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QUANTIFYING HABITAT UTILIZATION PATTERNS OF U.S. CARIBBEAN AND HAWAII REEF FISH TO DEFINE MARINE PROTECTED AREA BOUNDARIES: THE COUPLING OF GIS & ECOLOGY

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INTRODUCTION

NOAA's National Centers for Coastal Ocean Science (NCCOS) - Biogeography Program conducts mapping, research, and monitoring of tropical coral reef ecosystems to support wise management of coastal marine resources (Monaco et al. 2001). A biogeographic approach is utilized to integrate information on the distribution and quality of habitats and associated reef fish to define species affinities for specific habitats (Monaco et al. 2001, Kendall and Monaco 2002). Defining the strength of coupling between species and habitat is facilitated by integrating spatial statistics, ecological models and indices that are visualized in geographical information systems (GIS) (Monaco et al. 1998, Gill et al. 2001). The biogeographic approach enables implementation of a suite of reef fish ecology studies (RFES) that are underway in the US Caribbean and the main eight Hawaiian Islands (MHI). High-resolution digital benthic habitat maps derived from aerial photography and hyperspectral imagery (HSI) have been completed for the US Virgin Islands and Puerto Rico and for 60% of the MHI (Kendall et al. 2001, Coyne et al. 2003). The GIS-based maps are classified to 27 levels of habitats (e.g., seagrass, patch reef) and these habitats are located in cross-shelf zones (e.g., back reef).

Complementary reef fish ecology studies are underway in St. John and St. Croix, USVI and SW Puerto Rico to determine species occurrence, abundance, size, and trophic ecology based on random stratified sampling of habitats delineated on the digital habitat maps. Analogous RFES in the MHI are conducted in marine protected areas (MPA) (e.g., Marine Life Conservation Districts) to define species habitat utilization patterns. Biogeographic products include species distribution maps depicting the probability of encountering a species or groups of species based on their habitat affinities, maps of community metrics (e.g., species richness), and a suite of other spatially-articulated models.

The biogeographic approach enables the coupling of digital benthic habitat maps and species habitat utilization patterns to define biologically relevant MPA boundaries, define the strength of species habitat affinities, and evaluate MPA effectiveness. This capability is used by the US Caribbean Fisheries Management Council to define essential fish habitats, by the National Park Service in characterize US Virgin Islands marine parks and monuments, and by the University of Puerto Rico to define biologically relevant marine protected area boundaries. In the MHI, RFES support Hawaii's Department of Lands and Natural Resources (DLNR) in evaluation of MPA effectiveness based on characterizing the abundance and size of fishes. These, and other fish ecology parameters are compared and contrasted between MPAs under various management strategies (e.g., no harvest of fish, limited harvest).

METHODS

The specific areas where RFES are underway include Buck Island National Monument, just north of St. Croix, US Virgin Islands (USVI), south shore St. John, USVI, in southwestern Puerto Rico, and in Hawaii's marine life conservation districts (e.g., Waikiki, Oahu, Kona, Hawaii, Honolua, West Maui, Manele Bay, Lanai). The RFES rely on integrative mapping and monitoring of coral reef ecosystems to define species habitat utilization patterns (Monaco et al. 2002).

Benthic Habitat Mapping

In 1999, NOAA's National Ocean Service acquired and visually interpreted orthorectified aerial photography for the near-shore waters (nominally 25 meters water depth) of Puerto Rico and the U.S. Virgin Islands. In 2000, both aerial photography and hyperspectral imagery was collected for about 60% of the MHI. This imagery was visually interpreted (nominally 30 meters water depth) to develop benthic habitat maps (e.g. corals, algae, sand) (Coyne et al. 2003). Features visible in the Caribbean and Hawaiian imagery were mapped directly into a geographic information system (GIS). Visual interpretation of the imagery was guided by a hierarchical classification scheme that defines and delineates benthic polygon types based on insular-shelf *zones* and habitat *structure*s of the benthic community. Zones describe the insular-shelf location (e.g., back reef or fore reef), whereas habitat structure includes the cover type (reef, mangrove, submerged vegetation, unconsolidated sediments, etc.) of the benthic community (Kendall et al. 2001, Coyne et al. 2003).

Reef Fish Surveys

The digital habitat maps are used to stratify study areas into distinct zone-structure combinations, or strata. The RFES within strata are determined from the digital habitat maps of the southwestern shore of Puerto Rico, Buck Island, USVI, and the south shore of St. John, USVI (Kendall et al. 2001). A similar stratification process is used in the MHI. In both the Caribbean and Hawaii, SCUBA divers estimate fish abundance, density, and size at each sample location, and conduct micro-scale measurements of benthic habitat variables, such as percent cover of abiotic and biotic substrates, depth, and rugosity. The abundance and size of fishes is estimated independently at each site along a 25 X 4 m (Caribbean) or 25 x 5 m (Hawaii) visual belt transect. The belt-transect diver swims 25m on a random compass heading at a constant speed for 15 minutes. The diver identifies to the lowest possible taxon, counts, and estimates the size of all fishes observed within 2m (Caribbean) or 2.5m (Hawaii) on either side of a centerline (100 m^2 or 125 m^2 total area).

