Habitat Suitability Models: State of the Art, Chesapeake Applications

**David H. Secor
University of Maryland Center for Environmental Science
Chesapeake Biological Laboratory
P.O. Box 38
Solomons, MD 20688**

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Workshop Report

Habitat Suitability Models:
State of the Art, Chesapeake Applications

**Sponsored by the Chesapeake Bay Program's
Scientific and Technical Advisory Committee
The Chesapeake Research Consortium
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David H. Secor
University of Maryland Center for Environmental Science
Chesapeake Biological Laboratory
P.O. Box 38
Solomons, MD 20688

Executive Summary

Modeling efforts within the Chesapeake Bay have failed to effectively link water quality and habitat degradation or restoration to changes in living resource populations. Habitat suitability models represent a principal means to develop such associations but have not seen extensive development or application within the Chesapeake Bay ecosystem. A 1.5 day workshop, Co-chaired by Dr.s David Secor and Denise Breitburg (Smithsonian Environmental Research Center), was held in Baltimore as part of the March 2009 Chesapeake Bay Research Consortium's Ecosystem Based Management Conference. Experts presented state-of-the-art habitat suitability models that ranged from statistical approaches that permit water quality to be translated into living resource distribution maps to dynamic models that track individual oysters and fish as they respond to conditions that vary continuously. This report classifies habitat suitability and modeling approaches and includes synopses on approaches, provided by outside experts. As a summary of approaches the report should serve as a reference for near term efforts by the newly formed Chesapeake Bay Quantitative Ecosystem Teams (as part of effort led by Maryland Sea Grant) and future work by the Fisheries and Habitat Goal Implementation Teams of the Chesapeake Bay Program. Although the goal of the workshop was not to rank or otherwise prioritize modeling approaches, the following recommendations are presented:

1. There is are apparently two classes of models: (a) those that predict where living resources can potentially exist, which are immediately feasible in a practical sense; and (b) those that address habitats most likely occupied, requiring more complex modeling of oceanography, connectance, behavior, and trophic interactions.
2. Potential habitat can be modeled in a fairly straightforward way that makes use of the Chesapeake Bay monitoring data on water quality, natural reef and shoreline habitats, and living resources. Indeed, this approach can and should be used immediately to develop predictions of potential habitat.
3. Defining potential habitat is precautionary if protections can be afforded to all such habitats. Comparison between potential and realized habitat can serve as a reference point, permitting distributional responses to be referenced against some standard condition.
4. Models on external forcing of Chesapeake physicochemical conditions are increasingly sophisticated but remain unmatched in development with models that can incorporate internal factors such as behavior, complex life cycles, trophic interactions, and density dependent responses. Initial applications of such complex habitat models in the Chesapeake Bay and elsewhere show that they can provide relevant management guidance and merit priority in further development and application.
5. Management of the Chesapeake Bay will increasingly employ spatially explicit strategies. As such, externalities related to cost functions are critical to management. Procedures such as MARXAN can consider ecosystem services balanced against costs for protection/restoration. These too merit development and application in the Chesapeake Bay.

Report Structure

This report reviews how habitat is classified and modeled and provides recommendations for implementing existing habitat suitability models and developing new ones. Participants of the workshop generously supplied synopses of the state-of-the-art modeling approaches that they presented. These are included in this report. The content of the report follows:

1. Problem Statement
2. Habitat Classifications
3. Overview of Habitat Suitability Models
4. Recommendations
5. References
6. Synopses of Habitat Suitability Models
    a. Using Habitat Affinity Indices to Assess Value of Estuarine Fish Habitats (D. M. Nelson)
    b. Combining Generalized Additive Modeling and GIS for inference Description and Prediction of Marine Habitat Dynamics (J. Manderson)
    c. Ecophysiological Habitat Modeling (D. Secor)
    d. Landscape-based habitat production modeling in coastal nursery areas (R. Fulford, M. Peterson, P. Grammer)
    e. MARXAN Modeling in Estuarine Systems and Integration with Habitat Suitability Assessment (R. Zajac)
    f. Incorporating Habitat into Food Web Models using the Ecopath with Ecosim Software: Potential applications using the Chesapeake Bay Fisheries Ecosystem Model (H. Townsend)
7. Workshop Agenda
8. Additional Workshop Contributions
    a. New Foundations for Ecosystem-based Fisheries Management in Chesapeake Bay (J. Kramer and S. Green)
    b. Evolving toward ecosystem-based fisheries management: developing a practical approach towards evaluating environmental pressures on exploited Chesapeake Bay fish populations (R. Wood, E. Martino, X. Zjang, J. Jacobs, and D. Zotkin)

1. Problem Statement

The Chesapeake Bay Program has invested heavily in water quality assessments and models directed at external anthropogenic and natural forcings (aka integrated ecosystem assessments; Levin et al. 2008), such as current water quality (Cerco and Cole 1993; Cerco et al. 2003) and oceanographic and climate models (Li et al. 2005; Najjar et al. 2009). In comparison, modeling the distribution and production of living resource species has received scant attention and does not yet permit assessment of the critical links between recovered water quality and restored habitats, and improved living resources that managers and the public too often assume to exist. Thus, ecosystem assessments remain incomplete, calling for improved models that predict changes in living resources due to ongoing management efforts and future ecosystem change.

A relevant context for habitat suitability modeling is the current initiative on Ecosystem-Based Fisheries Management being considered by the Chesapeake Bay Program (led by Maryland Sea Grant and partners: http://www.mdsg.umd.edu/programs/policy/ebfm/resources/). As part of this effort, "Quantitative Ecosystem Teams" will seek to develop reference points related to habitat suitability. The effort requires critical scientific developments and decision frameworks to effectively implement assessment and reference points for habitat suitability as they pertain to environmental and fisheries management.

Workshop Goals
A workshop was held as part of the 2009 Chesapeake Bay Research Consortium's Ecosystem Based Management Conference (Co-Chaired by D. Secor and D. Breitburg), the goals of which were to (1) Present tutorials on several state-of-the-art approaches to habitat suitability modeling; and (2) Begin the work of the Habitat Quantitative Ecosystem Team on developing habitat models pertinent to striped bass habitat reference points (see Section 7). Twelve experts from within and outside the Chesapeake Bay community presented state-of-the-art tutorials on habitat suitability models and contributed brief tutorials (see Section 4). Attendance included outside experts, members of the newly developed Habitat Quantitative Ecosystem Team, and state, federal, academic, NGO, and industry scientists (attendance varying between 25 and 50), who discussed relevance and feasibility of the presented models.

2. Habitat Classifications

The observed distributions of living resources in any ecosystem represent a subset of the habitats available to an organism. Only in rare instances, should we expect that all habitats are filled to carrying capacity by a given species or community. Thus, in any hour, day, season or year, the distributions of living resources represent the intersection of (1) external environmental forcings that define all suitable habitats and (2) internal factors such as behavior, abundance, trophic interactions, and complex life cycles that define habit selection.   Here, I consider four habitat classifications that represent a hierarchy of internal factors that contribute to the conservation and recovery of living resources (Figure 1; terms modified from ICES 2008).

- Potential habitat: Habitats that fulfill threshold conditions for survival; often estimated through ecophysiological tolerances.
- Preferred habitat: Productive or behaviorally advantageous habitats, such as those supporting feeding, reproduction, or predation refuges; often estimated by habitats associated with high densities or through behavioral studies.
- Realized habitat: The subset of potential habitat actually occupied, depending on population status may be larger or smaller than preferred habitat domain; estimated through statistical treatments of distribution maps.
- Essential habitat: Habitats that support key life history functions such as growth, reproduction, and early survival. This classification has been adopted in U.S. fisheries management (Fluharty 2000; Breitburg 2006) but the term "essential"

term has resulted in some ambiguity in its application; a current definition entails ranking habitats by their relative contribution to population sustainability (Beck et al. 2000; Kraus and Secor 2005).

