ANNUAL REPORT FY 2013
HABITAT ASSESSMENT FUNDED RESEARCH

Project Title:
Accounting for habitat-dependent observation error in bottom trawl survey indices for pelagic stocks using butterfish (*Peprilus triacanthus*) as a model

Funding Fiscal Year: 2012-2013
Report Fiscal Year: 2013
Date Submitted: 11/27/13
InPort ID#: ______

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Goals: Overarching goals and objectives -
Stock assessments are primarily informed by federal fishery independent trawl surveys. These surveys, stratified by depth and latitude, are usually conducted with single deep draft survey vessels over long periods and often during periods of seasonal transition. Logistical constraints and the large number of stocks assessed prevent complete habitat coverage for any single stock, as well as consideration of dynamic ocean features controlling stock distributions (e.g. temperature, oxygen, food, predators). If not taken into account, incomplete habitat coverage can result in the underestimation of population sizes. Further, movements of large numbers of animals between un-sampled habitat and survey frames can be misinterpreted as changes in population size. Incomplete habitat coverage is a particularly important source of error for stocks with low landings. When landings are low, stock size is scaled primarily by the catchability of the stock in surveys. Incomplete habitat coverage is also an important potential source of observation error in regions where timings of seasonal migration and species distributions are changing rapidly in response to changes in the spatial dynamics of important ocean habitat features with climate change.

The overarching goal of our project was to develop an ecologically accurate method to estimate survey habitat coverage that could be formally integrated into catchability estimates in stock assessment models. In fish population assessment observation error can be accounted for in the catchability term (Q) of the simple equation:

$$N = \frac{C}{EQ}$$

in which the index of population size (N) equals catch (C) divided by sampling effort (E), times the catchability (Q) of the animals. Survey designs, sampling techniques and logistical constraints interact with variations in species distributions and behavior to produce two sources of observation error. Errors are caused by: *a)* incomplete coverage of species habitats and thus the population by the space-time frame of the survey and *b)* failure of the sampling gear to detect all animals within habitats in which they are present. Catchability Q can therefore be partitioned into these two components; stock availability (ρ) and sampling efficiency (δ), such that:

$$Q = \delta * \rho$$

where, ρ is an estimate of the proportion of the population falling within the survey frame. δ is the proportion of the true density of animals occupying a site captured by the sampling gear. *Specifically, our goal was to develop a habitat based estimate of stock availability (ρ_H) that can be integrated with estimates of δ in the calculation of survey catchability (Q).*

We developed our habitat based estimate of the availability (ρ_H) of marine fish populations to surveys using Atlantic butterfish, Peprilus triacanthus, as a model. Atlantic butterfish is a short lived (max age ~3 years), pelagic, schooling fish that ranges from Newfoundland to Florida.

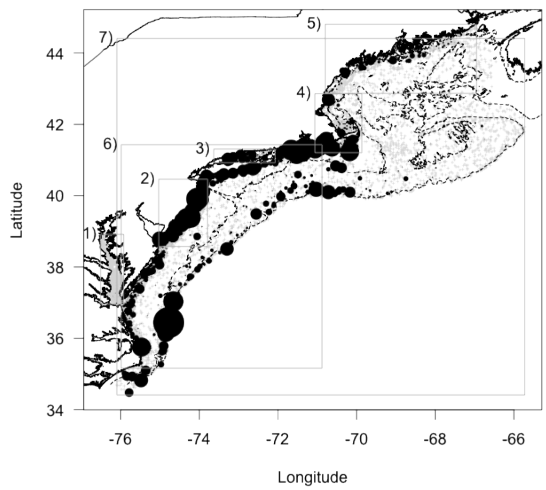


Figure 1. Study area extent and the fishery independent bottom trawl survey samples of butterfish and temperatures collected from 2008 through 2012 in 7 surveys used to calibrate the thermal niche model for Atlantic butterfish (Fig 3). The calibration dataset integrated surveys of 1) Chesapeake Bay, 2) coastal New Jersey, 3) Long Island Sound, 4) coastal Massachusetts, 5) coastal Maine and New Hampshire 6) the nearshore coastal ocean from Cape Hatteras, North Carolina to Martha's Vineyard, Massachusetts, as well as 7) deeper waters on the North West Atlantic Continental Shelf sampled by NOAA/NEFSC. Grey dots are stations sampled while black circles are scaled to indicate the relative size of positive catches of butterfish standardized by estimated swept areas of the trawl tows.

The species is most common north of Cape Hatteras into the Gulf of Maine where it uses a wide range of habitats from polyhaline reaches of coastal estuaries and sounds to deep waters along the outer edge of the continental shelf. *Seasonal migration, distributions and the timing of butterfish life history events appear to be strongly influenced by seawater temperature (Colton 1972, Berrien 1999, Manderson et al. 2011)*. North of Cape Hatteras most butterfish migrate inshore and toward the northeast as waters warm in the spring from deep overwintering habitats along the offshore edge of the continental shelf. Spawning follows spring migration; beginning offshore, and advancing inshore and to the northeast as waters warm above ~ 15^{o}C (Colton 1972, Berrien 1999). During the summer, juveniles and adults occupy shallow near-shore as well as deep offshore habitats. However, concentrations are highest along the inner continental shelf in the vicinity of coastal currents (Woodland et al. 2012). The northern edge of the species range expands and contracts in response to yearly variations in ocean temperature (Colton 1972). In recent years concentrations of butterfish have increased during warmer months in southern New England sounds and inshore waters in the Gulf of Maine (Collie et al. 2008, Howell & Auster 2012). These increases have been attributed to warming seawater temperatures. As near-shore temperatures cool in the fall, fish begin migrate to overwintering habitats offshore and to the southwest. Butterfish are usually absent from the coastal zone by late December.

The butterfish population in the northwest Atlantic has been assessed using fishery independent bottom trawl surveys conducted during Fall and Spring seasonal transition periods when temperature variability in the regional sea is extreme (Polyakov et al. 2005, Manning & Pelletier 2009, Shearman & Lentz 2010, Gawarkiewicz et al. 2012). To date assessments have primarily relied upon biomass indices estimated using a single federal survey (NOAA/NEFSC). The spatial frame of this survey encompasses continental shelf waters ranging in depth from ~21 m to 242 m from Cape Hatteras into the Gulf of Maine (~35.6N to -43.6 N, 75.6W to 66.6W).

The survey time frame includes an average of 58 days (44-101 days) during the fall (September through November) and 55 days (35-95 days) in the spring (February through April; Fig 1). Logistical constraints associated with survey extent, the draft of the vessel, scheduling, and diversity of species assessed (N~60) prevent comprehensive sampling of the entire range of habitats butterfish use. Nearshore habitats used during warm months and offshore overwintering habitats are considered to be under sampled. *The federal surveys are therefor vulnerable to environmentally driven changes in availability (ρ) and thus Q for the butterfish stock. Further survey catchability (Q) drives the scaling of population size in the butterfish stock assessment because industry landings have been low since the early 2000s.*

We developed a habitat based approach to estimate availability (ρ_H) for butterfish focusing on the development of a thermal habitat model to describe species distribution and range dynamics at a regional sea spatial scale and population level of organization. We focused on temperature for the following reasons. First, the high heat capacity and rate of heat transfer of seawater combined with the role of temperature in regulating metabolism and linked vital rates, make temperature the fundamental niche dimension controlling broad scale distributions of mobile ectotherms in the sea (Magnuson et al. 1979, Denny 1993, Brown 2004, Kooijman 2010). Secondly, recent changes in the distributions of many marine species at broad scales, have been attributed to changes in ocean temperatures with climate change (Petitgas et al. 2012, Cheung et al. 2013, Pinsky et al. 2013 and many others). Thirdly, numerical ocean circulation models are now accurate enough to hindcast ocean temperatures at grains and extents useful for marine resource assessment and management. Finally and consistent with all of the above, temperature appears to play a dominant role in regulating patterns of migration and spatial distributions of Atlantic Butterfish at the broad scales relevant to population assessment and management.

To achieve our goal of developing a thermal habitat based approach to estimate the availability of butterfish stock (ρ_H) to surveys that could be formally incorporated into catchability estimates in stock assessment models we set the following broad objectives:

1. Establish a functioning working group of experts in habitat ecology, stock assessment, oceanography, and management from government, academia, the fishing industry, and the fishery management council to advise, collaborate and ensure that our final product was accurate, useful, and acceptable for assessment.

2. Develop an accurate coupled biophysical model with a day time step and regional sea spatial extent that could be used to hindcast thermal habitat suitability for butterfish for surveys used in the assessment

3. Develop a habitat based index of availability (ρ_H) that could be used in the calculation of Q. ρ_H should be a dimensionless ratio of habitat suitability sampled to the total habitat suitability available during a survey. ρ_H must explicitly account for the effects of seasonal and inter-annual changes in habitat dynamics that drive species distribution shifts at broad scales. ρ_H must also take into account the trajectory of sampling on regional sea scale surveys with respect to habitat dynamics.

4. Demonstrate, in a simple manner, the application of the habitat based availability estimate (ρ_H) in the calculation of a survey based biomass estimate for butterfish in the North West Atlantic. Develop papers describing the approach for use as working papers for stock assessment data, modeling and review committee meetings as well as peer review publications.

