IMPORTANT HABITATS OF COASTAL NEW HAMPSHIRE

A Pilot Project for the Identification and Conservation of Regionally Significant Habitats

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Abstract

The Gulf of Maine Council on the Marine Environment, U.S. Fish and Wildlife Service Gulf of Maine Project, and the Huntsman Marine Centre cooperatively supported 2 pilot projects to map important habitats in U.S. and Canadian coastal areas. The pilot projects in Great Bay, New Hampshire and in Passamaquoddy Bay, New Brunswick were intended to develop methods for selection of evaluation species, for identifying and rating those species' habitats, for determining regionally important habitats based on that information, and for use of the maps and associated information in resource conservation. The analysis for Great Bay is described in detail, and maps of important habitats are displayed. These maps are being distributed to government agencies and to local conservation interests.

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Introduction

The Action Plan of the Gulf of Maine Council (GOMC) called for identification of "regionally significant habitats" for management, protection and restoration. The designation of regionally significant habitats was to be based on their utility to regionally important species. During 1993/1994 the Habitat Panel of the GOMC selected and ranked a list of such "priority species" according to social, commercial, ecological, and institutional criteria (Appendix A).

While there was broad agreement on the species list, questions remained about its application in identifying habitats. The designation of regionally significant habitats would require comparison of all potentially significant habitats in the watershed, a major undertaking. Instead, it was decided to conduct a Canadian and a U.S. pilot study to explore the methods and implications of the approach. The project areas, Great Bay and Passamaquoddy Bay, were selected on the basis of resource values and local interest in conservation via voluntary, management, and regulatory mechanisms. The pilot projects were to use the listed "priority species" but assess habitats within two embayments of the Gulf of Maine, rather than Gulf-wide. Following the development of standard analytical methods, additional areas of the Gulf can be examined in a comparable manner in later studies. Thus, while the potentially highest ranked habitats in the region may only be identified in future analysis, appropriately ranked regionally important habitats can be identified (and protected) via these pilot projects.

Tasks for the pilot projects included: 1) developing methods for mapping habitats which may be generally applicable throughout the Gulf of Maine, and which reflect the best use of available information; 2) mapping habitats specifically for "priority species" identified by the Council's Habitat Panel; 3) developing methods for combining habitat maps in order to highlight habitats which may be of greatest importance to the largest number of listed species; 4) producing maps and assembling other information with which local conservation interests may initiate protection/restoration projects. This analysis parallels another recent GIS analysis by the Great Bay Resource Protection Partnership (Sprankle 1996); the GOMC study complements the latter's terrestrial and fresh water emphasis. Conservation efforts are expected to be based on partnership techniques proven successful for the applicants in other Gulf localities.

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Methods

Selection of Study Area Boundaries

It became apparent that selection of the study area boundaries must be affected by political, social and ecological considerations. We had to include areas of interest to local conservation activists, include complete governmental jurisdictions, and include areas affecting or protecting critical marine resources. The initial proposal was for analysis of Great Bay, New Hampshire. Upon consultation with local conservation and scientific interests (Great Bay Resource Protection Partnership, New Hampshire National Estuary Project, Jackson Estuarine Research Laboratory) this was expanded to cover the waters and contiguous towns of Great Bay and Little Bay, their tributaries to the head of tide, and the Seabrook/Hampton estuary. To assure adequate consideration of resources near town borders, the study area boundary was drawn to include a 1 mile buffer zone around the towns (Figure 1).

Selection of Evaluation Species

One of the purposes of this pilot study is to establish methods for using the list of high priority species identified by the Habitat Panel for the GOMC. The list (Appendix A) contains 161 species, each assigned a numerical score based on carefully drawn criteria. The proposal for this pilot study suggested that the highest scored species from the list should be selected as candidate evaluation species. As a practical matter, it was estimated that an analysis could be performed within the time and cost constraints for about 12 to 20 species, and that this number of "Great Bay species" might be found among the top 30 of the GOMC list. To insure that priorities of local conservation interests were considered, we proposed adding 3 locally important species to the list of regionally important species.

We consulted with local experts from conservation organizations, agencies, and the University of New Hampshire to select evaluation species from the top increment of the GOMC list, and to nominate species of local interest. The responses were highly significant: there was only limited local interest in the designation of regionally significant habitats, and <u>many</u> locally interesting species were recommended. However, the experts did regard the top scored species of the GOMC list as locally important, and a majority of their candidates were also on the GOMC list, but ranked below the top 30. As a result, we produced a longer list of evaluation species than intended. These, however, could be aggregated to identify both regionally important and locally significant habitats.

The rationale for selecting species, whether of local interest or from the GOMC list, was that they meet either of 2 criteria: 1) the study area is likely to serve as important habitat for the species; 2) the species is regarded as important in the study area. The former category may include even uncommon species which rely on study area for some essential resources; the latter may include species which are also abundant elsewhere, but which are important as prey, predator, structure, or are of recreational or commercial significance within the study area. The evaluation species are presented in Table 1.

Table 1. Evaluation Species For The Great Bay Pilot Project

TOP GOMC SPECIES	GOMC SCORE	REASON FOR SELECTION
Irish moss	66	harvest, structure
soft shelled clam	66	harvest, prey
tufted red weed	62	harvest, structure
rockweed	61	harvest, structure
Atlantic salmon	61	harvest
winter flounder	60	harvest, predator
eelgrass	59	structure, producer
blue mussel	59	structure, prey
American shad	57	harvest
cordgrass	57	structure, producer
pollack	57	predator
lobster	56	harvest
LOCALLY SELECTED SPECIES		
alewife	55	harvest, prey
bald eagle	54	predator, special habitat available
striped bass	53	harvest, predator
common tern	51	predator, special habitat available
rainbow smelt	49	harvest, prey
black duck	48	harvest
Canada goose	46	harvest
great blue heron	42	predator, special habitat available
tomcod	36	harvest, predator, special habitat available
Atlantic silversides	NA	prey
salt meadow hay	NA	structure, producer
smooth flounder	NA	predator, special habitat available
blueback herring	NA	harvest, prey

TOP GOMC SPECIES	GOMC SCORE	REASON FOR SELECTION
American oyster	NA	harvest, structure

Methods for Identifying Habitats

Identification and mapping of habitats for the evaluation species requires the interpretation of data on the occurrences of each species, often by life stage, and may require appraisal of the environmental aspects of areas typically occupied. Habitats may be mapped by:

1) Mapping observed occurrences. The study area may be surveyed, each species sampled or counted directly in relation to mapped geographic features or coordinates, and boundaries drawn around occurrences or concentrations. Habitat quality can be estimated from the apparent intensity or duration of use. This method is likely to require extensive, comprehensive surveys, since occurrences may be highly variable over time. Counts are likely to be incomplete or biased when the species is elusive, or the habitat difficult of observation. The method doesn't require complete knowledge of habitat requirements or the species biology.

2) Use of habitat models. Model development includes:

a) Analysis. Associate occurrences by season and life stage to habitat factors in order to identify key environmental features and their relative suitabilities.

b) Synthesis. Construct comprehensive habitat models based on the literature, expert opinion, and testing against observations.

c) Application. Operate the model, then examine the suitability of mapped environmental features as habitat, by stage, season, or overall resource value. Habitat boundaries are formed by the extents of environmental features rather than occurrences of the species.

3) Expert opinion. Those most familiar with the local behavior and distribution of a species may be able to depict areas it frequently uses, as an overlay on a base map or aerial photo.

In general, highest level of confidence can be claimed by the first method, although important habitat components may be overlooked in areas that are difficult to sample. Observations are not transferable to new sites. In contrast, models may be applied throughout the range of the species characterization, providing basic environmental data are available. The level of confidence in a model must depend on the quality of those data and of the biological data and understanding that went into the model. Expert opinion is of highly variable accuracy; it suffers from limited documentation; local knowledge is not directly transferable to new sites.

Scoring of Habitats

The habitat analysis was conducted in 2 stages; 1) mapping of occurrences or of locations having suitable conditions for each species, including an estimate of habitat quality, and 2) combining habitat maps for the species, adjusting for the relative importance of the species or the relative scarcity of its habitat(s).

Mapping Habitats by Species

Our maps were created using a geographic information system (GIS), with which we analyzed and overlaid digital spatial data (coverages). The analyses used methods 1 and 2, or combinations of the two, depending on the availability of information (see Table 2).

Table 2. Methods Used for Mapping Habitat, and Basic Spatial Data

SPECIES	MAPPING METHOD	BASE MAPS
Irish moss	occurrences	coastline, Great Bay wetlands coverage, aerial photos
soft shelled clam	model	occurrences, substrate, bathymetry, temperature, salinity
tufted red weed	occurrences	coastline, Great Bay wetlands coverage, aerial photos
rockweed	occurrences	coastline, Great Bay wetlands coverage, aerial photos
Atlantic salmon	occurrences	NWI
winter flounder	model	substrate, bathymetry, temperature, salinity
eelgrass	occurrences	existing coverages
blue mussel	model	substrate, bathymetry, temperature, salinity
American shad	model + occurrences	NWI, salinity
cordgrass	occurrences	NWI, Great Bay wetlands coverage
pollock	model	substrate, bathymetry, temperature, salinity
American lobster	model	substrate, bathymetry, temperature, salinity
alewife	model + occurrences	NWI, salinity
bald eagle	occurrences	coastline
striped bass	model + occurrences	eelgrass, bathymetry, aerial photos, oyster and mussel bars
common tern	model + occurrences	bathymetry
rainbow smelt	model	substrate, bathymetry, temperature, salinity
black duck	model	NWI, bathymetry, clam and mussel beds, eelgrass
Canada goose	model	NWI, bathymetry, landcover, eelgrass
great blue heron	model + occurrences	NWI, bathymetry, eelgrass
tomcod	model	substrate, bathymetry, temperature, salinity
Atlantic silversides	model	substrate, bathymetry, temperature, salinity
salt meadow hay	occurrences	NWI, Great Bay wetlands coverage
smooth flounder	model	substrate, bathymetry, temperature, salinity
blueback herring	model + occurrences	NWI, salinity
American oyster	occurrences	

We first obtained information on occurrences or habitat requirements and associations for each species from the scientific and technical literature, and from local experts. We then digitized the occurrence information or operated models to produce coverages in which areas were assigned scores as estimations of their "habitat suitability" for each evaluation species.

Habitat suitability (USFWS 1980) is a numerical representation of the ability of an area to support at least some life stage of the species; relatively higher suitability values indicate potential for greater population density, reproductive success, growth rate, survival, etc.

Suitability models may predict the level of use of a habitat, and field sampling and surveys can be used to test or validate a model. While we did not have sufficient data for statistically testing our models, we did overlay available sampling data on habitat maps generated by the models to allow visual comparison. We adjusted the models to best fit the published relationships and the local distribution of the species. While suitable areas may not, in fact, be occupied because of population dynamics or because other factors are limiting, unsuitable areas should typically exhibit little usage by the species. Draft habitat suitability maps were plotted, including narratives on all life stage components of the models, how these were combined, and the available occurrence information. Local experts then reviewed these maps, and used their knowledge (method 3) as 'collateral data'. We also distributed description of the models for review by local and other experts. Only final maps of aggregated life stages are presented in this report; the intermediate information is archived at the Gulf of Maine Project.

Habitat suitability was indexed on a 0 to 10 basis, lowest to highest habitat value. Where occurrence information was used directly to create digital maps (e.g., for marine algae, cordgrass, bald eagle) the suitability of these sites were recognized by giving them a score of 10. Maps created by the operation of models on environmental data layers had a range of values according to the relative suitability of each layer.

Habitat suitability was considered by life stage and by season for many of the species. When combining suitability maps for these stages and seasons we took into account their probable interdependence. For example, mobile species such as fishes and birds may migrate when local habitats become seasonally unsuitable. In such cases, when potential use during one season is independent of value during other seasons or value to other life stages of the species, the habitat score for an area should reflect the most favorable conditions which occur during the year. This was expressed by calculating the maximum of the habitat suitability values among the seasons examined. On the other hand, plants or sedentary animals such as mussels, oysters, or clams are exposed to the entire range of conditions occurring within that area during the year; for these species habitat suitability may best be represented by a combination of seasonal values, or even the minimum or most stressful set of conditions.

Habitats which were relatively specialized and scarce (e.g., spawning habitats for some fishes) were combined with coverages for other life stages by using a maximum function, to insure the recognition of highest habitat valuation. The specifics of mapping are described in the narrative for each species. The figures in Appendix A display habitat suitability for each individual species.

Combining Habitat Maps for Groups of Species

The digital habitat maps were aggregated in two ways; to identify regionally important habitats and to identify locally important habitats. The former incorporated, in addition to habitat suitability, a measure of each species' importance derived from the GOMC criteria. Application of the criteria produced a set of scores based on characteristics of each species. Habitat for the highest scored species on the GOMC list was regarded as more important than equivalent habitat for a species with lower score. These scores were, in fact, used to index the values for the final map of regionally important habitats. Since local interests expressed little enthusiasm for the regional importance of the species, this index was not applied when producing maps for local conservation purposes.

The map of regionally important habitats was created from habitat maps for the top ranked GOMC species. We indexed their GOMC scores (see Table 1) on a 1 to 10 basis, then multiplied their habitat suitability values by that index and added the products on a cell by cell basis. The index values represent the species' scores in relation to the full range of scores for the GOMC list (18 to 66); they are presented in Table 3. The resulting map of regionally important habitats is presented as Figure 3.

Table 3. Index Values Representing Regional Importance; Applied to Top Ranked Gulf of Maine Council Species

GOMC SPECIES	INDEX OF SCORES (1 - 10)
Irish moss	9.96
soft shelled clam	9.96
tufted red weed	9.25
rockweed	9.08
Atlantic salmon	9.03
winter flounder	8.94
eelgrass	8.77
blue mussel	8.73
American shad	8.33
cordgrass	8.25
pollock	8.23
American lobster	8.06

The relative abundance of habitats or habitat components is generally of concern to conservationists, and was actually a ranking factor in creation of the GOMC list. Abundance or scarcity is related to risk; the impact on great blue herons, for example, from loss of one acre of nesting habitat is almost certainly more severe than from loss of one acre of the far more abundant feeding habitat. Local abundance or scarcity of habitat(s) was regarded as relevant to the local importance of habitats. It is not proportional to regional abundance, and so this factor was not used for creating the regional map.

To map locally important habitats (for all species, since the GOMC species also were regarded as locally important), we multiplied the habitat suitability values by an index representing the respective relative scarcity of each habitat within the study area. This was calculated from the extent of habitat for each species or stage, divided by the extent of the most abundant habitat. Relative scarcity was calculated by life stage or habitat function, where more than one of these was mapped (e.g., reproductive, juvenile, and adult habitats for some fishes; multiple habitats for black ducks). Thus, relatively rare habitat components could be highlighted, even where the overall habitat for a species might be extensive, or where some components were not mapped for all species. This index, also on a 1 to 10 basis, is enumerated in Table 4. The products (scarcity index times habitat suitability values) were summed on a cell by cell basis. The resulting locally important wetland and deepwater habitats are displayed in Figure 4.