Models used to assess these categories of habitat selection are generically termed Habitat Suitability Models. Their development and application is critical in agendas to incorporate habitat, water quality into strategies of spatial, environmental, and fisheries management.
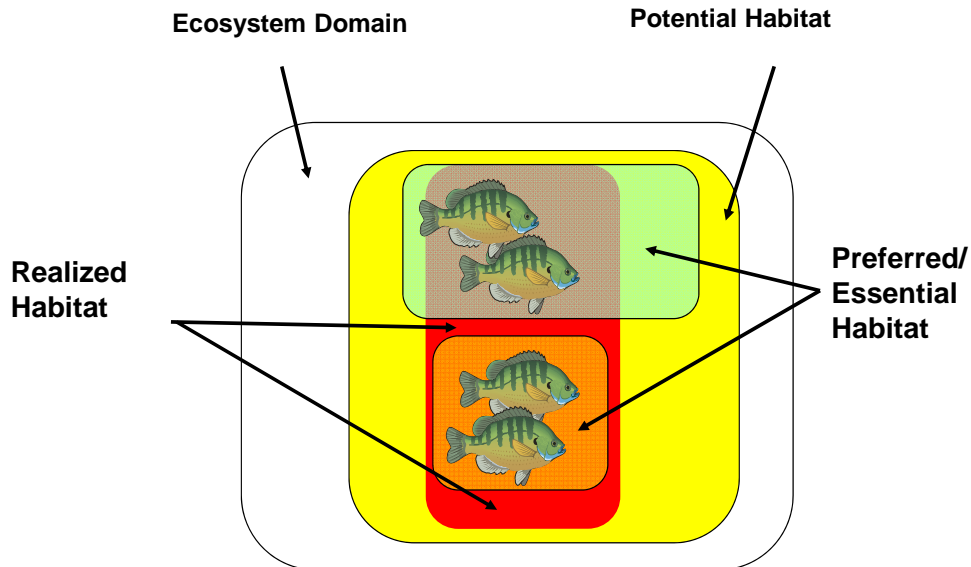

Figure 1. Habitat classifications for living resources. Note that potential and realized habitats nest in an ordered manner within the ecosystem, yet preferred and essential habitat volumes are dependent upon population status and behavior. For instance, preferred habitat may exist but remain uncolonized due to behavioral constraints (orange area). In contrast, realized habitat may represent only a subset of essential or preferred habitat (green area) at abundances below carrying capacity.

3. Overview of Habitat Suitability Models

Static Habitat Models--More traditional habitat suitability assessments have focused on potential and realized habitat (Figure 2). These were initially simple weighting schemes that defined statistical associations between habitat variables and species incidence or abundance. Geospatial habitat layers were then filtered using these statistical functions. The resultant static depictions of potential habitats have been used extensively by NOAA and other government and nongovernment agencies in defining essential habitat and sanctuaries. Defining habitat associations by this general approach will necessarily be limited based upon survey design, weighting issues, and are difficult to verify against a set of independent observations on realized habitat. More directed and nested sampling surveys designed to evaluate important habitat variables at relevant spatial and temporal scales (Figure 2; Nested GAM) can result in much more sophisticated depictions of potential versus realized habitat, but these can be quite intensive and difficult to

generalize at larger spatiotemporal scales. Ecophysiological models impart realism based upon first principals of physiological response to water quality but require intensive parameterization through laboratory studies and do not address issues related to behavior and community dynamics. Thus this class of models demonstrates a limitation common to all models – that a common modeling framework is unlikely to simultaneously address both generality and realism, and models will have to be tailored to the relevant habitat issue/indicator/reference point at hand.

Static Habitat Suitability Models, Emphasis: Potential Habitat

|	**Statistical** (D.M. Nelson)	**Ecophysiological** (D. Secor)	**Nested GAM** (J. Manderson)
Functional Relationship with Habitat Variable	Statistical associations from surveys	First Principles, parameterization through experiments	Statistical associations through directed field research
Maps (static)	Water quality and structure	Water quality	Water quality and structure
Goals/applications	Visualization tool EFH/ Sanctuaries	Water quality criteria Restoration/ Carrying Capacity	EFH at multiple scales/ Habitat Connectivity
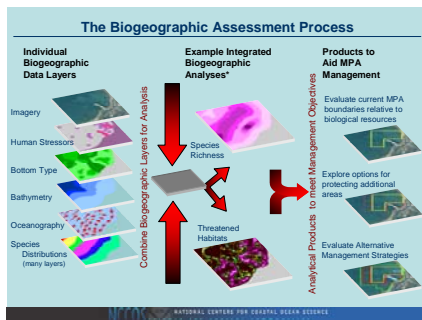
Figure 2. Static habitat models provide daily, seasonal, annual depictions of distributions of potential habitat based upon statistical or parameterized functional relationships between living resource responses (e.g., incidence) and habitat variables. They are fundamental to NOAA's Biogeographical Assessment Proccess: http://ccma.nos.noaa.gov/welcome.html . Names listed under each column are workshop presenters represent scientists who presented on each type of model.

Dynamic Habitat Models--Oceanographic modeling can yield dynamic projections of preferred and essential habitats. Models combining hydrology, bathymetry, water quality, hard substrate distributions, and behavior can be supported through process oriented studies in the laboratory and field, resulting in predictions relevant to improved siting of restored oyster reefs and shoreline development (North et al. 2008; Schulte et al. 2009; Figure 3). Through telemetry and intensive sampling methods, movement rules can be erected for juvenile and adult fishes, and applied to layers of habitat variables, providing dynamic depictions of habitat under changing landscapes (seascapes). These are typically intensive and complex modeling efforts that require careful attention to over-parameterization and calibration. Still, preferred habitat is a critical link in understanding how behavior mediates potential and realized habitat distributions.

Dynamic Habitat Suitability Models, Emphasis Potential and Preferred Habitat

|	**Larval fate** (E. North)	**Meta-population** (R. Lipcius)	**Mosaic- Landscape** (R. Fulford)
Functional Relationship with Habitat Variable	Dispersal and demographic functions	Dispersal and demographic functions	Movement rules and habitat response functions
"Maps" (dynamic)	Hydrology, bathymetry, water quality, reef areas	Hydrology, bathymetry, water quality, reef arrangement	Mosaic: Time Series of Landscape Maps
Goals/applications	Visualization tool, Restoration, Sanctuaries	Visualization tool Restoration, Sanctuaries	Prediction of EFH under changing "landscapes" Watershed, Climate
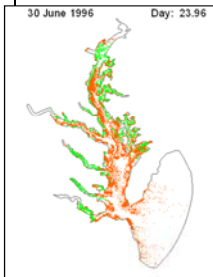
Figure 3. Dynamic habitat models provide continuous depictions of preferred habitat based upon dispersal processes or modeled behaviors (e.g., movement rules). Such efforts represent state-of-the-art research focused on improving oyster restoration in the Chesapeake Bay (e.g., http://northweb.hpl.umces.edu/videos_animations/Oyster_Larvae_Animations.htm. Names listed under each column are workshop presenters represent scientists who presented on each type of model.

Aggregate Models—Aggregate models is a bit of a catch-all, but is used here to classify models that consider "externalities" (Secor and Austin 2006), such as food web effects on habitat, ecosystem services, and climate (Figure 4). EcoSpace is an add-on to the principal food web model, Ecopath with Ecosim (EwE), permitting increased spatial resolution and aggregation of trophic interactions that occur at multiple scales. Conceptually, it should be possible to test residuals from such analyses for their association with habitat variables. Further, this approach could be used to address top down effects of food web components (e.g., menhaden and oysters) on water quality, a fundamentally different perspective than considered in most habitat suitability models. Currently the approach is nascent and has not seen substantive applications in the Chesapeake or elsewhere. Further, current applications of EwE within the Chesapeake Bay indicate that the model will serve principally as a heuristic tool: calibrations against observed living resource trends have thus far been poor. The annealing statistical procedure termed MARXAN seeks to balance the dilemma of 'fish need water, so fish habitat is everywhere' against cost functions – area, cost, etc. This approach is directly applicable to the Nature Conservancy tactic of 'where can we get the biggest benefit in habitat for each dollar spent' in habitat protection. Finally, there is the option of combining layers of living resource responses into the same modeling framework as being currently pursued by the research team at the Sarbanes NOAA Oxford Lab. This approach represents a portfolio of statistical, bioenergetic, and trophic models designed to address a range of striped bass habitat issues. A range of approaches to combine habitat,

food web and other drivers are now under consideration by the striped bass Habitat and Food Web Quantitative Ecosystem Teams.

