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Modeling the spatial distribution of commercially important reef fishes on the West Florida Shelf

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ABSTRACT

Understanding the spatial distribution of a species is an important precondition to successfully managing marine populations. For reef fishes, this is of particular importance due to the patchy nature of reef communities. This study estimated the spatial distribution of five reef fish species on the West Florida Shelf: gag grouper (*Mycteroperca microlepis*), mutton snapper (*Lutjanus analis)*, red grouper (*Epinephelus morio*), red snapper (*Lutjanus campechanus*), and vermilion snapper (*Rhomboplites aurorubens*). Estimation was done by combining large-scale fishery-dependent catch per unit of fishing effort with small scale fishery-independent video survey observation. Catch per unit of fishing effort was obtained from vessel logbook data while video observations of reef fish presence–absence and relative abundance were made by stratified random sampling on known reef and hard-bottom habitat in the Gulf of Mexico. Relative abundance estimates showed different abundance patterns for the five species depending on depth and geographical area. Variogram modeling suggested that gag grouper, mutton snapper, and red grouper were spatially autocorrelated on reef or hard-bottom habitats at short ranges of between 0.87 and 0.95 km, while red and vermilion snapper were found to be randomly distributed. Range estimates for gag grouper, mutton snapper and red grouper were supported by variograms of depth soundings in the Gulf which produced range estimates of between 1.56 and 6.34 km. Combining the relative estimates of abundance from catch per unit of effort with the spatial autocorrelation parameters from video surveys allowed us to provide stochastic fish abundance estimates at scales of about 2 km^2.

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1. Introduction

The spatial distribution of marine fish populations is important for developing appropriate management strategies such as defining essential fish habitat (Manderson et al., 2002) and establishing marine reserves (Jones, 2002). This is particularly true for reef fish assemblages, which can be characterized on multiple scales, typically occupying various patchy habitats during the course of their life, as well as being subjected to spatially heterogeneous predatory threats and environmental conditions (Sale, 1998). A large amount of information is available describing the spatial ecology of reef fish behavior including observations of feeding (Bullock and Smith, 1991; McCawley and Cowan, 2007), social behavior (Mueller et al., 1994; Lindberg et al., 2006), and reproduction (Coleman et al., 1996; Domeier and Colin, 1997). Reef fish spatial distribution and habitat use have been studied by analyzing fish stomach content, fish maturity state, tagging data, seasonal changes in spatial catch per unit of effort, and behavioral observations in the field (Ciannelli et al., 2008; Pittman and Brown, 2011; Topping and Szedlmayer, 2011). This wide body of information is useful for developing hypotheses about potential mechanisms by which fish are spatially distributed in a particular fashion at a given time.

As fisheries stock assessment and marine resource management moves toward a more holistic ecosystem approach (Link, 2002; Garcia et al., 2003), information that can be used to quantify how reef fish species are spatially distributed will become more necessary. In the absence of this information, many regional planners have historically used maps of "hard-bottom" as a proxy for marine biodiversity or spatial abundance patterns, due to the high correlation between these factors and hard-bottom habitat (DeBlieu et al., 2005; Ferdana et al., 2006). In many cases, however, the absence of this information has forced managers and biologists to ignore space altogether in population modeling and management, by assuming, for example, that all fishes have similar life history parameters throughout their range, and all are equally susceptible to fishing gear. These are poor assumptions because although it is possible to define the parameters that characterize a system at any scale, these parameters may be highly scale dependent. This is particularly

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important for reef fish systems, which are characterized by high variability in time and space (Chesson, 1998).

The spatial pattern of distribution of an organism can be characterized by its numerical abundance in a given location, and the degree to which the abundance in one location is related to other locations. This pattern of spatial relatedness or spatial autocorrelation is often quantified by a statistical tool called the variogram. Spatial autocorrelation measures how dependent or related observations are in geographic space. The variogram reflects the strength and shape of spatial autocorrelation and is an essential tool for mapping and statistically-based interpolation. Given a known abundance and a calculated variogram, it is possible to map the observed spatial distribution of an organism, and create simulated spatial datasets that reflect the abundance and distribution of a resource. These simulated datasets are useful tools for evaluating sampling strategies, bioeconomic modeling, and management strategy evaluation.

The objective of this study is to model the spatial distribution of five reef fish species on the West Florida Shelf in the Gulf of Mexico: gag grouper (*Mycteroperca microlepis*), mutton snapper (*Lutjanus analis)*, red grouper (*Epinephelus morio*), red snapper (*Lutjanus campechanus*), and vermilion snapper (*Rhomboplites aurorubens*). This is done in a two-step process by coupling the estimation of a spatial catch per unit effort (CPUE) index of abundance with a Gaussian random field simulation that uses the variogram parameter estimates (Cressie, 1993) from video survey data. Results of these analyses are contrasted with current knowledge on the ecology and biology of these reef fish species and with the spatial autocorrelation characteristics of reef and hard bottom habitats of the West Florida Shelf. Ultimately, the analysis was conducted to provide a spatial distribution of reef fish abundance to a spatially explicit individual-based bioeconomic model that represents the interaction between fisher behavior and fish population dynamics on the West Florida Shelf.

