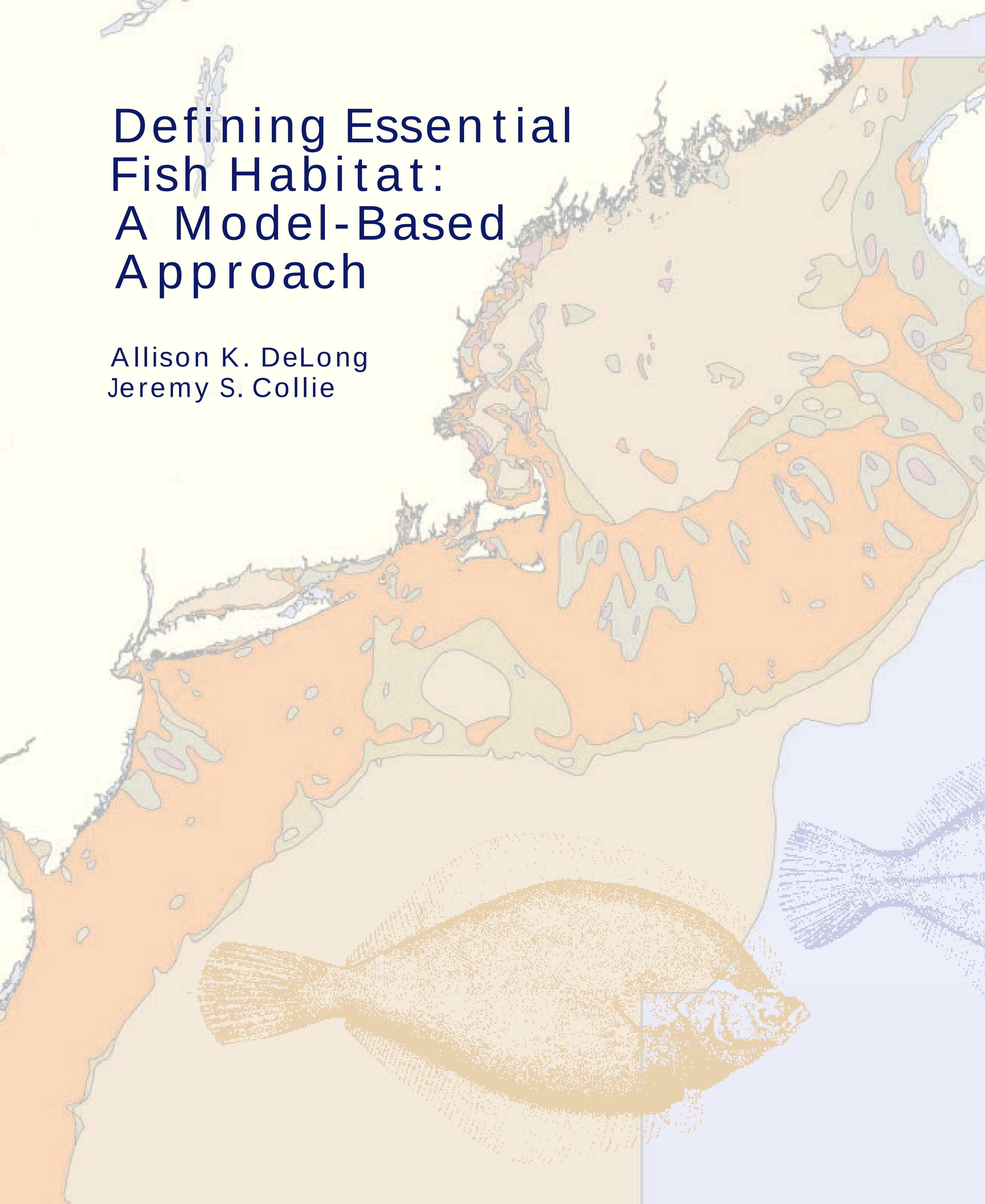
Defining Essential Fish Habitat: A Model-Based Approach