5. Perform outreach activities to describe methods, results and possible outcomes so that assessment scientists, fishery management councils and members of the fishing industry are familiar and accepting of the approach.

6. Attend and participate in stock assessment data, modeling, and stock assessment review meetings. Make changes to the product as required.

7. Outline a method to operationalize the approach. In the event it is accepted at the final stock assessment review, accurate and consistently delivery of the product will be required for future updates to the stock assessment.

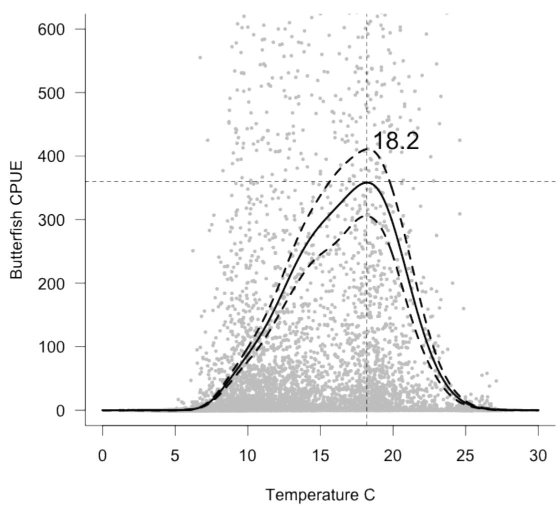


Figure 2. Generalized additive model using a penalized smoothing spline of the relationship between bottom water temperature and butterfish CPUE (catch standardized by swept area km^2 x 100) in the 7 fishery independent surveys from 2008 through 2012 integrated into the calibration dataset. Fit of the model is shown on the response scale relative to the CPUE data. The degree of smoothing was determined by Generalized Cross Validation using mgcv library defaults (Wood, 2006). Plot crops the y axis to better show the thermal response curve. The dotted vertical line is the approximate position of the thermal optima used as the start value for parameter estimation in the Johnson and Lewin Equation (Fig. 3). The horizontal line is set at the CPUE value on the y axis for the thermal optima. This CPUE was used to determine the start value for the scaling parameter C in maximum likelihood estimation.

Approach:

We organize our summary of work performed based on the 7 broad objectives described above

Establish a functioning working group of experts in habitat ecology, stock assessment, oceanography, and management from Government, Academia, the fishing industry, and the management council to advise, collaborate and ensure that our final product was accurate, acceptable and thus useful.

Twenty seven experts in ecological science, fishery practice, stock assessment and oceanography from government, academia, the fishing industry and the Mid Atlantic Fisheries Management Council (MAFMC) participated in two face to face working meetings of the OpenOcean study group (Table 1). We hosted a formal 2 day meeting in June 2012 to outline our general approach and discuss ways in which a final product could be developed that could be formally integrated into a stock assessment model. We hosted a second 2 day meeting in May 2013 to present a near final draft of the product. The scheduling of the second meeting gave us time to revise our product before the data meeting for the 2013 butterfish assessment which was held at the end of August 2013. Staff members of the Mid-Atlantic Fisheries Management council in charge of butterfish assessment and management and in developing an ecosystem based approach to fisheries management in the region attended these meetings. Many study group members provided advice and assistance required for the development of the final product outside of the two formal working meetings. We believe participation of both fishing industry experts and the lead assessment modeler in the working group were particularly important. Continued interactions with fishing industry experts ensured that the coupled bio-physical habitat model was accurate. Repeated interactions with the lead stock assessment modeler (Tim Miller) lead to the formal integration of the habitat model based estimate of availability into the Age Structured Assessment Program (ASAP) model for butterfish which we believe will be presented to the Stock Assessment Review Committee in late January 2014.

Development of an accurate coupled biophysical habitat model that could be used to hindcast thermal habitat suitability for surveys. Use hindcasts of habitat suitability in a index of availability (ρh) quantifying the proportion of habitat sampled to the total habitat suitability available in a way that accounted for the effects of seasonal and inter-annual changes in thermal habitat dynamics and the trajectory of sampling on regional sea scale surveys.

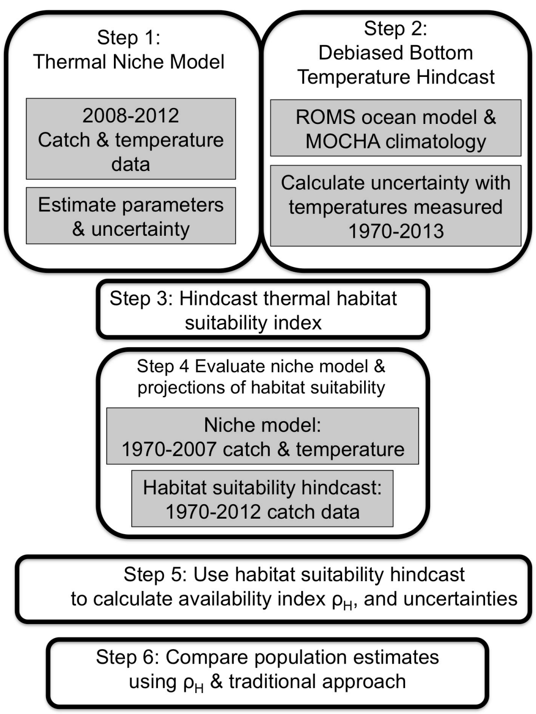


Figure 3. The 6 steps undertaken to develop a habitat based index of availability (ρh) of Atlantic Butterfish to surveys

Overall approach

We developed our habitat based index of availability (ρh) of Atlantic Butterfish to population assessment surveys in 5 steps. In step 1, we calibrated a thermal niche model for the species using fishery independent surveys conducted throughout the Northwest Atlantic. In step 2, we developed a hindcast of bottom temperature for Northwest Atlantic using historical climatology to debias output from a numerical circulation model. In step 3, we coupled the niche model to the debiased bottom temperature hindcast to project thermal habitat suitability (tHSI) for butterfish. In step 4) we used catch and *insitu* temperature data to evaluate the niche model and projections of tHSI made by the coupled model. In step 5) we used daily hindcasts of habitat suitability and locations and days of sampling to estimate the availability (ρ_H) of the butterfish stock to a regional assessment survey as the proportion of available habitat suitability sampled. In step 6) we demonstrated the application of the habitat based availability estimate (ρ_H) in the calculation of a survey based biomass estimate for butterfish in the North West Atlantic.

Step 1: Thermal niche model

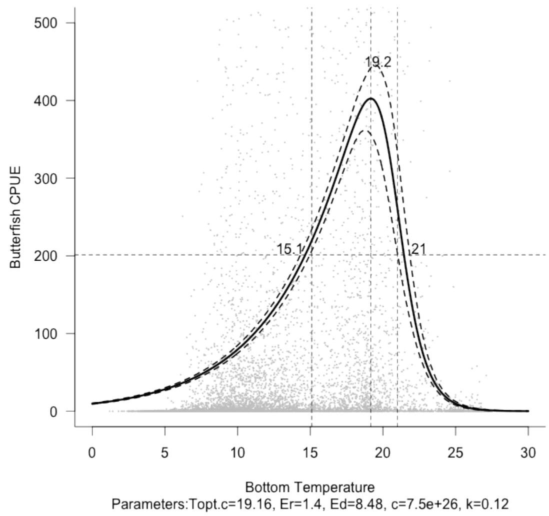


Figure 4. Plot of the thermal response curve for Atlantic butterfish constructed by estimating parameters of the Johnson and Lewin equation that (solid black line) minimized negative binomial likelihood using butterfish catch standardized by swept area estimates of trawl tows as the response (h) and bottom water temperatures as the independent variable. The function was parameterized using calibration data from 7 surveys the Northwest Atlantic from 2008-2012 (see fig 1). Dashed curved lines are 2.5% and 97.5% population prediction intervals. The horizontal line is located at half the maximum value of the parameterized equation. Vertical dashed lines indicate temperature in degrees centigrade of the optimal temperature (Topt) and at locations where the 2.5% population prediction interval crosses the ½ maxima.

We calibrated the thermal niche model for butterfish using catch densities in bottom trawls and bottom water temperatures measured from 2008-2012 in 7 fishery independent surveys conducted from shallow to deep water (5^{th} quantile=8 meters (M), 95^{th} quantile=194 M) over 12 degrees of latitude in the Northwest Atlantic (32.7N to 44.8N; N= 8957. Fig 1). We used data collected from 2008 through 2012 for calibration because seasonal sampling was completed in all 7 surveys during those years. Before combining catch data we used generalized additive modeling (GAM) to determine the general shape of the temperature response curve (Fig. 2) and whether the temperature response was influenced by survey, year and season to the degree that the data could not be merged. GAM indicated the data could be safely merged. Catch densities calculated as numbers of fish caught standardized by the area of the seabed swept per trawl tow was used as a proxy for relative habitat suitability.