Aggregate Models, Emphasis: food webs, externalities, management issues

	EwE with EcoSpace (H. Townsend)	**MARXAN** (R. Zajac)	**Oxford Laboratory** (Woods, Jacobs, Martino, Zhang)
Functional Relationship with Habitat Variable	Performed *a posteriori* following EwE	Statistical associations from surveys	Hybrid of statistical, bioenergetic, and trophic associations
"Maps" (dynamic)	Food-web and habitat variables assigned to be homogenous within each cell.	Water quality and structure	Water quality, aggregate Chesapeake properties (e.g., high/low flow years, forage indices).
Goals/ applications	Heuristic tool: Role of water quality, on multi-species interactions; Influence living resources on water quality	Multi-species decision tool for defining EFH or sanctuaries. Penalty=area, cost1	Focus on multiple indices (e.g., disease, recruitment, water quality) Red Light, Yellow Light indicators, Visualization tools

Figure 4. Habitat models designed to address externalities, such as food web dynamics (EwE), conservation costs (MARXAN), or species-specific issues (Oxford modeling efforts). Names listed under each column are workshop presenters represent scientists who presented on each type of model.

4. Recommendations

The hierarchy of habitat classification terms suggest an inverse relationship between what is most feasible to model (potential, realized habitat) versus what may be most critical to living resources (preferred, essential habitat).   Potential habitat can be modeled in a fairly straightforward way through static approaches (Figure 2), which provide an efficient means of making use of what is currently available from habitat variable and living resource datasets. Given its ease of application, it seems somewhat surprising that this approach is not already in use by the Chesapeake Bay Program or constituent state and federal members. Defining potential habitat in this manner is precautionary if protections can be afforded to all such habitats. Particularly in the face of climate and other environmental change, minority habitats (those that are infrequently utilized) can contribute to stability and persistence of living resources (Kraus and Secor 2005; Kerr et al. in press). Comparison between potential and realized habitat distributions can serve as a reference point, permitting distributional responses due to management actions and environmental change to be referenced against some standard condition.

Although calling for development of models of potential habitat with data and models we have in hand, I should also caution that such depictions can be biased due to unknown

effects of trophic interactions, behavior, complex life cycles, habitat arrangements (connectance), and density dependent effects (population status) (Breitburg 2006). These issues, if incorporated through habitat suitability models that focus on preferred habitat, should result in more targeted spatial management strategies such as protection of essential fish habitats. I note the rapid development of numerical and individual-based modeling approaches, which permit incorporation of behavior into habitat suitability models. Particularly in the Chesapeake Bay, such habitat models have already influenced management decisions and strategies regarding the restoration of oysters (Schulte et al. 2009; North et al. in press). Because highly sophisticated oceanographic and nutrient modeling already exists for the Chesapeake Bay, similar developments of dynamic habitat models merit development.

Management of the Chesapeake Bay will increasingly target spatially explicit strategies. As such, externalities related to cost functions, such as where nutrients are best managed, where shoreline is most efficiently restored, or where living resources are best protected are critical management questions. The MARXAN procedure is but one (e.g., Wainger et al. 2004) which can consider ecosystem services balanced against costs for protection/restoration that merits targeted development and application in the Chesapeake Bay.

In summary, habitat models that make use of the Chesapeake Bay monitoring data sets on water quality, natural reef and shoreline habitats, and living resource surveys can be effectively used immediately to develop predictions of potential and realized habitat. Indeed the high cost of monitoring has been justified based upon some link between habitat improvements and living resources, but rarely are statistical or predictive models applied to this premise. Federal law mandates identification of essential fish habitats, which is currently not supported by best available modeling approaches. Models on external forcing of Chesapeake physicochemical conditions are becoming increasingly sophisticated but remain unmatched by development of models that incorporate internal factors into essential habitat predictions such as behavior, complex life cycles, trophic interactions, and density dependent responses. Initial applications of habitat models in the Chesapeake Bay and elsewhere that incorporate these factors show that they can provide relevant management guidance and merit priority in further development and application.

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6. Synopses of Habitat Suitability Models

a. *Using Habitat Affinity Indices to Assess Value of Estuarine Fish Habitats*

Author: **David Moe Nelson**, Marine Biologist, NOAA/NOS Center for Coastal Monitoring and Assessment, 1305 East-West Hwy, 9th Floor. Silver Spring MD 20910. Phone 301-713- 3028 x154
david.moe.nelson@noaa.gov

Habitat Suitability Index (HSI) models can be used to support a wide variety of management needs, including analysis of essential fish habitat, or evaluation of spatial management scenarios. The analytical complexity of models can vary from relatively simple models based on expert knowledge and species distribution data, to spatially explicit models based on empirically-derived quantitative habitat affinities. The utility of any given Habitat Suitability Modeling (HSM) study is greatly enhanced if it is designed with specific hypotheses or management questions in mind – it is not merely a characterization of existing conditions, or prediction of future behavior. Managers and scientists must be engaged in a give-and-take dialog throughout the course of the entire project, so that technical staff have an idea of the relevant questions being posed, and managers understand the strengths and limitations of the results that they are seeking. NOAA's Biogeography Program and its partners have used GIS-based Habitat Suitability Modeling (HSM) approaches for a variety of species, in both estuarine and coastal marine waters. Models have been developed and applied to:
1. The ELMR project – using salinity as the defining habitat parameter
2. Eight fish and invertebrate species in Delaware's coastal marine waters
3. Eight fishes and invertebrate species in Casco and Sheepscot Bays, Maine
4. Oysters in Pensacola and Apalachicola Bays, Florida
5. Spotted seatrout in Gulf of Mexico estuaries
6. Brown shrimp in Galveston Bay
7. Marine fishes in California's National Marine Sanctuaries

NOAA's Estuarine Living Marine Resources (ELMR) project used estuarine salinity zones as the spatial framework for completing a consistent data base on the distribution, relative abundance, and life history characteristics of ecologically and economically important fishes and invertebrates in the Nation's estuaries (Nelson and Monaco 2000, Stone et al. 2004). Although the project was intended to capture existing information within a defined framework – it could also be considered as an extensive estuarine habitat model where abundance is predicted as a function of a single habitat parameter (salinity), along with time component defined by month. The Nationwide ELMR data base includes information for 153 species found in 122 estuaries and coastal embayments, and is divided into five study regions - West Coast, Gulf of Mexico, Southeast, Mid-Atlantic, and North Atlantic. For each species, five life stages are considered - adults, juveniles, larvae, spawning, and eggs - with some exceptions. Each estuary is subdivided into one to five salinity zones. Relative abundance is ranked by month for each life stage of each species, in each salinity zone of each estuary, based on analysis of survey data supplemented with expert review.

In Delaware's coastal zone, data on physical habitat parameters were compiled and mapped, including temperature, depth, and sediment type (Nelson et al. 2003). Existing scientific literature was reviewed to identify known habitat affinities of species. Habitat Suitability Index (HSI) values were derived by associating catch in fishery-independent trawl surveys with dominant environmental parameters. Eight species modeled include Atlantic surfclam, blue mussel, black seabass, summer flounder, winter flounder, scup, spiny dogfish, and smooth dogfish. Model results were mapped using ArcGIS to visualize the spatial distribution of sand resources, fishery resources, and predicted habitat suitability. These results were used to identify optimum sand borrow sites and predict potential biological impacts of beach sand renourishment activities.

