Scaling Our Understanding of Habitat Selection by Coral Reef Fishery Species

RONALD L. HILL[1*†], RICHARD S. APPELDOORN[1], BRIAN R. MURPHY[2], CONRAD W. RECKSIEK[2], and MARTHA PRADA[1]

[1] *Dept. of Marine Sciences*
University of Puerto Rico
Mayagüez, Puerto Rico 00681-9013
[2] *Deptartment of Fisheries, Animal and Veterinary Science*
University of Rhode Island
Kingston, RI 02881 USA
[†] *Current Address: NOAA/NMFS*
4700 Ave. U,
Galveston, Texas 77551 USA

ABSTRACT

Our ability to quantify habitat use by a managed species improves our capabilities to discern the species' biological needs, predict effects of environmental changes, test hypotheses concerning ecological relationships, or support protection of key habitats. The white grunt, *Haemulon plumieri*, is an important component of commercial, recreational and artisanal fisheries in the Caribbean and Gulf of Mexico. Broad scale surveys for white grunt in southwestern Puerto Rico, identified biotic and abiotic characteristics of coral reefs and reef associated habitats reflective of size-specific habitat requirements, producing a qualitative picture of habitat selections. Subsequent side scan sonar, transect sampling, and GIS mapping of the same area defined the full extent of positive and negative associations for the white grunt as well as other species. Comparisons of the qualitative and quantitative methods can define future directions for evaluating habitat use by coral reef species and selecting appropriate scales for ecological experimentation.

RESUMEN

Nuestra habilidad de cuantificar el uso de hábitat de una especie controlada mejora nuestra habilidad de percibir los requerimientos biológicos de la especie, pronosticar los efectos de los cambios del hábitat, justificar la protección de zonas clave, o probar hipótesis de procesos ecológicos. El roncador (*Haemulon plumieri*) es un componente de importancia comercial, de forma recreativa y artesanal de la pesquería del Caribe y el Golfo de Méjico. Estudios a grande escala del roncador, *H. plumieri*, en el sureste de Puerto Rico, identifican características bióticas y abióticas de los arrecifes de corales y hábitats asociados con los arrecifes que reflejan los requerimientos de hábitats de un tamaño concreto, produciendo una idea cualitativa de la selección de hábitats. Con el uso del sonar, muestras de transectos, y mapas de GIS de la misma zona, definieron la extensión de asociaciones positivas y negativas para el roncador y otras especies. Las comparaciones de métodos cuantitativos y cualitativos pueden definir la dirección futura de evaluación de hábitat que las especies de arrecifes usan y la selección de escalas apropiadas para la experimentación ecológica.

KEY WORDS: *Haemulon*, marine habitats, coral reefs, marine reserves

INTRODUCTION

Coral reef organisms exist in environments that are spatially structured from global to local scales. At the largest scale, coral reefs exist where environmental conditions are appropriate for the diverse communities of interacting organisms that produce and maintain reef structures. Locally, physiographic zonation (a shift in species, assemblages, or communities in response to changes in physical properties of the environment) was one of the early focuses of ecologists in their investigations of coral reefs (Hiatt and Strasburg 1960) and has been documented in the heterogeneous distributions of stony corals (Done 1982, Glynn 1976), reef fishes (Williams 1982, Williams and Hatcher 1983, McGehee 1994), and soft corals (Dinesen 1983).

The effects of habitat heterogeneity or patchiness on reef fish distributions depend largely on the species' life history traits and may occur at settlement or after. Some strongly site-attached species (e.g., some blenniids) are restricted to particular zones of the reef throughout their entire life cycle (Clarke 1996) while many other reef fishes (e.g., acanthurids, jacks, and grunts) have home ranges that encompass different reef zones and/or adjacent habitats (Ehrlich 1975, Ogden 1977, Sale 1980). A number of reef species, utilize a succession of habitats as their resource needs change ontogenetically (Lirman 1994, Eggleston 1995, Appeldoorn et al. 1997, Lindeman 1997, Nagelkerken et al. 2000).