To develop a parametric thermal niche model we used catch densities and bottom temperatures in the calibration set to estimate parameters for the Johnson and Lewin equation, a unimodal extension Boltzmann-Arrhenius function (Johnson & Lewin 1946). This equation has a basis in temperature dependent enzyme kinetics, can exhibit the classic left skewed asymmetry of thermal performance curves, and was used by (Dell et al. 2011) in a meta-analysis of temperature dependent variation in performance traits, including population densities for marine, freshwater, and terrestrial organisms. Several mechanistic and phenomenological functions have been used to estimate thermal performance curves (e.g. see Schoolfield et al. 1981, Corkrey et al. 2012; see Angilletta 2006, 2009 for review). We chose the Johnson and Lewin equation because it has relatively few parameters (N=4), can be asymmetric, and has a mechanistic basis.

In the Johnson and Lewin equation:

$$h(T) = ce^{-\frac{E_R}{k_b T}} \Big/ 1 + e^{-\frac{1}{k_b T}\left(E_D - \left(\frac{E_D}{T_{opt}} + k_b\, ln\left(\frac{E_R}{E_D - E_R}\right)\right)T\right)}$$

where the response (h) is a function of absolute temperature (T; degrees kelvin), a scaling constant (c), the Boltzmann's constant (k_b=8.62x10^{-5} eV K^{-1}, eV=electron volts, 1eV =23.06 kcal/mol), the thermodynamic activation energy for the increase in the response with temperature (E_R) up to the optimal temperature (T_{opt}), as well as activation energy for decline in the response at temperatures higher (E_D) than the optima. Left skewed asymmetry is produced when $E_R < E_D$.

We obtained estimates of the parameters E_R, T_{opt} (degrees centigrade), E_D, and c by minimizing negative binomial likelihood of the equation using catch densities as the dependent and bottom water temperatures as the independent variable. We used the bmle library in R (Bolker 2012) and methods described in Bolker (2008) and Millar (2011). We assumed that butterfish catch had a negative binomial distribution based on preliminary GAM. We chose starting values for the Johnson and Lewin equation based upon the smoothing spline fit with GAM to the relationship of catch density to bottom water temperature in the calibration data (Fig 2.). Preliminary parameter estimates were made without constraint using Nelder-Mead optimization. However obtaining the variance-covariance matrix that were required for hindcasting thermal habitat with uncertainties and deriving preferred profile confidence intervals (Millar 2011) for parameters required fixing the scaling coefficient (c) and imposing minimal lower boundary constraints (Topt.c=0, Er=0.001, Ed=0.002, k=0.001) using the L-BFGS-B nonlinear optimization method. We fixed c based on the GAM fit of catch to temperature and the preliminary maximum likelihood fit (Fig 2).

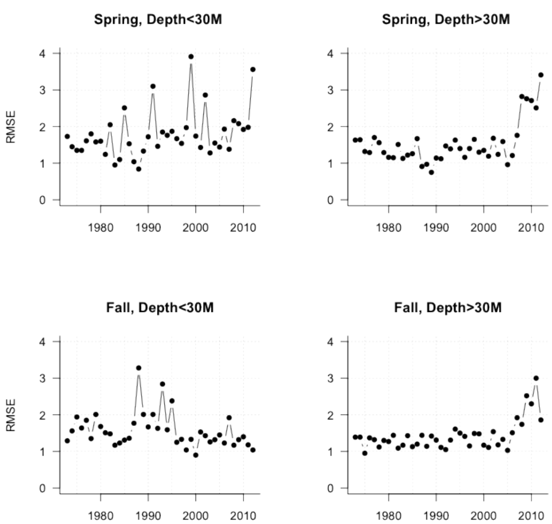


Figure 5. Root Mean Square Standard Errors RMSE calculated for the debiased ROMS bottom temperature hindcast in shallow and deeper waters (30M<Depth>30M), during spring and fall, from 1973-2012 calculated using bottom water temperatures measured *insitu*. These RMSEs were applied to debiased bottom temperatures from ROMS (T) to construct the warm (T + 2*RMSE) and cold states ocean states (T - 2*RMSE) for integration of uncertainties in the bottom temperature hindcast into the estimate of stock availability based on thermal habitat suitability ρ_H.

Step 2: Bottom temperature hindcast

We developed the hindcast of bottom temperature for seasonal fishery independent surveys from 1973 to 2012 using a 3-D numerical circulation model that we de-biased using a temperature climatology. Daily average bottom temperatures were hindcast over 55-years (1958-2012) using the Regional Ocean Modeling System (ROMS; Shchepetkin & McWilliams 2003 & 2005) model described in Kang et al. (in review). This model extends from the Gulf of Mexico to Nova Scotia, Canada and has a horizontal resolution of 7 km and vertical resolution of 40 terrain-following levels.

Bottom temperature hindcasts from the ROMS were debiased using Mid Atlantic Bight Ocean Climatology and Hydrographic Analysis (MOCHA) (Fleming & Wilkin 2010). This is a three-dimensional climatological analysis of temperature and salinity derived from the ODC World Ocean Database 2005 and the NOAA North East Fisheries Science Center oceanographic database. The climatology has a spatial extent from 45^{O}N to 32^{O}S, -77^{O}W to -64^{O}E, a horizontal resolution of 5 km, and 55 standard depths.

To debias the ROMS hindcast, daily average bottom temperature estimates from ROMS were interpolated onto the MOCHA grid. We then computed the difference between monthly mean modeled bottom temperature fields and expected monthly mean bottom temperatures from MOCHA. Monthly spatial differences were used to debias daily temperatures hindcast from

ROMS so they matched climatology more

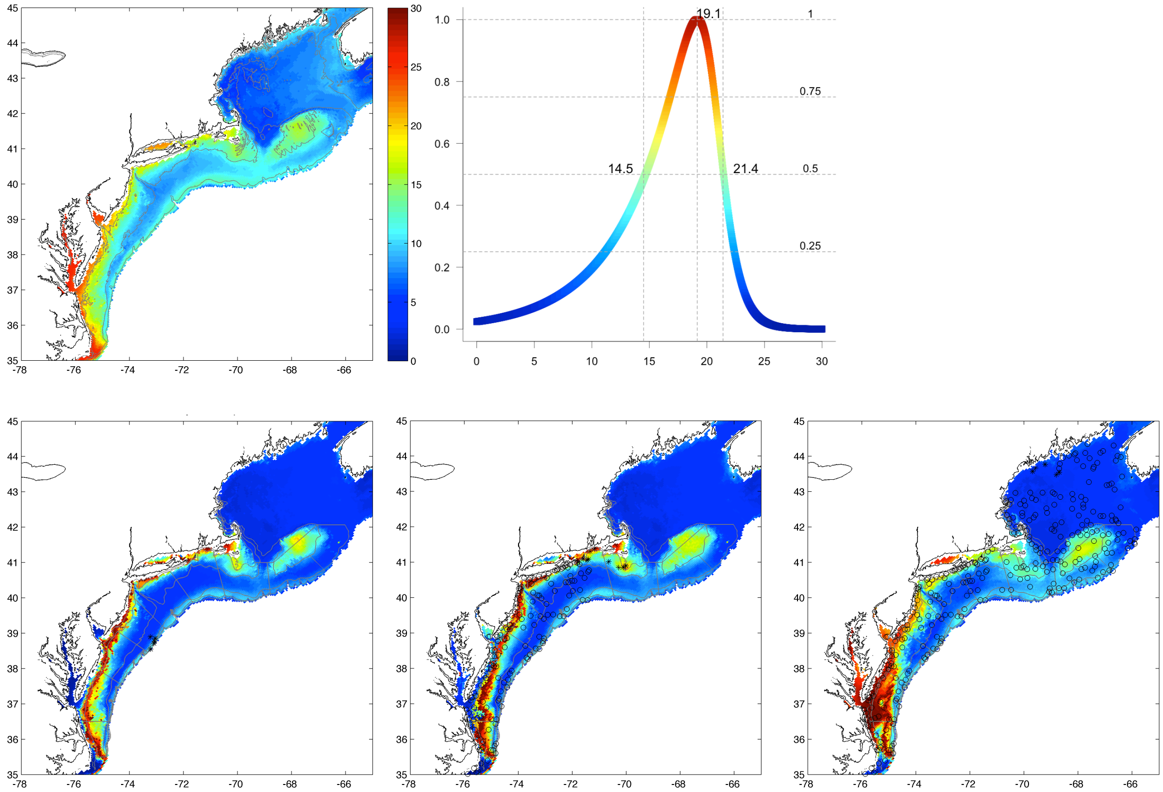


Figure 5. (top left) Debiased ROMs hindcast of bottom water temperature for September 5, 2001 for the model domain was coupled to realization of the thermal niche model scaled between 0 and 1 (top left) produce a hindcast of thermal habitat suitability for butterfish for September 5, 2001 (bottom left). Thermal habitat suitability is also hindcast for the median date of the 2001 fall survey (September 24, bottom center) and the final day of the survey (October 21, 2001' bottom right). Fifty, 150 and 200 meter isobaths are shown in the bottom temperature hindcast (top left). Lines in bottom panels show NEFSC survey strata. Asterisk indicate samples taken on the day of the habitat hindcast. Open circles are stations sampled before the hindcast date. Color scale on the habitat suitability plots (bottom panels) match that shown on the niche model response curve (top left). In the calculation of ρ_H the proportion of the total available habitat suitability sampled in each day extrapolated by strata are summed for the entire survey

closely. The de-biased hindcast of daily bottom temperatures had the same spatial extent and resolution as MOCHA (Fig. 5 top left).