In Casco and Sheepscot Bays of Maine, HSI values were calculated as a function of species' habitat associations and mapped available habitat (Brown et al. 2000). Based on published information and expert review, models were developed for alewife, American sand lance, Atlantic salmon, Atlantic tomcod, mummichog, winter flounder, American lobster, and softshell clam. Habitat maps were developed consisting of grid cells for seasonal temperature and salinity, depth, and predominant substrate type. The HSI models were run, reclassified, and mapped. Model performance was evaluated by expert review and non-parametric statistical tests comparing model results with species catch data.

In the Gulf of Mexico, an HSM approach was combined with a spatially and temporally-explicit hydrodynamic model to project potential effects of altered freshwater inflow on oyster populations of Apalachicola Bay, Florida (Livingston et al. 2000, Christensen et al. 1998). Results of these studies were directly relevant to a water allocation dispute affecting the entire region. Elsewhere in the Gulf of Mexico, HSM been applied in estuaries to spotted seatrout (Clark et al. 2003), white shrimp (Christensen et al. 1997), and brown shrimp (Clark et al. 2004) to refine the characterization of Essential Fish Habitat (EFH).

In marine waters off of California, an HSM approach was applied to nineteen species of fishes and invertebrates to provide essential information for reviewing the management plans and boundaries of three National Marine Sanctuaries (Cordell Bank, Gulf of the Farallones, and Monterey Bay) (NOAA 2003). The depth gradient was found to be the habitat parameter with the most pronounced effect on observed and predicted distributions, along with substrate type. Species modeled were primarily demersal (associated with bottom habitats), and included rockfishes, flatfishes, and Dungeness crab.

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b. *Combining Generalized Additive Modeling and GIS for inference, description and prediction of Marine Habitat Dynamics*

Author: **John P. Manderson** ,Behavioral Ecology Branch , NMFS. James J. Howard Marine Highlands, New Jersey: john.manderson@noaa.gov

Marine organisms have evolved in a viscous environment with a high heat capacity and solute concentrations similar to intracellular milieus in which drag rather than gravity is the dominant force controlling movements. Physiology, dispersal, and fitness of marine organisms are therefore tightly coupled to many scales of pelagic as well as benthic habitat heterogeneity as the animals make dramatic ontogenetic habitat transitions required to complete their life cycles. Pelagic habitat characteristics, often forced by the atmosphere and dynamic in space and time, are frequently the most important factors directly or indirectly regulating vital rates. Marine habitats are therefore dramatically different than terrestrial habitats; fully 3 spatial dimensional with "fast" temporal dynamics. However, researchers are usually constrained by logistics and lack of environmental information to adopt Eulerian frameworks, and to stratify field studies in reference to geographic and/or structural bottom features that are stable in space over time. When field studies are designed with a Eulerian framework and spatially dynamic habitat features have strong effects on distribution, abundance or specific vital rates, exploratory regression techniques can be effectively used to make inferences about and to describe spatial habitat dynamics. Generalized Additive Modeling (GAM) is a particularly powerful nonparametric regression technique for inference and description when the forms of species responses to spatially dynamics habitat gradients are nonlinear and unknown.

I review a research program in which GAM, combined with GIS, was applied to results of field surveys and experiments to visualize the spatial dynamics of suites of habitat characteristics controlling distributions, rates of larval settlement, growth and mortality for the early life stages of a commercially important flatfish on a mid Atlantic nursery ground. Projections of GAM results in space and time using GIS elucidated the temporal evolution and devolution of habitat suitability for specific early history processes, the importance of spatial and temporal constraints imposed by earlier processes on later processes, and the space-time scales of influence of nested sets of habitat characteristics strongly regulating specific vital rates. The dynamic habitat framework developed from visualizations of GAM results in GIS allowed us to conceptualize the ways in which habitat effects on individuals at local sub-population level may be translated upscale through meta-population dynamics to regional population dynamics.

Following description of the project, I outline simple guidelines for independent variable selection in GAMs developed using open-source R software and the mgcv library (http://cran.r-project.org/), that are more thoroughly described in Ciannelli and Chan (19??) and Wood (2006). These guidelines include the incorporation of linear terms and interactions between habitat variables when appropriate. GAM, which is nonparametric multiple regression technique shares all the limitations and dangers of multiple linear

regression. However, because GAM uses flexible smoothing splines to model nonlinear species response, the technique is more susceptible to overfitting and the modeling of nonsensical response curves than its linear analogues. GAM is best used for hypothesis generation, visualization and for identifying the possible forms of mechanistic, parametric habitat response functions to be tested and parameterized in well designed laboratory and field studies. With those caveats in mind, GAM can be used as a first step toward statistical prediction of the spatial dynamics of habitat for modeled species life stages.

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c. Ecophysiological Habitat Modeling

Author: **David Secor**, Chesapeake Biological Laboratory, University of Maryland
Center for Environmental Science, Solomons, MD 20688
secor@umces.edu

Theory and Background

Ecophysiological modeling represents a powerful quantitative and conceptual approach to predict environmental effects on fish production. Winberg's (1956) classic mass balance equation expressed individual metabolic and production rates as functions of environmental factors. For some time there have been "off-the-shelf" bioenergetic modeling packages and inputs available to compile the effects of forage and temperature as factors driving fish bioenergetics (e.g., Hewett and Johnson 1992; Hartman and Brandt 1995), but more complex, multivariable habitat models have been pursued, which have important application to estuarine systems (Luo et al. 2001; Neill et al. 2004; Wuenschel et al. 2004; Niklitschek and Secor 2005; Costantini et al. 2008).

One class of ecophysiological models predicts the effects of temperature, dissolved oxygen, and salinity according to Fry's classes of nonlinear environmental effects on physiology (Fry 1971). These functions include controlling (steep dome shaped curves), masking (shallow upward concave shape curves), and limiting (saturating curves) effects for temperature, salinity and dissolved oxygen (DO), respectively. Importantly for estuarine applications is that DO rather than forage can act as the primary limiting factor (Neill et al. 2004; Niklitschek and Secor In Press).   This type of model specifies that oxygen supply must first meet basal metabolic demands, and then any remaining oxygen is utilized for growth, the so-called "aerobic scope for growth." Thus, physiological rates are assumed to be driven by temperature (controlling factor), but limited by the aerobic scope, i.e., the oxygen available in the tissues to sustain oxidative processes (van Dam and Pauly 1995). Aerobic scope for growth is expected, in turn, to be reduced by additional metabolic costs, especially those imposed by either hypo- or hyper-osmotic conditions (masking effects).

Implementation

Operationally, ecophysiological models can be applied to geo-referenced habitat layers (temperature, DO, and salinity) much like habitat preference or affinity scores in the well known Habitat Suitability Index approach (e.g., Rubec et al. 1999). Here however, combining habitat layers into a composite index is based upon an integrated model of ecophysiological response rather than under an equal weighting scheme, which is often the default of other applications. Further, the predicted response is in production units, which facilitates application to performance measures and reference points. Relationships between fish production and key water quality or other habitat resources (e.g., forage base, substrate type) are determined in directed laboratory experiments informed by models of ecophysiological response (Fry 1971; Neill et al. 1994). The ecophysiological model then serves as a filter for geo-referenced habitat data, which is

translated into maps of potential growth. For systems such as the Chesapeake with extensive water quality sampling, ecophysiological models can efficiently translate a fundamental understanding of biotic effects into habitat suitability maps at multiple spatial and temporal scales.

Limitations

The premise of the approach is that potential production, whether in fact "realized" or not, is an index of habitat value. Also, no dynamic due to changes in overall abundance or forage levels are included in available formulations. Thus, the approach is assuming steady state carrying capacity and examining how changes in physicochemical parameters detract from this potential production. These limitations indicate that careful attention should be given to testing the model against field observations (Rice and Cochran 1984; Niklitschek and Secor In Press) and in applying the model to appropriate issues and reference points.

