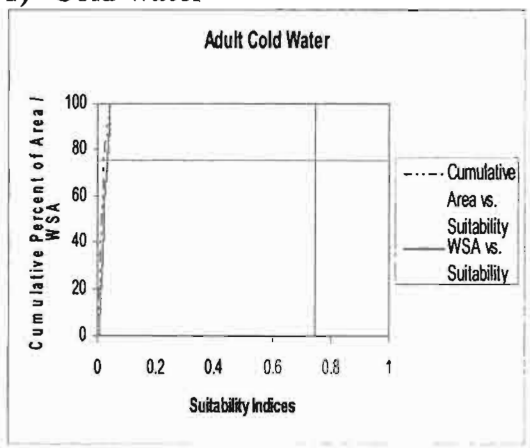
(9) Warm-water, age at maturity > 3, high vegetation preference.

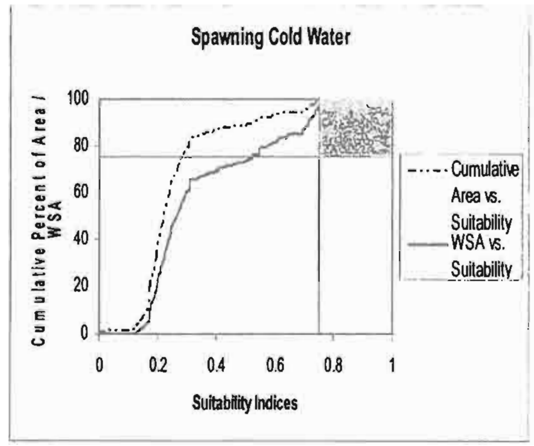


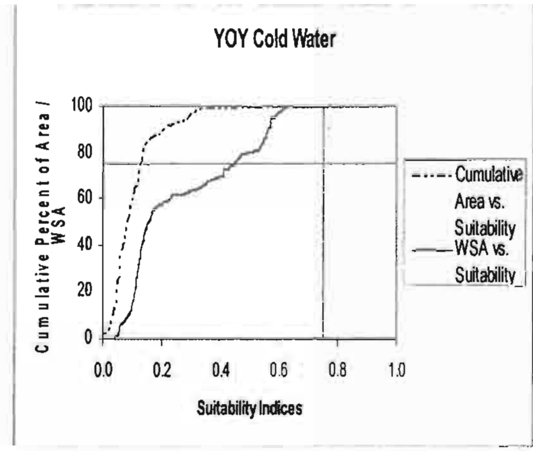
APPENDIX G: Habitat Rarity Assessment Graphs

Graphs of cumulative area (dashed line) and cumulative weighted suitable area – WSA (solid line) for Bay of Quinte habitat suitability database indices showing the application of the 75 percent area and 0.75 suitability cut-offs for identifying rare, highly suitable patches: 1) Cold-water, 2) Cool-water and 3) Warm-water groups by life stage (adult, spawning, and yoy), age at maturity (LT2, <= 2 years; GT2 > 2; LT3 <= 3; GT3 > 3) and vegetation preference (low or high).