We measured the skill of the debiased temperature hindcast as well as temperatures from ROMs and MOCHA) using bottom water temperatures measured *insitu* on the 7 fisheries independent bottom trawl surveys, recorded in the NODC World Ocean Database, and recorded in the NOAA Northeast Fisheries Science Center hydrographic database. We calculated pearson correlations, centered root mean square differences (RMSD), root mean standard errors (RMSE) and ratios of standard deviations of modeled or climatological temperature estimates and *insitu* temperatures. These statistics were calculated for shallow (bottom depth ≤ 30M) and deep water (bottom depth >30M) during spring and fall from 1973-2012.

To capture uncertainties in debiased bottom temperatures in hindcasts of habitat suitability we used root means square standard errors (RMSE) to develop hindcasts of warm and cold ocean states. We applied RMSEs stratified by water depth (30≤ D>30), season (spring and fall) and year 1973-2012 to mean debiased ROMS bottom temperatures (T) to construct warm (T

+ 2*RMSE) and cold states (T – 2*RMSE). Mean debiased ROMS bottom temperatures and warm and cold states were used to hindcast thermal habitat suitability and calculate of the habitat based index of availability (ρ_h) for Butterfish.

Step 3: Hindcast of thermal habitat suitability index

The niche model parameterized using maximum likelihood was rescaled to produce thermal habitat suitability values rescaled between 0 and 1 (tHSI; 0=unsuitable habitat, 1= suitable habitat). We coupled the rescaled niche model to mean debiased bottom temperature estimates, as well as the cold and warm ocean states. Projected maps of tHIS shared the resolution (5 km) and depth range (10-350m) of the debiased bottom temperature hindcast. We restricted the spatial extent of habitat suitability projections to 35^{O}N to 45^{O}N, and -78^{O}W to -65^{O}E for the availability (ρ_H) calculation (Fig 5).

Uncertainties in thermal niche model parameter estimates were integrated with uncertainties in the bottom temperature hindcast in the following manner. One thousand multivariate random deviates of the niche model parameters (T_{opt}, E_r, E_d) were generated using mean estimates and the variance-covariance matrix for parameter estimates calculated in minimizing the negative binomial log likelihood of the Johnson-Lewin equation (Bolker 2008). These deviates were used to make daily projections of thermal habitat suitability for each of the bottom temperature hindcasts; the mean hindcast state (debiased ROMS) as well as a cold (mean – 2 annual RME), and warm states (mean + 2 annual RMSE).

Step 4: Evaluation of niche model & projections of thermal habitat suitability

We used catch data from the seven fisheries independent bottom trawl surveys to evaluate the thermal niche model and projections of it. Mean thermal habitat suitability index values (tHSI) for the samples were calculated by coupling the thermal niche model to bottom temperatures measured *insitu*, debiased bottom temperature estimates from ROMS (debiased ROMS +/- 2 annual RME) and the raw ROMS bottom temperatures. tHSI values were classified into 10 ordered groups ranging from 0-1. These tHSI classes were used to analyze trends in probability of sample occupancy and standardized catch densities of butterfish in field samples in an evaluation dataset.

We evaluated the thermal niche model using bottom temperatures measured *insitu* and catch data collected before 2008 and not used in niche model calibration (N=31,499 samples). All of data was used to evaluate projections of tHSI from the debiased model based bottom temperature hindcasts (+/- 2 RMSE; 37,515 samples).

We used binomial (GAM) with a cubic

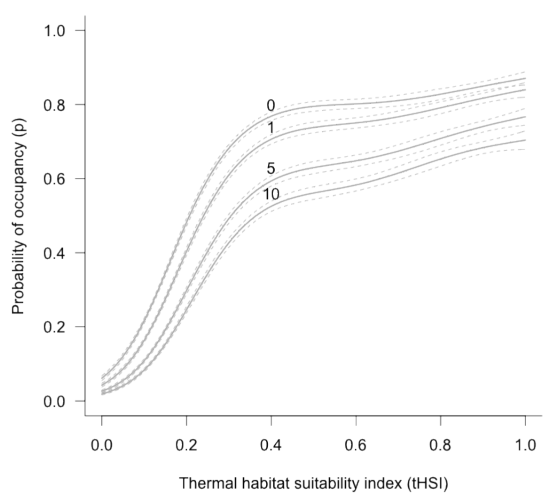


Figure 6. Comparison between catch data available for 7 fishery independent surveys collected from 1970 -2007 not used in niche model calibration and thermal habitat suitability (tHSI) predicted using bottom water temperatures measured *in situ* in the niche model. Probabilities of sample occupancy (+/- 2 standard error) for butterfish thermal HSI classes generated with GAM. The effects of incidental catch associated with field sampling error was explored by varying the numbers of fish caught used as the threshold for absence from 0-10.

spline smoother (k=5) to estimate probabilities of sample occupancy (+/-se) with trends in tHSI predicted for evaluation samples. To investigate potential effects of field sampling errors (e.g. incidental surface water catches, sample contamination, species mid-identification) we used catches of 0, 1, 5 and 10 fish as thresholds for absence. Boxplots were used to examine trends in median standardized catch densities of butterfish with thermal habitat suitability (tHIS). To detect potential spatial biases, we mapped positive catches of butterfish occurring in samples with tHSI values <0.1 ("false negatives"), as well as samples with high HSI values where fish were not collected ("false positives") during the first and second halves of the year. We performed the spatial analysis using tHSI predicted using bottom temperatures measured *insitu* and the mean debiased temperature hindcast.

Step 5: Estimate of availability of butterfish ρ_h to assessment surveys

We used sampling locations, sampling dates and daily projections of tHSI (e.g. Fig 5) from the coupled niche model-bottom temperature hindcast to calculate a habitat based index of availability ρ_h that is an estimate of the proportion of cumulative habitat suitability available in the regional sea sampled during a survey period. ρ_h is calculated as follows:

$$\rho_h = \sum_{k=1}^{o} \frac{HSI_{k_{j,i}} * \frac{Area\ of\ sample\ strata_k}{p}}{\sum_{j=1}^{n} HSI_{j,i} * Area\ of\ j}$$

where the model based estimate of habitat suitability, HSI (0-1) for sample *k*, occurring in location *j* on day *i* ($HSI_{k_{j,i}}$) is extrapolated to the geographic area sample k represents in the survey design. This extrapolation is achieved by multiplying $HSI_{k_{j,i}}$ by the *area of the sample strata* (km^2) in which sample k occurred divided by the total number of samples (*p*) taken within that strata over the duration of the survey. This value of HSI that the station represents is then divided by the sum of the habitat quality of all locations *j* multiplied by their surface areas within the domain of the model on day *i* when sample *k* was taken. In our example locations (*j*) are pixels of the model grid with surface areas of 25 km^2. These proportions of the daily habitat suitability sampled at the stations *k*=1…*o* are summed to calculate the habitat based estimate of the availability of the stock to the entire survey (ρ_H). This habitat based availability estimate ρ_H is a dimensionless ratio that estimates the proportion of the total habitat suitability available to the species within the model domain that was sampled within the space-time frame of the survey. It explicitly accounts for the effects of seasonal and inter-annual changes in habitat dynamics that drive species distribution shifts at broad scales, as well as the trajectory of sampling on regional sea scale surveys that can take several months to complete.

For demonstration purposes we computed ρ_H with uncertainties for NEFSC bottom trawl surveys conducted during the Spring and Fall from 1973 through 2012. For the 2013 butterfish stock assessment ρ_H was calculated for inshore and offshore NEFSC bottom trawl survey strata as well as the NEAMAP inshore surveys during both the spring and fall surveys. Abundance indices from these surveys, strata and seasons are considered in the Age Structured Assessment Program (ASAP) model for 2014 butterfish assessment. For each survey ρ_H was calculated using tHSI calculated from 1000 realizations of the niche model defined by random deviates of parameter estimates coupled to each of the 3 bottom temperature hindcasts. Median and 2.5%, and 97.5% confidence intervals for the availability ρ_H of the butterfish stock to the NEFSC survey were calculated for the debiased bottom temperature hindcast as well as the cold (hindcast - 2 RMSE), and warm (hindcast + 2 RMSE) ocean states.

Step 6: Population estimates using ρ_H

For simplicity of explanation, we demonstrated the use of our habitat based estimate of stock availability to surveys ρ_H using the simple method to estimate observed butterfish population biomass outside the assessment model used in the 2009 Atlantic Butterfish stock assessment (SARC 49; http://www.nefsc.noaa.gov/publications/crd/crd1003/pdfs/butterfish.pdf; Pg 71). In this approach, the observed population biomass estimate B_t is calculated as follows:

$$B_t = \frac{A}{a\rho\delta C}\mathrm{I}_t$$

Here, biomass (B) in year *t*, is a function of the survey based index of biomass I_t (mean kg of fish per tow^{-1}). I_t is scaled to population biomass by multiply it by the total survey area *A,* divided by *a* , the swept area of the average survey tow*,* times *ρ,* the availability estimate of the proportion of the population occurring within the survey frame, times δ, the efficiency of the sampling gear times C, a constant (10^6) that scales biomass measured in kilograms to 1000 metric tons. For demonstration we estimated observed population biomass B_t using published biomass indices I_t, survey tow swept areas *(a)* and survey areas (A) developed for NEFSC fall bottom trawl survey (http://static.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/516db438e4b048c970493b41/1366144056161/3-Butterfish_Updates_for_2014_Specs.pdf; Table 1). Survey gear efficiency δ was fixed at 0.21 based on an empirical estimate (Richardson, in prep). We substituted our habitat based estimate of availability ρ_h for ρ. We also calculated B_t using the same parameters except that ρ was chosen based on the 2009 population assessment. In 2009, the availability ρ of butterfish to the NMFS survey was unknown and determined by consensus of the working group to fall between 0.5 and 0.9 and to be stable over time.