The approach depends upon intensive laboratory experimentation with often variable biotic responses, requiring careful experimental design and statistical considerations in developing ecophysiological models. Multivariable models can be quite complex in their interactions and non-linear effects, which indicates sensitivity tests should be conducted to reduce over-parameterization (Bartell et al. 1986). Estuaries can show strong selection for certain life history traits, so experiments should be conducted on local populations. Also, because bioenergetic responses are sensitive to fish size, this approach is best applied to single life history stages.

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d. Landscape-based habitat production modeling in coastal nursery areas

Authors: **R.S. Fulford,**
            M. S. Peterson,
            P. Grammer, University of Southern Mississippi Department of Coastal
            Sciences, Gulf Coast Research Laboratory, 703 E. Beach Drive, Ocean
            Springs, MS 39564
            Richard.Fulford@usm.edu

Theory and Background

An understanding of the relationship between habitat quality and production in exploited fish populations has been codified in the Essential Fish Habitat (EFH) concept that is a necessary component of all federal fishery management plans (Rosenburg et al. 2000). This requirement stresses the need for an incorporation of habitat influences into the management process, but provides only broad guidance as to scope or approach which has led to a largely descriptive effort to delineate EFH. What is needed is a mechanism to identify and describe quantitatively the current state of key habitat for exploited fish populations. More importantly, managers need information on how fish production will respond to change, as this will provide tools for adaptive management based on the growing body of data regarding change in landscape characteristics.

A large body of literature deals with the application of landscape based habitat models to animal survival and production in terrestrial ecosystems (e.g., Johnson 1992, Turner et al. 1993, Schumaker et al. 2004). At the landscape scale habitat is projected onto a hierarchal grid from the quality of an individual habitat unit back up to the scale of the entire landscape. These models address animal response to habitat characteristics in terms of hierarchal effects on vital rates (e.g. growth and reproduction), movement, and inter- and intra-specific interactions.

The challenge for model development is to define relevant habitat scale and the neighborhood of influence for a particular organism and life stage of interest. These are particularly challenging questions in an aquatic environment where organism response to temporal vs. spatial variation in the habitat landscape can vary greatly.

Peterson (2003) developed a conceptual model of the habitat mosaic that considered both temporal and spatial variation in habitat quality. This model differentiated structural habitat consisting of habitat variables that differ spatially more than temporally (e.g., bathymetry, rooted macrophyte density) and dynamic habitat consisting of more temporally variable characteristics (e.g., temperature and salinity). The former is the more traditional definition of habitat while the latter is usually described as environment, but both combine to define quality of any particular habitat unit. Peterson (2003) suggested that most particularly larval and juvenile fish immigrating into coastal nursery areas may respond to each of these habitat components at different scales and that the relative value of particular habitat components to fish production must account for the entire habitat mosaic, as well as how fish respond to change in the mosaic. At the

landscape scale both structural and dynamic habitat components can be accounted for in a common framework. These data can then be used to develop landscape-based individual-based models that describe how fish respond to the habitat mosaic and what components of the mosaic are most critical for maintaining fish production.

<u>Implementation</u>

Landscape-based models use a grid layer approach to describe both habitat characteristics and the state of individual fish residing on the landscape (Molofsky 1995). The model then consists of s set of rules that describe how animals perceive and respond to the landscape mosaic in terms of movement and growth. Individual search and movement are described based on a neighborhood that delimits the space around the individual that is perceivable. This neighborhood is used as input data for movement decisions that occur in three steps; decision to move, direction, and decision to stop. All of these steps are made based on the influence of the neighborhood, but the neighborhood moves with the individual so the influence of previous neighborhoods can be retained as spatial memory creating distinct patterns of correlated movement. Both the decision to move and the decision to stop are based on heterogeneity in the habitat mosaic, defined tendency to move 'up or down' the habitat gradient, and realistic limits on movement distance within a particular timestep. Animal production is then defined based on the influence of destination habitat on individual growth. The linkage between habitat quality and individual growth is most often described using physiological tolerances and predator/prey availability in a similar manner to an ecophysiological growth potential model (See Secor this workshop).

Landscape-based habitat models utilize remotely sensed data on land use/land cover (LULC) to generate digital maps of the habitat mosaic. This approach is limited in aquatic environments as many important habitat characteristics either cannot be measured remotely or are measured at too coarse a temporal scale to be of value. This limitation can be overcome using rapid in-situ data collection techniques (Peterson et al. 2007) combined with spatial interpolation. Water quality data in particular can be collected through time at a high level of spatial resolution so that it can be combined with data on LULC to produce maps of the habitat mosaic for a particular system. The result is a timeseries of landscape maps; each describing spatial heterogeneity in the habitat mosaic either for each habitat component separately of as a function of a suite of habitat variables. This map timeseries is then used as model input to produce the habitat grid driving individual movement and production.

Model output is comprised of both individual and population level descriptions of realized movement, distribution, and production. Initially, model simulations can be used to delineate the relative importance of spatial vs. temporal habitat heterogeneity to movement decisions and production. These data can be compared to field observations of distribution and production to validate the assessments for a particular fish and ecosystem. The use of ubiquitous species for a particular ecosystem type will allow for some generalization of findings to other similar ecosystems. Ultimately such models can be used to ask questions regarding the impact of targeted habitat change such as the impacts of sea level rise on coastal habitat, or the likely effect of small scale habitat

restoration.   Landscape-based habitat models allow for the more efficient use of raster-based GIS data as well as a framework for linking predictions about individual responses to habitat quality at multiple scales to population level production.

Limitations

Landscape-based models provide a framework for addressing fish response to both temporal and spatial change in habitat quality. As such they are best suited for understanding the effect of habitat alternations on population level processes. Further, the data requirements of landscape-based modeling in an aquatic environment are relatively high. In an aquatic ecosystem, simply defining the important habitat characteristics for inclusion in the model can be challenging as the relative influence of particular vectors (e.g., dissolved oxygen) may differ widely based on fish species, and interactions with other habitat variables.   Further the influences of all habitat variables must be transformed to a common framework to allow for inclusion in the model as a landscape grid. Thus water quality data typically collected at a coarse spatial scale and landscape data typically collected at a coarse temporal scale must be rectified. In addition to the habitat data, we must also define the perceptual neighborhood for a particular fish species and life stage, as well as functional relationships between individual vital rates and habitat metrics. Data are available for well studied ecosystems and species and these provide an opportunity to develop the landscape-based modeling framework and how it might be applied to other ecosystems and species of interest.

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e. MARXAN Modeling in Estuarine Systems and Integration with Habitat Suitability Assessment

Author: **Roman Zajac**, Dept. of Biology and Environmental Science, University of New Haven, 300 Orange Ave. West Haven, CT 06516
rzajac@newhaven.edu

Background and Theory

There is an increasing need to identify, understand and manage ecological resources and dynamics in a spatially explicit fashion at system-wide and regional scales, encompassing ecosystems and landscapes. Various modeling approaches have been, and are being developed to assess how target species are distributed across space in estuarine systems relative to their habitat and physiological requirements. Paralleling these efforts has been the development of models that attempt to identify areas, habitats and/or landscape configurations that could meet conservation / management goals that focus on species and/or habitats. One of these latter modeling approaches is simulated annealing as formulated in MARXAN software (Ball and Possingham 2000, Game and Grantham, 2008). Simulated annealing is a probabilistic optimization method to find a good approximation to the global minimum of a given function in a defined region (search area). In MARXAN, the function that is used is:

$$\textit{Objective Function (Total Cost)} = \Sigma\ \textit{Cost} + (\textit{BLM} * \Sigma\ \textit{Boundary}) + \Sigma\ (\textit{SPF}*\textit{Penalty})$$

Where,
• *Cost* is the cost of the selected planning units (e.g., their area, an economic or social cost, or combinations of these,
• *BLM* is the boundary length modifier and *Boundary* is the boundary length of solution areas; together they determine the number and individual sizes of reserves by setting the cost of the spatial dispersion of the solutions,
• *SPF* is the "species" penalty factor and can be used to set the importance of a specific conservation target; *Penalty* is a value added to the objective function for every target that is not
met, based on the additional boundary length and cost that would be needed to represent that target.