The effects of habitat distribution on fish abundances and distributions are of practical importance for fishery managers, particularly in tropical reef fisheries. Conventional fishery management methods are data intensive; in most tropical settings the infrastructure for data collection is lacking (Pauly 1979). Fishery management can be augmented through enhanced conservation of essential fish habitat (EFH) and the establishment of marine reserves (Roberts and Polunin 1991, Bohnsack 1996, 1998). EFH is defined in the Magnuson-Stevens Fishery Conservation and Management Act (1996) as *those waters and substrate necessary to fish for feeding breeding, spawning and growth to maturity* (16 U.S.C. §§1801 *et seq*). Under US federal fishery management regulations, EFH must be described and identified for all managed species; and, fishery management councils and the National Marine Fisheries Service must conserve EFH. Marine reserves (no-take zones) can effectively increase abundance and size of heavily fished species in tropical settings (Roberts and Polunin 1993, Russ and Alcala 1996). They are, in theory, simple to develop and enforce. The effectiveness of management, as evidenced by changes in population or community structures, can be monitored non-destructively using an appropriate permutation of the various visual census methods available (PDT 1990, Bohnsack 1996, Appeldoorn 1998). Knowledge of habitat use and dependence can contribute to the design and placement of effective marine reserves (Appeldoorn et al.1997, Recksiek and Appeldoorn 1998, Chiappone and Sullivan Sealey 2000) and is necessary to meet the EFH mandates of US federal fishery regulations..

This paper compares three complementary approaches for assessing habitat use by reef fishery species. The first used broad scale surveys of nearshore habitats to locate common haemulid habitats and identify characteristics that distinguish juvenile white grunt habitats from those of other species. The second used a stratified transect sampling procedure and *in situ* habitat mapping to document use of habitats by all species. The third used systematic benthic mapping and habitat characterization produced by side scan sonar. The objective in comparing the approaches is to delineate the range of information and advantage of each approach and suggests ways they complement one another in assessing habitat use by fish.

METHODS

Site Description

This research was conducted offshore of La Parguera on the southwest coast of Puerto Rico. The coastal waters of La Parguera support artisanal and recreational fisheries that catch resident and transient reef fish, conch, and spiny lobster from coral reefs and reef-associated habitats. The coastline surrounding La Parguera is, or was historically, lined with mangroves and is protected by a series of coral reef platforms (Figure 1).

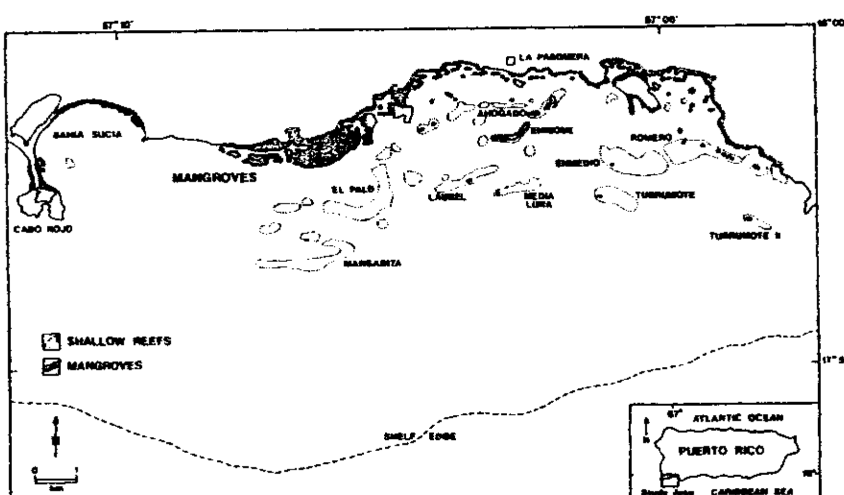

Figure 1. Study area: La Parguera coral reef ecosystem showing mangrove-lined shoreline and series of reef lines extending offshore.

An inner platform of intermittent emergent or near emergent reefs borders and parallels the shoreline. Several reef crests have been colonized by red mangroves (*Rhizophora mangle*) providing additional fish habitat in the prop roots. Backreef areas are typically sand bottom with mixed seagrasses and small patch reefs, soft coral fields, and/or isolated hard corals. A second, mid-shelf line of reefs, about 1 km offshore, and the outer-shelf reefs, about 3 km offshore (e.g., Media Luna and Turrumote), both have a mix of habitats similar to the inner reef line. A fourth line of submerged reefs occurs at the edge of the insular shelf, up to 8 km offshore. These shelf-edge reefs rise to a depth of approximately 15 - 20 m below the surface, mainly with typical spur and groove configuration. Since they are not emergent, they do not offer the same sheltering effects as the three inshore reef lines. Deeper areas (~20 - 40 m) between the shelf-edge, outer, and inner reefs offer additional habitats (e.g., algal flats, deep patch reefs) not found in the shallower strata.