The habitat based estimate of stock availability to surveys ρ_H was also used with the empirical estimate of sampling efficiency δ developed by Richardson to constrain catchability in the Age Structured Assessment Program (ASAP) model for butterfish which being developed for the SARC 58 scheduled for January 2014. These methods are described by Miller et al., in prep.

Outreach activities to describe methods, results and possible outcomes so that assessment scientists, fishery management councils and the fishing industry are familiar with the approach.

Throughout our project we repeatedly presented the approach and held meetings in which we solicited advice from number of parties including NEFSC stock assessment scientists, the Mid-Atlantic Fisheries Management council (MAFMC), MAFMC SSC members and staff as well as fisherman, processors and other representatives of the small mesh trawl fishery.

Attendance and participation in stock assessment meeting.
Attend and participate in person for the duration of all working meetings held to develop the 2013 NEFSC assessment model for Atlantic Butterfish.

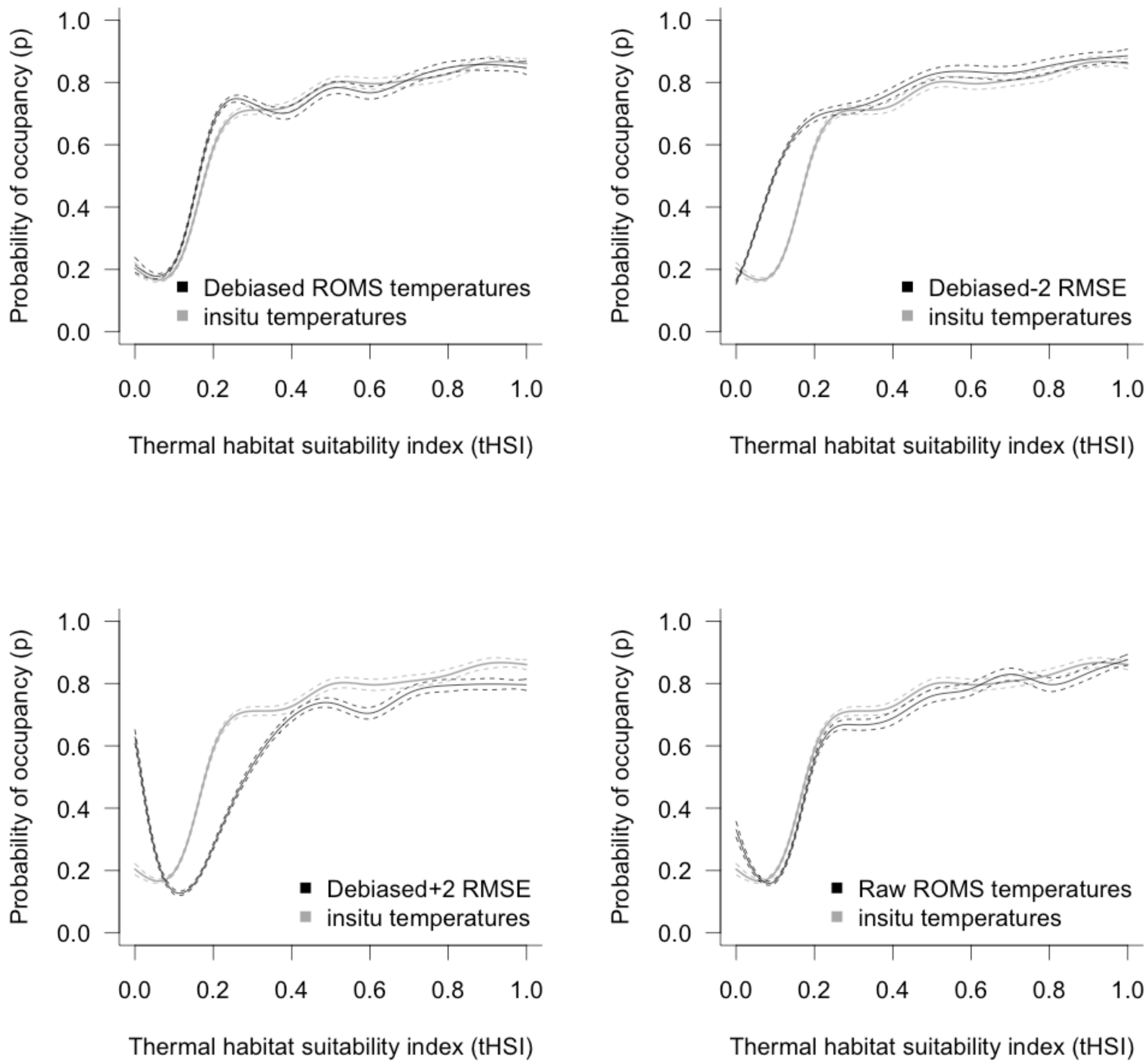


Figure 7 Comparison of sample occupancy probabilities calculated for model based projections of thermal habitat suitability *(black lines with 2 SE confidence bands)*and thermal habitat suitability projected with *insitu* temperature *(grey lines with 2 SE confidence bands)* using all catch data available from the 7 fishery independent surveys. tHSI values projected using bottom temperatures from the debiased ROMs (top left) followed by the ROMS (bottom right) produced patterns of occupancy that matched those produced when tHSI values were projected using temperatures measured *insitu*

Operationalization of the approach: If our method is accepted in the 2014 assessment in January it will need to be operationalized. We believe there is an update to the assessment scheduled for June 2014. As a result we have begun to establish guidelines.

- The main body of the code should be on a government server
    - Data components such as the ocean hindcast need not be on a government server
- The code should be compiled in ipython which can translate across standard languages such as matlab and R.

- The code should be modular so that it is easily modified
- The code well annotated and transparent and invite comment. The method can be improved in an open source manner.

Work Completed:

Establish a functioning working group of experts in habitat ecology, stock assessment, oceanography, and management from Government, Academia, and the Fishing Industry to advise, collaborate and ensure that our final product was accurate, acceptable and thus useful.

Establishing the working group was absolutely essential to the success of this project to date. First it allowed us leverage the expertise of members with a great diversity of skills and perspectives. It was critical in developing an understanding of the problem and a workable, ecologically accurate, parsimonious solution that could be integrated into a stock assessment model. The importance of integrating the insights of fisherman who spend 300+ days on the water constantly refining their assimilative mental models of fish habitat associations and behavior as well as fish processors who are networked with many fisherman and have been observing trends in landings 365 days a year for many years cannot be underestimated. Their participation was essential to making the habitat modeling approach as accurate and parsimonious as it could be given the data and other resources available to us. It was interactions with the fishing industry in an earlier project funded by NEFSC coop research that made us aware of the potential problems associated with incomplete survey habitat coverage combined by the dramatic and ongoing effects of changing climate on stock distributions in the mid Atlantic region in the first place. The importance of experts in the highly technical field of ocean physics who could provide bottom temperature hindcasts was certainly critical. This project leveraged an NRC postdoc (Andre Schmidt) who lead most of the temperature hindcasting work.

Face to face 2 day working group meetings allowed us to close intellectual gaps that were greatest between habitat ecologists (academic and "practical" aka fisherman) and stock assessment scientists. Habitat ecologists focus on species environmental relationships in space and time, often at the individual level of organization and on fine scale details and exceptions to the rules. Stock assessment scientists aggregate across space and ignore other important extrinsic factors to focus on the population level of organization and who are arguable forced by the SARC review process to focus on statistical precision at the expense of ecological accuracy. The working meetings forced those occupying Mars or Venus to close intellectual gaps and find an appropriate workable solution.

Finally, we assembled the best group of experts in habitat ecology, stock assessment, oceanography, and management from Government, Academia, the Fishing Industry, and Fishery Management Council staffers to advise and collaborate with us to solve the problem at hand. The working group gave these leaders in their fields a stake in the game. We believe these leaders "spread the word" that the working group was making a best effort to find a sound scientific solution to a problem that could be directly affect assessment and management. A term of reference was developed for the 2013 Butterfish assessment that required review of our work. We believe this term of reference would not have been developed without pressures associated with "spreading the word" through the working group and in our other outreach activities. Finally we intend continue working with the group established on HAIP funding on an ongoing

NOAA Fate funded project and other related projects to integrate ecological considerations into the assessment of small forage species central to the mid-Atlantic Bight Food Web.

Development of an accurate coupled biophysical habitat model that could be used to hindcast thermal habitat suitability for surveys. Use hindcasts of habitat suitability in a index of availability (ρh) quantifying the proportion of habitat sampled to the total habitat suitability available in a way that accounted for the effects of seasonal and inter-annual changes in thermal habitat dynamics and the trajectory of sampling on regional sea scale.

