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SPECIAL SECTION: SPATIAL ANALYSIS, MAPPING, AND MANAGEMENT OF MARINE FISHERIES

Introduction to a Special Section: Spatial Analysis, Mapping, and Management of Marine Fisheries

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The Magnuson–Stevens Fishery Conservation and Management Act of 1996 mandated that the National Marine Fisheries Service develop guidelines to assist fisheries management councils nationwide in the creation of essential fish habitat (EFH) regulations (NMFS 1996). The amended act (Magnuson–Stevens Fishery Conservation and Management Reauthorization Act of 2006) required regional fishery management councils to set annual catch limits (ACLs) and accountability measures (AM) by 2011 for all managed species to ensure that overfishing would not occur. It also required that the councils create fisheries ecosystem plans to better relate fishery species to their supporting ecosystems through ecosystem-based fisheries management. Unfortunately, due to limitations on funding, resources, and available data, it is difficult to fully implement these requirements.

Most of the marine fisheries data used to support stock assessments and management are collected by fisheries-dependent monitoring (FDM) when the fish are landed. The fishermen report their catches from large statistical zones as either catch per day or catch per trip. In most cases, no associated environmental, habitat, or geographically specific fishing location data are reported. An alternative is to collect georeferenced catch, effort, and environmental data at sea using government-sponsored fishery-independent monitoring (FIM). But FIM surveys are expensive and funding is becoming more difficult to obtain.

While it is obvious to most anglers and commercial fishermen that estuarine and marine species occupy various habitats throughout their life histories, single-species stock assessment models often do not include georeferenced catch-per-unit-effort (CPUE) and associated environmental data. Part of the problem has been that better analytical tools were needed to quantify fish–habitat relationships. Fortunately, there have been large improvements in GIS software, models, statistical approaches, and computing capabilities. The papers presented in this special section demonstrate recent developments in modeling and mapping to better support the spatial management of marine fisheries.

Bryan et al. (2016) describe the feasibility of a regionwide FIM probability survey of coral reef fishes in Puerto Rico and the U.S. Virgin Islands. Four years of underwater visual survey data were collected and used in conjunction with detailed bathymetric maps and bottom habitat maps to develop a probability sampling design. Stratification by depth and habitat produced a more efficient survey design for estimating fish density. These authors found that controlling survey precision over a region required less sampling effort than controlling precision for smaller areas within the larger survey frame. The regional sampling design thus allowed more cost-effective surveys with higher precision. The article shows the importance of defining management objectives prior to the development of FIM surveys.

Harford et al. (2016) studied cross-shelf occupancy probabilities for juvenile groupers in the Florida Keys. A FIM-based diver visual survey was used to quantify the occupancy patterns of Black Grouper *Mycteroperca bonaci* and Red Grouper *Epinephelus morio* below minimum size limits. Logistic regression and site occupancy models were used to quantify predicted occurrence probability with respect to latitude and across depth and vertical relief gradients. Multilevel models revealed variance structures of fish distributions not revealed by fixed-effects models. Both grouper species demonstrated occurrence responses that varied with the regional topographic features of the reef tract.

Rubec et al. (2016b) collected georeferenced FDM catch, effort, and environmental data on commercial shrimp fishing vessels on the West Florida Shelf (WFS) using an electronic logbook and a wireless data logger. Interpolated habitat grids were derived from circulation modeling, benthic mapping, and other data. The CPUE of pink shrimp *Farfantepenaeus duorarum* was related to bottom temperature, bottom current direction, current speed, bottom type, depth, aspect, and vessel monitoring system (VMS) zone. Upwelling onto the WFS occurred from June to December 2004 and downwelling from January to June 2005. A seven-factor habitat suitability model was used to generate distribution maps of adult pink shrimp CPUE monthly for 16 months. Significantly greater mean CPUEs during 2004 occurred in optimum zones, which were associated with upwelling bottom currents of 3 cm/s originating from the northwest. A VMS map depicting zones of high fishing activity was associated with trawlable bottom, while zones of low fishing activity were related to the distribution of hard bottom or mixed hard bottom. The maps produced during the study can support the delineation of EFH and habitat areas of particular concern for pink shrimp on the WFS.