Table 4. Index Values Representing Relative Scarcity of Habitats; Applied to all Species for Mapping Locally Important Habitats
(1 = most abundant: 10 = most rare)

SPECIES/STAGE	CELLS	ACRES	INDEX (1 TO 10)
Irish moss	786	159	10
soft shelled clam			
adult	37903	7658	8.4
reproductive	34555	6981	8.5
tufted red weed	311	63	10
rockweed	1011	204	10
Atlantic salmon	547	111	10
winter flounder			
adult	51444	10394	7.8
juvenile	51521	10409	7.8
reproductive	21512	4346	9.1
eelgrass	10709	2164	9.5
blue mussel	15710	3174	9.3
American shad			
larval/juvenile	8240	1665	9.6
reproductive	1389	281	9.9
cordgrass	2110	426	9.9
pollock	54135	10937	7.7
American lobster			
adult	21571	4358	9.1
juvenile	4952	998	9.8
reproductive	0	0	-
river herring			
reproductive	2194	443	9.9
juvenile	10197	2060	9.6
bald eagle	363	73	10
striped bass	55286	11170	7.6
common tern			
nesting	1418	286	9.9
feeding	86252	17426	6.3
rainbow smelt			
reproductive	2341	473	9.9
adult/juvenile	54174	10945	7.7
black duck			
breeding	209470	42321	1
brood rearing	209470	42321	1
migration	209477	42322	1
wintering	11822	2388	9.5

SPECIES/STAGE	CELLS	ACRES	INDEX (1 TO 10)
Canada goose			
migration	132439	26758	4.3
wintering	19612	3962	9.2
great blue heron			
nesting	618	125	10
feeding	206028	41625	1.1
tomcod			
adult	47975	9693	7.9
juvenile	47975	9693	7.9
reproductive	36958	7467	8.4
Atlantic silversides			
adult	55280	11169	7.6
reproductive	15286	3088	9.3
salt meadow hay	31146	6293	8.7
smooth flounder			
adult	57142	11545	7.5
juvenile	51797	10465	7.8
reproductive	19490	3938	9.2
American oyster	3036	613	9.9
TOTAL STUDY AREA	1182747	238959	
MOST ABUNDANT HABITAT	209875	42403	

Environmental Themes

Certain environmental data sets were used as base maps or layers when modeling habitats, or to delineate occurrences as habitats. These include bathymetry, temperature and salinity, and substrate of coastal waters. Landcover and vegetation maps also were essential for this analysis; these are described in the following sections.

Bathymetry

Bathymetry information is particularly critical for modeling habitats of coastal organisms. While many fishes and invertebrates have preferences and limitations regarding water depth, it is the actual exposure and submergence of intertidal habitat which controls the penetration of land-based and marine plants and animals into the adjacent domain. The location and extent of this intertidal zone is based on bathymetry and tide range.

A GIS bathymetry coverage of Great Bay and Little Bay was obtained from New Hampshire GRANIT. This had been based on a survey by the Jackson Estuarine Laboratory. It was found that, in processing the original point data, locations were generalized, and thus the coverage accuracy considerably degraded. We were able to replace the processed values for Great Bay with the original point data, obtained from Dr. Carl Friedrichs of Virginia Institute of Marine Science. An extensive series of sounding was obtained from the U.S. Army Corps of Engineers for the Piscataqua River and for Hampton Harbor. Point data also were obtained from NOAA (Hydrographic Survey Data on CD-ROM) for all of coastal New Hampshire.

We digitized contour lines from NOAA charts to supplement the point data, particularly along edges of tributary channels. Bathymetric data was lacking for the head of tide portions of the Salmon Falls and Squamscott Rivers, for Sagamore Creek and for Spinney Creek; aerial photos show subtidal conditions for these areas, and so they were arbitrarily designated -3' mean low water (mlw) in depth.

Few soundings were available for intertidal areas, particularly approaching the elevation of high tide. As an estimate of bathymetry for nearshore areas we interpreted shoreline and marsh attribute information from National Wetland Inventory (NWI) digital maps. Mean high water for Great Bay is between +7 and + 8 feet, mlw. Therefore, NWI polygons designated as upland were assigned an elevation of +10 feet mlw; freshwater marshes contiguous with tidal waters were given a value of +9'; irregularly flooded salt marsh was assumed to be + 8 feet (at and above mean high tide), regularly flooded ("low") marsh was assigned an elevation of +4 feet. This NWI interpretation was used to "mask" the irregular outer boundary of the interpolated data. The combined point and line data were used to generate a triangulated irregular network (TIN) in ARCINFO, and the TIN used to create a lattice (grid-cell coverage). The lattice was created with the same cell dimension (93.493 feet) as the GRANIT landcover grids, for all tidal waters within the study area. Depths were calculated as integer values in feet below mean low water.

Temperature and Salinity of Coastal Waters

Temperature and salinity levels are important in determining the distribution of estuarine and marine fishes and invertebrates. We had to decide on the methods for characterizing these dynamic environmental parameters. Both vary continuously, and so may be expressed as averages or range of the extremes over some period or interval. Adverse or extreme events are not likely to be predictable and thus difficult to deal with when modeling habitats. Instead, we characterized salinity and temperature conditions as the average of values during winter, spring, summer and fall. This was relatively practical, but obscured effects from severe short term events and from annual variations.

Our calculations were based on field measurements by Great Bay Watch, the Jackson Estuarine Laboratory, Normandeau Associates (Seabrook Environmental Studies 1995), New Hampshire Department of Public Health Services, and ourselves. Data spanned 1976 through 1996, and were most complete for the period after 1992, for April through November. Long term records of temperatures and salinities existed for the Jackson Laboratory site and for the Seabrook power plant; these were used to calculate seasonal averages and variation. For each parameter and each season we selected "typical" years, in which salinity and temperature values were close to the long term averages. We calculated the deviation of values for the selected years from the long term means, and used this to normalize records from each of the outlying field stations (applied as a ratio for salinity, addition or subtraction of the difference for temperature).

Several of the field stations had only partial records for the period January through March. We selected surrogate stations with complete records and used these to interpolate winter values for the former based on the relationship of other temperature and salinity readings for the two stations. Thus, if the station without data for winter had .85 the salinity of the surrogate based on an average of the spring and fall measurements, the value assigned was .85 times that of the surrogate's winter values. In order to extend the analysis to the outer boundaries of the study area we assigned measured values from the most comparable stations to heads of tide and to the ocean.

The resulting information was assigned to a point coverage of stations. Coverage attributes were mean temperatures and salinities for each season. These values were spatially interpolated in ARCINFO as a triangulated irregular network (TIN), which was used to generate a grid cell coverage, compatible with the other data layers.

Substrates of Great Bay and the Seabrook/Hampton Estuary

As substrates we include intertidal and subtidal benthic features such as rock and shell, sediments, and associated macro-vegetation. These form the structure to which invertebrates may attach, or into which they may burrow, and which can offer cover or spawning habitat for a number of fish species.

Substrate data for Great Bay were obtained primarily from NOAA's National Estuarine Inventory (Nichols, 1993). We digitized polygons representing the extents of sediment types from NOAA paper maps, but used NWI digital maps to form the upland or marsh boundaries. The NOAA information extended throughout Great Bay, Little Bay, and the Piscataqua River down to about I-95 bridge. The original sediment sample points (Armstrong 1974 and Capuzzo and Anderson 1973) were examined when interpreting polygon boundaries. We labeled Spinney Creek, a semi-impounded tributary, as having clayey silt, based on reduced flow. Modifications and additions also were made based on comments from John Nelson, NHF&G.

Sediments in the Seabrook/Hampton Estuary were interpreted from NWI digital data, basing this on hydrographic features common to this area and Great Bay, and also from on-site observations. Thus, deep channels with strong tidal currents were labeled as having sand and gravel bottoms; bars and outwash fans at the mouths of tidal channels as silty sand; basins where currents were reduced as sandy silt; flats at sides of major channels as sand/silt/clay; smaller tidal marsh channels as clayey silt.

In both Great Bay and Seabrook/Hampton Estuary we identified rocky substrates from a GIS coverage of sites having attached macro-algae. We mapped shell substrates using oyster and blue mussel occurrences, saltmarshes were derived from NWI, and eelgrass vegetation was added as a substrate 'modifier' from an eelgrass coverage. Those sources are described in more detail in subsequent chapters.

Landcover, Hydrology and other Basemaps

Wetlands

National Wetlands Inventory maps delineate and characterize freshwater and coastal wetlands and deepwater habitats as small as about 40 feet in width, and to about .25 acre in area. NWI maps are prepared primarily by stereoscopic analysis of high altitude aerial photographs, and are classified using a system described in Cowardin et al. 1979. We used NWI digital map products. When assembling coverages for particular species we selected wetlands according to the NWI attributes of vegetative structure, the system they were associated with, and their flooding regime.

The Great Bay Aerial Salt Marsh Mapping Project (Ward et al. 1991) mapped marshes and intertidal algae vegetation in Great Bay and the Piscataqua River. This was obtained as a digital coverage from New Hampshire GRANIT. The Salt Marsh Mapping Project polygons had been digitized with greater precision (original photography 1:12000), but lower spatial accuracy than NWI information. We adjusted ('rubber sheeted') the former by overlaying it on a registered color infrared image mosaic (see below).

Landcover

We obtained digital landcover from New Hampshire GRANIT. The coverages had been classified from satellite imagery and had a suitable cell size, assortment of classes, and spatial extent for our analysis. We used the 'active agriculture' class when mapping habitat for Canada geese.

Aerial Photography

Small scale (~ 1:58,000) aerial photos of the study area were obtained from the EROS Data Center (NAPP and NHAP). We obtained 1:12,000 and 1:9,000 scale color infrared photos of Great Bay from L. Ward, Jackson Estuarine Research Laboratory, and of southern New Hampshire from Normandeau Associates, respectively. The photos were scanned, then the digital products were geo-referenced and rectified by overlaying them on digital coastline, wetlands, and roads coverages. The images then were assembled into mosaics which served as a base for mapping shallow water features and for spatially adjusting an existing coverage of Great Bay wetlands and algae.

Other Basemaps

Other digital layers (coastline, roads, ponds and streams, political boundaries) were obtained from New Hampshire GRANIT and used as spatial references in mapping and analysis.

Habitat Themes

Following are narratives describing the specifics of the habitat analysis, by species. Habitat for each species is portrayed in a specific figure in Appendix A.

Algae GIS Habitat Mapping

Irish moss (*Chondrus crispus),* tufted red weed *(Mastocarpus stellata)* and rockweed, *(Ascophyllum nodosum)* are three species of macroalgae common to Gulf of Maine marine and estuarine intertidal areas. These plants often occur in adjacent stands. Their distribution is influenced by tidal elevation, salinity, wave energy, exposure to ice, and substrate. While all three typically grow adhering to rocky substrate, a form of rockweed (*ecad scorpioides*) grows in saltmarshes, over organic and sandy soils. These species are of major ecological importance as cover or structure for fishes, birds, and invertebrates, and as primary producers of organic matter for coastal food chains; they also are of commercial importance as food and sources for pharmacologic products.

Algae habitat was identified from observations by Mathieson and Fralick (1972) and Mathieson and Hehre (1986); these data were supplied to us by A. Mathieson in a tabulated format, by species, with coordinates and descriptions of stations. We used the coordinates to produce a GIS point coverage, then verified or manually relocated the points (on 1:24,000 coastline base maps) to best correspond to the narrative descriptions. We were advised that the points represented the general locations of patches of algae.

The Great Bay Aerial Salt Marsh Mapping Project (Ward et al. 1991) delineated intertidal algae vegetation in Great Bay and the Piscataqua River, by aerial photo-interpretation. We used scanned copies of the original photos to screen-digitize additional algae polygons within our study area. Unlike the point occurrences, these polygons were not identified by species. On the other hand, the polygons showed the actual boundaries of the vegetated areas. We used GIS procedures to select polygons within 200' of the above point locations, then identified those polygons on the basis of the nearest point occurrence. The combined final coverage was converted to a grid-cell format. Each point occupies one cell, or about 0.2 acres, while polygons converted to clusters of cells. All were assigned a habitat quality score of 10 (0 to 10 scale) since the actual presence of the species demonstrated the suitability of conditions.

Softshell Clam GIS Habitat Model

Softshell clam, *Mya arenaria,* are harvested recreationally in coastal New Hampshire, and are ecologically important as filter feeders and as a food source for other invertebrates, fishes, and birds. The following tables are components of a model to map clam habitat. Most of the information was compiled by Brown et al. (unpub.) from the other sources listed; the model was adjusted to fit conditions occurring at known clam beds in Great Bay and the Hampton/Seabrook Estuary. Known clam beds were digitized from maps by New Hampshire Fish and Game (Nelson et al. 1981, 1982), Normandeau Associates (1995) and from sites drawn on base maps for us by R. Langan (Jackson Estuarine Research Laboratory).

The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable.

Suitability is calculated for each season, to accommodate annual changes in salinity and temperature. Habitat values for reproductive and for larval/spat stages were computed as the most favorable conditions which occur in either spring or summer. Habitat values for adult and juvenile stages were computed as the geometric mean of suitability index values for all four seasons, since clams cannot escape persistently unfavorable conditions. The extent of reproductive habitat then was reduced in order to correspond to areas having adult habitat values of at least 2.5 (out of a possible 10). Since habitat for larvae and spat appeared to be widely abundant, overall habitat was regarded as the maximum value from either reproductive or adult habitat maps.

SUBSTRATE PREFERENCES

Sources: Brown et al., unpub., Fefer & Schettig 1980, Newell and Hidu 1986.

Substrate Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition

LARVA/SPAT	
clayey silt	1
silt	1
sand/silt/clay	5
sandy silt	1
silty sand	5
Sand and gravel	5
rock/shell	9
eelgrass	10

ADULT/JUVENILE, REPRODUCTION	
clayey silt	2
silt	1
sand/silt/clay	10
sandy silt	5
silty sand	10
Sand and gravel	1
rock/shell	1

eelgrass	[regarded as same value as underlying sediment]

SALINITY PREFERENCES
Sources: Brown et al., unpub., Fefer & Schettig 1980, Newell and Hidu 1986, Stickney 1959.
Salinity (ppt) Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition

LARVA/SPAT

0 to 14	0
14 to 16	5
16 to 32	10
32 to 35	8

ADULT/JUVENILE

0 to 3	0
3 to 5	1
5 to 15	3
15 to 20	5
20 to 35	10

REPRODUCTION

0 to 9	0
9 to 16	1
16 to 20	7
20 to 35	10

TEMPERATURE PREFERENCES
Sources: Brown et al., unpub., Fefer & Schettig 1980, Kennedy and Mihursky 1971, Newell and Hidu 1986.
Temperature (C) Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition

LARVA/SPAT

10 to 13	3
13 to 18	5
18 to 22	10
22 to 23	5
23 to 24	1

ADULT AND JUVENILE

-1 to 3	1
3 to 9	5
9 to 12	7
12 to 19	10
19 to 21	5
21 to 29	1

REPRODUCTIVE

-1 to 9	0
9 to 10	1
10 to 15	5
15 to 21	10
21 to 23	7

23 to 25	1
26 to 30	0

DEPTH PREFERENCES

Sources: Brown et al., unpub., Fefer & Schettig 1980, Newell and Hidu 1986, Stickney 1959.

Depth (feet, mlw*)	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
LARVA/SPAT	
+8 to +6	2
+6 to 0	5
0 to -70	10
ADULT AND JUVENILE	
+8 to +5	0
+5 to +3	1
+3 to +2	3
+2 to -1	10
-1 to 9	1
9 to 30	0
REPRODUCTIVE	
+8 to +5	0
+5 to +3	1
+3 to +2	3
+2 to -1	10
-1 to 9	1
9 to 30	0

Atlantic Salmon GIS Habitat Mapping

Atlantic salmon, *Salmo salar*, historically were a premier recreational and food fish species in New England. Overharvest, degradation of water quality and obstruction of streams has caused a drastic decline, which has been only partly corrected by stocking of young fish and construction of some fishways. Following is a description of life stages, and the information for mapping existing salmon habitat in the study area.