RESULTS

The Biogeography Program's reef fish ecology studies are most advanced in the Caribbean and the majority of the results are in press in Christensen et al. (*In Press*). This study demonstrates the use of the biogeographic process to define species habitat utilization patterns in southwestern Puerto Rico. Analyses common between both the Caribbean and Hawaii RFES include determining the size and number of fish and the calculation of mean species density, sighting frequency, richness, and diversity within each zone, structure, and stratum (zone-structure combination).

Example Caribbean Results

Hierarchical clustering of species presence (overlap) indicates several patterns in the composition of fish assemblages among Puerto Rico habitat strata. Species richness is greatest among reef sites, followed by mangrove sites, and submerged vegetation sites. There is a distinct grouping of sites by habitat, indicating that species composition is more similar among sites within the same structure than among zones. Reef sites have significantly higher mean species diversity than submerged aquatic vegetation (SAV) sites. Species richness at reef sites is significantly higher than in SAV sites, but there is no difference among sites in reef and mangrove structures is not.

Many forces acting in concert shape the assemblage structure of a reef fish community. At the scale of a single patch-reef, a multitude of ecological forces such as localized predation and competition may be the primary factors in shaping post-settlement communities. By increasing study scale to tens of kilometers, the relative effects of habitat zone and structure on community assemblages become apparent. Habitat structure is the overriding factor shaping southwestern Puerto Rico reef fish assemblages (Christensen et al. *In Press*). Values of both diversity and richness are highest on the reef structure and lowest in SAV. The lower diversity in mangroves and vegetation is accounted for by the dominance of a few species in each habitat.

The abundance and distribution of single families, species, and even life stages, show strong spatial correlations with habitat type. Thus, a mosaic of habitats should be preserved to support reef fish populations. Exclusion of any habitat type would most certainly impose a "bottleneck" at which population maintenance and growth potential might be significantly reduced (Christensen et al. *In Press*).

Preliminary Hawaii Results

The RFES are underway in Hawaii DLNR's marine life conservation districts (MLCDs) and fishery management areas (FMAs) of the MHI. The use of the digital benthic habitat maps is a powerful tool to examine the efficacy of MPAs using a spatially explicit, stratified random sampling design. Analysis of benthic cover validates the *a priori* classification of habitat types and provides justification for using these habitat strata to conduct stratified random sampling and analyses of fish habitat utilization patterns. Hardbottom habitats (colonized and uncolonized) had more species, more individuals, and higher biomass than the macroalgae (SAV) habitat types and the sandy areas, which had few, if any fish present on surveys.

Within the Waikiki study area, number of species, number of individuals, and biomass are higher in the Waikiki MLCD, regardless of habitat type. Comparisons within habitat types show the MLCD has higher values for all fish assemblage characteristics, followed by the FMA with the open access areas (i.e. fishing allowed) having the lowest values for most assemblage characteristics.

For the West Maui study area, fish biomass is significantly higher in the Honolua-Mokule‘ia MLCD compared to open access areas for all habitat types (colonized hard bottom, uncolonized hard bottom, and soft sediments). The proportion of piscivorous fishes is nearly twice as high in the Honolua-Mokule‘ia MLCD compared with areas open to fishing for both colonized and uncolonized hardbottom habitats.

In most cases, when compared within habitats, fish assemblage characteristics are higher in West Maui compared with Waikiki. Comparisons of fish assemblages between West Maui and Waikiki show the greatest number of species, greatest number of individuals and highest biomass occurring in the colonized hardbottom habitats of the Honolua-Mokule‘ia MLCD.

MANAGEMENT IMPLICATIONS

The reef fish ecology studies of NOAA/NCCOS’s Biogeography Program illustrate the need for a deliberate analysis of reef fish distribution among all habitats available in the seascape to develop better informed resource management solutions. In the past, studies have often focused on reef sites as they generally support higher biological diversity than do SAV, mangrove, or unconsolidated sediment habitats. The RFES provide a spatially-explicit approach of sufficient scale to address the issues of MPAs and identifying essential fish habitats (EFH).

It is critical to include a component of habitat connectivity in the development of any management strategy. The Biogeography Program’s RFES at Buck Island Reef National Monument, St. Croix found that juvenile French grunts when occupying reef sites, are primarily found if soft bottom foraging habitats are within 300 meters of the sample site (Kendall et al. *In Press*). This provides further evidence of significant habitat connectivity, and that sampling protocols that explicitly include a spatial “effect” are necessary to explore and develop sound strategies for MPA delineation.

A logical progression of events leading to the definition of a MPA would first include an assessment of the function of available habitats relative to managed fishery resources. The resulting demonstration of areas of importance would then be used to develop criteria for boundary delineation. A georectified mesoscale benthic habitat map provides a unique opportunity to approach pertinent community-level and autecological issues that require examination of large regions. The concept of EFH and the principles behind developing MPAs necessitate examination of greater spatial ranges than those at which typical scientific experiments are conducted. Rather than focusing on a single patch-reef or embayment, the biogeographic approach enables stratification of hundreds of km^2 of shelf waters into broad and biologically-significant categories of zone and structure. The approach aids in defining the forces that shape large-scale assemblage structure, and address specific questions about particular families of economically and ecologically important species at the scale at which management decisions are typically implemented. By implementation of the biogeographic approach using GIS technology, the capability to define and evaluate MPAs can be developed based on robust statistical analysis of habitat and species distributions, species abundance, and ecological function of habitats.

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