Step 1: Thermal niche model

The thermal niche model for butterfish generated by estimating parameters for the Johnson & Lewin equation that maximized negative log likelihood of catch densities given bottom water temperatures in the calibration dataset was highly asymmetric (Fig 3, E_R= 1.4; E_D= 8.5). The function rose gradually from cold temperatures through a half maximum of 15.1 ^{o}C to an optimal temperature (T_{opt}) of 19.2 ^{o}C (Figure 3). The response then declined rapidly to an upper half maxima at 21 ^{o}C and low values at temperatures above 25 ^{o}C. The form of this parametric niche model was similar to the thermal response derived using a spline smoother in GAM (Fig. 2).

Step 2: Bottom temperature hindcast

Debiasing the bottom temperature hindcast from ROMs using MOCHA climatology reduced root mean standard errors (RMSE) and increased the accuracy of the hindcast with respect to temperatures measured *insitu*. The mean RMSE of debiased temperatures averaged 1.57^{o} C (0.75-3.91). RMSE was higher where bottom depths ≤ 30 M than in deeper water, and higher in the spring than the fall (Fig. 4; RMSE μ (min-max). Fall: Depth ≤ 30M, μ=1.57 (0.90-3.28); Depth > 30M μ=1.43 (0.95-3.00). Spring: Depth ≤ 30M, μ=1.77 (0.84 -3.91), Depth > 30M, μ=1.52 (0.75-3.41)). Root mean standard errors of debiased model temperatures were less than 2^{o} C in deep water during spring and fall until 2008 when they increased (Fig. 4). In shallow water, debiased temperatures had RMSEs that were occasionally ≥ 2^{o} C during the fall from the late 1980s to the mid 1990s. During the spring debiased temperatures in shallow water had RMSEs ≥ 2^{o} C occasionally throughout the 1973-2012 time series.

Step 3: Hindcasting the thermal habitat suitability index

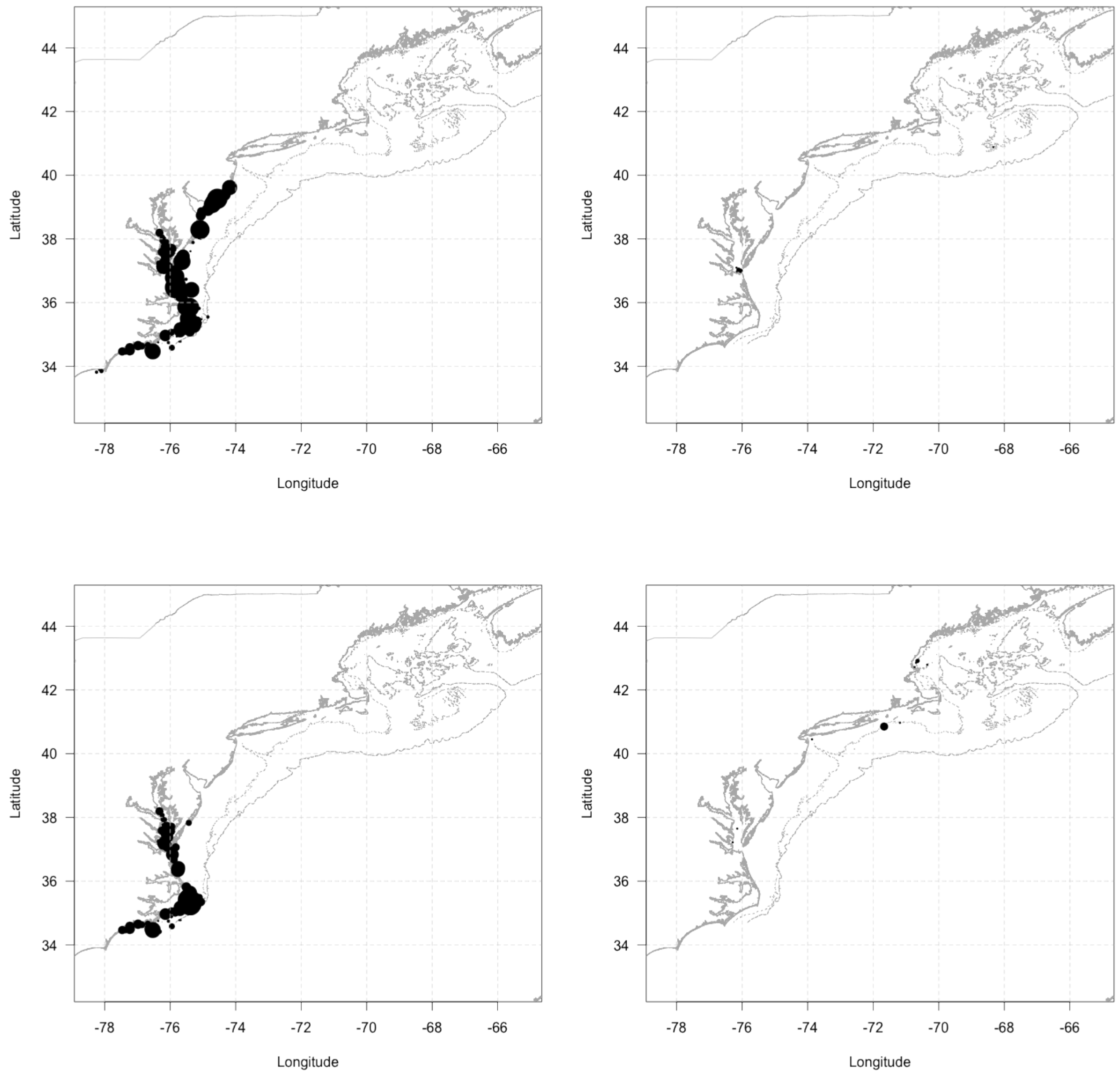
See figure 5 for an example hindcast

Step 4: Evaluation of niche model & projections of thermal habitat suitability

Trends in butterfish occupancy and standardized catch density in samples not used in niche model calibration were well explained by trends in the thermal habitat suitability index calculated using temperatures measured *insitu* in the niche model (Fig. 6; catch densities not shown). Probability of sample occupancy rose rapidly from a minimum of 6% (SE= 0.3) at tHSI=0 (N=1486) to an asymptote of 77% (SE=0.6) at tHSI=0.4 (1861samples) (Fig. 6). Probability of occupancy then increased more gradually to reach a maximum of nearly 90% at tHSI = 1 (p=87%, SE= 0.9; total N=1121 samples). When the threshold for absence was increased to account for possible field sampling errors, tHSI values of 0 produced sample occupancy probabilities of 4% (SE= 0.2) when the threshold for absence was increased to 1 fish and 1.9% (SE= 0.1) for 10 fish. Median standardized catch densities of butterfish also increased with tHSI predicted using bottom temperatures measured *insitu* (not shown). Median (MED) CPUEs were zero (median absolute deviation MAD=0) at tHSI<0.2. CPUE increased rapidly as tHSI increased to 0.5 (MED CPUE=8, MAD=12). Catch per unit effort then increased more gradually at higher tHSI values.

Predictions of thermal habitat suitability made using mean debiased bottom temperatures from the ROMS model produced patterns of sample occupancy most similar to those generated when tHSI values were predicted using bottom temperatures measured *insitu* (Fig 7). Raw ROMS bottom temperatures produced low tHSIs that had slightly higher sample occupancy. The warm ocean state (debiased temperatures + 2RMSE) produced low tHSIs that dramatically over predicted occupancy. Thermal habitat suitability values generated using the cold ocean state (debiased temperatures - 2RMSE) also over predicted sampled occupancy at tHSI values <0.2 but to a much lesser degree than the warm ocean scenario. Trends in the central tendency of butterfish catch with tHSI values generated using the debiased bottom temperatures from ROMs and the cold ocean state generally matched those produced when tHSI was predicted using bottom temperatures measured *insitu* (not shown). When temperatures generated for the warm ocean state were used, samples with low tHSI values produced relatively high abundances. These results suggest that sample occupancy and butterfish catch density were best explained when the

Most of samples of butterfish with thermal habitat suitability indices < 0.1 (“false negatives”) were concentrated in the nearshore coastal zone in the southern mid-Atlantic during the 2nd half of the year (Fig. 8). Warm bottom temperatures ranging from 24 to 29 ^{o}C measured *insitu* or predicted by the debiased ROMS during September produced nearly all of these samples. When tHSI was calculated using temperatures measured *insitu* for evaluation samples not used in niche model calibration (Total N=14,616), 1.9% of autumn samples were identified as false negatives. The debiased bottom temperature hindcast generated “false negative” tHSI values for 1.3% of fall evaluation samples (Total N=17,045). Less than 1% of evaluation samples had tHSI



values

Figure 8. Evaluation of spatial pattern in evaluation samples that produced butterfish but were predicted to have low thermal habitat suitability (<0.1; ie “false negatives”) based on coupling the thermal niche model to bottom temperatures measured insitu (top panels) and the debiased bottom temperatures hindcast from ROMS (bottom panels). Evaluating of the accuracy of the niche model coupled to insitu temperatures used samples collected prior to 2008 and not used in the calibration of the niche model. Left panels evaluate model accuracy during the second half of the year (primarily September and October). Right panels evaluate model accuracy during the first half of the year (Primarily March-May). Symbols are scaled to abundance

< 0.1

and produced 10 or more fish (0.8% for *insitu* temperatures and 0.6% for debiased temperatures from ROMS hindcast).