Danie et al. (1984) provides the following summary of salmon life history. Atlantic salmon ascend freshwater streams to spawn on gravel substrate from mid-October to mid-November. In Maine, eggs incubate for 175 to 195 days depending on water temperature, and hatch in April or early May. After hatching, the 15 mm long yolk-sac larvae (alevins), remain buried in the gravel depressions for up to 6 weeks while absorbing the yolk-sac for nourishment. The resulting 25 mm long fry begin foraging for themselves and emerge, usually at night, from the gravel depressions. Larger freshwater juveniles (parr) will remain in riffle sections of streams until they are 125-150 mm in length, which may take from 2 to 3 years. Failure to attain this length by spring or early summer of the year, will prevent parr from transforming into smolts (seaward migrating juveniles). After attaining this critical length, parr undergo smoltification which includes physical and physiological changes adaptive to a migration to a marine environment. The parr marks disappear and the skin develops a silvery pigmentation from deposition of guanine in the skin, the tail lengthens and becomes more deeply forked, and schooling behavior develops. Increases in water temperature and water level trigger downstream migration of smolts. Smolts from the western Atlantic migrate, within 3 m of the surface of the ocean, to feeding areas in the Davis Strait between Labrador and Greenland. Atlantic salmon will return to natal rivers to spawn after 1 (grilse) or 2 (bright salmon) years at sea. Salmon accumulate in estuaries, bays, and river mouths, before ascending streams. Upstream migration of salmon coincides with increases in water flow. Adult salmon do not feed while in freshwater. Atlantic salmon do not consistently die after spawning, and many spent fish (kelts) survive the winter in freshwater and begin to feed again. Mortality is high when kelts enter saltwater. Those kelts that survive and migrate to feeding grounds in the Davis Strait, may become repeat spawners.

Mapping of Habitat

Because obstructions on tributary streams prevent upstream migration of Atlantic salmon in the study area, we did not specifically map spawning habitat. Salmon fry are stocked in tributaries of the Cocheco and Lamprey Rivers where habitat is suitable for juvenile salmon. The goal of these stocking efforts is to provide angling opportunity downstream, from returning adult fishes. Our mapping of juvenile habitats was based on NHF&G stream surveys; we selected polygons from NWI digital maps which corresponded to areas delimited by Douglas Grout (NHF&G). These areas were scored 10 (0 - 10 scale) since they are known to satisfy environmental requirements of juvenile salmon.

Winter Flounder GIS Habitat Model

The winter flounder, *Pleuronectes americanus,* is an important bottom fish for commercial and recreational harvest. Populations have declined significantly in the Gulf of Maine due to overfishing. The following tables are components of a model to map winter flounder estuarine habitats. The information was compiled from summaries by Buckley 1989, and by Brown et al. (unpub.), and by examination of conditions associated with collection sites in Great Bay and the Seabrook/Hampton estuary.

The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Suitability is calculated for each season, to accommodate annual changes in salinity and temperature.

Habitats were mapped based on needs of juveniles, adults, and of reproductive and larval stages. Winter flounder occur in New Hampshire estuaries throughout the year and are mobile, thus able to avoid seasonally unsuitable conditions. Accordingly, juvenile and adult habitats were based on the average of suitability values for each of four seasons. The reproductive/larval habitats were mapped as the maximum or most favorable score of either winter or spring, in consideration of some flexibility in the timing of reproduction. We noted that our winter and spring 'typical' temperature data bracketed the conditions favorable for spawning; since optimal temperatures must occur somewhere between the onset of winter and end of spring we dropped temperature as a variable for the winter flounder reproductive/larval stage. Winter flounder overall habitat was mapped as the maximum score for either juvenile, adult, or reproductive/larval habitat. This ensures valuation for habitats which may support stages from and into which the species may migrate to other coastal areas.

SUBSTRATE PREFERENCES

Sources: Armstrong 1995, Bigelow and Schroeder 1953, Buckley 1989, Brown et al., unpub., Tort 1993, MacDonald et al. 1984.

Substrate	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
ADULT AND JUVENILE	
clayey silt	1
silt	1
sand/silt/clay	4
sandy silt	2
silty sand	10
Sand and gravel	8
rock/shell	1
eelgrass	7
REPRODUCTION, LARVAE	
clayey silt	0
silt	0
sand/silt/clay	1
sandy silt	0

silty sand	10
sand and gravel	10
rock/shell	1
eelgrass	1

SALINITY PREFERENCES
Sources: Brown et al., unpub., Buckley 1989, Rogers 1976, Tort 1993, Targett & McCleave 1974, MacDonald et al. 1984.

Salinity (ppt)	**Suitability Index: 0 to 10 scale, 0 = unsuitable, 10 = optimal condition**
ADULT	
0 to 8	0
8 to 10	1
10 to 14	4
14 to 35	10
JUVENILE	
0 to 8	0
8 to 10	1
10 to 14	4
14 to 35	10
REPRODUCTION, LARVAE	
0 to 5	0
5 to 15	1
15 to 25	8
25 to 35	10

TEMPERATURE PREFERENCES
Sources: Brown et al., unpub., Casterlin and Reynolds 1982, Tort 1993, Buckley 1989, McCracken 1963, Van Guelpen and Davis 1979, Rogers 1976, Targett and McCleave 1974.

Temperature (C)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
ADULT	
-1 to 0	1
0 to 1 1	5
11 to 15	10
15 to 21	5
21 to 26	1
JUVENILE	
-1 to 7	1
7 to 12	5
12 to 19	10
19 to 22	5
22 to 27	1
REPRODUCTION, LARVAE	
-1 to 0	1

0 to 1	5
1 to 5	10
5 to 6	5
6 to 10	1
10 to 28	0

DEPTH PREFERENCES
Sources: Brown et al., unpub., Buckley 1989, McCracken 1963, Van Guelpen and Davis 1979, MacDonald et al. 1984.

Depth (feet, mlw*)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
ADULT	
+8 to 6	0
6 to 0	2
0 to -9	5
-9 to 150	10
150 to 300	5
300 to 600	1
JUVENILE	
+8 to 0	0
0 to -30	10
-30 to 60	5
60 to 150	1
REPRODUCTION, LARVAE	
+8 to 0	0
0 to -30	10
-30 to 60	5
60 to 150	1

Eelgrass GIS Habitat Mapping

Eelgrass (*Zostera marina) is a* submergent vascular plant typically growing in subtidal inshore waters along the middle and northern Atlantic seaboard. It requires a muddy to sandy sediment, which is usually associated with moderate water currents and limited wave action. Eelgrass beds serve as structure and cover for marine and estuarine vertebrates and invertebrates, and as a primary producer of organic matter. Short (1992) documented the value of eelgrass to the Great Bay ecosystem.

DATA SOURCES: Dr. Fred Short (Jackson Estuarine Research Laboratory) provided us with a coverage of eelgrass beds in Great Bay based on 1990 photography, and a hard copy map of additional areas in the Piscataqua River mapped from a 1995 field survey. We obtained a coverage of eelgrass in the Piscataqua River produced by Seth Barker (Maine DMR), based on true color 1992 to 1995 1:12,000 aerial photos. We also digitized a map depicting eelgrass beds in Great Bay, Little Bay, and the Piscataqua River from 1980-1981 surveys by New Hampshire Fish and Game. The F. Short 1995 map and the Fish and Game maps were scanned, registered, and clipped to avoid overlap with uplands/intertidal wetlands and areas over 30' deep.

MAPPING OF HABITATS: Our eelgrass coverage was created by combining data from the above sources, updating or replacing older polygons representing specific eelgrass beds with the most accurate sources. Most of the polygons from the oldest surveys were matched with and replaced by polygons from the other coverages. The 1980-1981 survey mapped extensive eelgrass beds in Little Bay; these beds have been absent or greatly reduced in recent years (F. Short, pers. comm.), and so we did not regard them as currently suitable habitat. They were retained for reference in an intermediate coverage. The final habitat coverage included all polygons from the F. Short 1990 coverage and the S. Barker coverage, and polygons from the F. Short 1995 map which were not represented in either of those two coverages.

The polygon coverage was converted to grid-cell format. All cells were assigned a habitat quality score of 10, or optimal habitat, since the actual presence of the species demonstrated the suitability of conditions.

Blue Mussel GIS Habitat Model

The blue mussel, *Mytilus edulis,* is a largely intertidal shellfish common to coastal waters of the middle and north Atlantic. It is commercially harvested and cultivated in the Gulf of Maine, and forms reefs which serve as as structure for fishes and invertebrates. Mussels are an important prey of fishes and birds, particularly waterfowl. The following tables are components of a model to map blue mussel habitat. Information was compiled from summaries by Newell 1989, and by examination of conditions associated with known mussel beds in Great Bay. Known mussel beds were digitized from maps in Nelson et al. (1981, 1982) and from sites drawn on base maps for us by Richard Langan (Jackson Estuarine Research Laboratory). We also located and mapped beds by field survey, using GPS to determine spatial coordinates.

The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid-cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Suitability is calculated for each season, to accommodate annual changes in salinity and temperature.

Habitats were mapped for conditions needed by juveniles and adults, for reproduction, and for larval stages. The latter included planktonic stages and settlement of larvae onto a substrate. Because juvenile and adult mussels are sessile and cannot avoid adverse temperatures or salinities, their habitat suitability values were computed as the geometric mean of values for all four seasons. An area that was completely unsuitable for any season would, therefore, register as unsuitable on the habitat map. The reproductive/larval habitats were mapped as the maximum or most favorable score of either spring or summer, in consideration of the flexibility in the timing of reproduction. The substrate limitations on juvenile and adult habitat restrict the value of habitats which might otherwise be useful to larvae. Therefore, overall habitat was mapped as the geometric mean of the combined juvenile/adult habitat and the combined reproductive adult habitat. This gives maximum scores to areas which are suitable for both stages, moderate value to areas which are at least useful to both stages, and no value to areas which are unsuitable for either stage.

SUBSTRATE PREFERENCES

Substrate	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
ADULT AND JUVENILE	
clayey silt	0
silt	0
sand/silt/clay	0
sandy silt	0
silty sand	3
Sand and gravel	5
rock/shell	10
eelgrass	0
REPRODUCTION, LARVAE	
clayey silt	0
silt	0

sand/silt/clay	0
sandy silt	0
silty sand	3
Sand and gravel	3
rock/shell	10
eelgrass	10

SALINITY PREFERENCES

<u>Salinity (ppt)</u> <u>Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition</u>

Salinities between 5 and 15 ppt are tolerated by adults and juveniles for relatively short periods; in the study area mussels only survive the year within areas having 'typical' salinities above 15 ppt for all 4 seasons.

ADULT AND JUVENILE,

0 to 15	0
15 to 18	5
18 to 35	10

REPRODUCTION AND LARVAE

0 to 15	0
15 to 18	2
18 to 35	10

TEMPERATURE PREFERENCES

<u>Temperature (C)</u> <u>Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition</u>

ADULT AND JUVENILE

-1 to 5	1
5 to 12	6
12 to 20	10
20 to 26	8
26 to 28	1
28 to 32	0

REPRODUCTION, LARVAE

-1 to 5	1
5 to 10	4
10 to 20	10
20 to 22	5
22 to 26	1
26 to 32	0

DEPTH PREFERENCES

<u>Depth (feet, mlw*)</u> <u>Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition</u>

ADULT AND JUVENILE

+8 to 4	3
4 to -6	10
-6 to 18	7
18 to 30	1
30 to 90	0

REPRODUCTION, LARVAE

+8 to 4	3
4 to -90	10

American Shad GIS Habitat Model

American shad (*Alosa sapidissima*) is an anadromous clupeid fish, ranging from Florida to the St Lawrence River. It formerly was abundant enough to be of major importance as a food source; dams and degradation of water quality in spawning rivers have greatly reduced historic runs. We mapped shad habitat using a combination of occurrence (known use) information and habitat relationships to environmental features.

SPAWNING HABITAT

Shad ascend freshwater tributaries and spawn in slow-flowing sections of rivers (Scott and Scott 1988). Spawning occurs at water temperatures < 23 degrees C. (Scott and Scott 1988) and > 10 degrees C. (Leim 1924, Williams and Daborn 1984 cited in Scott and Scott 1988). Shad spawn in Canadian tributaries between May and July (Scott and Scott 1988). Because of the paucity of other information on spawning habitat requirements of American shad, we mapped spawning habitat only from known occurrences (D. Grout, New Hampshire Fish and Game Department). These areas were scored as 10 (0 - 10 scale) since they in fact must meet shad environmental requirements.

LARVAL HABITAT

Shad eggs are pelagic and are carried downstream by the current (Weiss-Glanz et al. 1988). Incubation time of eggs is dependent on water temperature (Scott and Crossman 1973, Marcy 1976). Eggs cease developing at water temperatures of 7 degrees C. and abnormalities occur at 22 degrees C. (Leim 1924). Eggs and larvae survive in water at salinities between 7.5 and 15 ppt, but mortality occurs when salinity reaches 22.5 ppt (Leim 1924). The salinity regime in which eggs hatch successfully remains unclear (Weiss-Glanz et al. 1988). At hatching, larvae are approximately 7 mm total length (TL) and are planktonic (Marcy 1976), and grow to 12 mm TL when the yolk-sac is absorbed (Jones et al. 1978). Transformation to the juvenile stage occurs at 25 - 28 mm TL at 2 - 3 weeks of age (Jones et al. 1978).

Distribution of larval habitat was mapped only within rivers where spawning is known to occur. Habitat was regarded as those reaches having salinities < 15 ppt during the spring season (April - June). These were given a score of 7.5 (0 - 10 scale) since actual presence of larvae has not been documented. The paucity of information on other environmental requirements prevented development of a more rigorous model.

JUVENILE HABITAT

Juveniles occur in natal rivers during summer (Weiss-Glanz et al. 1988). Decreasing water temperature is the stimulus for downstream movement of juveniles into brackish water and finally to the sea (Weiss-Glanz et al. 1988). Because of the paucity of information on juvenile habitat requirements, we mapped early juvenile habitat as only those sections of rivers where they have been collected (D. Grout, NHF&G). These areas were scored as 10 (0 - 10 scale) since they in fact must satisfy shad environmental needs. Clearly, environmental requirements and tolerances change as juveniles migrate from freshwater nursery areas to the sea.

COMBINED HABITATS

The above spawning, larval and juvenile habitat information was combined into a grid-cell coverage of overall habitat for American shad, using the maximum value from any of the stages on a cell by cell basis.

Cordgrass and Salt Hay GIS Habitat Models

Smooth cordgrass (*Spartina alterniflora)* and salt hay, *(S. patens)* occur in estuarine areas along the New Hampshire coast. These vascular plants often grow in adjacent stands, or grade from one into the other, based on soil elevation, permeability, and salinity. Both species are of major ecological importance as habitat for fishes, birds, mammals, and invertebrates, and as primary producers of organic matter for coastal food chains. In the current context their habitats are appraised in terms of their suitability for growth of these plants; other aspects are considered in the analyses for fish and wildlife species which rely on the plant communities.

DATA SOURCES: Cordgrass habitat was identified from the actual persistent occurrence of the plants. Marsh vegetation of coastal New Hampshire has been mapped from aerial photography by National Wetlands Inventory (NWI). The Great Bay Aerial Salt Marsh Mapping Project (Ward et al. 1991) mapped marsh and algae vegetation of Great Bay and the Piscataqua River. Digital coverages were obtained of both data sets from NWI and from New Hampshire GRANIT, respectively.

MAPPING OF HABITATS: Polygons designated by NWI as estuarine intertidal emergent were selected, then attributed to *S. alterniflora* or *S. patens* according to the NWI modifiers. Those areas NWI characterized as 'regularly flooded' were regarded as *S. alterniflora*; those designated 'irregularly flooded' were labeled *S. patens*.

We selected the more detailed Salt Marsh Mapping Project polygons and used these to supplement or replace the corresponding NWI polygons. Vegetation was designated as *alterniflora* or *patens* according to configuration and location. Polygons that were long and narrow (area / perimeter < 40) were mostly fringing or linear features, dominated by the low marsh species *S. alterniflora*. The wider polygons in saline portions of the estuary were identified as high marsh, predominantly *S. patens*.