Allison K. DeLong
Jeremy S. Collie

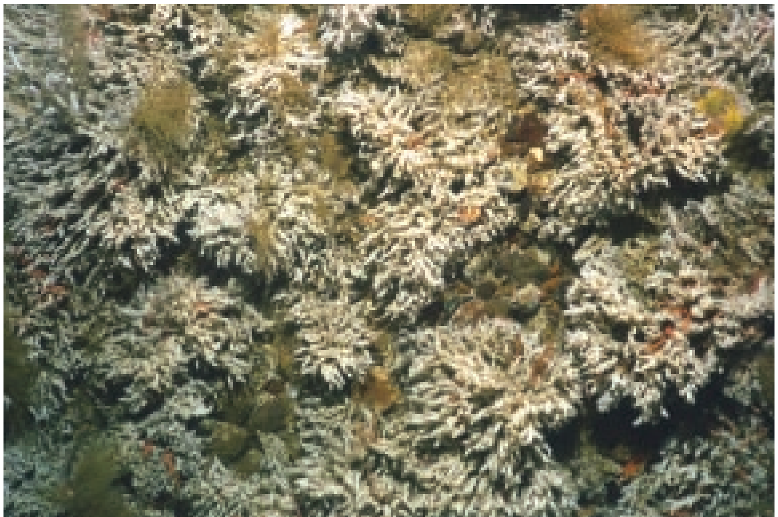


Introduction

In the Magnuson-Stevens Fishery Conservation and Management Act of 1996, Congress mandated the National Marine Fisheries Service (NMFS) and the eight regional fishery management councils to identify essential fish habitat (EFH) for all managed fish species. EFH is defined as “those waters and substrate necessary for spawning, breeding, feeding, or growth to maturity.” The conservation of EFH is important to building and maintaining sustainable fisheries. In offshore waters (greater than three miles from shore), the councils use EFH definitions to comment on proposed federal activities and as the basis for setting up seasonal and year-round fishery closures.

In New England and other regions of the United States, the current EFH definitions are based on the fish distributions observed in fishery-independent survey data. Fishery surveys are carefully standardized such that catch-per-tow and tow location can be used as a spatial measure of relative abundance. The mean of the survey catch data is calculated in pre-defined 10-minute-by-10-minute quadrants covering the species range. The quadrants with higher relative abundance are taken to represent EFH. Maps are then created that portray the smallest regions containing 50, 75, and 90 percent of the population (calculated as the sum of the quadrant means). For most species, EFH currently is defined to include the geographic quadrants associated with the 90th population percentile. As a result, most of the species range is defined as EFH, and the “best of the best” habitat and habitat attributes that constitute EFH remain unknown. For example, Figure 1 shows the northern portion of the current EFH designations for Atlantic cod.

This pamphlet describes a new method that we have developed to define EFH, and we encourage its application as a plausible alternative to the present approach. Our new model-based method uses location variables (latitude and longitude), sampling year, and habitat-related characteristics (e.g., water depth, water temperature, and sediment type) to quantify a species’ distribution. The model is used to predict catch-per-tow over a finely spaced grid of locations covering the species’ range. These predictions then can be used to generate population percentiles like those used in the current method. But the new method bases EFH definitions on habitat attributes and changes in stock abundance, and it can be used to obtain smooth and continuous regions representing any desired population percentile—both of which go beyond the ability of the current method. In addition, definitions can be updated as new survey data and additional habitat variables become available. Three applications of this approach are demonstrated in this pamphlet.



Winter flounder swims in Narragansett Bay. Photo by Jerry Prezioso, NEFSC.