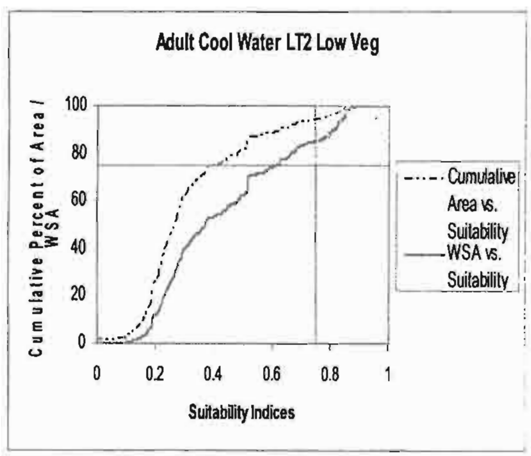
1) Cold-water

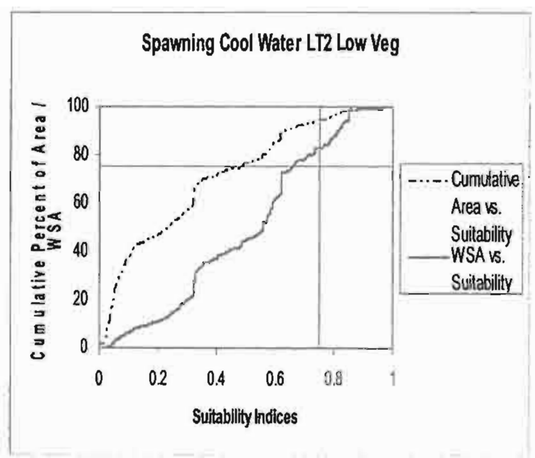


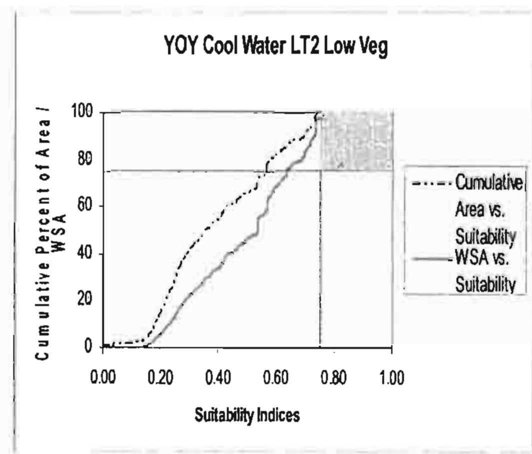




2) Cool-water

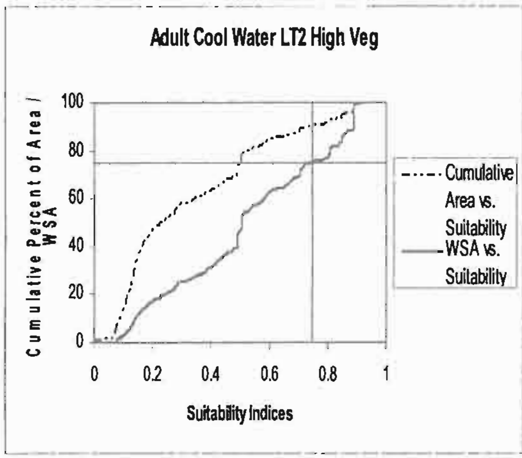