The combined polygon coverage was converted to a grid-cell format. All cells were assigned a habitat quality score of 10, or optimal habitat, since the actual presence of the species demonstrated the suitability of conditions.

Pollock GIS Habitat Model

The pollock, *Pollachius virens,* is a gadid (cod-like) fish, typically found in deep waters of the Gulf of Maine south to the Carolinas. Pollock are harvested commercially, with a limited recreational fishery. The following tables are components of a pollock habitat model, based on information compiled from the literature and by examination of conditions associated with fish collection sites in Great Bay (Nelson et al. 1981).

The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid-cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Suitability is calculated for each season, to accommodate annual changes in salinity and temperature.

Only juvenile pollock ("harbor pollock") are found in relatively shallow inshore waters, such as Great Bay and the Seabrook/Hampton estuary. Habitats were mapped for conditions needed by juveniles during the spring, summer and fall of the year. Since this fish is highly mobile and able to avoid seasonally unsuitable conditions, habitat values were based on the maximum or most favorable score of these seasons.

SUBSTRATE PREFERENCES
Sources: MacDonald et al. 1984, Ojeda and Dearborn 1990, Rangeley and Kramer 1995a.

Substrate	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
clayey silt	3
silt	3
sand/silt/clay	7
sandy silt	5
silty sand	10
Sand and gravel	10
rock/shell	9
eelgrass	7

SALINITY PREFERENCES
Sources: MacDonald et al. 1984, Rangeley and Kramer 1995b.

Salinity (ppt)	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
0 to 6	0
6 to 9	1
9 to 13	2
13 to 23	5
23 to 26	7
26 to 32	9
32 to 36	10

TEMPERATURE PREFERENCES
Sources: Bigelow and Schroeder 1953, MacDonald et al. 1984, Ojeda and Dearborn 1990, Rangeley and Kramer 1995b, Scott and Scott 1988.

Temperature (C)	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
-1 to 3	0
3 to 4	5
4 to 7	7
7 to 11	10
11 to 18	6
18 to 20	2
20 to 26	1

DEPTH PREFERENCES

Sources: Bigelow and Schroeder 1953, MacDonald et al. 1984, Rangeley and Kramer 1995a.

Depth (feet, mlw*)	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
+8 to 6	0
6 to -6	10
-6 to 70	5

Lobster GIS Habitat Model

The American lobster, *Homarus americanus,* is a decapod crustacean of major commercial importance in the Gulf of Maine. There is a commercial and recreational fishery in Great Bay. The following tables are components of a model to map lobster habitat. Most of the information was compiled by Brown et al. (unpub.) from the sources listed below.

The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid-cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Suitability is calculated for each season, to accommodate annual changes in salinity and temperature.

Habitats were mapped for adult, juvenile, and reproductive stages. The latter included the period during which females carry eggs; the short planktonic stages were assumed not to be limiting. For each stage, habitat suitability values were computed as the geometric mean of values for each of four seasons. Because of the mobility of lobsters, different stages may find required conditions at different localities. Therefore, overall habitat was mapped as the maximum value from either juvenile, reproductive or adult habitat maps.

SUBSTRATE PREFERENCES
Sources: Able et al. 1988, Botero and Atema 1982, Brown et al., unpub., Campbell 1990, Cooper and Uzmann 1980, Wahle 1993, Phillips, Cobb and George 1980, Pottle and Elner 1982, Hudon & G. Lamarche 1989.

Substrate	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
JUVENILE	
clayey silt	0
silt	0
sand/silt/clay	3
sandy silt	0
silty sand	2
Sand and gravel	9
rock/shell	10
eelgrass	5
ADULT, REPRODUCTION	
clayey silt	0
silt	0
sand/silt/clay	3
sandy silt	0
silty sand	3
Sand and gravel	8
rock/shell	10
eelgrass	5

SALINITY PREFERENCES
Sources: Brown et al., unpub., Reynolds and Casterlin 1985, Cooper and Uzmann 1980.

Salinity (ppt)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
JUVENILE	
0 to 11	0
11 to 18	1
18 to 21	3
21 to 35	10
ADULT	
0 to 7	0
7 to 18	1
18 to 21	3
21 to 35	10
REPRODUCTION	
0 to 17	0
17 to 20	1
20 to 26	5
26 to 35	10

TEMPERATURE PREFERENCES

Sources: Brown et al., unpub., Phillips, Cobb and George 1980, Reynolds and Casterlin 1979, Reynolds and Casterlin 1985, Phillips and Sastry 1980.

Temperature (C)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
JUVENILE	
0 to 2	0
2 to 5	1
5 to 7	5
7 to 20	10
20 to 25	5
25 to 28	1
28 to 32	0
ADULT	
-1 to 5	1
5 to 7	5
7 to 20	10
20 to 25	5
25 to 28	1
28 to 32	0
REPRODUCTIVE	
-1 to 7	0
7 to 15	10
15 to 20	5
20 to 32	0

DEPTH PREFERENCES

Sources: Brown et al., unpub, Campbell 1990, Ojeda and Dearborn 1989, Phillips, Cobb and

George 1980.

Depth (feet, mlw*)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
JUVENILE	
+8 to 0	0
0 to -6	5
-6 to 300	10
300 to 700	5
ADULT, REPRODUCTIVE	
+8 to 0	0
0 to -9	5
-9 to 20	7
20 to 700	10

Canada Goose GIS Habitat Model

The Canada goose, *Branta canadensis*, is a large and abundant waterbird of the Atlantic coastal flyway. Although resident populations have been increasing in the Northeast, migratory birds still are important to hunters. The Atlantic coast migratory population of the Canada goose breeds from Labrador and Newfoundland to Quebec. It now winters largely in the mid-Atlantic states and the Carolinas; those migrating further south have been reduced to 10% of the pre-1960's levels (Malecki et al. 1988). Changes in agricultural practices (larger fields, more corn fields), milder winters, and creation of new wildlife refuges have encouraged the altered migration patterns. The extreme form of this "shortstopping" behavior is the development of resident (non-migratory) populations. In Canada's St. Lawrence valley, goose numbers and length of stay during spring and fall "staging" also has increased with the introduction of corn culture and heavy spring flooding (Reed et al. 1977).

In addition to the geographic shift, the birds now feed more commonly on uplands than occurred historically (Malecki et al. 1988). Canada geese classically fed on moist soil and aquatic plants; this now is supplemented with corn and other upland grains, and pasture plants (Harvey et al. 1988). Geese feed in marshes and fields up to 13 km from water, foraging first in fields adjacent to water (Reed et al. 1977). There they eat farmland grasses/grains (leaves, roots, seeds), sedge tubers, or marsh grass seeds and roost on flooded grasslands, marshes, or open water. Canada geese feed heavily on eelgrass (*Zostera marina*) in shallow offshore waters (Thayer et al. 1984), and on marine algae (Whitlatch 1982).

DATA SOURCES

Since migratory Canada geese do not nest within the study area, we developed simple habitat models to map just migration and wintering habitats. Habitat maps were constructed by operating these models with digital base maps including: bathymetry, NWI wetland types, eelgrass distribution, and landcover (active agriculture).

MIGRATION HABITATS

Mapping of migration habitats was based on availability and types of foraging areas during these seasons. Water depths > 2 feet prevent access to food resources; deep marine and estuarine wetlands were assigned a suitability of 0. We had no data from which to assign various scores for the quality of migration habitat. Therefore, all wetland types potentially used by foraging Canada geese during migration were given a “neutral” value of 5 (0 - 10 scale). This included eelgrass beds and other coastal and interior wetland types (Table 5) within the suitable depth range, and agricultural fields >= 5 acres.

Table 5. Wetland Suitability as Canada Goose Migration Habitat.

NWI CODE	DESCRIPTION	SUITABILITY SCORE (0 - 10)
PEM	Palustrine Emergent	5
L2AB	Lacustrine Littoral Aquatic Bed	5
L2EM2	Lacustrine Littoral Nonpersistent Emergent	5
E2AB	Estuarine Intertidal Aquatic Bed	5
E2EM	Estuarine Intertidal Emergent	5
PAB	Palustrine Aquatic Bed	5
E1UB	Estuarine Subtidal Unconsolidated Bottom	0
E2US	Estuarine Intertidal Unconsolidated Shore	0
M2RS	Marine Intertidal Rocky Shore	0
M2US	Marine Intertidal Unconsolidated Shore	0
M1UB	Marine Subtidal Unconsolidated Bottom	0
PUB	Palustrine Unconsolidated Bottom	0
PUS	Palustrine Unconsolidated Shore	0
L1UB	Lacustrine Limnetic Unconsolidated Bottom	0
PFO	Palustrine Forested	0
PSS	Palustrine Scrub-Shrub	0
R1UB	Riverine Tidal Unconsolidated Bottom	0
R2UB	Riverine Lower Perennial Unconsolidated Bottom	0
R2US	Riverine Lower Perennial Unconsolidated Shore	0
R3UB	Riverine Upper Perennial Unconsolidated Bottom	0
R5UB	Riverine Unknown Perennial Unconsolidated Bottom	0
M2AB	Marine Intertidal Aquatic Bed	0

WINTERING HABITATS

During winter, ice and snow limit availability of freshwater wetlands as foraging habitat, and Canada geese concentrate in Great Bay and Little Bay, and in agricultural fields within 1 km of these tidal waters (pers. comm. Ed Robinson, NHF&G). Although eelgrass beds are unavailable to foraging Canada geese when ice develops on Great Bay, these beds are of vital importance when clear. Therefore, eelgrass beds were given a suitability score of 10 and active agricultural fields within 1 km of Great Bay and Little Bay a score of 5.

The migration and wintering habitat coverages were combined using the maximum score for either function.

American Oyster GIS Habitat Mapping

The American oyster, *Crassostrea virginica*, is a popular shellfish for harvest, and also creates structure for other invertebrates and fishes. The commercial harvest in Great Bay and tributaries is economically significant. Habitats for oysters wer e mapped from locations of known beds. Oyster beds were digitized from maps in Nelson et al. (1981, 1982) and from sites drawn on base maps for us by Richard Langan (Jackson Estuarine Research Laboratory). We field verified locations of many of these beds using GPS to measure their geographic coordinates.

Polygons representing these beds were converted to a grid-cell format and scored 10 (0-10 scale); habitat was regarded as highly suitable based on persistent occurrence of oysters.

Rainbow Smelt GIS Habitat Model

Rainbow smelt, *Osmerus mordax*, is a relatively small freshwater and estuarine fish which is recreationally harvested during its winter spawning migrations. There exists some commercial fishery within Great Bay. Smelt occur from the Canadian Maritime provinces to Massachusetts. The following tables are components of a smelt habitat model. The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Suitability is calculated for each season, to accommodate seasonal changes in salinity and temperature.

Substrate, depth, temperature, and salinity data for the winter (January - March) and spring (April - June) months were used to model spawning habitat. Since the ‘typical’ temperature values we calculated for these seasons bracketed the preferred values, we assumed that suitable temperatures occur in the study area between the onset of winter and end of spring. Therefore, we actually operated our model only on the substrate, depth, and salinity data sets. Spawning habitat suitability values were combined using the maximum suitability score for the winter or spring periods. The maximum suitability score reflects the highest quality spawning habitat available in either period.

Substrate, depth, and temperature data for the winter, spring, summer (July - September) and fall (October - December) months were used to model adult and juvenile habitat. We did not find preferred salinity values or any distinction between habitat requirements for these two life stages, based on a review of the literature, and so used one common model. Habitat quality for the combined juvenile and adult life stages, was computed as the arithmetic mean of habitat suitability values for each of the 4 seasons. Habitat quality for all life stages combined, was computed as the maximum suitability score for spawning, juvenile, and adult life stages.

SPAWNING HABITAT PREFERENCES

SUBSTRATE PREFERENCES

Sources: Hulbert 1974**,** Crestin 1973, comments from NHF&G fishery biologists

Substrate	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
REPRODUCTIVE	
silt	0
sandy silt	0
sand/silt/clay	5
sand and gravel	10
shell and rock	5
silty sand	5
clayey silt	0
cordgrass	0
eelgrass	0
ADULTS, JUVENILES	
silt	5

sandy silt	5
sand/silt/clay	5
sand and gravel	5
shell and rock	5
silty sand	5
clayey silt	5
cordgrass	5
eelgrass	10

SALINITY PREFERENCES
Sources: Bigelow and Schroeder 1953, Crestin 1973, Clayton 1976, Murawski et al. 1980
Salinity (ppt) Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition

REPRODUCTIVE

0 to 1	10
1 to 3	5
3 to 35	0

ADULTS, JUVENILES
We did not find information on the salinity requirements juvenile or adult life stages, and therefore characterized habitat from substrate, temperature, and depth parameters. These were combined using a geometric mean.

TEMPERATURE PREFERENCES
Sources: McKenzie 1964, Crestin 1973, Clayton 1976.
Temperature (C) Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition

REPRODUCTIVE

-1 to 0	0
0 to 4	5
4 to 10	10
10 to 15	5
15 to 20	1

ADULTS, JUVENILES

-1 to 0	0
0 to 4	5
4 to 20	10
20 to 29	5

DEPTH PREFERENCES
Sources: Hulbert 1974, Bigelow Schroeder 1953.
Depth (feet, mlw*) Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition

REPRODUCTIVE

+8 to +1	0
+1 to 0	5
0 to 15	10
15 to 70	5

ADULTS, JUVENILES

+8 to -6	0
-6 to 0	5
0 to 18	10
18 to 70	5

* mean high water approximately +8'

River Herring GIS Habitat Model

Alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) are commonly termed “river herring”. These are anadromous clupeid fishes, ranging from the mid Atlantic to Nova Scotia. River herring still are harvested recreationally and commercially during their spawning runs, but are far less abundant than historically. Both species also are important prey of larger fishes, birds, and marine mammals. They are treated together because of similarities in appearance and overlap of biological habits. Accordingly, the following model should be generally applicable to both species within the Gulf of Maine.

SPAWNING HABITAT

Alewives and blueback herring spawn in tributaries of the Great Bay estuary between April and July (Nelson 1981). Alewives spawn above the head of tide in freshwater ponds, lakes, and slow-flowing rivers and streams (Bigelow and Schroeder 1953, Scott and Scott 1988). Blueback herring spawn over hard substrates in fast-flowing water of rivers and streams and over organic material in slower-flowing rivers and streams (Pardue 1983). Alewives spawn in tributary waters at water temperatures between 9 to 27 degrees celsius (Bigelow and Schroeder 1953, Cianci 1969, Edsall 1970, Kissil 1974). Blueback herring spawn in tributary waters at water temperatures between 14 and 26 degrees celsius (Bigelow and Schroeder 1953, Loesch and Lund 1977, Pardue 1983). We found no reports of either species spawning in brackish water. Substrate type does not appear to be critical during spawning (Bigelow and Schroeder 1953, Edsall 1964, Mansueti and Hardy 1967). After spawning, adults return to the sea (Bigelow and Schroeder 1953).

Because of the paucity of information on spawning habitat requirements of these two alosids, we mapped spawning habitat of river herring as those sections of rivers where spawning is known to occur (D. Grout, NHF&G). These areas were scored as 10 (0 - 10 scale) since they in fact meet all environmental requirements.

LARVAL HABITAT

Water-hardened eggs are pelagic and drift downstream (Loesch and Lund 1977). Incubation time for eggs is related to water temperature (Edsall 1970). The larval stage lasts from yolk-sac absorption (2 - 5 days) at a mean total length (TL) of 5.1 mm, until transformation to the juvenile stage at 20 mm TL (Mansueti 1962, Cianci 1969). Larvae were collected in salinities of < 12 ppt in Chesapeake Bay (Dovel 1971). Therefore, in rivers where spawning occurs, we mapped habitat for larvae as those reaches which have salinities < 12 ppt. These areas were given a score of 7.5 (0 - 10 scale) based upon apparent suitability of conditions, but where presence of larvae has not been documented.