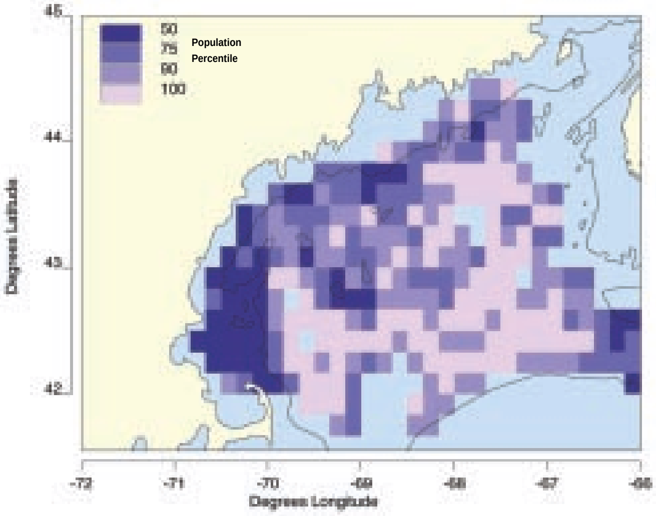


Figure 1. Current EFH definition for Atlantic cod in the Gulf of Maine.

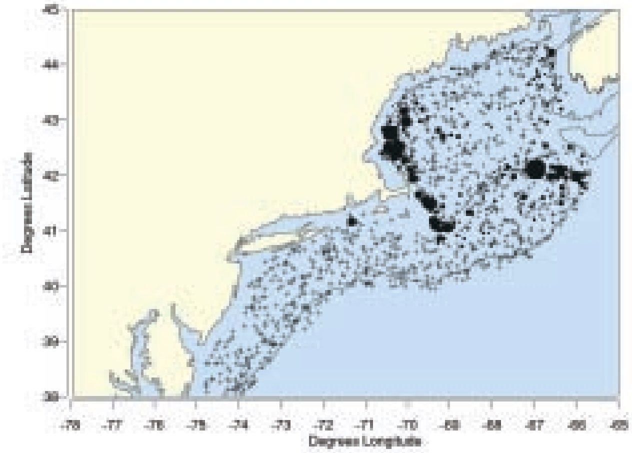


Figure 2. NEFSC survey catch-per-tow for Atlantic cod from 1997–2000. Circles indicate presence of cod with the size of the circle proportional to the catch; the “+” indicates sampled area where no cod was found. The solid line is the 100 m isobath.

Photos left and far left: Gravel habitats on northern Georges Bank (depth 80 m). Photos by Dann Blackwood, U.S. Geological Survey.

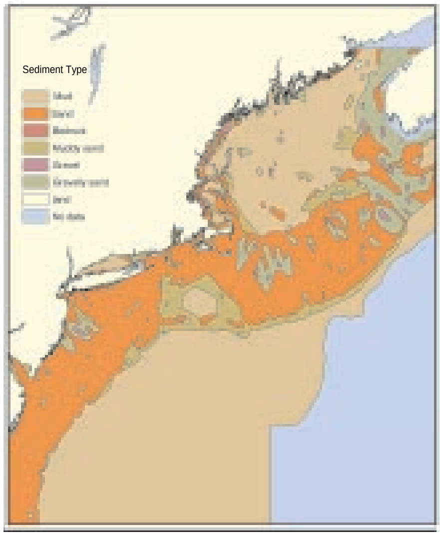


Figure 3. Surficial sediments from Poppe, L.J., J.S. Schlee, B. Butman, and C.M. Lane. 1989. Map showing distribution of surficial sediment, Gulf of Maine and Georges Bank. U.S. Geol. Surv. Misc. Invest. Ser., Map 1-1987-A. Silt and clay sediments were merged into a general mud category.

