Integrating Fish Fauna and Habitat Assessments: A Fundamental Step in Developing Fishery Reserve Design Criteria

CONRAD W. RECKSIEK[1], BRIAN R. MURPHY[1],
RICHARD S. APPELDOORN[2] and KENYON C. LINDEMAN[3]
[1]Department of Fisheries, Animal and Veterinary Science
University of Rhode Island
Kingston, RI 02881 USA
[2]Department of Marine Sciences
University of Puerto Rico
Mayaguez, Puerto Rico 00681-9013 USA
[3]Division of Marine Biology and Fisheries
RSMAS, University of Miami
Miami, FL 33149 USA

ABSTRACT

We report on a preliminary sampling and analysis protocol for the insular shelf of southwest Puerto Rico that identifies coastal habitats of particular significance to early life stages of representative species. This can facilitate fishery reserve designs that include habitats essential for long-term fishery production and ecosystem conservation. The spatial framework employed uses a cross-shelf habitat matrix with a vertical axis that includes a hierarchy of structural habitat types and a horizontal axis that includes an estuarine to shelf-edge gradient of geomorphological zones. This framework aids the quantification of areal habitat cover and size distributions of species within diverse structural habitat categories across multiple cross-shelf gradients. Structural habitats or geomorphic zones can be collapsed or expanded according to data availability. Such attributes aided the design of a sampling program used to map substrates of key cross-shelf habitats in the La Parguera area of Puerto Rico. Representative fish faunas, i.e., those of trophic and fishery significance, were quantified by visual assessment after mapping transect substrates. This allowed the estimation of relative areas of differing habitat types and size-specific fish densities from transect-based visual assessments. Superimposing density data for differing life stages using available GIS datalayers of cross-shelf habitat distributions for the La Parguera area may yield a practical set of habitat selection criteria for the design of viable marine fishery reserves.

KEY WORDS: Haemulidae, mangrove habitats, marine reserves

INTRODUCTION

Establishing quantitative associations between fish populations and their habitats is of critical interest in determining the proposed boundaries of no-take fishery reserve areas. In establishing marine fishery reserves (MFR), managers should be able to justify their area selections in terms of which species, life history stages, and habitats are being protected (Roberts et al. 1995). If the structural and functional values of habitats are well understood, habitats can be ranked according to which habitat attributes and life stages are most essential to preserving the integrity of the system. However, the availability of both:

i) detailed and tractable habitat classifications, and
ii) fish abundance data collected in concert with existing habitat classification systems, is often limited.

Multiple abiotic and biotic variables can both describe and influence the distributions of organisms across spatially heterogeneous shelf systems. Various approaches for characterizing diverse arrays of habitats exist and many have focused on either structural attributes of bottom-types or water column characteristics. Approaches which combine these attributes in geographically logical manners may have considerable utility. For example, cross-shelf spatial frameworks that stratify complex spatial systems using fine-scale structural habitats and larger-scale geomorphic zones can foster detailed examinations of multiple habitat types across continental and insular shelf systems (Lindeman et al. 1998, Recksiek and Appeldoorn 1998, Appeldoorn et al. in press).

We report on preliminary results from the use of cross-shelf habitat frameworks in southwest Puerto Rico to map distributions of multiple life stages across diverse habitats and geomorphic zones. We focus on preliminary examples of ontogenetic variations in cross-shelf habitat use among early life stages of common coastal marine fishes.

METHODS

Cross-shelf spatial frameworks employ matrices with vertical axes representing structural habitat types and horizontal axes representing geomorphic strata across the shelf area under study. The habitat types include structures on a scale of 1 m^2, while the geomorphic strata are physiographic proxies for wind exposure, distance from shore, and depth across the shelf. By superimposing the structural habitats on the vertical axis and geomorphic strata on the horizontal axis, a cross-shelf habitat matrix of primary habitat combinations across the shelf is produced (Lindeman et al. 1998). Intersections of individual habitat types and geomorphic strata form cells in the matrix termed cross-shelf habitats. For example, one cross-shelf habitat is mangrove roots within the mainland inshore geomorphic stratum. A variety of species and life stage abundance measures can then be stratified within the matrix to examine ontogenetic patterns of habitat use within and among species, as well as combinations of habitat descriptors at differing spatial scales.