JUVENILE HABITAT

Juvenile river herring occur in tidal freshwater and estuarine areas in spring and early summer, moving upstream as more saline waters encroach (Warinner et al. 1969, Pardue 1983). Salinity < 5 ppt is considered optimal for early juvenile river herring (Pardue 1983). Juvenile river herring migrate from freshwater-estuarine nursery areas to coastal waters between late summer and fall, as water temperatures decline (Warinner et al. 1969, Burbridge 1974, Loesch 1987, Gray 1991).

Because of the paucity of information on later juvenile habitat requirements of these two alosids, we mapped only their early juvenile habitat. This included locations where juveniles have been collected (New Hampshire Fish and Game Department) and which have salinities

< 5 ppt. Adjacent waters having salinities < 5 ppt were scored as 7.5 (0 - 10 scale) based upon the apparent suitability of conditions, but where presence of juveniles has not been documented.

Larval, early juvenile, and spawning habitat were combined using the maximum score of either, to produce a coverage of overall habitat for these stages of river herring. Additional data and analysis will be needed to identify whether later juvenile stages use more saline habitats within the estuary, or migrate quickly out to sea.

Striped Bass GIS Habitat Model

Striped bass, *Morone saxatilus*, are perhaps the most important game fish of coastal New England. Stripers apparently do not spawn in New Hampshire, but adults and juveniles migrating up the coast from Chesapeake Bay and Hudson River breeding centers can be seasonally abundant in coastal and estuarine waters. The following describes a simple habitat model for striped bass. The information was compiled from the literature, discussions with biologists from New Hampshire Fish and Game, and information provided by local anglers.

We attempted to identify striped bass feeding/resting habitats in Great Bay and the Hampton/Seabrook Estuary using base maps which depict the following factors:

DEPTH
Striped bass occur in water depths ranging from the deepest sections of the Piscataqua River (-70' mean low water) to relatively shallow flats (approaching the mean high water line).

STRUCTURE
Bass use dropoffs, where deeper water is adjacent to tidal creeks and flats, as feeding or holding areas. These offer cover, and supply food organisms carried out with the tide. For the same reasons bass frequent oyster, mussel or eelgrass beds. We digitized dropoffs from color infrared 1:12000 aerial photos, including the edges of flats, marsh or shallower tributaries and adjacent deeper channels.

LOCAL KNOWLEDGE
We were provided with information on areas which are persistently used by fishermen (courtesy of Doug Grout, NHF&G, and by Al Gonsalves, John Cloyd and Richard White). Areas worked regularly by anglers in boats can be taken to indicate relatively high concentrations of striped bass, since most of the open waters of the bay are just as available. Land based anglers, in contrast, are more limited by access to areas which may or may not be attractive to fish.

We scored habitat suitability based on the occurrence of one or more of the above factors; overlapping occurrences were taken to indicate particularly attractive habitat. Therefore, areas having either 1) suitable water depth, 2) deeper water adjacent to flats and marshes, 3) known oyster, mussel or eelgrass beds, or 4) favored fishing locations, were each scored as 2.5 out of a possible 10. Areas in which any of the 4 factors overlapped were scored an additional 2.5 per factor, giving a maximum score of 10.

American Black Duck GIS Habitat Model

Waterfowl are important in coastal New Hampshire from recreational (hunting, viewing) and ecological perspectives. One of the species on the GOMC list, the American black duck (*Anas rubripes*), is of special interest, due to a continued decline in population. The following model for black ducks considers habitat use during four life stages: breeding, brood-rearing, migration, and wintering. Black ducks appear to select wetland habitat on the basis of vegetative structure, perhaps associated with food and cover requirements, (Ringelman 1980).

HABITAT REQUIREMENTS

Habitat for breeding pairs include: (1) nesting cover and substrate (Reed 1970), (2) visual isolation from other pairs), and (3) high quality foraging areas (USFWS 1988). Following hatching of the eggs, hens move their broods to rearing wetlands, often considerable distances from the nest site (Ringelman and Longcore 1982). Habitat requirements for brood-rearing include: (1) cover from predators and weather, and (2) invertebrate-rich wetlands (USFWS 1988). Reproductive habitats (breeding pair, nesting, and brood-rearing) must be managed as a unit to ensure successful production of black ducks (USFWS 1988). Migration and winter habitat requirements include: (1) high quality foraging areas and (2) cover from weather (Lewis and Garrison 1984).

BREEDING PAIR HABITAT

Hens may use a diversity of sites for nesting, covering the range from uplands to lowland cover types. Therefore, we made the assumption that where suitable breeding pair habitat occurred, hens could locate suitable nest sites in the vicinity.

A variety of wetlands provide habitat for breeding black ducks. In inland Maine, wetland selection by breeding pairs (pre-laying, laying, and incubation periods) in order of preference was palustrine emergent, broad-leaved deciduous forested, and broad-leaved deciduous scrub-shrub types. Unconsolidated organic bottom, needle-leaved evergreen forested, and broad-leaved evergreen shrub wetlands were used in a proportion less than their availability (Ringelman et al. 1982). Ephemeral pools were important foraging sites for pairs breeding at inland freshwater wetlands (Ringelman et al. 1982). Streams having sandy or stony bottoms interspersed with invertebrate-rich detrital patches were used in a proportion in excess of availability (Ringelman et al. 1982). Black ducks nesting in coastal salt marsh in Nova Scotia foraged in the tidal marsh (Reed and Moisan 1971).

Researchers have documented a variety of wetlands that provide habitat for breeding black ducks, but few studies (Seymour and Jackson 1996) have objectively evaluated their relative suitabilities. Seymour and Jackson (1996) documented black duck use of estuarine, lacustrine, riverine, and palustrine wetlands during the breeding season over a 16 year period. Breeding black duck pairs used the following, in decreasing order: inland freshwater ponds and marshes, rivers, estuaries (not including tidal marsh), lakes, and tidal marsh sites (Seymour and Jackson 1996). We used that information to assign suitability scores to NWI wetland types (Table 6).

BROOD-REARING HABITAT

Hens will move their broods considerable distances to rearing wetlands. In inland Maine, hens and broods traveled as far as 3.3 km from the nest to a rearing wetland (Ringelman and Longcore 1982). In Nova Scotia hens moved broods up to 12 km from inland palustrine wetlands to a tidal marsh (Seymour and Jackson 1996). Streams serve as travel corridors to rearing wetlands (Ringelman and Longcore 1982, Seymour 1984, Seymour and Jackson 1996). Small (<0.02 ha) ephemeral pools were often used by broods en route to rearing wetlands (Ringelman and Longcore 1982).

At inland freshwater wetlands in Maine, broods used emergent ponds in a proportion greater than their availability (based on water surface area) and lakes and evergreen scrub-shrub wetlands were used less than their availability. Dead scrub-shrub, unconsolidated bottom, and aquatic bed wetlands were not used by broods (Ringelman and Longcore 1982). Hens and their broods were associated with larger wetlands having alder, willow, and herbaceous vegetation (palustrine emergent and deciduous scrub-shrub classes). These had greater water surface area than wetlands not used by broods, based on discriminant analysis (Ringelman and Longcore 1982). Wetlands with large areas of open water, submerged aquatic vegetation, or ericaceous shrub vegetation were rarely used by broods (Ringelman and Longcore 1982). Rearing wetlands all contained active beaver colonies. Palustrine emergent wetlands provided structure for high densities of invertebrates, protein rich foods required by developing young. Scrub-shrub and deciduous forested wetlands provide cover from predators and weather (Ringelman and Longcore 1982).

In an estuarine environment along the St. Lawrence River in Nova Scotia, newly hatched black duck broods foraged in widgeon grass (*Ruppia maritima*) pools within the *Juncus* and *Spartina patens* zones of the upper marsh and, as they got older, used portions of the *Spartina alterniflora* zone in the lower marsh. Black ducks may associate with these vegetative and physiognomic features because of a combination of edge, cover, and invertebrate abundance (Reed and Moisan 1971). Seymour and Jackson (1996), over a 16 year period, observed an association of brood size at fledging and wetland type. Brood size decreased in the following sequence: inland freshwater ponds and marshes, estuaries (not including tidal marsh), lakes, and tidal marsh sites. Greater cover from predators and weather and potentially lower predator densities in palustrine wetlands may have contributed to the highest brood size at fledging in these wetlands (Ringelman and Longcore 1982). Greater predator densities in tidal marshes may have contributed to the lowest brood size at fledging in these wetlands (Seymour 1984). NWI wetland types were characterized as brood-rearing habitat (Table 6) based on mean brood size at fledging.

MIGRATION HABITAT

Black ducks migrate into and through the study area from southern wintering habitats around March through mid-April. Maximum numbers of black ducks occur around Great Bay August through March (Short 1992). During the Fall migration they pass back through from northern areas around October through November.

North of Chesapeake Bay, black ducks feed on tidal flats and use emergent wetlands, ice-free bays, rivers, and coastal reservoirs as rest areas. Eelgrass, widgeon grass, and smooth cordgrass are important plant food items, while snails, mussels, and clams are important animal foods in coastal bays and marshes (Lewis and Garrison 1984). We also characterized wetlands as migration habitat according to their NWI categories (Table 6).

WINTER HABITAT

Some black ducks winter in Great Bay and protected coastal waters, from December through February. During the winter, food availability, disturbance, and weather are factors that affect habitat use by black ducks (Lewis and Garrison 1984). Inland wetlands are likely to be frozen, so only shellfish and eelgrass beds would be routinely available. Animal matter made up the greatest portion of the diet of coastal wintering black ducks in Maine (Hartman 1963, Jorde and Owen 1990). Soft-shelled clams (*Mya arenaria*) and the little macoma clam (*Macoma balthica*) constituted 46% of the total food volume and occurred in four-fifths of the gizzards collected from black ducks (n=138) in the Penobscot Bay estuary during autumn and winter. High density soft-shelled clam beds attracted large flocks of black ducks (Hartman 1963). Snails and amphipods constituted 8% and 7% respectively, of the total food volume (Hartman 1963). Animal matter comprised 96% and plant material 4% of the aggregate dry weight of esophageal samples collected from wintering black ducks in a marine environment of coastal Maine (Jorde and Owen 1990). Periwinkles (*Littorina* spp.), amphipods and blue mussels (*Mytilus edulis*) comprised 68% and soft-shelled clams 6% of the aggregate dry weight of food items collected (Jorde and Owen 1990). Periwinkles and amphipods are typically found in association with intertidal marine macro-algae.

MAPPING OF HABITATS

Habitats were mapped from digital themes including: bathymetry, wetlands (NWI), eelgrass and algae distribution, and blue mussel and soft-shelled clam beds. These data were overlaid and processed on a cell by cell basis to create grid-cell coverages for each of the four life stages. Scores were assigned on a 0 to 10 scale (10 being the most suitable habitat) as follows.

Table 6. Wetland Suitability as Black Duck Habitat*.

NWI CODE	DESCRIPTION	Breeding pair	Brood rearing	Migration
PEM	Palustrine Emergent	10	10	10
PFO	Palustrine Forested	10	10	7.5
PSS	Palustrine Scrub-Shrub	10	10	7.5
E2AB	Estuarine Intertidal Aquatic Bed	7.5	2.5	7.5
E2EM	Estuarine Intertidal Emergent	7.5	2.5	7.5
E2US	Estuarine Intertidal Unconsolidated Shore	7.5	7.5	7.5
E1UB	Estuarine Subtidal Unconsolidated Bottom	7.5	7.5	7.5
R1UB	Riverine Tidal Unconsolidated Bottom	7.5	5	5
R2UB	Riverine Lower Perennial Unconsolidated Bottom	7.5	5	5
R2US	Riverine Lower Perennial Unconsolidated Shore	7.5	5	5
L2AB	Lacustrine Littoral Aquatic Bed	5	5	7.5
L2EM2	Lacustrine Littoral Nonpersistent Emergent	5	5	10
PAB	Palustrine Aquatic Bed	5	2.5	7.5
M1UB	Marine Subtidal Unconsolidated Bottom	2.5	2.5	2.5
M2RS	Marine Intertidal Rocky Shore	2.5	5	7.5
M2US	Marine Intertidal Unconsolidated Shore	2.5	5	2.5
M2AB	Marine Intertidal Aquatic Bed	2.5	5	7.5

NWI CODE	DESCRIPTION	Breeding pair	Brood rearing	Migration
PUB	Palustrine Unconsolidated Bottom	2.5	2.5	2.5
PUS	Palustrine Unconsolidated Shore	2.5	2.5	2.5
R3UB	Riverine Upper Perennial Unconsolidated Bottom	2.5	2.5	5
R5UB	Riverine Unknown Perennial Unconsolidated Bottom	2.5	2.5	5
L1UB	Lacustrine Limnetic Unconsolidated Bottom	2.5	5	2.5

***Suitability Scored 0 (unsuitable) to 10 (optimum)**

Marine and estuarine wetlands having water depth > 1 foot are too deep for foraging by black ducks; these were assigned a value of 0. Within the correct depth range, eelgrass beds (*Zostera marina*) were scored a suitability value of 7.5 (0 - 10 scale) as breeding pair, brood-rearing, migration and winter habitats. Blue mussel and soft-shelled clam beds were scored a suitability value of 10 for both migration and winter habitats. Beds of the marine algae we mapped in this study (rockweed, Irish moss, and tufted red weed) were scored a suitability value of 7.5 for both migration and winter habitats. Palustrine, lacustrine, estuarine, and marine wetlands were used in the characterization of breeding, brood-rearing, and migration habitats (Table 6) but not winter habitat because of ice conditions limiting their availability during winter months.

COMBINING HABITAT SUITABILITY SCORES FOR ALL LIFE STAGES

For successful reproduction, both breeding pair habitat and brood-rearing habitat must be available, of sufficient quantity, and quality, and juxtaposed on the landscape for successful reproduction (USFWS 1988). Therefore, on a cell by cell basis we calculated a reproductive habitat suitability score as the geometric mean of breeding pair habitat and brood-rearing habitat scores. If either of the reproductive habitat components were 0 the overall reproductive suitability would be 0. On the other hand, the relative mobility of mature black ducks allows them to fly to alternate areas to use supplementary resources. Therefore, to identify the overall habitat for black ducks, we overlaid the reproductive, migration, and winter habitat coverages and selected the highest suitability score for each cell.

Common Tern GIS Habitat Model

Common terns, *Sterna hirundo,* are waterbirds that feed on small fishes in coastal in inland shallow waters. Tern populations have declined in the Gulf of Maine as nesting sites are disturbed by humans and taken over by gulls. The following describes a simple foraging habitat model for the tern. The biological information was compiled from the literature, discussions with biologists from New Hampshire Fish and Game, and comments from New Hampshire Audubon Society.

Common terns nest in coastal New Hampshire on islands and back dune areas. Recent nest sites were mapped from Andrews, 1990, and the New Hampshire Coastal Colonial Waterbird Inventory, 1995.

Terns feed by diving on schools of small fishes, often over tide rips, at beaches, inlets, or along convoluted shorelines, to about 22 km from nesting colonies, and up to 1 km from shore (Pearson 1968, Duffy 1977, Erwin 1978, Nisbet 1977). However, terns mostly feed within 6 km of colonies (Austin 1946, Pinkowski 1980). Prey items include young sea herring, mackerel, and bluefish, sand lance, or anchovy (Heinemann 1992).