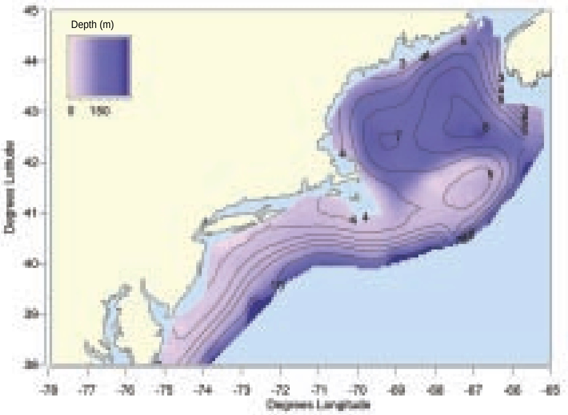


Figure 4. Depth in meters (colors) and spring temperatures (degrees C, contour lines) during the period from 1990–2000 as interpolated from the NEFSC survey data.

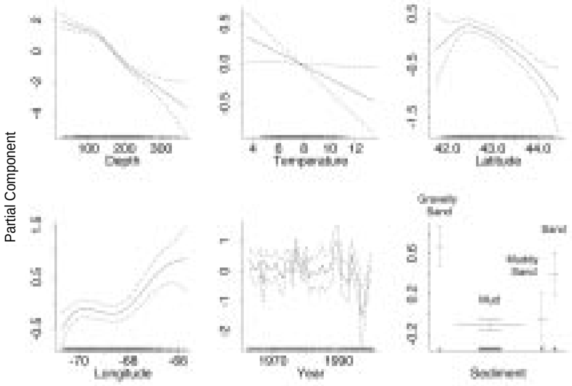


Figure 5. GAM output for Gulf of Maine cod in the fall. The solid line shows the predicted values, broken lines indicate the standard errors, and the "rug plots" on the x-axis indicate the range of variables over which measurements were taken.

The Method

We focused on three commercially important species in the northwest Atlantic—Atlantic cod, winter flounder, and yellowtail flounder—and used NMFS Northeast Fisheries Science Center (NEFSC) bottom trawl survey data. This data set is the same one used to develop the current definitions of EFH. The trawl survey encompasses about 230 stations from Cape Hatteras, N.C., to the Scotian Shelf and has been conducted every fall since 1963 and every spring since 1968.

Statistical models were fitted to the survey data to predict abundance as a function of habitat variables and geographic location. The model is expressed by the following equation:

$$\log(\text{Abundance}) = \text{Mean} + \text{Sediment} + \text{Depth} + \text{Temperature} + \text{Year} + \text{Latitude} + \text{Longitude} + \text{Error}$$

Year is included to express changes in overall stock abundance through time. The remaining variables are spatially explicit. The resulting model can be used to estimate abundance at any geographic site once the sediment type, depth, water temperature, and location identifiers are supplied. Figures 2 (previous page) through 4 provide a pictorial representation of the equation. The map of Atlantic cod survey catches (Fig. 2) indicates the regions of high and low abundance at each of the survey stations. These catches are assumed to be a function of sediment type (Fig. 3) and depth and temperature (Fig. 4).

A variety of models could be used to relate fish abundance to the habitat variables. We choose to use generalized additive models (GAMs, with Poisson distributed errors) because they allow for nonlinear relationships between the catch data and habitat variables. Separate models are fitted for each species, stock, and survey combination. The models are stock-specific due to changes in habitat availability along the coast and to the limited ability of fish to move great distances. Species stock definitions are based on the surveys used in the NEFSC stock assessments. The models were fitted and figures created in S-Plus. The best model for each season and stock includes a combination of linear or curvilinear responses of the continuous variables and the coefficients of the significant categorical variables.

The GAM fits for Gulf of Maine Atlantic cod explain 47 percent of the variability in the fall survey data and 41 percent in the spring data. The partial components, as represented by the y-values on the GAM plots, express the relationship between the observed catches and each habitat variable (Figs. 5 and 6). Habitat variables with higher partial components are associated with larger catches and, hence, more suitable habitat. The GAMs indicate that Atlantic cod prefer shallower waters and temperatures between 4 C and 6 C. Cod abundance is highest at about 42.5˚ latitude. There is a general increase in abundance to the east; however in the spring, there is a pocket of low abundance at about minus 69˚ longitude. In the fall, there is a significant sediment effect; cod prefer sand and gravelly sand over mud and muddy sand. In spring, the sediment effect is insignificant. Finally, both surveys indicate significant changes in abundance through time.