Butterfish rarely occurred in samples with low tHSI values during the first half of the year. Only 5 catches (Total N= 16,883) clustered at the mouth of Chesapeake bay had tHSI <0.1 predicted with *insitu* temperatures (Fig. 8c). All but one of these samples occurred in warm water in late June. The debiased ROMS bottom temperatures hindcast produced 14 observations (Total N= 21,022) falling into this category during the spring. These samples were not spatially clustered and occurred in waters identified as cold as well as warm water based on the niche model (Fig. 8d).

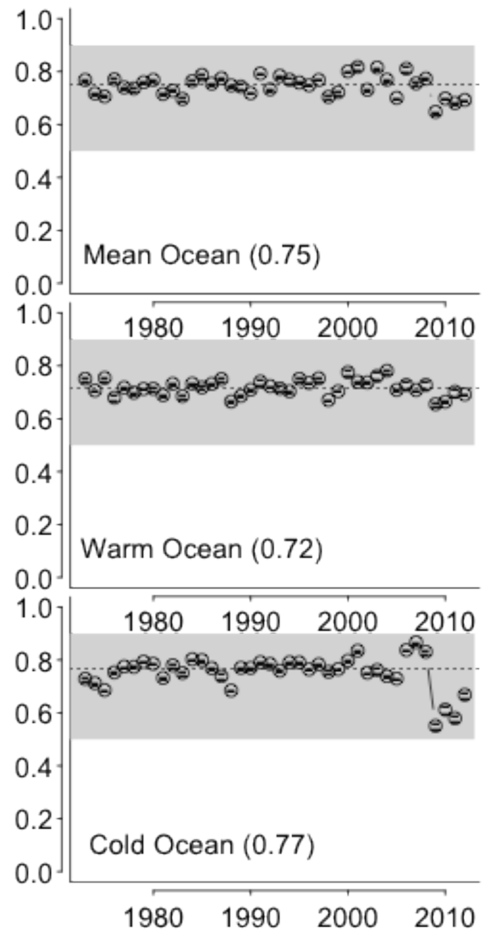


Figure 8. Estimates of time varying availability (ρ_H) of Atlantic Butterfish to NOAA/NEFSC bottom trawl surveys conducted during the autumn calculated using thermal habitat suitability index values derived by coupling the niche model to debiased hindcasts of bottom temperature from the ROMS circulation model. Circles are the median estimate while dashes falling within circles are 2.5 % & 97.5% confidence limits. The niche model was coupled to the debiased ROMS bottom temperature hindcast (top panel, mean ocean) and the debiased ROMS temperatures +/- 2 x the root mean square error (RMSE) (warm ocean, middle panel; cold ocean, bottom panel). Dashed horizontal lines indicate median availability (ρ_H, also indicated in parenthesis) for each time series. Gray rectangles indicate the consensus bounds used for **ρ** in the 2009 NEFSC stock assessment for butterfish.

Fish were absent from samples with high thermal habitat suitability indices (>0.5) projected using bottom temperatures measured *insitu* or debiased from ROMS on Georges Bank, throughout the nearshore mid-Atlantic Bight and along the shelfbreak in the vicinity of Cape Hattaras (not shown). This pattern is to be expected since fish were otherwise abundant in these areas and probabilities of sample occupancy range from ~75 to 85 % for tHSIs >0.5 (i.e. fish were expected to be absent from 15-25%). During the spring, samples with tHSIs >0.5 in which fish were absent were concentrated along the coast of New Jersey, Chesapeake Bay and in the Vicinity of Hattaras. Butterfish were otherwise present in all these areas during the spring except

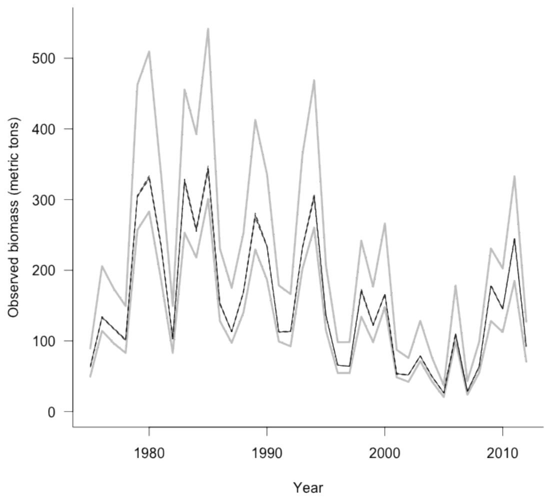


Figure 9. Time series of observed biomass estimated from the NEFSC fall bottom trawl survey. Black lines are biomass estimates calculated using the median (solid), and 2.5% and 97.5% quantiles (dashed) of the habitat based estimate of the availability of the butterfish stock ρ_H to the survey. Gray lines are biomass estimates calculated with the bounds for ρ ($0.5 \geq \rho \leq 0.9$) used in the 2009 stock assessment. Area covered by a single trawl a=0.0112, area covered by survey A = median 42,842 as in (http://static.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/516db438e4b048c970493b41/1366144056161/3-Butterfish_Updates_for_2014_Specs.pdf; Table 1). Sampling efficiency was set to δ= 0.21 based on empirical analysis (Richardson et al. in prep)

the upper reaches of Chesapeake Bay. Fish have, however been collected in the upper Chesapeake during the Autumn.

Step 5: Estimate of availability of butterfish ρ_h to assessment surveys

Estimates of the availability (ρ_h) of butterfish to the fall NEFSC bottom trawl survey from 1973 to 2012 calculated using thermal habitat suitability estimated by coupling the niche model to debiased bottom temperature fell well within the bounds determined by consensus in the 2009 stock assessment (0.5-0.9, Fig 9). The sampled proportion of the thermal habitat suitability available within the model domain fluctuated between 65% and 82% when mean debiased temperatures were used (median=75%, 2.5 % Confidence limit (CL)=64%, 97.5% (CL)=83%). Estimates of the proportion of sampled thermal habitat suitability were slightly lower when the niche model was coupled to the warm ocean state (Debiased ROMS temperatures + 2RMSE: median=72%, 2.5 % & 97.5% CL =65% & 79%) and slightly higher when tHSI was calculated using the cold ocean state (Debiased ROMS temperatures - 2RMSE: median=77%, 2.5 % & 97.5% CL =54% & 87%). Estimates of butterfish availability to the survey (ρ_H) generated using bottom temperatures hindcast using the mean and cold ocean states became noticeable more variable in the late 1990s.

Step 6: Compare population estimates using ρ_h and traditional approach.

Using an ecologically defensible and accurate, habitat based approach to estimate the availability of the butterfish stock ρ_H reduced the uncertainties in the observed biomass estimates when compared with an approach in availability was determined to fall between 0.5 and 0.9 by consensus of the assessment working group (Fig. 10). That range of values results in an 80% difference in the population biomass estimate. Using the habitat based estimate of availability the biomass estimate varied by 30%. The availability estimate determined by consensus was fixed over time. ρ_H varied over time as a result of changes in the timing of the survey, the timing of seasonal transition, the trajectory of thermal habitat and the trajectory of sampling on the survey. These variations were accounted for in the development of the biomass estimate.

Our habitat based estimate of availability ρ_H has been integrated into the 2014 butterfish assessment in 2 ways. First, it has been integrated with empirical estimates of survey efficiency δ developed by Richardson to compute time varying catchability (Q) in the Age Structured Assessment Program (ASAP) model for butterfish that is being developed for the SARC review in January 2014. Secondly it was used along with the empirical estimate of δ to create an upper bound for Q=0.15 in the base ASAP assessment model during the November 18-27, 2013 modeling meeting. The model based estimate of Q made by the preliminary model was greater than 1.

Figure 10. Runs of the Age Structured Assessment Program (ASAP) model for butterfish developed during the assessment modeling meeting (November 18-27, 2013) in preparation for SARC 58 scheduled for January 2014. Runs with habitat based index of availability (H), natural mortality estimated internally in the model (M), and C length-based calibration estimated withi the model.

Outreach activities to describe methods, results and possible outcomes so that assessment scientists, fishery management councils and the fishing industry are familiar with the approach.

Presentations describing our approach were given to the fishing industry at workshops of the Marine Research Education Program, a summit on Squid Management hosted by the MAFMC, the Commercial Fishery Research Foundation workshop on Small Forage Species, A meeting of the Garden State Seafood Association, and several other smaller workshops with the MAB small mesh trawl fishery.

The work was presented to managers at a several meetings of the Mid-Atlantic Fisheries Management Council and an East Coast Fisheries Forum focused on Habitat and Management.

In addition the work was been presented in a number of academic settings including a meeting of the Fisheries Working Group of the National Research Council, a CINAR workshop on the Mid-Atlantic Bight Shelf Slope Front, the ICES Working Group Meeting on the Northwest Atlantic Regional Sea, ICES annual Science Conference and the 2nd International Symposium of the American Institute of Fishery Research Biologists

Attendance and participation in stock assessment meeting.