Habitat Surveys

Single-taxa search — The taxa-based approach focused on assessing habitat use by the white grunt, *Haemulon plumieri* and other sympatric haemulid species (Hill 2001). The goal was to locate schooling sites and identify habitat characteristics, specific to particular species or size classes of grunts, that would reliably predict haemulid schooling sites. Shallow water habitats off La Parguera were surveyed from 1993 to 1996. Sites from Cayo Romero (east of La Parguera) to Isla Margarita (the westernmost reef platform off La Parguera) were surveyed (Figure 1) while snorkeling or SCUBA diving. The surveys encompassed lengthy swims searching all habitats, including seagrass beds, sand areas, and mangrove prop roots and circumnavigating coral reefs. Surveys were conducted opportunistically across all four reef lines. Locations and physical characteristics (i.e., depth, location, and type) of schooling sites, total numbers in schools of haemulids, species composition, and estimates of range and mean size were recorded on underwater paper or slates. More detailed methods and results are presented by Hill (2001).

Cross-shelf Habitat Matrix (Stratified Habitat-Faunal Sampling) — Local knowledge, including information gathered during the single-taxa searches, was used to develop a matrix, based on distance from shore, depth, wind and wave energy, and habitat types, to organize habitat-species associations. The cross-shelf habitat (CSH) classification system, based on the principles of Lindeman (1997) but modified to fit the local conditions, was reported in Appeldoorn et al (2001b). The shelf was divided into three primary physiographic regimes (Inner Shelf, Intermediate Shelf and Outer Shelf) and each regime was partitioned into geomorphic zones (e.g., Windward Shallow, Channel Axis, etc.) (Figure 2). Twenty habitat types were identified within four categories, using the terminology of Lindeman (1997): 1) trees, 2) grasses & algae, 3) sediments, and 4) hardbottom & invertebrates. The habitat types were cross-referenced to the geomorphic zones, forming a matrix for graphic depiction, data organization and analysis.

Representative physiographic zones were selected for replicate sampling. Transects (24 x 4 m) were marked by a measuring tape and contiguous 1 m^2 quadrats were mapped *in situ*. Maps identified dominant habitat type (from the CSH list) of each quadrat and structural features. Mapping was followed by visual census of selected fish species, chosen for their fishery or ecological importance. These fish data were spatially defined by points (single fish), polygons (fish schools), or lines (roaming species). All mapping and census data were transferred to a geographical information system (GIS) for data management and analysis. The GIS provides for spatial analysis of habitats and faunal assemblages. More detailed methods are contained in Recksiek et al. (2001) and Appeldoorn et al. (2001b).

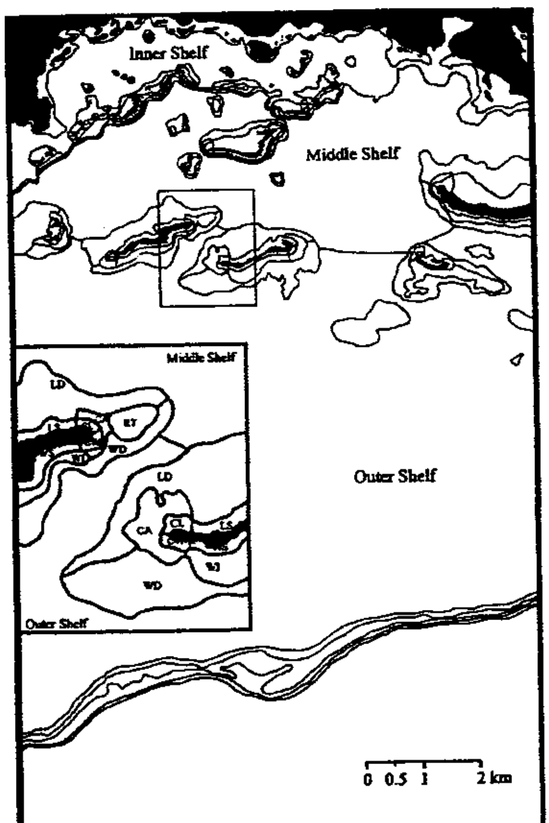

Figure 2. Cross-shelf Habitat (CSH) Matrix Space Example. Physiographic regimes (e.g., Middle Shelf, Outer Shelf) are defined by cross-shelf position, e.g., distance from shore. Geomorphic zones (e.g., LD = Leeward Deep; CA = Channel Axis) combine geomorphic structure, depth, position relative to wind and wave energies, and other morphological differences. Habitats, as sampled, are defined within geomorphic zones (modified from Appeldoorn et al. 2001b)