Predicting abundance and making maps

The fitted models can be used to predict abundance at any site of interest for which depth, temperature, and sediment are known. The GAMs for Gulf of Maine cod were used to predict abundance over a finely spaced grid of points that cover the stock area. Habitat attributes were determined at each point. Sediment came from the U.S. Geological Survey Geographic Information System (GIS) coverage (Fig. 3) and temperature and depth were interpolated from the survey data (Fig. 4). Results of the time period from 1990 to 2000 are shown at right.

The two maps of the predicted distribution of Atlantic cod, based on the two surveys and two temperature regimes, are similar (Fig. 7). The color gradations from dark to light purple show the predicted population percentiles. For example, the portion of the region colored in the darkest purple shows the 10th population percentile, or the smallest region that holds 10 percent of the population. This region has the highest predicted densities of Atlantic cod, because it is the smallest area with the most fish. The 20th percentile would include the 10th percentile and the region delineated by the next lighter shade of purple. Due to the inclusion of sediment type in the model, the maps from the fall survey data are more irregularly shaped than the map based on the spring survey data. For example, the detail in the region north of Cape Cod (Fig. 7a), which is based on the fall survey data, reflects the underlying sediment distribution, whereas the model using the spring survey data does not clearly delineate this area. The high-density region in the southeast portion of the maps is due to an irregularly shaped survey stratum and most likely consists of the Scotian Shelf population.

Since the maps of population percentiles from the modeling exercise are consistent over years and seasons, it is possible to define EFH using the GAM approach. These new maps can be compared with the existing definition of Atlantic cod EFH in the Gulf of Maine. The two methods are based on the same survey data and yield similar results (Figs. 1 and 7). However, the current EFH definition for Gulf of Maine cod is more fragmented, less detailed, and covers the majority of the stock area (Fig. 1). The GAM–based maps are smoother and contain more information. It is possible to examine the GAM output and the habitat characteristics to explain why a given region is considered EFH. For example, the highest density area of Atlantic cod, located just north of Cape Cod, Mass., is a relatively shallow, colder region.

This procedure also was applied to Georges Bank winter and yellowtail flounders (Figs. 8 and 10). The GAM for Georges Bank winter flounder using the fall survey data explains 48 percent of the variability in the data. There were dome-shaped depth and temperature responses, with preferences for depths of about 50 meters (m) and temperatures of about 14 C. Population abundance increases to the north and west. As with the current definition of EFH for winter flounder on Georges Bank (Fig. 9), our map (Fig. 8) shows that the best habitat is located along the northern portion of the Bank. However, the new map shows a narrow band representing the "best" habitat.

The GAM model for Georges Bank yellowtail flounder explains 44 percent of the variability in the spring survey data. We found a curvilinear relationship with depth, with preferences for depths of about 90 m and preferences for temperatures less than 6 C. The highest abundances are to the south and east. Again, our map (Fig. 10) compares well with the existing EFH definition for yellowtail on Georges Bank (Fig. 11), but provides new levels of detail.