We attended and participated in person for the duration of the data meeting (last week of August, 2013) and modeling meeting (November) for the 2013/2014 NEFSC assessment of Atlantic Butterfish. (Manderson, Richardson, Kohut, Palamara (software technician) and several other workgroup members).

Operationalization of the approach: We have begun to think about the requirements and details of operationalizing our approach in the event that it is accepted by the SARC in January. This will be required in the short run because we believe there is an assessment update scheduled for June 2014. Several assessment scientists have also discussed the possibility of applying the method to other stocks in the near future including Atlantic Mackeral. Operationalizing the approach could allow the method to be used easily for multiple stocks.

Applications:
We believe our time varying habitat based availability index ρ_H will be considered in the catchability parameter of the ASAP assessment model for Atlantic Butterfish to be presented at the 58th SARC scheduled for the end of January 2014. The estimate of the proportion of potential habitat surveyed combined with empirical estimates of sampling efficiency for the stock developed by Richardson (in prep) is an important advance in providing reasonable, ecologically defensible estimates of survey catchability (Q). This is extremely important for stocks with low fishing mortality rates and population biomass estimates that are primarily scaled based on catchability (Q). Our approach is also important because it can account for survey observation error associated with changes in species distributions and migratory phenology with changes in the spatial dynamics of important habitat features such as temperature. If accepted and operationalized the approach should prove valuable for the assessment of many populations of mobile pelagic ectotherms occupying management regions impacted by ocean conditions that are changing as a result of changing climate. It has been suggested that we apply it to other stock in the near term. Further our method should be useful for estimating survey observation errors associated with incomplete habitat coverage for factors other than just temperature.

Publications/Presentations/Webpages:

Papers in prep:

OpenOcean (in prep). ACCOUNTING FOR HABITAT DEPENDENT SPECIES DISTRIBUTION SHIFTS IN MARINE FISH POPULATION ASSESSMENTS. Intended outlet Ecological Applications.

OpenOcean (in prep). ACCOUNTING FOR HABITAT DEPENDENT SPECIES DISTRIBUTION SHIFTS IN MARINE FISH POPULATION ASSESSMENTS. Draft working paper for SARC 58.

David E. Richardson, John P. Manderson, Jon A. Hare, Richard J. Bell, Chris Bonzek (in prep) Multisurvey analysis of the maximum bounds of butterfish catchability on the Northeast Fisheries Science Center Fall Trawl Survey. Draft working paper for the SARC 58.

Palamara et al. (in prep). Space time scales of variability in thermal habitat dynamics simulated for Atlantic Butterfish.

OpenOcean Study Group (2013) Development of an operational thermal niche model for marine population assessment: an example for a temperate pelagic forage fish. Draft working paper for the 2013 Butterfish Assessment (August Data Meeting)

Andre Schmidt et al (2013) Bottom Temperature Estimation and Validation. Draft working paper for the 2013 Butterfish Assessment (August Data Meeting)

OpenOcean Study Group (2013) A method to estimate the availability (ρh) of Atlantic Butterfish to surveys using a thermal niche model coupled to debiased hindcasts of bottom temperature from a ROMS model. Draft working paper for the 2013 Butterfish Assessment (August Data Meeting)

Presentations:

Manderson. Biological Modeling. Short Lived Species Workshop sponsored by Commercial Fisheries Research Foundation and MARACOOS. South Kingston Rhode Island. Sept. 4-5

OpenOcean 2013. An index of availability (ρ_h) of Atlantic Butterfish to surveys using a thermal niche model coupled to debiased hindcasts of bottom temperature from a ROMS model. 2013 Butterfish Stock Assessment Data Meeting. Woods Hole, Massachusets. August, 2013

OpenOcean 2013. Integrating habitat dynamics into population & ecosystem assessment using cooperative research within an IOOS framework. Fisheries Working Group. National Research Council. Highlands New Jersey. July 30, 2013

OpenOcean 2013. Integrating habitat dynamics into population & ecosystem assessment using cooperative research within an IOOS framework. East Coast Fisheries Forum. Annapolis Md. June 27, 2013

Palamara, L., J. Manderson, J. Kohut, G. DiDomenico, E. Curchitser, D. Kang, M.J. Oliver, C. Dobson, & A. Snow. 2013. Putting the dynamics of the ocean into marine spatial planning: temporal variation in butterfish habitat. American Society of Limnology and Oceanography Aquatic Sciences Meeting, New Orleans, LA. Abstract ID 10576. 17-22 February 2013

OpenOcean 2013. Climate change, thermal habitat dynamics, habitat coverage bias & population dynamics in offshore forage species (butterfish & longfin squid) central to the MAB food web. Mid-Atlantic Fisheries Management Council Meeting February, 14, 2013. Hampton Rhoads, Virginia.

OpenOcean 2013. A simple approach to packing space into time and a thermal habitat indicator for ecosystem assessment. NART Data visualization workshop. Portsmouth, New Hampshire. February 5, 2013

OpenOcean 2013. A simple approach to packing space into time and a thermal habitat indicator for ecosystem assessment. ICES Working Group Meeting on the Northwest Atlantic Regional Sea. Halifax, Nova Scotia. February 1, 2013

OpenOcean 2013. Climate change, thermal habitat dynamics, habitat coverage bias & foodweb dynamics with special reference to butterfish. NEFSC Seminar Series Woods Hole Laboratory January, 24, 2013

OpenOcean 2013. Climate change, thermal habitat dynamics, habitat coverage bias & population dynamics in offshore forage species (butterfish & longfin squid) central to the MAB food web. MAFMC Squid Summit, Riverhead Long Island January, 16, 2013.

OpenOcean 2013. Insights into shelf break front dynamics, winter habitat, & keystone forage populations gained from collaborations with fishermen. CINAR Shelfbreak Workshop. Providence Rhode Island January, 08, 2013

Manderson 2012: One academic ecologists view of how to get marine habitat ecology into the science informing ecosystem management. Session on Ecosystem Science in Marine Resource Education Program. Baltimore, Maryland November, 27 2012

Kohut J., Manderson J. 2012 Can we improve stock assessments by using dynamic habitat models and fishery-dependent surveys as a supplement to current fishery-independent surveys? F18: 2012 ICES Annual Science Conference, Bergen Norway September 17-21, 2012

Manderson J.P. 2012. Does our habitat paradigm cross the land-sea boundary? Keynote address at 2nd National Habitat Assessment Workshop. Seattle, Washington September 5, 2012.

Manderson J. P. 2012 "Steps toward an operational seascape ecology in support of the management of sustainable ecosystems" 2nd International Symposium of the American Institute of Fishery Research Biologists on "The Relative Importance of Fishing and the Environment in the Regulation of Fish Population Abundance.” June 26-28 2012, New Bedford MA.

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Members of the OpenOcean Study Group established to collaborate on the development of an approach to integrate habitat into catchability parameters for stock assessment models

Name	Institution	Expertise
Adams, Charles	North East Fisheries Science Center, NMFS	Stock Assessment
Churchister, Enrique	Rutgers University	Ocean Modeling
Didden,Jason	Mid Atlantic Fisheries Management Council	Stock Assessment
Didomenico,Greg	Garden State Seafood Association	Fishing industry
Dobson,Colin	Rutgers University	CINAR Intern
Georgas,Nikitas	Stevens institute	Ocean Modeling
Hare,Jon	North East Fisheries Science Center, NMFS	Oceanography, Marine Ecology
Hoey,John	North East Fisheries Science Center, NMFS	Cooperative Research
Jech,Mike	North East Fisheries Science Center, NMFS	Marine Ecology, Fisheries Hydroacoustics
Jeff Kaelin	Lunds Seafood	Fisheries Economics & Management
Jensen,Olaf	Rutgers University	Stock Assessment
Kohut,Josh	Rutgers University	Oceanography
Lackner,Hank	Independent	Fisherman Ecologist
Latour,Rob	Virginia Institute of Marine Science, MAFMC SSC	Stock Assessment
Manderson,John	North East Fisheries Science Center, NMFS	Marine Habitat Ecology
Miller,Tim	North East Fisheries Science Center, NMFS	Stock Assessment
Monsen, Geir	Seafreeze Ltd. Processor	Butterfish ecology /Fishery Economics
Moore, Peter	MARACOOS Mid Atlantic Regional Association Coastal Ocean Observation System	Public Outreach
Morin,Peter	Rutgers University	Ecology, theoretical & empirical
Palamara,Laura	Rutgers University	Ecological & Ocean data processing & Modeling
Quinlan ,John	South East Fisheries Science Center, NMFS	Ecosystem & Stock assesment
Richardson,Dave	North East Fisheries Science Center, NMFS	Oceanography, Marine Ecology, Stock assessment
Roebuck,Chris	Independent	Fisherman Ecologist
Schmidt, Andre	SMAST, UMASS Dartmouth	Physical Oceanography, Modeling
Seagraves, Rich	Mid Atlantic Fisheries Management Council	Ecosystem Assessment
Snow, Amelia	Rutgers University	CINAR Intern
Townsend, Howard	North East Fisheries Science Center, NMFS	North East Fisheries Science Center, NMFS