Benthic Mapping and Systematic Sampling — A 22-ft. fiberglass boat with a bow cabin was used to deploy the Side Scan Sonar (SSS) and navigation system (Details of the SSS equipment set-up can be found in Appeldoorn et al. 2001a). A 300-kHz transducer (fish) was towed 3-5 m off the bottom over a 100-m wide swath. Connections between a differentially-corrected Geographic Positioning System (GPS) and the SSS image acquisition software provided geo-referencing for the SSS images as they were collected. All data were recorded to hard disk.

In post-processing image analysis, filters were used to improve the quality of single images (Appeldoorn et al. 2001a). Single images were merged to form large mosaics using GIS software. Generated mosaics were visually interpreted based on variations in the sonar echo return signals; and, polygons, with similar echo return texture, were defined. Polygons were then related to habitat types based on interpreter experience and groundtruthing information. Groundtruthing, using divers or a tethered black and white underwater video camera, was used to check the accuracy of the interpretation and to revise the delineation of the different polygons on the mosaic. Ground truthing by divers was particularly important to get a general perception of habitat areas. Mosaics joined into GIS maps provide a well organized means to extrapolate transect, point counts, or gear sampling across the mapped area.

RESULTS AND DISCUSSION

Studies have shown that in spite of a broad appearance of overlap in general habitat use (e.g., seagrass bed, type of reef) there is a great deal of specificity demonstrated by the distributions of coral reef fishes (Sweatman 1983, Shulman 1985, Booth 1992, Buchheim and Hixon 1992, Eggleston 1995, Appeldoorn et al. 1997, Hill 2001). While each of the three methods described here offers a different framework for sampling and different levels of qualitative to quantitative investigation, the methods are complementary and can lead to the same observations. The interpretations or analyses of the findings however are quite different.

Single-taxa Search

Using the single-taxa search approach, schools of grunts were found throughout the La Parguera reef ecosystem in almost all habitat types (Hill 2001). The only habitat types consistently lacking in grunts were muddy bay bottom areas, such as Bahia Fosforescente and other mangrove-lined bays, where no grunts were found. Eight species of haemulids were found (*Haemulon aurolineatum*, *H. carbonarium*, *H. chrysargyreum*, *H. flavolineatum*, *H. macrostomum*, *H. parra*, *H. plumieri*, *H. sciurus*). Generally schools were mixed, containing more than one haemulid species; although, usually one species was numerically dominant. In many cases, species with similar appearances (e.g., goat fish or juvenile snappers) were mixed into the grunt schools. Schools were generally well matched in appearance and size of individuals. Dominance in the schools could generally be linked to different habitat types or characteristics.

A number of spatial patterns were observed. For example, schools of juvenile grunts, while prevalent on the intermediate and outer reefs, are essentially lacking on the outermost, shelf-edge reefs. On these deeper offshore reefs, adults of several haemulid species (e.g., white, French, bluestriped, Spanish) can be found, mostly as solitary individuals; although, white grunts are sometimes in pairs or small groups. Adult white, French, and bluestriped grunts are also common on the deeper forereefs of the mid-shelf and inner-shelf reefs in areas with high relief. On the submerged mid-shelf and inner reef lines (e.g., Ahogado), white grunt adults are frequently seen at the top of the forereef, but upon approach, they flee down the reef face to the base of the reef (Hill 2001).