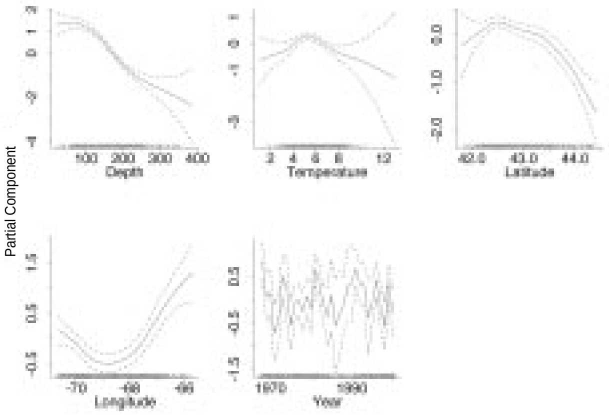


Figure 6. GAM output for Gulf of Maine cod in the spring. The solid line shows the predicted values, broken lines indicate the standard errors, and the "rug plots" on the x-axis indicate the range of variables over which measurements were taken.

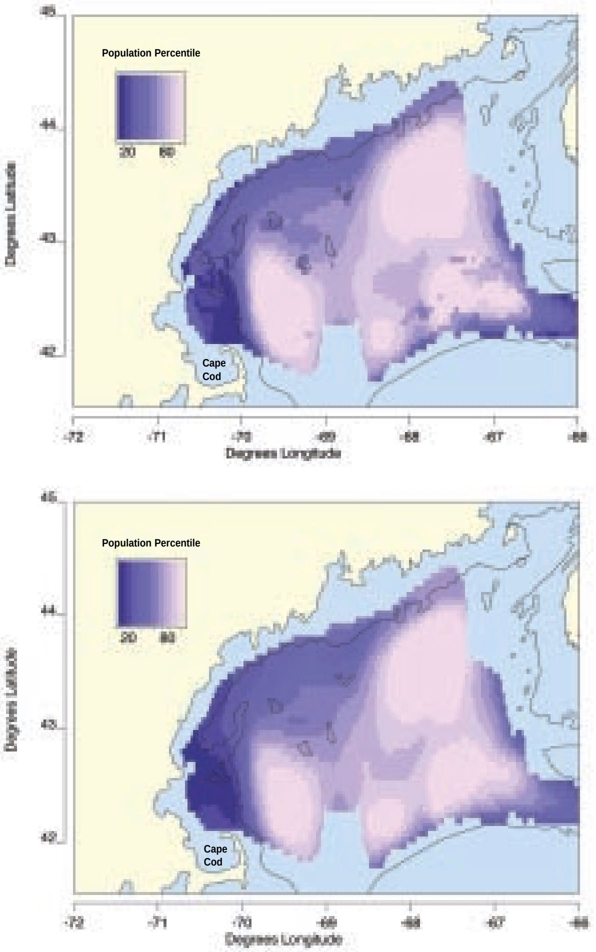


Figure 7. Maps of predicted population percentiles using a) GAMs from fall survey data and temperatures from the years 1990–99; and b) GAMs from spring survey data and temperatures from the years 1990–2000. The black lines indicate the 100 m isobath.

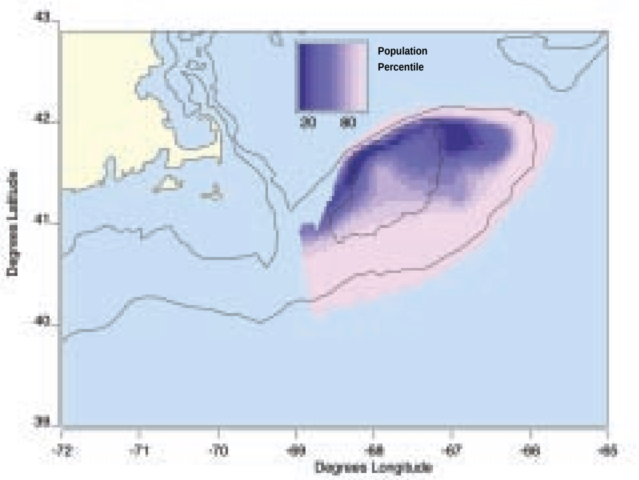


Figure 8. GAM–based EFH designations for Georges Bank winter flounder using the fall survey data. The black lines indicate the 50 m and 100 m isobaths.