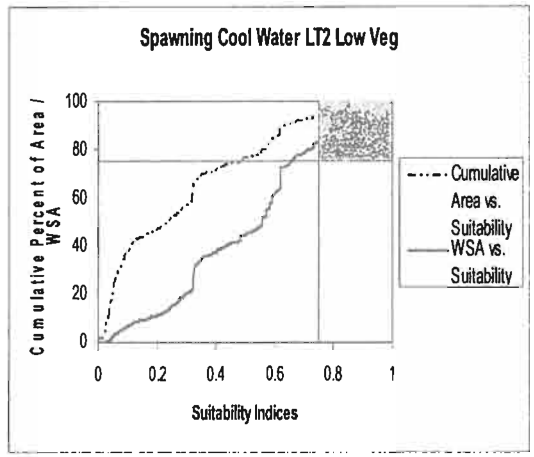


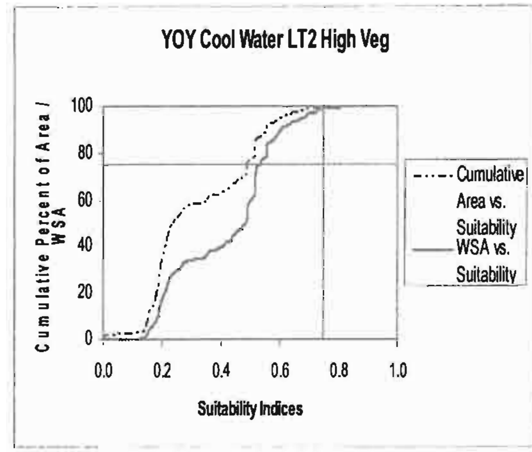


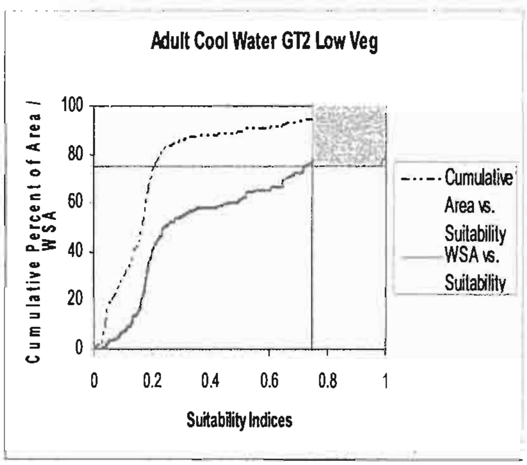
Appendix G continued/2.

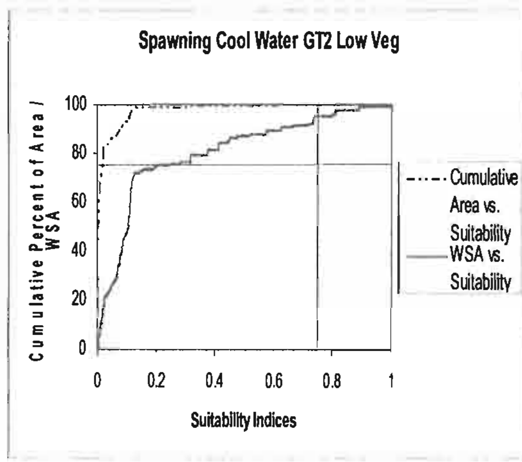
2) Cool-water continued.