HABITAT MAPPING

We identified the tern nesting islands and saltmarsh north of Hampton from NWI digital base maps. These polygons were selected, labeled with feature name, and placed in a new coverage. Feeding habitats were identified based on bathymetry of coastal waters and distance from colony sites.

HABITAT SCORING: NESTING

Because the tern nesting areas are known to be in use they were recognized as “suitable”, and scored 10 (0 to 10 scale).

HABITAT SCORING: FEEDING

All of our coastal study area is within 20 km of existing tern colonies, and so all suitable feeding areas are within range of nesting terns. Areas within 6 km of colonies were regarded as being of relatively higher value because of the shorter access time and reduced energy usage for adult birds feeding chicks. The most suitable foraging areas are shallow waters, where small fishes cannot dive to avoid terns. Tidal waters down to -2' mean low water were regarded as being of highest value; areas from -2' to -30' were scored as intermediate value, while areas deeper than this were not scored.

	DEPTH mlw	SCORE
Within 6 km of nesting colony	+5' to -2'	10
	-3' to -30'	5
beyond 6 but within 20 km of nesting colony	+5' to -2'	5
	-3' to -30'	3

Atlantic Silverside GIS Habitat Model

The Atlantic silverside, *Menidia menidia,* is a small relatively common inshore fish of the mid-Atlantic coast. Silversides school in shallow estuarine waters, and are an important prey of larger fishes and birds. They are used as bait in marine recreational fisheries. The following tables are components of a model to map silverside habitat. Most of the information was derived from Fay et al. 1982 and Bigelow and Schroeder 1953. The resulting habitat scoring (suitability index values) was adjusted, based on conditions occurring at collection sites in coastal New Hampshire at which silversides were relatively abundant. Collection data were obtained from New Hampshire Fish and Game (Nelson et al. 1981), Normandeau Associates 1974, and Normandeau Associates 1995.

The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid-cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Silversides typically leave estuaries in winter, so suitability was calculated for spring, summer, and fall conditions. Habitat values for the adult stages were computed as the average for the three seasons, while reproductive habitat was defined from the most favorable of either spring or summer conditions. Overall habitat was mapped from the maximum score for either adult or reproductive stages.

SUBSTRATE PREFERENCES

Substrate	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
ADULT	
clayey silt	6
silt	4
sand/silt/clay	7
sandy silt	8
silty sand	10
Sand and gravel	10
rock/shell	9
cordgrass	10
eelgrass	10
SPAWNING	
clayey silt	0
silt	0
sand/silt/clay	0
sandy silt	0
silty sand	0
Sand and gravel	0
rock/shell	0
cordgrass	10
eelgrass	10

SALINITY PREFERENCES

Salinity (ppt)	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition

ADULT	
0 to 4	1
4 to 7	4
7 to 18	7
18 to 36	10
SPAWNING	
0 to 10	0
10 to 20	7
20 to 30	10
30 to 36	8

TEMPERATURE PREFERENCES

Temperature (C)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
ADULT	
-1 to +3	0
3 to 8	5
8 to 15	7
15 to 25	10
25 to 28	7
28 to 31	2
SPAWNING	
0 to 9	0
9 to 13	7
13 to 30	10

DEPTH PREFERENCES

Depth (feet, mlw*)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
ADULT	
+8 to +6	5
+6 to 0	10
0 to -7	7
-7 to 30	1
30 to 90	0
SPAWNING	
+8 to 0	10
0 to -5	7
-5 to 70	0

* mean high water approximately +8'

Smooth Flounder GIS Habitat Model

The smooth flounder, *Pleuronectes putnami,* is an estuarine flatfish which is relatively common in Great Bay. Though occasionally taken by fishermen, these fish are typically smaller than the more sought after winter flounder. The following tables are components of a smooth flounder habitat model. The information was compiled primarily from a dissertation by Armstrong (1995) and by examination of conditions associated with fish collection sites in Great Bay (Nelson et al. 1981, 1982) and the Seabrook/Hampton estuary.

The model operates on four parameters: substrate, salinity, temperature, and depth. The model indexes the relative suitability of each environmental parameter on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid-cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Suitability is calculated for each season, to accommodate annual changes in salinity and temperature.

Habitats were mapped for conditions needed by juveniles, by adults, and for reproduction and larval stages. Smooth flounder occur in New Hampshire estuaries throughout the year and are mobile, thus able to avoid seasonally unsuitable conditions. Accordingly, juvenile and adult habitats were based on the average of suitability values for all four seasons. The reproductive/larval habitats were mapped as the maximum or most favorable score of either winter or spring, in consideration of some flexibility in the timing of reproduction. Smooth flounder overall habitat was mapped as the maximum score for either juvenile, adult, or reproductive/larval habitat. This ensures valuation for habitats which may support stages from and into which the species may migrate to other coastal areas.

SUBSTRATE PREFERENCES

Sources: Armstrong 1995, Bigelow and Schroeder 1953, MacDonald et al. 1984.

Substrate	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
ADULT AND JUVENILE	
clayey silt	2
silt	3
sand/silt/clay	9
sandy silt	10
silty sand	10
Sand and gravel	6
rock/shell	1
eelgrass	7
REPRODUCTION, LARVAE	
clayey silt	0
silt	0
sand/silt/clay	1
sandy silt	0
silty sand	10
Sand and gravel	10
rock/shell	0
eelgrass	3

SALINITY PREFERENCES

Source: Armstrong 1995.

Salinity (ppt)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
ADULT	
0 to 1	0
1 to 9	7
9 to 22	10
22 to 28	5
28 to 35	0
JUVENILE	
0 to 3	0
3 to 10	5
10 to 28	10
28 to 35	5
REPRODUCTION, LARVAE	
0 to 3	0
3 to 10	5
10 to 15	8
15 to 22	10
22 to 28	5
28 to 35	0

TEMPERATURE PREFERENCES

Sources: Bigelow and Schroeder 1953, Targett and McCleave 1974.

Temperature (C)	**Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**
ADULT	
-1 to 0	1
0 to 7	5
7 to 19	10
19 to 25	5
25 to 26	2
JUVENILE	
-1 to 3	1
3 to 10	5
10 to 22	10
22 to 26	5
22 to 28	1
REPRODUCTION, LARVAE	
-1 to 0	1
0 to 1	5
1 to 5	10
5 to 6	5

6 to 10	1
10 to 28	0

DEPTH PREFERENCES

Sources: Armstrong 1995, Bigelow and Schroeder 1953, MacDonald et al. 1984, Targett and McCleave 1974; overlay of NHF&G fyke net collections with depth map.

Depth (feet, mlw*)	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
ADULT	
+8 to 6	0
6 to 3	2
3 to 0	4
0 to -30	10
-30 to 60	5
60 to 300	1
JUVENILE	
+8 to 6	1
6 to 2	7
2 to -8	10
-8 to 30	5
30 to 60	1
60 to 300	0
REPRODUCTION, LARVAE	
+8 to 0	0
0 to -30	10
-30 to 40	5
40 to 60	1
60 to 150	0

Great Blue Heron GIS Habitat Model

Wading birds are conspicuous wildlife of coastal and inland wetlands, and long have been regarded as biological indicators of environmental quality. The great blue heron, *Ardea herodias*, occurs in the study area and is on the GOMC species list. The following describes a simple foraging habitat model for the great blue heron in relation to known nesting habitats. The biological information was compiled from the literature and data from the New Hampshire Audubon Society.

Nesting Habitats

Locations of great blue heron breeding colonies were provided by Chris Martin, New Hampshire Audubon Society. Five colonies have been occupied in recent years within the study area and three more colonies adjacent to it. We mapped nesting habitat as the entirety of the specific scrub/shrub or forested wetland NWI polygons encompassing the nest sites. These were selected from digital maps. All were scored as having a habitat suitability of 10 (0 to 10 scale), based on the observed level of use.

Foraging Habitats

The relative value of foraging habitat is related to intrinsic characteristics (abundance of prey, accessibility of prey) and, for these colonial nesting birds, distance from roosts or colony sites (Erwin et al., 1993). Themes used to characterize foraging habitat suitability included bathymetry, NWI wetland types, and eelgrass distribution. Habitat suitability scores were assigned in two phases: (1) scoring by cover type and depth, and (2) scoring based on distance from known colony sites.

1. <u>Score based on wetland type and depth</u>: Habitat quality for foraging herons was evaluated using data on relative use of wetland types. In Maine, breeding great blue herons used inland freshwater wetlands associated with greater wetland area, more extensive beds of emergent vegetation, longer shorelines, and less open water than unused wetlands (Gibbs et al. 1991). Wetland types used by herons in order of decreasing use (individuals/100 hours of observation) were palustrine emergent, palustrine aquatic bed, palustrine scrub-shrub, lacustrine, palustrine forested, and palustrine unconsolidated bottom (Gibbs et al. 1991). Use of wetlands for wading bird foraging is likely to be associated with the abundance and the availability of prey. Chapman and Howard (1984) regarded estuarine intertidal wetlands as more valuable than marine wetlands for common egrets, which have feeding habits similar to those of great blue herons. The former is likely to have more concentrated and vulnerable prey. NWI wetland types were scored as shown in Table 9 ('SUITABILITY SCORE 0-5'). Eelgrass beds were scored as estuarine intertidal aquatic bed. Estuarine and marine wetlands where water depth was deeper than 2 feet mlw were considered unavailable to foraging herons and assigned a value of 0.

2. <u>Score based on distance from colony sites:</u> Wading bird colonies apparently are located at sites remote from predators and disturbance, yet within range of wetland foraging areas (Gibbs and Woodward 1984). Wetlands within a 10 km radius of breeding colonies were considered higher value foraging habitat than similar wetlands located beyond this distance. Closer wetlands offer savings in travel time and energy expenditure for adult birds and reduced exposure of young birds at the colony sites. Wetlands within a 10 km radius of breeding colonies were scored double (Table 7; 'SCORE IF <10 km FROM COLONY') the habitat suitability of more distant areas (Banner and Libby 1995).

Table 7. Wetland Suitability as Great Blue Heron Foraging Habitat.

NWI CODE	NWI TYPE	SUITABILITY SCORE (0 - 5)	SCORE IF <10 km FROM COLONY
PAB	Palustrine Aquatic Bed	5	10
PEM	Palustrine Emergent	5	10
E2AB	Estuarine Intertidal Aquatic Bed	5	10
E2EM	Estuarine Intertidal Emergent	5	10
L2AB	Lacustrine Littoral Aquatic Bed	5	10
E2US	Estuarine Intertidal Unconsolidated Shore	3.75	7.5
E1UB	Estuarine Subtidal Unconsolidated Bottom	3.75	7.5
L2EM2	Lacustrine Littoral Nonpersistent Emergent	3.75	7.5
PFO	Palustrine Forested	3.75	7.5
PSS	Palustrine Scrub-Shrub	3.75	7.5
M2AB	Marine Intertidal Aquatic Bed	2.5	5
R1UB	Riverine Tidal Unconsolidated Bottom	2.5	5
R2UB	Riverine Lower Perennial Unconsolidated Bottom	2.5	5
R2US	Riverine Lower Perennial Unconsolidated Shore	2.5	5
M1UB	Marine Subtidal Unconsolidated Bottom	1.25	2.5
M2RS	Marine Intertidal Rocky Shore	1.25	2.5
M2US	Marine Intertidal Unconsolidated Shore	1.25	2.5
PUB	Palustrine Unconsolidated Bottom	1.25	2.5
PUS	Palustrine Unconsolidated Shore	1.25	2.5
L1UB	Lacustrine Limnetic Unconsolidated Bottom	0	0
R3UB	Riverine Upper Perennial Unconsolidated Bottom	0	0
R5UB	Riverine Unknown Perennial Unconsolidated	0	0

Tomcod GIS Habitat Model

The tomcod, *Microgadus tomcod,* is a small cod-like estuarine fish which ascends tributaries of Great Bay in winter. They reside in eelgrass or over shell beds much of the year. Tomcod are caught by anglers incidental to the smelt fishery. The following tables are components of a model to map their habitat. Most of the information was compiled by Brown et al. (unpub.) from the other listed sources. The resulting habitat scoring (suitability index values) was adjusted, based on conditions occurring at collection sites in Great Bay at which tomcod were relatively abundant.

The model indexes the relative suitability of each of four parameters (substrate, salinity, temperature, and depth) on a 0 to 10 basis, with 10 being optimal and 0 being unsuitable. These suitability index values are combined by computing their geometric mean for each grid cell in the study area. Thus, optimal habitat for any life stage would occur where the index values were the maximum for each of the four inputs; no value is attributed to areas where any condition is completely unsuitable. Suitability is calculated for each season, to accommodate annual changes in salinity and temperature. Habitat values for adult and juvenile stages were computed as the average of values from each of 4 seasons, while reproductive habitat was defined from the most favorable of either fall or winter conditions. Overall habitat was mapped as the maximum score for either adult, reproductive, or juvenile stage.

SUBSTRATE PREFERENCES (all stages)
Sources: Brown et al., unpub., Tort 1993, MacDonald et al. 1984, Laprise and Dodson 1990, Stewart and Auster 1987.

Substrate	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
clayey silt	3
silt	6
sand/silt/clay	7
sandy silt	8
silty sand	10
Sand and gravel	10
rock/shell	10
eelgrass	10

SALINITY PREFERENCES
Sources: Brown et al., unpub., Fried et al. 1973, Peterson et al. 1980, Tort 1993, Townsend 1984, Targett & McCleave 1974, MacDonald et al. 1984, Laprise and Dodson 1990, Stewart and Auster 1987.

Salinity (ppt)	Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition
ADULT	
0 to 5	1
5 to 9	5
9 to 27	10
27 to 36	8
JUVENILE	
0 to 2	3

2 to 5	6
5 to 26	10
26 to 29	5
29 to 36	1

SPAWNING

0 to 1	6
1 to 2	8
2 to 8	10
8 to 10	5
10 to 22	1
22 to 36	0

TEMPERATURE PREFERENCES

Sources: Brown et al., unpub, Fried et al. 1973, Tort 1993, Townsend 1984, Targett & McCleave 1974, Stewart and Auster 1987.

Temperature (C) **Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**

ADULT AND JUVENILE

0 to 2	5
2 to 4	7
4 to 17	10
17 to 20	7
20 to 26	2

SPAWNING

0 to 1	1
1 to 2	5
2 to 4	7
4 to 10	10
10 to 12	7
12 to 13	2

DEPTH PREFERENCES

Sources: Bigelow and Schroeder 1953, Brown et al., unpub., Laprise and Dodson 1990, MacDonald et al. 1984, Stewart and Auster 1987.

Depth (feet, mlw*) **Suitability Index: 0 to 10 scale; 0 = unsuitable, 10 = optimal condition**

ADULT AND JUVENILE

+8 to +4	4
+4 to -6	10
-6 to 18	7
18 to 30	1
30 to 90	0

SPAWNING

+4 to 0	7
0 to -7	10
-7 to 12	7
12 to 70	0

* mean high water approximately +8'

Bald Eagle Roosting Habitat Mapping

The bald eagle, *Haliaeetus leucocephalus*, represents to the public a symbol of environmental quality. From an ecological perspective, eagles may be significant predators on waterfowl and fishes. While eagles do not nest around Great Bay, they have been observed wintering there more frequently in recent years than in the early 1980's (DeLuca 1993, Cook et al. 1995).

The Great Bay study area includes several bald eagle winter roost sites and the foraging habitats to support them. Because most of the open waters of Great Bay apparently offer suitable feeding habitats we mapped only the vicinities of regularly used roost sites. Since these are in actual use they were assumed to provide all requisites, and thus were scored 10 on a 0 - 10 scale.

Roosting habitats were mapped as uplands surrounding specific roost sites diagramed in DeLuca, 1993, and roost areas illustrated in the Pease Air Force Base Draft Environmental Impact Statement, 1991.