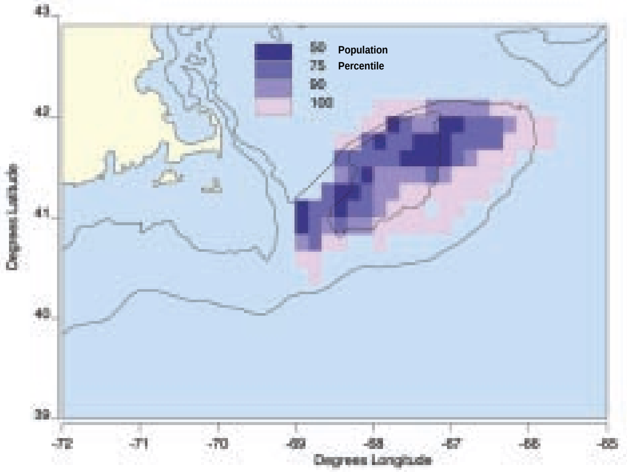


Figure 9. Current EFH definition for winter flounder on Georges Bank. EFH is defined by the 90th percentile, which also includes the 50th and 75th percentiles.

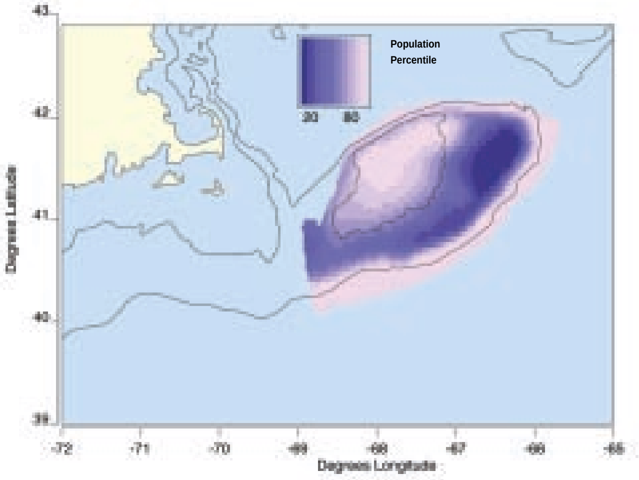
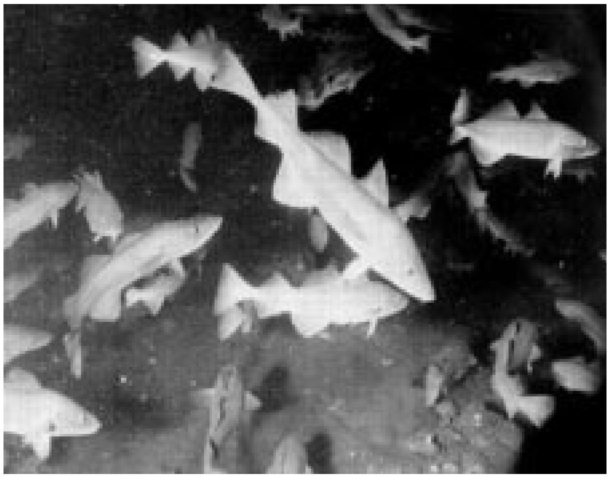


Figure 10. GAM–based EFH for Georges Bank yellowtail flounder using the spring survey data. The black lines indicate the 50 m and 100 m isobaths.

Application to Management

New model-based methods for defining EFH base species distributions on habitat characteristics, rather than simply mapping historic patterns of survey catches. In the examples shown here, the GAMs are capable of explaining a significant fraction of the variability in the survey data. The maps based on the models are easier to interpret and less disjoint than the current EFH maps. A model-based EFH map can be created for fish populations where survey data over much of the species' range are available. The best data are derived from a random sampling survey design and certain known habitat-related attributes at the survey stations that can be interpolated over a finely spaced grid of points.