The lower the value of the objective function, the better the solution. Modeling comprises setting a set of conservation goals (scenarios) and then running the algorithm to find the best possible solution for that set of goals. Conservation goals can be based on specific target species, habitats and/or other biodiversity / resource components. For example, one might want to insure that a certain percentage of the overall area of each habitat type in a particular estuary be included in one reserve. The target percentages of each habitat and the requirement of one reserve comprise a cost. Goals can also be constrained by specific locations, desired spatial extent and configuration of the reserve or reserve network. The overall area of the estuary is divided into planning units (equal sized square / hexagon

cells) and the area of each habitat or abundances of species if that is the target, is determined fro each cell. This information is then used by MARXAN to test alternate selections of planning units that attempt to minimize the objective function (Total Cost), relative to the conservation goals for that scenario. Multiple solutions can be obtained for a particular scenario, and subsequent analyses can focus on comparing solutions for the degree of spatial overlap to determine which planning units are consistently included in solutions to ascertain the "best" overall solution. Solutions can also be compared to other types of spatial data to assess their efficacy relative to conservation goals. A good, general overview of how the process works can be found at http://www.mosaic-conservation.org/cluz/marxan_intro.html. See also: http://www.uq.edu.au/marxan/resgame/index.html

MARXAN is being used for reserve design in both marine (e.g. Beck and Odaya 2001, Sala et al. 2002, Airame et al. 2003, Leslie et al. 2003, Cook and Auster 2005, Neely and Zajac 2008) and terrestrial (e.g. Miller et al., 2003, Kiesecker et. al. 2009) environments (see also the MARXAN website www.uq.edu.au/marxan/ for additional examples).

Implementation

MARXAN is freely available on the web (see above URL). The MARXAN site also has links to tutorials and publications. A Geographic Information System (GIS) is used to prepare spatial data for input into MARXAN, and also to display the solutions. Much of the currently available documentation in terms of tutorials and examples, and interfacing MARXAN with GIS is based on using ArcView GIS for this purpose (e.g.http://www.marineebm.org/resources/marxan_tutorial_expert.doc) although an ArcGIS interface, Protected Areas Network Design Application (PANDA), is available (see http://www.mappamondogis.it/panda_en.htm). The learning curve for developing and running MARXAN models will vary with the user's knowledge of GIS in terms of developing needed data files and eventual display of results, but MARXAN itself if fairly straightforward. Digital data on the spatial distribution of the conservation targets (habitats, species) is necessary, as well as data that may be used to assign penalties / constraints. Data preparation is aided by using the GIS interface tools noted above. Several modifications of MARXAN are being developed which extend its capabilities including, for example, the ability to model different use zones in a region / system, new interface and routines to use probabilistic inputs. In terms of reserve design, digital data on impacts, human uses, resource extraction, and other similar types of data would be needed to assess potential conflicts in and around the solution areas identified by MARXAN.

Limitations

Perhaps the most significant limitation for using MARXAN as a planning tool is the availability of accurate data sets of the spatial distribution and characteristics of habitats, species populations and communities and a well developed framework for incorporating the model results into related research and management. For example in a recent

workshop (see Marxan Good Practices Workshop Summary Report at http://www.pacmara.org) much of the focus was on how MARXAN results are used to help develop marine protected areas / reserves relative to competing issues and stakeholder concerns. In terms of MARXAN models being used for habitat suitability assessments, it must be kept in mind that it is not an ecological model as it does not predict the spatial distribution of species and communities based on their responses to some set of environmental factors based on what is known of their ecology. However, it can identify spatial arrangements of mixes of species or habitats based on specified criteria (e.g. areas that include some percentage of the total species pool and/or target species). The MARXAN model results can then be interfaced with various types of modeling results to assess habitat suitability on an ecosystem basis and in relation to the joint distributions and ecological responses of species groups. Another important aspect of using these models is having data that can potentially test model results, especially if conservation targets are based on proxy variables (e.g. bottom type) for species communities and/or populations.

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*f. **Incorporating Habitat into Food Web Models using the Ecopath with Ecosim Software: Potential applications using the Chesapeake Bay Fisheries Ecosystem Model***

Author: **Howard Townsend** – NOAA Chesapeake Bay Office, Cooperative Oxford Laboratory, 904 South Morris Street, Oxford, Maryland 21654 Howard.Townsend@noaa.gov

In this synopsis, the Chesapeake Bay Fisheries Ecosystem Model (CBFEM), developed using the Ecopath with Ecosim (EwE) software is described, and the potential for its use as a management support tool incorporating habitat and food-web relationships in the Chesapeake Bay is outlined. A brief description of the EwE software is given. Methods for using the software to incorporate habitat and food web relationships, using forcing and mediation functions, into a single modeling system are discussed. As a first version of the CBFEM has been developed and validated, this model, in combination with forcing and mediation functions, is readily available as a tool for understanding food-web habitat interactions and exploring management options. A brief description of other components of the EwE software (Ecospace and Ecoseed) is given, and how they can be used as a habitat-based management tool is explained. Only a prototype spatial version of the CBFEM has been developed using Ecospace. Additional developmental work would be necessary to make a spatial CBFEM available as a tool for understanding food-web habitat interactions in the Chesapeake.

CBFEM

Among other models being used in the region, the scientific community has helped to develop the Chesapeake Bay Fisheries Ecosystem Model (CBFEM) (Christensen et al 2008) using the Ecopath with Ecosim (EwE) software (Christensen et al 2004). The CBFEM was created in response to a management need in the Chesapeake Region for a quantified estimate of trophic pathways in the Bay. This information can be used to understand how one fish stock affects another within the food web and how the Bay fisheries impact both target and non-target species. Because the life histories and population dynamics of the thousands of organisms that live within the Bay are complicated, a model is necessary to provide an accurate synthesis of the system.

Currently, the model includes 45 functional groups of organisms, representing all trophic levels. The input data primarily includes assessment results from the Chesapeake Bay and Atlantic Coast stocks (including biomasses, mortality rates, catches, and effort) supplemented with fisheries-independent survey data (fisheries and biological oceanography studies); ecological studies (as available from researchers and institutions in the region); and parameter estimates obtained from literature where necessary to supplement local data. More information about the specifics of the model is available in the CBFEM technical report (Christensen et al 2008). The trophic groups in the current CBFEM are listed in Appendix A.

The strength of any model to be used for testing management action outcomes is measured by how well it is validated based on observed data for that system. This is true whether the model is a traditional single-species or a multispecies model. A 1950 Ecopath model was created to represent a snapshot of roughly what the Chesapeake Bay system may have looked like in the middle of the twentieth century. This model was then run time-dynamically using Ecosim and tuned to observed data or to data estimated from other models for the time period 1950-2002 to estimate changes in biomass over 50 years. The projection forward for 50 yrs using the CBFEM can incorporate habitat factors, as quantified in habitat suitability models, and how these factors influence fish populations directly (i.e., through driving fish biomass production) and indirectly (through habitat mediation).

To determine how external factors (e.g., habitat) influence the food web, we can consider the CBFEM to be the baseline model. That is to say, the model that encapsulates trophic interactions, fisheries effects, and the effects of primary production on the fisheries ecosystem are taken to be the "simplest" hypothesis. We can then incorporate habitat suitability models as forcing and mediation functions (Appendix B for further explanation of these functions) into the baseline model and test for improved model fit (sum of squares) to determine if the additional factors (i.e., habitat) appreciably improve the fit of the model to the data. Habitat suitability models provide us with *a priori* hypotheses about factors likely to influence fish stocks. We expect that additional factors will improve the fit, and this will help determine the extent to which habitat influences fish stocks and the food web.