Farmer et al. (2016b) note that although the Gulf of Mexico Fishery Management Council (GMFMC) managed 42 finfish stocks under the Reef Fish Fishery Management Plan, stock assessments only existed for 10 species. One approach for data-limited species would be to group them into stock complexes with a single ACL. This was evaluated using both FDM and FIM data from the Gulf of Mexico. Multivariate statistical analysis revealed several consistent assemblages among reef fish species. The study also considered the geographic and depth distribution of each species, life history characteristics, and exploitation patterns and vulnerabilities. Maps were produced depicting the spatial distributions of six shallow-water snapper species, six midwater snapper/triggerfish species, and four species of jacks. The clustering of shallow-water snappers was reasonably tight. Clustering the rare snapper species was done primarily through nodal analysis and the use of a weighted mean cluster association index. The results were used to provide guidance to the GMFMC in setting ACLs for stocks and stock complexes in their 2011 Comprehensive ACL/AM Amendment.

Farmer et al. (2016a) evaluated alternatives to a winter closure of pot gear in relation to projected impacts on the catch of Black Sea Bass *Centropristis striata* and the relative risk of entanglement for North Atlantic right whales *Eubalaena glacialis*. Different spatial and temporal area closures were evaluated in relation to ACLs using overlays of seasonal Black Sea Bass pot gear effort models (based on captains' logbooks) and North Atlantic right whale population distribution models (based on sightings per unit effort data). The South Atlantic Fishery Management Council considered 12 alternatives. The preferred alternative was projected to result in a relatively low risk of entanglement for North Atlantic right whales off North Carolina, South Carolina, and the east coast of Florida. This framework demonstrates the use of temporally dynamic spatial overlays in assessing the impacts of time–area closures with multiple objectives.

Froeschke and Froeschke (2016) developed a two-stage boosted regression tree (delta-BRT) model to characterize the distribution of Southern Flounder *Paralichthys lethostigma* in Texas estuaries at varying population sizes. Gill-net data collected by FIM sampling from 1977 to 2012 were analyzed using a model of this type to correlate distribution with environmental conditions and seasonal or long-term changes in abundance. Depth, temperature, distance from tidal inlets, and salinity were the primary environmental factors used to predict the spatial distribution and abundance of Southern Flounder. Models were fit using cross validation and variance was estimated using nonparametric bootstrapping. The mapped results showed a coastwide decline in abundance from 1980–1984 to 2005–2009, but the magnitude of the decline varied across the study area, suggesting that there were disproportionate changes in abundance. The greatest declines were observed in the southernmost estuaries (upper and lower Laguna Madre). Notable declines were also evident in Baffin Bay during the October and November spawning period. South Texas estuaries support the greatest proportion of age-2 and older Southern Flounder, and this was the most variable region when periods of historically high and low abundance were compared. Analytical tools such as delta-BRT are now available to support the spatial management of marine–estuarine species.

Rubec et al. (2016a) developed spatial models for 87 species life stages in Tampa Bay capable of dealing with FIM sampling data with an excess of zero catches. An analysis of juvenile pink shrimp summer data is presented as an example of the methods applied. Environmental data gathered from 1998 to 2008 were interpolated to produce seasonal habitat grids for temperature, salinity, and dissolved oxygen and annual grids for depth and bottom type. Seasonal habitat suitability models were developed using the gamlss package in R. The full model selected either a delta-gamma generalized additive model (GAM) or a delta-beta GAM. The best reduced model was identified based on the lowest Akaike information criterion. The predicted CPUE grid (number/m^2) created can be used to estimate population numbers either across the estuary or within selected areas. The modeling approach is statistically rigorous and can support fisheries management through the delineation of EFH or habitat areas of particular concern and the creation of fisheries ecosystem plans in support of ecosystem-based fisheries management. It also can be used to support oil spill response and natural resource damage assessment. The population estimates could be used to support setting ACLs.

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