The distribution of white grunts and sympatric species around the inner shelf reef of San Cristobál illustrates differences in species' distributions. Subadult and adult white, French and bluestriped grunts are frequently found on the forereef of San Cristobál. Schools of medium sized juveniles can also be found, typically located at the ends of the forereef near the channels running along each end of the reef. In the backreef, a sand lagoon with scattered hard and soft coral colonies is the dominant habitat. Dense *Acropora cervicornis* thickets mark the northern boundary of the lagoon and a medium to high relief reef line drops into a deeper sand channel on the southern side separating the lagoon from an adjacent reef. Within the lagoon, small coral colonies are scattered; these structures are frequently populated with small-sized juvenile grunts. They are typically dominated by French grunts with fewer white grunts (Figure 3). Within the *A. cervicornis* thickets, schools of larger juveniles, dominated by white grunts are found. In the deeper sand channel colonies of *A. cervicornis* are common; but, these colonies typically support schools of small-sized tomtates mixed with French grunts. Although these habitats might all be called "*A. cervicornis* in sand," the differences in depth (lagoon vs channel) and branch density or water flow (single colonies vs thickets) seem to be reflected in their use by different species and different size classes. The differences in the size frequency distributions are consistent through time and can be seen across the La Parguera coral reef ecosystem in similar habitats.

CSH/Stratified Transect Approach

At this time 67 transects have been completed, distributed in 7 geomorphic zones and 18 different habitat types. A total of 13,582 individuals and 40 taxa (36 identified to species) belonging to 10 families were censussed (Recksiek, et al. 2001). Three taxa comprised 65% of the total fish abundance among all cross-shelf habitats combined: striped parrotfish, French grunt and redtail/yellowtail parrotfish (the later two grouped as indistinguishable). Seven haemulid species were identified. *H. aurolineatum*, recorded during the single-taxa searches, has not been encountered during the transect surveys. Size estimates (Total Length) ranged from one (1) cm to thirty (30) cm covering the range from early juveniles to adults. The French grunt (*H. flavolineatum*) size class distributions and densities are plotted in a subset of cross-shelf habitats for comparison with other sampling methods (Figure 4).

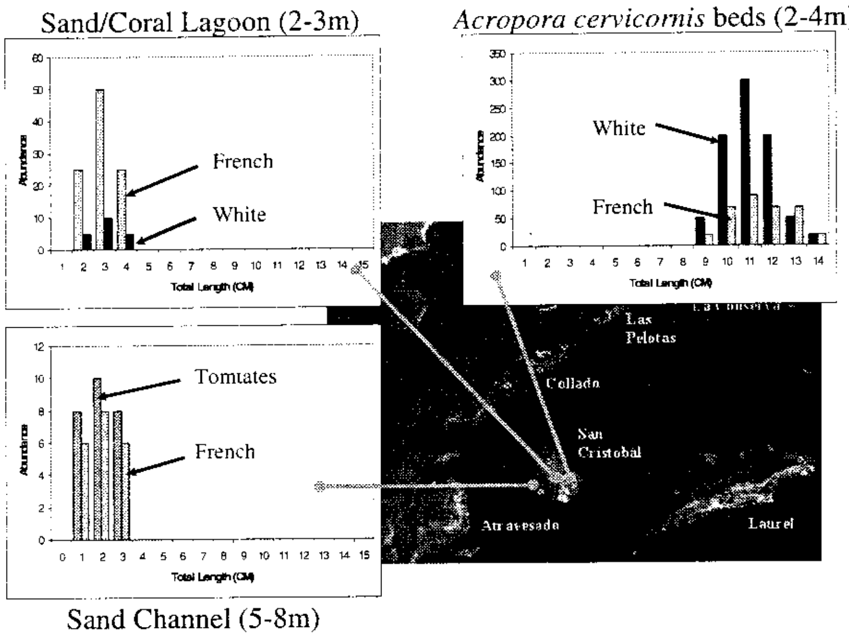

Figure 3. Grunt schools recorded at San Cristobál reef: in the main part of the sand lagoon (Sand/Coral Lagoon), in the *A. cervicornis* thickets on the north of the lagoon (*Acropora cervicornis* beds), and in the *A. cervicornis* colonies found in the channel to the south of the lagoon (Sand Channel). Species dominance and size frequencies vary with depth, position in lagoon, and density of coral colonies.

Using this stratified sampling system, it can be demonstrated that species' densities within habitat types vary according to cross-shelf position (Recksiek et al. 2001) and that densities of different life stages vary according to structural habitat types (Figure 4). Early juvenile French grunt were recorded in seagrass and mangrove habitats in three different strata: Intermediate Shelf-Leeward Shallow, Inner Shelf-Leeward Shallow, and Inner Shelf-Windward Inshore. However, mid-sized juveniles and adults were virtually absent from seagrass habitats and noticeably rarer in mangroves. The exception being higher densities of medium sized juveniles in Inner Shelf-Leeward Shallow mangrove habitats (Figure 4b). Adults were found only in shallow coral reef habitats in the Inner Shelf-Windward Intermediate and Inner Shelf-Windward Shallow strata (Figure 4c). Such findings lend correlative support to previous studies indicating ontogenetic migrations and habitat shifts in tropical grunts documented by Appeldoorn et al. (1997) and Brothers and MacFarland (1981).