These methods can be implemented readily for ecosystem-based management. To implement this method would only require the development of suitable forcing or mediation functions to represent the habitat factors of interest. The main drawback to these methods are that habitat and biogeochemical processes of interest can only act as forcing functions for the fisheries food web based on statistical relationships. The extent to which upper trophic level organisms influence the biogeochemical and habitat process is not captured in this modeling system. To do so would require that this model be coupled with additional models or the use of other models and software. The current version of EwE (i.e., version 6) accommodates the direct coupling of models through a flexible, modular programming structure using the Microsoft .NET framework, so model coupling is feasible but would require additional development.

Ecopath with Ecosim

The Ecopath with Ecosim (EwE) software is a modeling tool used to evaluate quantitative trophic interactions within an ecosystem in order to assess options for ecosystem-based management of fisheries. To run the Ecopath model, four groups of basic input parameters must be entered into the model for each of the species groups: diet composition (DC), biomass accumulation (BA), net migration (E), and catch (Y). Three of the following four additional input parameters must also be input: biomass (B), production/biomass (P/B – NOTE: P/B≈Z, total mortality), consumption/biomass (Q/B), and ecotrophic efficiency (EE). Forcing functions have been developed for the system,

including one for climate, primary production, and habitat area. The model uses the input data along with mass balance equations (0.1) and a routine for matrix inversion to estimate any missing basic parameters so that mass balance is achieved.

$$B_i \square (P/B_i) \square EE_i - \sum_{j=1}^{n} \left(B_j \square (Q/B)_j \square DC_{ji} \right) - Y_i - E_i - BA_i = 0 \qquad (0.1)$$

The mass-balanced linear equations of Ecopath are then re-expressed as coupled differential equations (0.2) so that they can be used by the Ecosim module to simulate what happens to the species groups over time.

$$\frac{dB_i}{dt} = g \sum_{j=1}^{n} Q_{ji} - \sum_{j=1}^{n} Q_{ij} + I_i - \left(M_i + F_i + e_i \right) B_i \qquad (0.2)$$

where dB_i/dt represents the growth rate during the time interval dt of group (i) in terms of its biomass, B_i, g_i is the net growth efficiency (production/consumption ratio), M_i the non-predation ('other') natural mortality rate, F_i is fishing mortality rate, e_i is emigration rate, I_i is immigration rate, (and $e_i \cdot B_i - I_i$ is the net migration rate).

Model runs are compared with time series data and the closest fit is chosen to represent the system. The Ecosim module can be used to simulate various scenarios with different strengths of habitat mediation and egg production forcing for the system to help estimate how habitat factors influence the fisheries ecosystem. In addition, fishing and habitat related parameters can be manipulated to explore the interactions between fish and habitat management policies in a Management Strategy Evaluation (MSE) approach.

Ecopath with Ecosim extensions – Ecospace and Ecoseed

Ecospace is a module of the EwE software that supports the creation of spatially explicit food web models. Ecospace requires the full development of Ecopath and Ecosim modules of the EwE software. Ecospace was developed as a spatial meso-scale version of Ecosim. Ecosim dynamics are replicated over a spatial grid of 'homogenous' cells. That is to say, a cell can be of only one habitat type, but multiple habitat types can be represented and a trophic group's habitat preferences can be delineated. Cells are linked via dispersal of organisms and fishing effort and allocation. In addition, Ecospace can incorporate an advection model. It can be used to account for spatial variation in productivity and cost of fishing. During the course of an Ecospace run, habitat preferences can result in differential dispersal, feeding, and predation rates among cells. In addition, migration patterns can be incorporated.

The original concept behind Ecospace was to provide only coarse predictions of how spatial management and fishing effort distribution could result in changes in trophic interaction patterns. Computational constraints prevented the full suite of EwE age/stage-structure (multi-stanza trophic group) dynamics from being incorporated. Recent programming advances in EwE have allowed the incorporation of an individual-based model (IBM) approach to be used to model the age/stage-structure dynamics in Ecospace.

Currently, the Ecospace module for the CBFEM has been developed only as a prototype for display.

Currently Ecoseed, a routine of Ecospace for optimal location and sizing of MPAs, is under development. A spatial information exchange has also been developed between Marxan and Ecospace/Ecoseed to quantitatively and jointly consider biodiversity and fishery objectives in spatial management.

The Ecospace and Ecoseed modules of the CBFEM have not been fully developed. A prototype CBFEM Ecospace module (spatial CBFEM) has been developed, but additional development and validation would be required to make this a suitable tool for understanding habitat-food web interactions. Upon development of a spatial CBFEM, implementing the Ecoseed module would be a straightforward task.

Appendix A. Trophic groups in CBFEM

Sequence	GroupName	Sequence	GroupName
1	Striped bass YOY	24	Non reef assoc. fish
2	Striped bass resident	25	Littoral forage fish
3	Striped bass migratory	26	Sandbar shark
4	Bluefish YOY	27	Other elasmobranchs
5	Bluefish adult	28	Piscivorous birds
6	Weakfish YOY	29	Non-piscivorous seabirds
7	Weakfish Adult	30	Blue crab YOY
8	Atl. croaker	31	Blue crab adult
9	Black drum	32	Oyster YOY
10	Summer flounder	33	Oyster 1+
11	Menhaden 0-1	34	Soft clam
12	Menhaden adult	35	Hard clam
13	Alewife and herring	36	Ctenophores
14	American eel	37	Sea nettles
15	Catfish	38	Microzooplankton
16	White perch YOY	39	Mesozooplankton
17	White perch adult	40	Other suspension feeders
18	Spot	41	Other in/epi fauna
19	American shad	42	Benthic algae
20	Bay anchovy	43	SAV
21	Other flatfish	44	Phytoplankton
22	Gizzard shad	45	Detritus
23	Reef assoc. fish		

Appendix B. Forcing and Mediation Functions

Habitat factors and habitat suitability models can be used as egg-production forcing functions (for multi-stanza groups) based on habitat factors to influence egg production. In essence this can add variability over time to the fixed biomass production (P/B) parameter for any species or trophic group that has age structure include in the model. The variability can be seasonal or interannual. Seasonal variability based on habitat suitability may result in shifting peaks of egg production and demonstrate how timing of food (i.e., larval fish) can affect predator species within the ecosystem. Previously, this type of match/mismatch hypothesis (*sensu* Cushing 1975) could not be tested in an ecosystem context. Interannual variability in production may account for variability in the biomass of prey species and the predators that rely upon them.

In addition, we use trophic mediation functions to assess indirect effects of habitat changes. A mediation forcing function is one that affects the feeding rate of one trophic group on another. For example, increases in phytoplankton (attributable to nutrient loading) may reduce water clarity resulting in an increased search rate by visual predators on prey.

The combination and interaction of these types of factors may account for considerable variability in the fish biomass time series and contribute significantly to our ability to better manage fish through habitat management.

In EwE, mediation and forcing functions can be applied to affect consumption (Q). Thus EwE can allow for extensive modification of consumption when using Ecosim. The equations (0.3) and (1.4) below demonstrate the potential applications.

$$Q_{ij} = \frac{a_{ij} v_{ij} B_i B_j T_i T_j S_{ij} \dfrac{M_{ij}}{D_j}}{v_{ij} + v_{ij} T_i M_{ij} + a_{ij} M_{ij} B_j S_{ij} \dfrac{T_j}{D_j}} \tag{0.3}$$

where a_{ij} is the rate of effective search for i by j, T_i represents prey relative feeding time, T_j the predator relative feeding time, S_{ij} the user-defined seasonal or long term forcing effects, M_{ij} the mediation forcing effects, and D_j represents effects of handling time as a limit to consumption rate:

$$D_j = \frac{h_j T_j}{1 + \sum_k a_{kj} B_k T_k M_{kj}} \tag{0.4}$$

where hj is the predator handling time.