Review of the Analysis

We requested many of the same persons who provided the information for our analysis to review our graphic interpretations and model outputs. Review was at two levels. Local experts were asked to review both the models or interpretations and the resulting habitat maps. Species experts outside of New Hampshire were asked only to review the narratives. The information was sent to: Fred Short, Richard Langan (Jackson Estuarine Research Laboratory); Michael Burt (Huntsman Marine Centre); Joe McKeon (USFWS); John Moring (University of Maine, Orono); Steve Jury, Hunt Howard, University of New Hampshire, Durham; Lew Flagg, Linda Mercer (Maine DMR); Steve Brown (NOAA - SEA Division); Douglas Grout, Bruce Smith (New Hampshire Fish and Game Department); Peter Auster (University of Connecticut, NURC).
Comments were incorporated into the models, which were rerun to produce final versions of the maps.

Discussion

The Great Bay pilot study was initiated to: (1) develop methods for selection of evaluation species, (2) develop methods for assessing habitat suitability and mapping habitat of selected species, (3) identify regionally important habitats using this information, and (4) facilitate protection of mapped habitats.

We found that the selection of study area boundaries and selection of evaluation species are closely related. The methods used in this study were successful in assembling information about Great Bay. However, the study area boundary cut across habitats of a number of species, reducing the potential scope of use of the information for management. For some migratory species (e.g., great blue heron) this cannot be avoided even with a Gulf of Maine perspective. As a practical matter, we suggest that future investigations use watersheds as biological units of study. This would insure the inclusion of upstream spawning habitats of anadromous fishes. The importance of these fishes within the GOM is reflected in the GOMC species rankings; Atlantic salmon GOMC ranking = 5, American shad 21, alewife 31, and striped bass 36. Among migratory birds, black duck hens may use streams and rivers as travel corridors, connecting nesting habitat with productive foraging areas in the estuary. Using the watershed as the “biological unit” to define a study area may thus include the diversity of habitats required by all life stages of a species, and also display threats to those habitats from non-point source pollution.

The selection of species from the GOMC list and addition of species of local interest made for too long a list. Inclusion of only GOMC species would not have been acceptable since the local partners had little interest in conserving habitats solely because they were of regional significance. If the Council is to rely on local conservation initiatives it will be necessary to either educate local interests of the value of the regional perspective (think regionally, act locally), or to focus on areas where regionally important species are prominent and are locally appreciated. The Council might support a screening pilot project to identify the general localities of sites where habitats of the top ranked species are likely to overlap, then promote identification of important habitats at those places.

We mapped the distribution of habitats for various life stages for 25 species. General habitat models were necessary given the number of species, number of life stages, and time constraints for completion of the pilot study. It is apparent that standards need to be established for assessing habitat suitability and mapping habitat of the GOMC species. Points to consider in drafting these standards should include; (1) the number of species for which habitat will be mapped, (2) the life stages to be mapped, and (3) the type of model or use of occurrence data for portraying habitat of each species, including the level of accuracy, variables to use, seasons, and how to combine seasonal and life stage information. We suggest forming habitat committees or workshops, to include biologists, modelers, and fishermen or naturalists familiar with habitat requirements of the species. These committees should investigate the feasibility of developing more rigorous, statistical models, including regional habitat requirements of migratory species. For example, a regional model might find black duck winter habitat the priority in the States and breeding and brood-rearing habitat the priority in the Provinces.

The habitat models require testing or validation. While the review undertaken during this pilot is helpful in bringing the models up to the ‘state of the art’, publication of the models and meetings of habitat committees or workshops would encourage further development. Publication would allow the model data needs to be used as justification for survey work.

Use of the Analysis for Conservation Purposes

The analysis has identified specific high value sites within the study area, and documented habitat utility for key species. Three steps need to be taken to translate this information into conservation actions: 1) dissemination of the information; 2) specifying the types of actions to be taken, and 3) acquisition of funding to carry out the actions. Thus, this analysis can be used as justification for matching grants to purchase lands, or justification for regulatory protection or multiple- use management sensitive to resource needs.

Dissemination of Information

We have assembled and/or produced technical information in the form of this report and as digital data. These should be made available to governmental, ngo and academic professionals and to knowledgeable lay persons. More general distribution will require production of a popular version of the report, translating the information and summarizing it to focus on the major findings.

We supplied draft maps of environmental themes and habitats, and associated narratives, to reviewers, showed them to Conservation Commissioners from coastal towns and to members of the Living Resources Team of the New Hampshire Estuary Project. All of our environmental and species coverages will be supplied to New Hampshire’s central repository, GRANIT, and to the Jackson Estuarine Research Laboratory. We anticipate that the GOMC will publish and distribute the analysis, including posting of digital versions, to make it widely available to conservation interests.

Specification of Actions

The next step is to relate the habitat information from the analysis to potential management, regulatory, and land acquisition actions. Each of these actions can promote conservation most effectively in particular contexts. For example, management can be used to enhance habitat, but may be limited where land is subject to other uses; regulation may not be limited to specific areas, but usually can only maintain the status quo. Purchase of land or easements can allow exclusive rights to manage or protect areas, but this method is limited by relatively high cost. One way to decide on the most effective type of action is to examine the level of threat to the habitat. Banner and Gormley (1996) noted that existing regulation protected much of the highest value habitats identified in Casco Bay, Maine. Most of the lower value habitats at risk from projected land development could be protected by relatively small increases in regulatory setbacks. The remaining high value habitats at risk were relatively small in area, and thus realistic candidates for protection by purchase.

The information in the present report is suitable for further processing to identify habitats most at risk of destruction or degradation. One way of examining threats from future development is to conduct a “buildout” analysis, then overlay the expected development on existing habitats to see which are affected (Banner and Gormley 1996). The New Hampshire Estuaries Project proposes to conduct such a buildout analysis to evaluate potential loss of living resources. Once the threatened habitats are identified, lead agencies should promulgate a strategy for protection. This may take the form of outreach for voluntary conservation on private lands, land purchase by conservation entities or local, state, federal agencies, special designations (sanctuaries, reserves) for private/public lands and waters, or modification of management to multiple use of public lands by the current resource agencies. In some circumstances (where threats are of low level and/or involve a relatively narrow zone around key habitats) this may take the form of zoning setbacks, conservation districting or management; in others (significant unique features, such as bird-nesting islands or heritage sites) the strategy may be to acquire land or an easement.

Once local interests have this information they will be in a position to use it for municipal planning and voluntary habitat protection. The latter may take advantage of a number of funding opportunities for conservation actions, some of which are listed in Appendix C.

Literature Cited

Able, K. W., K.L. Heck, Jr., M.P. Fahay, and C.T. Roman. 1988. Use of salt-marsh peat reefs by small juvenile lobsters on Cape Cod, Massachusetts. Estuaries, 11(1), 83-86.

Andrews, R. 1990. Coastal Waterbird Colonies: Maine to Virginia 1984-85; Part 1. Maine to Connecticut. U.S. Fish and Wildlife Service, MA. 429 pp.

Armstrong P. 1974. Copper, zinc, chromium, lead, and cadmium in the unconsolidated sediments of Great Bay Estuary, New Hampshire. M.S. Thesis. University of New Hampshire, Durham. 85 pp.

Armstrong, M.P. 1995. A comparative study of the ecology of smooth flounder, *Pleuronectes putnami*, and winter flounder, *Pleuronectes americanus*, from Great Bay estuary, New Hampshire. Dissertation, Univ. of New Hampshire. 130 pp.

Austin, O.L. 1946. The status of the Cape Cod terns in 1944: a behavior study. Bird-Banding 17:10-27.

Banner, A. and J. Libby. 1995. Identification of important habitats in the lower Casco Bay watershed. U. S. Fish and Wildlife Service, Gulf of Maine Project. 75 pp.

Banner, A. and M. Gormley. 1996. Identification of important Casco Bay fish and wildlife habitats at risk from future development. U. S. Fish and Wildlife Service, Gulf of Maine Project. 13 pp.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Bull., U.S. 74(53). 577 p.

Botero, L. and J. Atema. 1982. Behavior and substrate selection during larval settling in the lobster *Homarus americanus.* J. Crust. Biol. 2(1):59-69.

Brown, S., S. Jury, K. Buja and A. Banner. unpub. GIS Modeling of fisheries habitats of Casco Bay and the Sheepscot Estuary, Maine. NOAA/SEA DIVISION, Silver Springs, MD and USFWS, Falmouth ME.

Buckley, J.L. 1989. Species Profile: Winter flounder (North Atlantic). Biol. Rep. 82(11.87):12 p.

Burbridge, R. G. 1974. Distribution, growth, selective feeding and energy transformations of young-of-the-year blueback herring in the James River, Virginia.
Trans. Am. Fish. Soc. 103:297-311.

Campbell, A. 1990. Aggregations of berried lobsters (*Homarus americanus*) in shallow waters off Grand Manan, Eastern Canada. Can. J. Fish. Aquat. Sci., 47, 520-523.

Capuzzo, J.M. and F.E. Anderson. 1973. The impact of chromium accumulation in an estuarine environment. Ph.D. Dissertation. University of New Hampshire, Durham. 170 pp.

Casterlin, M.E. and W.W. Reynolds. 1982. Thermoregulatory behavior and diel activity of yearling winter flounder, *Pseudopleuronectes americanus.* Env. Biol. Fish. 7(2):177-180.

Chapman, B.R. and R.J. Howard. 1984. Habitat suitability index models: great egret. Biol. Rept. 82(10.78), U.S. Fish and Wildlife Service.

Cianci, J.M. 1969. Larval development of the alewife and the glut herring. M.S. Thesis. University of Connecticut, Storrs. 62 pp.

Clayton, G. R. 1976. Reproduction, first year growth and distribution of anadromous rainbow smelt, *Osmerus mordax* (Mitchill), in the Parker River-Plum Island sound estuary, Massachusetts. M.S. Thesis, University of Massachusetts, Amherst, 105 pp.

Cook, R.A., C.J. Martin, D. DeLuca, and L.S. Deming. 1995. New Hampshire Endangered Species Program Status and Management Report. 1 April 1994 - 31 March 1995. New Hampshire Audubon Society Report for U.S. Fish and Wildlife Service, Federal Aid.

Cooper, R.A. and J.R. Uzmann. 1980. Ecology of juvenile and adult *Homarus*, p 97-142 in Cobb, J. S., and B.F. Phillips (eds.) The Biology and Management of Lobsters Vol. 1. NY: Academic Press.

Cowardin, L.W., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv. 103 p.

Crestin, D. S. 1973. Some aspects of the biology of adults and early life stages of the rainbow smelt, *Osmerus mordax* (Mitchill), from the Weweantic River estuary, Wareham-Marion, Massachusetts, 1968. M.S. Thesis, Boston University, MA 92 pp.

Danie, D. S., J. G. Trial, and J. G. Stanley. 1984. Species profiles: life histories and environmental requirements of coastal fish and invertebrates (North Atlantic) Atlantic salmon. U. S. Fish and Wildlife Service, FWS/OBS-82/11.22. 19 pp.

DeLuca, D. 1993. Wintering eagles on Great Bay. Great Bay National Estuarine Research Reserve Tech. Rept. 1.

Dovel, J. R. and P. Cheek. 1966. Distribution, food habits, and growth of young clupeids, Cape Fear River System, North Carolina. Proc. Annu. Conf. Southeast Assoc. Game Fish Comm. 20:250-260.

Duffy, D. 1977. Breeding populations of terns and skimmers on Long Island Sound and eastern Long island: 1972-1975. Proc. Linn. Soc. N.Y. 73:1-48.

Edsall, T. A. 1970. The effect of temperature on the rate of development and survival of alewife eggs and larvae. Trans. Am. Fish. Soc. 99:376-380.

Edsall, T. A. 1964. Feeding by three species of fishes on the eggs of spawning alewives. Copeia 1964:226-227.

Erwin, M.E., G.M. Haramis, D.G. Krementz and S.L. Funderburk. 1993. Resource protection for waterbirds in Chesapeake Bay. Envir. Manag. 17(5): 613-619.

Erwin, R.M. 1978. Coloniality in terns: the role of social feeding. Condor 80:211-215.

Fefer, S. I., and Schettig, P. A. 1980. An ecological characterization of coastal Maine (North and East of Cape Elizabeth). US Fish and Wildlife Service FWS/OBS-80/29, vol 2.

Fried, S.M. 1973. Distribution of demersal fishes in Montsweag Bay-Back River and lower Sheepscot River estuaries, Wiscasset, Maine. M.S. thesis, Univ. of Maine, Orono, ME. 48 pp.

Gibbs, J. and S. Woodward. 1984. Breeding colonies of great blue herons on Maine coastal islands. Maine Chapt. The Nature Conservancy, 1984.

Gibbs, J.P., J.R. Longcore, D.G. McAuley and J.K. Ringelman. 1991. Use of Wetland Habitats by Selected Nongame Water Birds in Maine. U.S. Fish Wildl. Serv., Fish Wildl. Res. 9. 57pp.

Gray, C. L. 1991. Alewife *Alosa pseudoharengus* species profile. Rhode Island Dept. of Env. Mgmt. 23 pp.

Hartman, F. E. 1963. Estuarine wintering habitat for black ducks. J. Wildl. Manage. 27(3):339-347.

Harvey, W.F., R.A. Malecki, and E.C. Soutiere. 1988. Habitat use by foraging Canada Geese in Kent County, Maryland. Trans. NE Sect. WIldl. Soc. 45:1-7.

Heinemann, D. 1992. Foraging ecology of roseate terns breeding on Bird Island, Buzzards Bay, Massachusetts. Report to USFWS, Newton Corner, MA. 54 pp.

Hudon, C., and G. Lamarche. 1989. Niche segregation between American lobster *Homarus americanus* and rock crab *Cancer irroratus.* Mar. Ecol. Prog. Ser., 52, 155-168.

Hulbert, P. J. 1974. Factors affecting spawning site selection and hatching success in anadromous rainbow smelt (*Osmerus mordax*, Mitchill). M.S. Thesis, University of Maine, Orono, 43 pp.

Jones, P. W., F. D. Martin, and J. D. Hardy, Jr. 1978. Development of fishes of the Mid-Atlantic Bight. An atlas of egg, larval, and juvenile stages. Vol. 1, U. S. Fish Wildl. Serv. Biol. Serv. Program FWS/OBS-78/12.

Jorde, D. G. and R. B. Owen, Jr. 1990. Foods of black ducks, wintering in marine habitats of Maine. Can. Field Nat. 104:300-302.

Kennedy, V.S. and J.A. Mihursky. 1971. Upper temperature tolerances of some estuarine bivalves. Chesapeake Sci. 12(4):193-204.

Kissil, G. W. 1974. Spawning of the anadromous alewife, *Alosa pseudoharengus*, in Bride Lake, CT. Trans. Amer. Fish. Soc. 103(2):312-317.

Laprise, R. and J. Dodson. 1990. The mechanism of retention of pelagic tomcod, *Microgadus tomcod*, larvae and juveniles in the well-mixed part of the St. Lawrence Estuary. Env. Biol. of Fishes 29:293-302.

Leim, A. H. 1924. The life history of the shad (*Alosa sapidissima*) (Wilson) with special reference to the factors limiting its abundance. Biol. Board Can., Contrib. Can. Biol. 2:163-284.

Lewis, J. C. and R. L. Garrison. 1984. Habitat suitability index models: American black duck (wintering). U. S. Fish and Wildlife Serv. FWS/OBS-82/10.68. 16 pp.

Loesch, J. G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. Amer. Fish. Soc. Symp. 1:89-103.

Loesch, J. G. and W. A. Lund. 1977. A contribution to the life history of the blueback herring. Trans. Am. Fish Soc. 106:583-589.