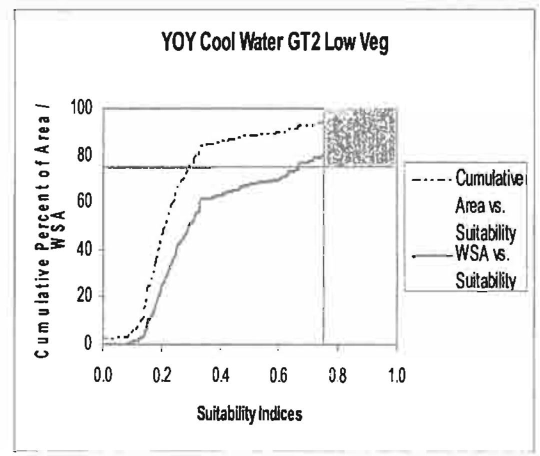






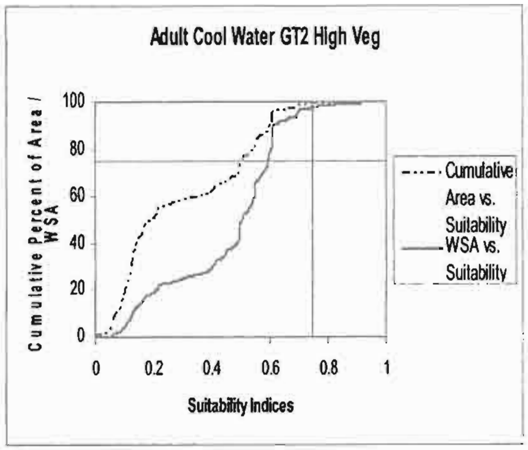


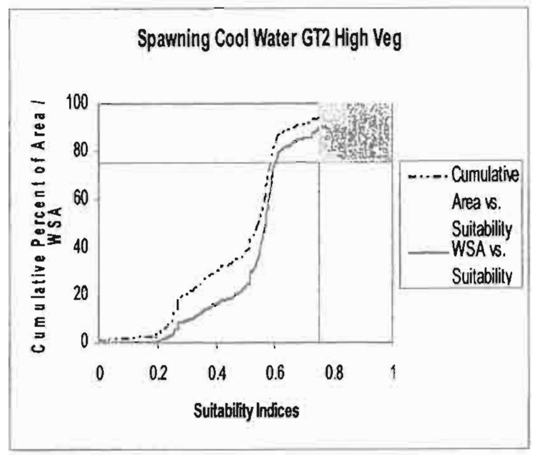


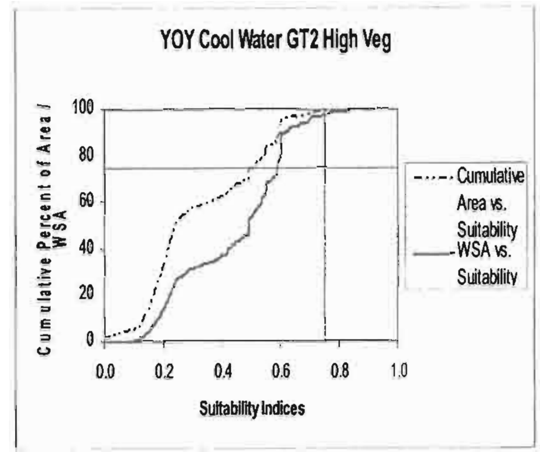


Appendix G continued/3.

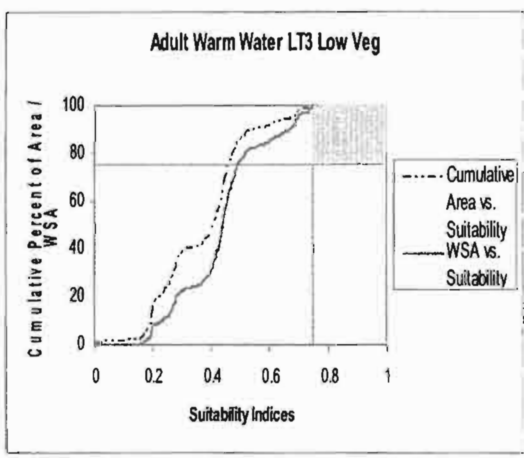
2) Cool-water continued.