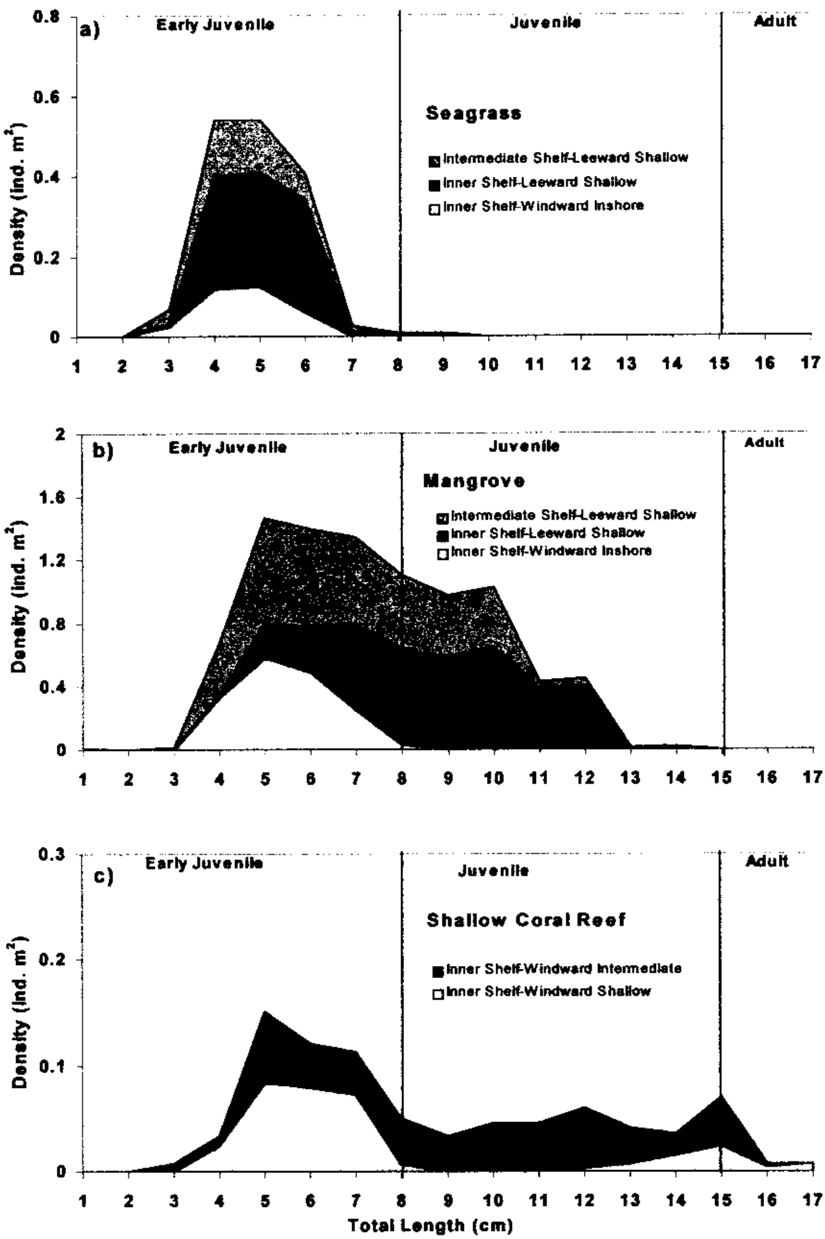

Figure 4. Size distributions of French grunts sampled by CSH-stratified mapped transect method. Habitats located in different cross-shelf strata (defined by physiographic regimes-geomorphic zones) are shown. Differences among habitats and within habitats among strata are evident.