7. Agenda

Ecosystem Based Management: the Chesapeake and other Systems,
http://www.chesapeakemeetings.com/EBM/

Habitat Suitability Models - State of the Art, Chesapeake Applications

Venue: 2:00 pm March 24 to 5:30 pm March 25, 2009, Baltimore Inner Harbor Marriott, see
http://www.chesapeakemeetings.com/EBM/ for location, registration and lodging information.

Session Leads: D. Secor, UMCES; D. Breitburg, SERC

Session Description: **In a current model of Ecosystem-Based Fisheries Management under development (Dr. Jonathan Kramer, Maryland Sea Grant lead), Quantitative Ecosystem Teams will seek to advance targets and reference points related to (1) Habitat Suitability; (2) Stock Assessment; (3) Foodweb Dynamics; and (4) Socioeconomics. Critical developments and decisions will be needed to effectively implement assessment and reference points for habitat suitability as they pertain to management. The goal of this session is to (1) Present tutorials on several state-of-the-art approaches to habitat suitability modeling; and (2) Begin the work of the Habitat Quantitative Ecosystem team on developing habitat models pertinent to striped bass. All meetings are open for general attendance.**

Tuesday, 24 March, 2:00 – 5:20 pm
2:00-2:25
Dr. Jonathan Kramer, Director, Maryland Sea Grant
Operational Structure for Ecosystem Based Fisheries Management for Chesapeake Bay

2:25-2:50
Dr. Denise Breitburg, Senior Scientist, Smithsonian Environmental Research Center
Habitat as the Core of the Ecosystem Approach for Fisheries Management

2:50-3:30
Dr. David Moe Nelson, Scientist, NOAA National Ocean Service Biogeography Program
Using Habitat Affinity Indices to Assess Value of Estuarine Fish Habitats

3:30-4:00 Break
4:00-4:40
Dr. John Manderson, Scientist, Ecosystem Processes Division, NMFS JJ Howard Lab.
Using Generalized Additive Modeling (GAM) to Develop Single Species Habitat Models.

4:40-5:20
Dr. David Secor, Professor, Univ. MD Center for Environmental Science
Using Ecophysiological Modeling to Develop Single Species Habitat Models.

Wednesday, 25 March, 8:30 – 5:20 pm
8:30-9:10
Dr. Elizabeth North, Assistant Professor, Univ. MD Center for Environmental Science
How does coupling hydrodynamic, larval transport, and demographic models enhance our prediction of habitat suitability?

9:10-9:50
Dr. Rom Lipcius, Professor, Virginia Institute of Marine Science
Modeling Metapopulation Connectivity and Carrying Capacity in Nursery Habitats.

9:50-10:30
Dr. Roman Zajac, Chair, Environmental Science Program, University of New Haven
Applying the MARXAN Design Model to Estuarine Habitat Management.

10:30-11:00 Break
11:00-11:40
Dr. Richard Fulford, Assistant Professor, Univ. S. MS Gulf Coast Research Laboratory
Identifying critical habitat across multiple scales with a landscape modelling approach.

11:40-12:20
Dr. Howard Townsend, Scientist, NOAA Chesapeake Bay Office
Ecopath, Ecosim, and Ecospace: tools for evaluating habitat and foodweb dependencies.

12:30-2:00 Lunch

2:00 – 2:20
Ms. Shannon Green, Maryland Sea Grant Fisheries Ecosystem Coordinator
Introduction of Habitat Quantitative Ecosystem Co-Chair, Team, and Activities

2:20 – 3:30
Dr. Robert Wood, Director, NOAA Cooperative Oxford Laboratory
Dr. Jon Jacobs, Scientist, NOAA Cooperative Oxford Laboratory
Dr. Edward Martino, Scientist, Univ. MD Center for Environmental Science
Dr. Xinsheng Zhang, Scientist, NOAA Cooperative Oxford Laboratory
Habitat Suitability Models for Chesapeake Bay Striped Bass.

3:30 – 4:00 Break

4:00-4:30
Habitat Suitability Models for Chesapeake Bay Striped Bass (continued).

4:30-5:00
Chesapeake Bay Habitat QET Discussion.

8. Additional Contributions

a. *New Foundations for Ecosystem-based Fisheries Management in Chesapeake Bay*

Authors: **Jonathan G. Kramer**, Maryland Sea Grant College Program, University System of Maryland, 4321 Hartwick Rd. Suite 300 College Park, MD 20742

kramer@mdsg.umd.edu

Shannon L. Green, Maryland Sea Grant College Program, University System of Maryland, 4321 Hartwick Rd. Suite 300 College Park, MD 20742

green@mdsg.umd.edu

Management of economically and ecologically important fisheries in Chesapeake Bay has become more complex over the past decade. Competing interests and a suite of stressors that emanate from sources across the watershed have increased pressure on key fish species. Declines in commercially important stocks have focused the attention of policy makers and the public. Together, these factors have led to the call for a new approach to fisheries management — one that moves beyond single species management to a more integrated ecosystem approach. The completion of the landmark fisheries ecosystem plan for Chesapeake Bay provides the foundation for implementing regional ecosystem-based fisheries management. Over the past 18 months, Maryland Sea Grant has worked with a diverse group of partners to develop an organizational structure to support the development of ecosystem based management plans for five species (striped bass, blue crab, menhaden, alosines and oysters). Our approach recognizes the important roles and standing of the state agencies (MD DNR and VMRC) as well as the key fisheries commissions (PRFC and ASMFC) with jurisdiction over Bay species. It is designed to provide decision support tools for fisheries managers as well as to those in non-fisheries sectors whose decisions have major impacts on the sustainability of Bay species and their associated fisheries. These tools will ultimately integrate factors extending across biological, geographic and socioeconomic boundaries. To date, we have implemented a process that will provide strong scientific and technical analyses leading to the development of quantitative reference points for these species. The process recognizes that input from a diverse array of participants and stakeholders is essential as are effective mechanisms to engage key managers across the region. Over the long-term, success will depend on how well we can build and sustain an inclusive structure that yields credible policy recommendations that managers can translate into tangible actions.

b. ***Evolving toward ecosystem-based fisheries management: developing a practical approach towards evaluating environmental pressures on exploited Chesapeake Bay fish populations.***

Authors: **Robert Wood**, Cooperative Oxford Lab (NOAA), 904 S.Morris St. Oxford MD, bob.wood@noaa.gov
E. Martino, Chesapeake Biological Lab (UMCES), , martino@cbl.umces.edu
X. Zjang, Cooperative Oxford Lab, Xinsheng.Zhang@noaa.gov
J. Jacobs, Cooperative Oxford Lab, John.Jacobs@noaa.gov
D. Zotkin, Institute for Advanced Computer Studies, University of Maryland College Park, MD dz@umiacs.umd.edu

The evolution from traditional single species fisheries management to an ecosystem-based approach will be a long road. However, with the declining state of the world's fisheries and coastal ecosystems there appears to be consensus among fisheries managers, scientists, and concerned citizens for the need to begin the transition immediately, acknowledging our incomplete knowledge of fisheries and the factors that influence them, and without a clearly defined path to journey's end. This journey, like any other begins with the first step. A partnership consisting of researchers and managers from the Cooperative Oxford Laboratory (NOAA and MDNR), UMCES, and The Earth System Science Interdisciplinary Center (NOAA-NASA-U.MD) have developed a proof-of-concept prototype decision support tool that is designed to augment results of traditional single-species stock assessments by characterizing, through the use of quantitative models, pressures on fish populations (in this case, the striped bass) that result from interannually varying environmental stressors. We will
present this proof-of-concept prototype for review through a series of short talks describing the quantitative sub-models that underpin this tool and will briefly demonstrate its functionality. The authors hope to obtain comments on the potential usefulness of this approach in advancing our evolution towards ecosystem-based fisheries management in Chesapeake Bay.