Longcore, J. R. and J. P. Gibbs. 1988. Distribution and numbers of American black ducks along the Maine coast during the severe winter of 1980-1981. Waterfowl in Winter. Univ. of Minnesota, Minneapolis, MN 277-389.

MacDonald J.S., M.J. Dadswell, R.G. Appy, G.D. Melvin and D.A. Methven. 1984. Fishes, fish assemblages and their seasonal movements in the lower Bay of Fundy and Passamaquoddy Bay, Canada. Fish. Bull., U.S. 82(1): 121-139.

Malecki, R.A., S.E. Sheaffer, and J.W. Enck. 1988. Influence of agricultural land use changes on wintering Canada Geese in the Atlantic flyway. Trans. NE Sect. Wildl. Soc. 45: 8-15.

Mansueti, R. J., and J. D. Hardy, Jr. 1967. Development of fishes of the Chesapeake Bay region, an atlas of egg, larval, and juvenile stages, Part 1. Nat. Resour. Inst., University of Maryland, Baltimore. 202 pp.

Marcy, B. C., Jr. 1976. Early life history studies of American shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. Am. Fish. Soc. Monogr. No. 1:141-168.

Mathieson, A.C. and E.J. Hehre. 1986. A synopsis of New Hampshire seaweeds. Rhodora 88:1-138.

Mathieson, A.C. and R.A. Fralick. 1972. Investigations of New England Marine Algae V. The algae vegetation of the Hampton-Seabrook estuary and the open coast near Hampton, New Hampshire. Rhodora 74:406-435.

McCracken, F.D. 1963. Seasonal movements of the winter flounder, *Pseudopleuronectes americanus* on the Atlantic coast. J. Fish. Res. Bed Can. 20(2):551-586.

McKenzie, R. A. 1964. Smelt life history and fishery in the Miramichi River, New Brunswick. Bull. Fish. Res. Board Can. 144. 77pp.

Murawski, S. A., G. R. Clayton, R. J. Reed, and C. F. Cole. 1980. Movements of spawning rainbow smelt, *Osmerus mordax*, in a Massachusetts estuary. Estuaries 3(4):308-314.

Nelson, J.I., J. Falicon, G. Lamb, D. Miller and S. Perry. 1981. Inventory of the Natural Resources of Great Bay Estuarine System. New Hampshire Fish and Game Department.

Nelson, J.I., J. Falicon, G. Lamb, D. Miller and S. Perry. 1982. Great Bay Estuary Monitoring Survey. New Hampshire Fish and Game Department. 199 pp.

Newell, Roger I.E. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North and Mid-Atlantic). Blue Mussel. Biol. Rept. 82(11.102) TR EL-82-4. US Army Corps of Eng. and U.S. Fish and Wildlife Serv.

Newell, C. and H. Hidu. 1986. Species Profile: Life Histories and environmental requirements of coastal fish and invertebrates (North Atlantic)-softshell clam. USFWS Biol. rep. 82(11.53)TR EL-82-4:16 p.

Nichols, M.M. 1993. National Estuarine Inventory: Supplement. Sediment Characterization of North Atlantic Systems, New England. Coastal Resources Foundation, Gloucester VA 23061 33 pp.

Nisbet, I.C.T. 1977. Courtship-feeding and clutch size in Common Terns. Pp.101-109 in B. Stonehouse and C. Perrins (eds.). Evolutionary ecology. (Vol. 2. Biology and environment.) 310 pp.

Normandeau Associates. 1995. Seabrook Station 1994 Environmental Studies in the Hampton-Seabrook Area. A Characterization of Environmental Conditions During the Operation of Seabrook Station.

Normandeau Associates. 1974. Piscataqua River Ecological Study. Normandeau Associates, Inc., Bedford, New Hampshire.

Ojeda, F.P. and J.H. Dearborn. 1990. Diversity, abundance and spatial distribution of fishes and crustaceans in the rocky subtidal zone of the Gulf of Maine. Fish. Bull. 88(2):403-410.

Pardue, G.B. 1983. Habitat suitability index models: alewife and blueback herring. USFWS, FWS/OBS-82/10.58. 22 pp.

Pearson, T.H. 1968. The feeding biology of sea-bird species breeding on the Farne Islands, Northumberland. J. Anim. Ecol.37:521-552.

Peterson, R.H., P.H. Johansen, and J.L. Metcalfe. 1980. Observations on early life stages of Atlantic tomcod, *Microgadus tomcod.* Fish. Bull. 78(1):147-158.

Phillips, B.F., J. S. Cobb and R.W. George. 1980. General biology, p.2-72 in Cobb, J. S., and B.F. Phillips (eds.) The Biology and Management of Lobsters Vol. 2. NY: Academic Press.

Phillips, B.F. and A.N. Sastry. 1980. Larval ecology, p. 11-50. in Cobb, J. S., and B.F. Phillips (eds.) The Biology and Management of Lobsters Vol. 1. NY: Academic Press.

Pinkowski, B.C. 1980. Adaptations of Common Terns nesting on an inland reservoir. Prairie Nat. 12: 111-113.

Pottle, R. A., and R.W. Elner. 1982. Substrate preference behavior of juvenile American lobster, *Homarus americanus*, in gravel and silt-clay sediments. Can. J. Fish. Aquat. Sci., 39, 928-932.

R.W.Rangeley and D.L. Kramer. 1995a. Tidal effects on habitat selection and aggregation by juvenile pollock, *Pollachius virens,* in the rocky intertidal zone. Mar. Ecol. Prog. Ser. 126:19-29.

Rangeley, R.W. and D.L. Kramer. 1995b. Use of rocky intertidal habitats by juvenile pollock *Pollachius virens.* Mar. Ecol. Prog. Ser. 126:9-17.

Reed, A. and G. Moisan. 1971. The *Spartina* tidal marshes of the St. Lawrence estuary and their importance to aquatic birds. Naturaliste Can. 98:905-922.

Reed, A. 1970. The breeding ecology of the black duck in the St. Lawrence estuary. D.Sc. Thesis. University Laval, Quebec. 175 pp.

Reed, A., G. Chapdelaine and P. Dupuis. 1977. Use of farmland in Spring by migrating Canada geese in the St. Lawrence valley, Quebec. J. Appl. Ecol. 14: 667-680.

Reynolds, W. W., and M.E. Casterlin. 1979. Behavioral thermoregulation and activity in *Homarus americanus.* Comp. Biochem. Physiol. 64A:25-28.

Reynolds, W. W., and M.E. Casterlin. 1985. Vagile macrofauna and the hydrographic environment of the Saco River Estuary and adjacent waters of the Gulf of Maine. Hydrobiologia, 128, 207-215.

Ringelman, J. K., J. R. Longcore, and R. B. Owen, Jr. 1982. Breeding habitat selection and home range of radio-marked black ducks (Anas rubripes) in Maine. Can. J. Zool. 60:241-248.

Ringelman, J. K. and J. R. Longcore. 1982. Movements and wetland selection by brood rearing black ducks. J. Wildl. Manage. 46(3):615-621.

Ringelman, J. K. 1980. The breeding ecology of the black duck in south-central Maine. Ph.D. University of Maine, Orono. 89 pp.

Rogers, C.A. 1976. Effects of temperature and salinity on the survival of winter flounder embryos. Fish. Bull. 74(1):52-58.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 p.

Scott, W. B. and M. G. Scott. 1988. Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219:731 p.

Seymour, N. and W. Jackson. 1996. Habitat-related variation in movements and fledging success of American black duck broods in northeastern Nova Scotia. Can. J. Zool. 74:1158-1164.

Seymour, N. R. 1984. Activity of black ducks nesting along streams in northeastern Nova Scotia. Wildfowl 35:143-150.

Short, F.T. 1992. (ed.) The ecology of the Great Bay Estuary, New Hampshire and Maine: an estuarine profile and bibliography. NOAA-Coastal Ocean Program Publ. 222 pp.

Sprankle, K. 1996. Identification of important habitats in the Great Bay focus area using a geographic information system. USFWS, Newington, NH. 18 pp.

Stewart, L.L. and P.J. Auster. 1987. Species Profiles: Life Histories and Environmental Requirements of Coastal fishes and Invertebrates (North Atlantic)-Atlantic tomcod. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.76). 8 pp.

Stickney, A.P. 1959. Ecology of the Sheepscot River Estuary. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fisheries. No. 309. 21 p.

Targett, T.E. and J.D. McCleave. 1974. Summer abundance of fishes in a Maine tidal cove with special reference to temperature. Trans. Am. Fish. Soc. 103(2):325-330.

Thayer, G.W., W.J. Kenworthy, and M.S. Fonseca. 1984. The ecology of eelgrass meadows of the Atlantic coast: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/02. 147 pp.

Tort, M.J. 1993. Environmental Variables Influencing Species Composition and Abundance of Intertidal Fish Assemblages in a North-temperate Estuary. M.S. Thesis, Univ. of Maine, Orono. 81 pp.

Townsend, D. 1984. The relations between larval fishes and zooplankton in two inshore areas of the Gulf of Maine. J. Plankton Res. 5(2):145-173.

USFWS. 1988. American black duck breeding habitat enhancement in the northeastern United States: a review and synthesis. Biological Report No. 88(4).

USFWS. 1980. Habitat Evaluation Procedures (HEP). U.S.D.I. Fish and Wildlife Service. Division of Ecological Services. ESM 102.

Van Guelpen, L. and C. Davis. 1979. Seasonal movements of the winter flounder in two contrasting inshore locations in Newfoundland. Trans. Am. Fish. Soc. 108:26-37.

Wahle, R. A. 1993. Recruitment to American lobster populations along an estuarine gradient. Estuaries, 16(4), 731-738.

Ward, L.G., A.C. Mathieson and M.J. Dzierzeski. 1991. Great Bay Aerial Salt Marsh Mapping Project , Jackson Estuarine Research Laboratory. New Hampshire Coastal Program. 14 pp.

Warinner, J. E., J. P. Miller, and J. Davis. 1969. Distribution of juvenile river herring in the Potomac River. proc. Annu. Conf. Southeast Assoc. Game Fish Comm. 23:384-388.

Weiss-Glanz, L. S., J. G. Stanley, J. R. Moring, and D. Moran. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic), American shad. USFWS Biol. Report 82(11.59).

Whitlatch, R.B. 1982. The ecology of New England tidal flats: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-81/01. 125 pp.

Appendix A: Figures

Appendix B: GOMC Species List

Appendix C: Federal Grant Opportunities for Habitat Protection

Voluntary habitat protection strategies include conservation easements, land acquisition, restoration and management, agricultural incentives and conservation education. Conservation organizations and private landowners interested in protecting or restoring nationally important fish and wildlife habitat can compete for federal grants. Nationally important habitat includes coastal wetlands, nesting islands, or habitat for endangered/threatened species, migratory birds, anadromous fish and certain marine mammals. Successful grant proposals must be matched by non-federal contributions, in the form of cash, material, equipment, protected lands or in-kind services. The following cooperative initiatives and matching grant opportunities can provide funds for acquisition, easement or technical assistance:

North American Waterfowl Management Plan Grants: This international effort to conserve the continent's remaining wetlands and increase migratory bird populations provides large matching grants (up to $1,000,000). The North American Waterfowl Management Plan identified Joint Ventures, regions of high waterfowl value needing protection. Within Joint Ventures, federal and state agencies, conservation groups and private citizens are encouraged to apply for grants and work together to conserve and manage priority wetland habitat. Funds, authorized under the North American Wetlands Conservation Act, can be used to manage, restore and/or acquire habitat, through purchase or easement. In addition, a pilot small grants program (less than $50,000) was established in 1996 to encourage new partnerships. Federal funds must be matched or exceeded by non-federal contributions, in the form of cash, goods, services and/or land. Any federal, state or private organization that can demonstrate its ability to hold and manage land for wildlife values in perpetuity is eligible to receive a North American grant.   The Great Bay Resource Protection Partnership is promoting the application of North American Waterfowl Management Grants for protection of wildlife habitats around Great Bay.   Further information can be obtained from New Hampshire Fish and Game, The Nature Conservancy of New Hampshire, or the Fish and Wildlife Service Great Bay National Wildlife Refuge.

National Coastal Wetlands Conservation Grants: This matching grant program, authorized by the Coastal Wetlands Planning, Protection and Restoration Act, and administered by the U.S. Fish and Wildlife Service, distributes funds to state conservation agencies to acquire, restore, or manage coastal and Great Lake wetlands for fish and wildlife values. Applications are rated on the basis of resource values, including wetland type, endangered/threatened species, anadromous fish, biodiversity, long-term conservation value and partnerships. Nationwide, recent grants have ranged from $10,000 to $1,000,000.

National Fish and Wildlife Foundation Grants: The National Fish and Wildlife Foundation, a nonprofit organization, was established by Congress to award grants for conservation activities that support fish, wildlife and plant conservation. The Foundation uses federal funds as seed money to attract additional private donations. Once the Foundation at least matches its original Congressional appropriation, it releases grants on a matching grant basis to conservation organizations worldwide. Programs include habitat protection and restoration, research, education and management. Grants typically range from several thousand dollars to more than $100,000 and can be directed to federal and state agencies, universities, corporations, and private conservation organizations. Fisheries Across America is a separate grant program coordinated by the National Fish and Wildlife Foundation dedicated to restoring riparian and in-stream habitat, managing fisheries, eradicating exotic species, and monitoring and protecting habitat.

Land and Water Conservation Fund: Federal land management agencies can request money from this fund to acquire lands for federal protection. State agencies can also request money from this fund to acquire land and expand outdoor recreation opportunities. Funding must be approved by Congress.

U.S. Fish and Wildlife Service Challenge Cost Share Grants: This program encourages partnerships by awarding matching federal funds to manage, restore and enhance fish and wildlife habitat and provide educational services to visitors. Priority funding is directed to national wildlife refuges and national fish hatcheries, but habitat protection and restoration projects on private lands are also eligible. Challenge Grants are typically limited to $15,000 or less.

Partners for Wildlife: The U.S. Fish and Wildlife Service's Partners for Wildlife Program provides technical assistance to solve land management problems, identify partners and coordinate restoration work on private lands. The Partners for Wildlife Program concentrates on restoring degraded freshwater and saltwater wetlands, riparian (stream-side) habitat, and habitat for migratory songbirds, endangered and threatened species, and fishes. Restoration costs may be shared by any combination of governmental agencies, private organizations and the private landowner. Cost-effective restoration projects that provide the greatest fish and wildlife benefit for the least money are most likely to receive attention from the Partners program. The landowner must commit to maintaining restored habitat for a minimum of ten years.

Partnerships for Wildlife: This matching grant program, administered by the U.S. Fish and Wildlife Service, provides grants for state fish and wildlife agencies focusing on species which are NOT hunted or fished, or NOT protected under the Endangered Species Act or the Marine Mammals Protection Act. Priority is given to projects involving species at risk of becoming threatened or endangered. Grants can be used for resource management and research, land acquisition, restoration or enhancement, education and/or promoting non-consumptive forms of wildlife recreation (i.e. photography, viewing). States must provide 1/3 of the cost, private groups can contribute 1/3 of the cost, and the Partnerships Program provides the final 1/3. Each state is limited to $250,000 annually from this program.

Other federal and state funds: In addition to funding through the programs described above, the U.S. Department of Agriculture, the Environmental Protection Agency and the Army Corps of Engineers also provide funds for wetland restoration. Through the

Coastal America Program, federal agencies identify potential restoration projects and pool available resources to carry out priority projects. Other habitat protection funding opportunities may be available through your state government. In some states, lotteries, credit cards, income tax check-offs, vanity license plates and bond issues provide funds for habitat protection.

Additional information on federal and cooperative habitat protection initiatives may be obtained from:

Stewart Fefer, Project Leader or
Lois Winter, Outreach Specialist
Gulf of Maine Project
U.S. Fish & Wildlife Service
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