Stratified sampling, based on the CSH matrix, using mapped transects of defined areas allows additional analysis and extrapolations not justified with the single-taxa search and other more qualitative sampling methods. Species diversity measures can be calculated for multiscalar levels (Murphy, MS thesis manuscript), as can habitat diversity measures (Appeldoorn et al. 2001b). Both measures provide ecological information about the system and provide insights into the validity of CSH matrix groupings. Mapped transects and species densities permit fine-scale analysis of habitat-species relationships and more reliable extrapolations to estimate total population sizes within the defined system. All fish species and habitat data is being analyzed for associations, primarily using multidimensional scaling analysis (Murphy manuscript). Future plans include analysis of habitat features for associations of species with particular aspects of the habitats and additional tests of the validity of the habitat matrices and classifications.

SSS Benthic Mapping

The entire area of La Parguera, approximately 442 Nm of SSS transect lines, has been surveyed. The mosaics, 19 in all, are in final processing. Habitat types have been differentiated based on the strength of signal return which varies according to benthic characteristics. Habitat types, including reef platforms, patch reefs, isolated coral heads, mixed coral-gorgonian areas, sandy bottoms, seagrass beds, and algal bottoms, have been mapped and quantified (Appeldoorn et al. 2001a). Reflection sensitivities and resolutions as fine as 10 cm provide sufficient detail to distinguish different densities of algae, ripple marks in sandy bottoms, and fine from coarse sediments. A number of uncharted patch reefs with interesting characteristics, i.e., algal halos, have been located in zones that were previously believed to be soft sand or mud bottoms covered with algae. The identification of unknown habitats and features will allow modification and improvement of the CSH matrix and enable more accurate stratification of sampling effort. A number of sampling efforts are underway that make use of the detailed SSS benthic mapping. Sampling of fish species on previously unknown patch reefs are being compared with similar areas of continuous reef habitat (Prada, PhD dissertation manuscript). The SSS mapping is being used as the basis for spatially-based trophic modeling, focused sampling of species that move diurnally between habitats, and to analyze the spatial distribution of fishing traps. Future studies will find the SSS habitat mapping invaluable for sampling design. A complete mapping of habitats will also allow confident extrapolation from site-specific samples to system-wide estimations of fish populations and length-frequency distributions.

CONCLUSIONS

The single-taxa search method is simple and inexpensive but it is time-consuming and requires intuitive interpretation of field data. It requires accurate understanding of spatial differences in habitats (leeward vs windward vs channel) and relies on assumptions regarding the important characteristics of habitats. In many cases, its findings of correlations between species and locations or habitats should be considered hypotheses rather than conclusions until they have been tested. Extensive field notes, often recording characteristics and findings that may, at the time, seem of secondary importance, are critical to the ability to reinterpret samples if future conflicts arise.

The CSH-based stratified sampling with *in situ* mapping provides a more organized framework for sampling habitats and fish. It provides a more robust sampling of habitat features and characteristics to link with fish distributions. Density estimates are more reliable for interpretation of habitat importance than abundance or presence/absence data. The data can be analyzed by a number of statistical tests, providing greater support for hypothesized ecological associations. It samples the complete suite of species encountered so analysis of data provides more information needed by fishery managers. The method requires some prior knowledge of the ecosystem and accurate interpretation of the influence of cross shelf position and geomorphology. It requires slightly more advanced technologies (GPS, GIS) and is more time consuming than the single-taxa search method for covering the same areas.

The SSS benthic mapping is presented here as a demonstration of a more complete but more complex method for gathering species-habitat association data. It provides a clearly quantitative means to identify sampling strata and a well-defined framework for gathering, analyzing, interpreting, and extrapolating data. It is more expensive and time-consuming than the other two techniques presented here but it has also pointed out some gaps in our knowledge of habitats in the Parguera system (previously unidentified patch reefs).

While these three sampling methods have been presented as alternatives, it has also been stressed that in this case they were used sequentially, in complementary fashion. The single-taxa search was a means to develop familiarity with the entire ecosystem, quickly learn of habitat types used by different species and life stages, and capture data on species and habitat distributions. This information went into the development of the CSH matrix for La Parguera. The CSH-based transects and mapping of habitat features in fish sampling transects allowed more accurate interpretation of linkages between habitats/habitat features and densities of different fish species and life stages, generating hypotheses for future testing. The SSS benthic mapping provided additional insight into unknown habitats that can be used to correct the CSH matrix and reassess the findings from some benthic sampling. It forms the most complete framework for further ecological sampling. Any of these techniques can be used to document habitat use by managed species, contributing to the data necessary to describe and identify EFH and to identify areas appropriate for marine reserve designations. The choice of methods for future research depends on the goals of the research and on the resources available.

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