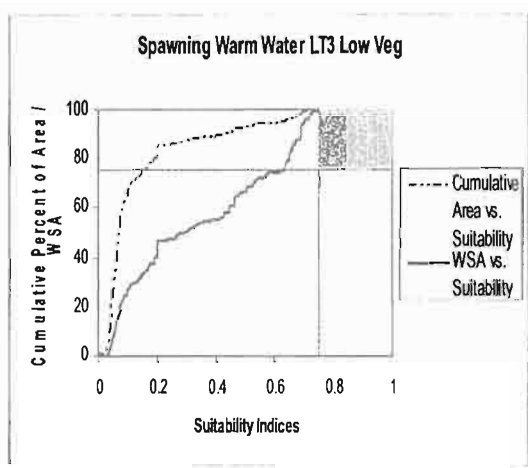


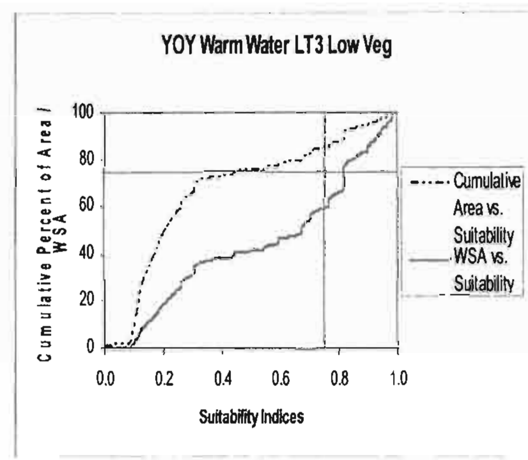




3) Warm-water

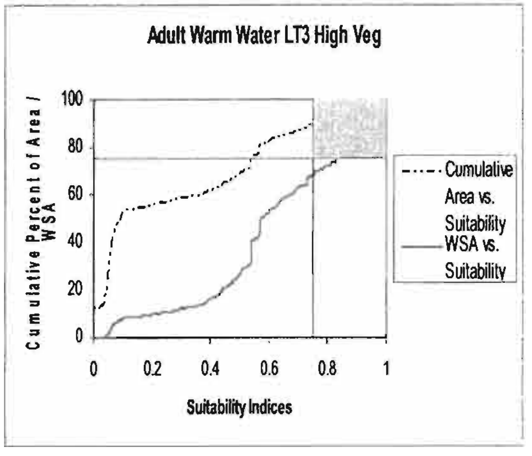


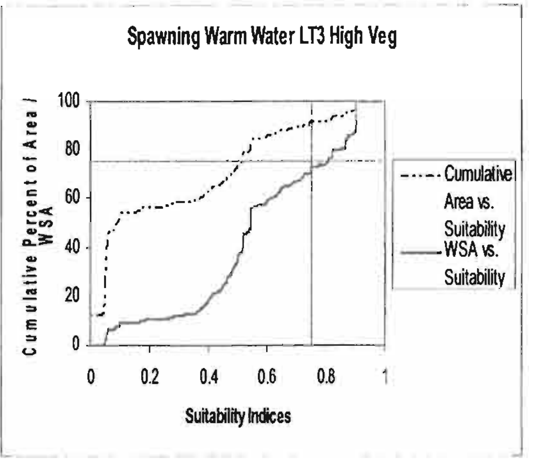


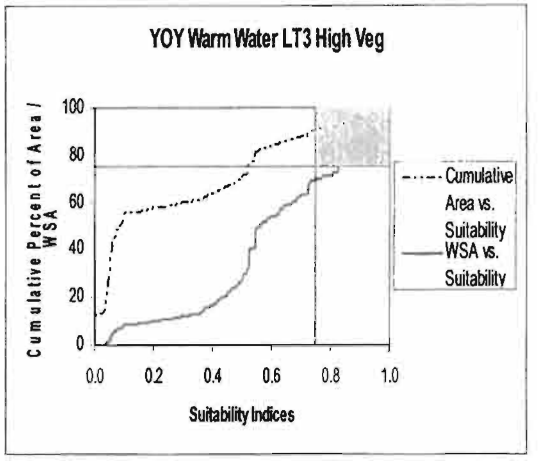


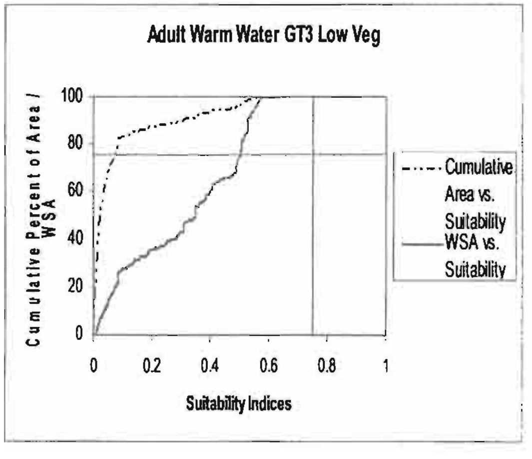
Appendix G continued/4.