2. Materials and methods

2.1. Relative fish abundance from catch per unit of fishing effort

The National Marine Fisheries Service (NMFS) Coastal Logbook Program collects data by fishing trip on catch and effort for permit holding commercial fishing vessels in the Gulf of Mexico since 1993. Since the program's inception, participants have reported their spatial location as blocks of longitude and latitude rounded to the nearest degree. These one degree longitude by one degree latitude spatial areas, are referred to as NMFS statistical grids. The Coastal Logbook Program started to collect information on fishing depth starting in 2005. Since depth strata run parallel to the coast in the Gulf of Mexico, depth is spatially correlated to the distance away from the shore and can be used as proxy for distance offshore.

The intersection of NMFS statistical grids with contours of like depths can be used to define smaller spatial areas in the Gulf of Mexico in order to determine more precisely where fishing effort occurred. This more precise definition of space was used to estimate a CPUE index for various spatial partitions of the West Florida Shelf. Three years for which depth was recorded (2005 through 2007) were grouped together into fifteen different combinations of depth and statistical grid partitions, hereafter referred to as depth/area strata. These depth/area strata were defined by the interaction of five 20 m depth strata with the aggregation of NMFS statistical grids into three overall areas: grids 1 and 2, grids 3 through 7, and grids 8 through 10 (Fig. 1). Hereafter, the combination of grids 1 and 2 will be referred to as "southwest Florida," combination of grids 3 through 7 will be referred to as "West Florida", and combination of grids 8 through 10 will be referred to as "Florida pan-handle."

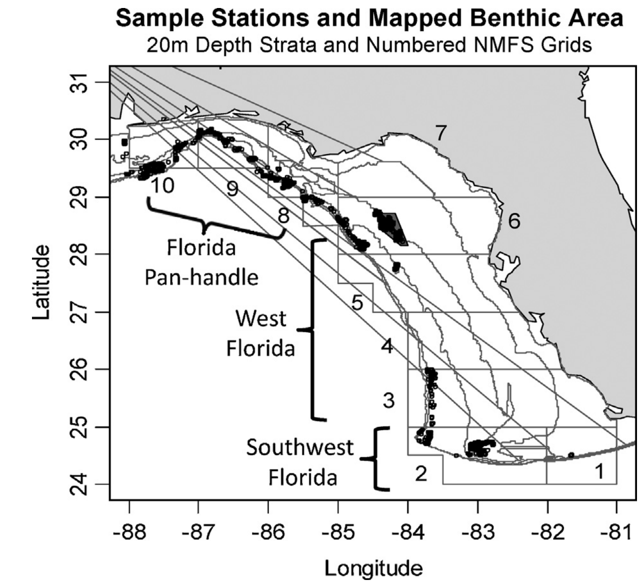

Fig. 1. West Florida Shelf in the Gulf of Mexico showing 20 m depth/area strata, small circles representing SEAMAP reef fish sampling stations, and gray polygon representing the benthic portion of the Gulf that was acoustically sampled.

This grouping was done to provide enough observations to each of the spatial stratifications. Generalized linear models (GLM) were developed using logbook data from these years and the least square means were estimated for each depth/area stratum.

The logbook data contained many zero observations because for a given species in the logbook data, there were a large number of unsuccessful units of effort, meaning strata that contained a positive effort value and zero catch. Analysis of such data using a standard GLM approach could lead to bias in the analysis. As a result, the delta-lognormal method (Pennington, 1983, 1996; Lo et al., 1992) was used to overcome this problem (Stefansson, 1996), where a binomial model was used to model whether the species of interest was encountered on a fishing trip, and a lognormal model was used to model the CPUE using records with positive catches for the species of interest. Results from these two models were then combined to generate an index of relative abundance (Hinton and Maunder, 2004).

CPUE from the commercial handline fleet was used to estimate each index, where catch equaled the kilograms of fish of a given species caught, and effort was a measure of the days away at sea times the number of crew on each vessel. Standardized CPUE for only the handline gear was estimated because this gear type was the most commonly used in the reef fish fishery. This assumed that a standardized index derived from handline data (73% of trips) alone provided an appropriate standardized index for all stocks considered. Other gears that participate in the commercial demeral fishery in the Gulf of Mexico include bottom longline (about 11% of trips), trolling (16% of trips), diving (5% of trips) and other (1% of trips).

2.2. Spatial autocorrelation of fish abundance

The Southeast Area Monitoring and Assessment Program (SEAMAP) is a joint state/federal program which conducts fishery independent surveys throughout the federal waters of the southeastern United States. One component of this program is the offshore reef fish video survey which samples reef fishes on the Gulf of Mexico hard bottom, reef areas, and banks, including ridges and pinnacles found on the continental shelf, shelf edge and slope (Dennis and Bright, 1988; Moe, 1963; Rezak et al., 1985; Smith et al., 1975). The survey uses a four camera array baited with squid, where