In order to designate EFH for the entire range of a species, GAMs can be fitted and abundances predicted for each stock. The predictions can then be merged and population percentiles calculated and mapped. Finally, modern statistical software programs make this type of analysis feasible within a moderate time frame.



Atlantic cod on Georges Bank. Photo courtesy of the NEFSC Photo Archives.

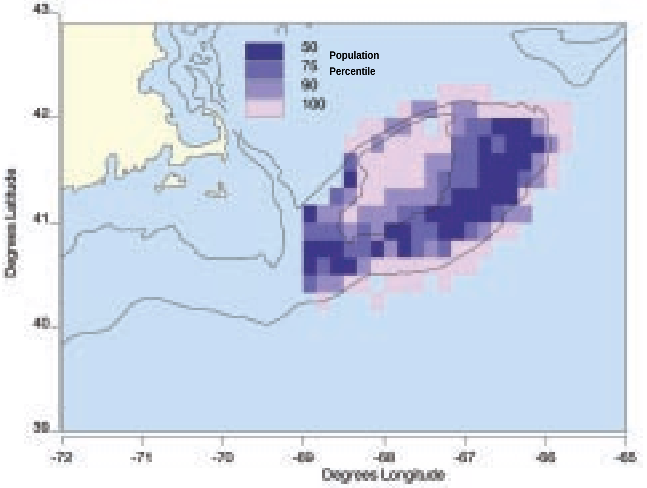


Figure 11. Current EFH definition for yellowtail flounder on Georges Bank. EFH is defined by the 90th percentile, which also includes the 50th and 75th percentiles.

Acknowledgements

We thank the following staff of NMFS for their assistance with this project: Bottom trawl survey data from the NEFSC database were provided by Steven Cadrin, NMFS. Michael Pentony, NMFS, provided GIS coverages of the current EFH designations. John O'Reilly, NMFS, provided the isobaths used in plotting the maps. This publication is sponsored in part by Rhode Island Sea Grant, under NOAA Grant No. NA16RG1057. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

Additional copies of this publication are available from the Rhode Island Sea Grant Communications Office, University of Rhode Island Bay Campus, Narragansett, RI 02882-1197. Order P1695.

Loan copies of this publication are available from the National Sea Grant Library, Pell Library Building, University of Rhode Island Bay Campus, Narragansett, RI 02882-1197. Order RIU-T-04-002.

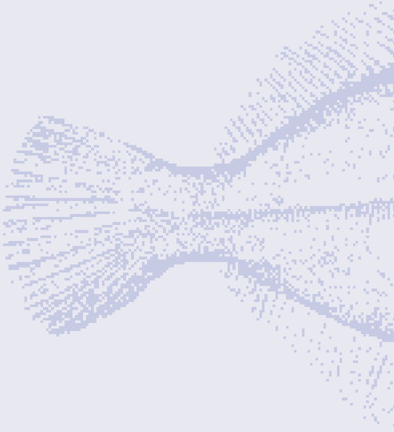
This document should be referenced as:
DeLong, A.K. and J.S. Collie. 2004. Defining Essential Fish Habitat: A Model-Based Approach. Rhode Island Sea Grant, Narragansett, R.I. 4pp.

Cover credits

Front and back covers: Fish illustrations courtesy of the NEFSC Photo Archives (www.nefsc.noaa.gov/cgi-bin/photo.pl?)
Back cover: Photo courtesy of the Rhode Island Sea Grant Sustainable Fisheries Extension Program

For Further Reference

Northeast Region: http://www.nero.noaa.gov/ro/doc/newefh.html
Southeast Region: http://caldera.sero.nmfs.gov/habitat/efh/efhhome.htm
Northwest Region: http://www.nwr.noaa.gov/1habcon/habweb/msa.htm
Southwest Region: http://swr.nmfs.noaa.gov/efh.htm
Alaska Region: http://www.fakr.noaa.gov/habitat/efh.htm



Printed on recycled paper