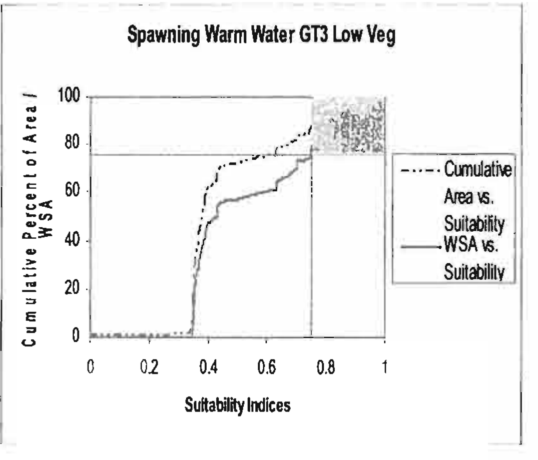
3) Warm-water continued.

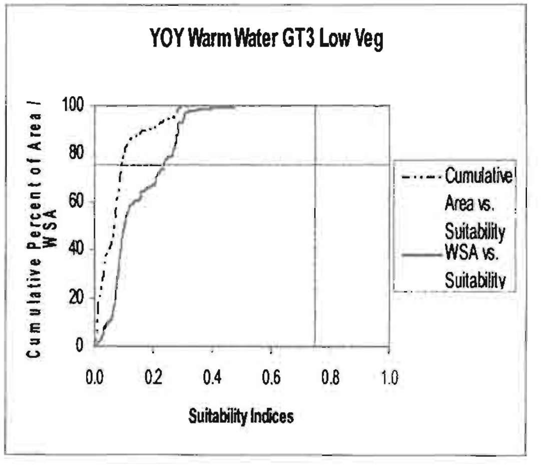






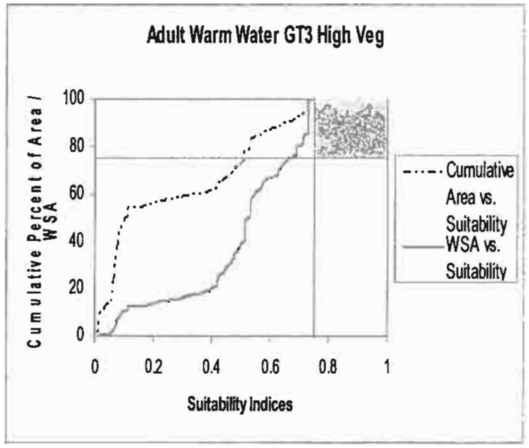


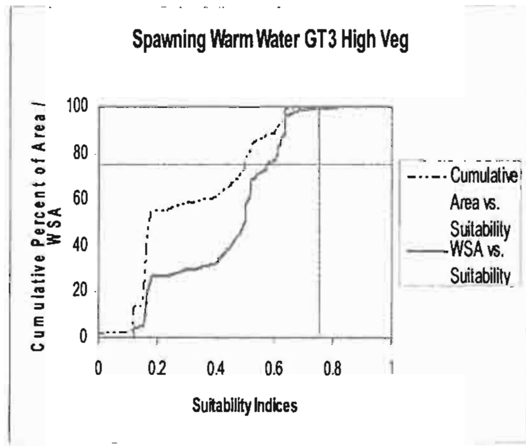


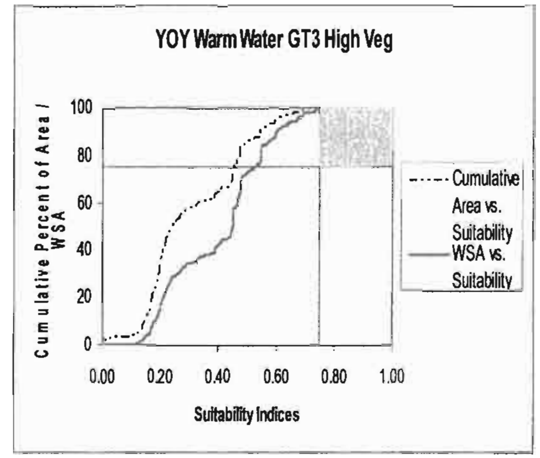


Appendix G continued/5.

3) Warm-water continued.







4) Composite Suitability Index.