A preliminary cross-shelf habitat (CSH) matrix for the La Parguera area of the southwest shelf of Puerto Rico was assembled at a workshop in the spring of 1998 involving approximately ten fish biologists familiar with the area. This was the basis for the revised spatial matrix for La Parguera used in the present study (Figure 1). The matrix contains 20 structural habitat types and 36 geomorphic zones within three broad categories of the insular shelf (inner through outer shelf). We here focus on a subset of cross-shelf habitats within the La Parguera CSH framework based on a larger investigation in progress (Appeldoorn et al. in press). We emphasized transects in three geomorphic strata: Windward Inshore (WI), Leeward Shallow (LS), and Windward Shallow (WS). Most strata examined occurred within a depth range of 0 -3 m. Preliminary analyses focused on two structural habitat types: Mangrove Roots (MR) and Dead Coral-High Relief (DH) (Figure 1).

Transects were oriented along isobaths or parallel to local features such as mangrove cays or shallow reefs. The transects measured 24 m by 4 m ($96m^2$). A measuring tape was used as the transect center line. Structural habitat types were mapped *in situ* by a diver. A 1 m^2 square of plastic pipe was used by the diver to map habitats along the tape (illustrated for two transects within the windward inshore geomorphic zone in Figure 2). When the structural habitat within a meter square was largely homogeneous, the entire square was considered one habitat type; when heterogeneous, the square was subdivided into multiple habitat types (Figure 2).

The transect's fish fauna was assessed after mapping by a diver proceeding slowly above or alongside the transect area. Generally two passes through the transect were required, the first to assess roaming species, the second to assess site-attached fishes, e.g., damselfishes. We recorded 40 representative species. By representative, we mean species that are of likely trophic or fishery significance. This preliminary report emphasizes two common species of grunts (Haemulidae), ecologically and economically important components of the La Parguera ichthyofauna. For example, one of these species, the French grunt (*Haemulon flavolineatum*), was the most abundant species censused in La Parguera mangrove habitats by Rooker and Dennis (1991).

To estimate density of 1 cm total length classes over each structural habitat type, fishes were assessed according to three modes: points, polygons, or lines. When one or more fishes were sighted at a single location, a coded point corresponding to the individual fish or group of fish was recorded on a data sheet with an overlaid transect grid. In the second case, a figure was drawn on the data sheet's grid drawing to represent the area occupied by a school of a site-attached species, regardless of whether or not the polygon crossed habitat types. In the third case, designed for roaming species, a line was sketched on the drawing.

Fishes noted at each of those modes were recorded on the data sheet using a simple coding system. At each point, polygon, or line, the numbers of individuals together with the apparent range of total lengths (cm) were recorded. Lengths were judged after training using fish models (Rooker and Recksiek 1992); in situ lengths were estimated after that experience using memorized hand/finger configurations (Beets pers. comm.). Species were recorded to the lowest taxon possible; most fishes were identified to species. When a group contained more than one species, as is often the case for juvenile grunt schools, the numbers of constituent taxa were estimated (densities of each were estimated as described below).

Sketches on the grid drawings of our field data sheets were scanned to create maps of transect areas using ArcView and ArcInfo GIS software. This software enabled calculation of the areal coverage of each habitat type within each transect. For fish assessments, we also entered the points, polygons, or lines, together with component taxa, to the database so we could overlay them onto habitat maps of each transect (Figure 3). When the polygons crossed habitat types, respective areas were determined using GIS procedures; the areas were needed to calculate densities. In practice, line counts have occurred rarely; to date, we have considered the location of first sightings as a "point."

The fish data were entered into a spreadsheet to enable density calculations by species, total length interval, and cross-shelf habitat cell. Species density in a given habitat type was calculated on the basis of estimated numbers of fishes in the transect occurring over respective habitat areas (obtained from the GIS). When more than one individual was noted, the calculation of species abundance across size classes required three inputs: number of individuals, minimum total length, and maximum total length. By dividing the total number of individuals by the number of 1-cm size classes, a uniform frequency distribution was generated. For example, if 12 individuals were recorded from 6 - 10 cm TL, the mean number of individuals per size class is 2.4. This transformation was automatically performed by the spreadsheet upon entry of fish counts; one record therefore included computed length frequencies from the siting. When the record was derived from a polygon that crossed habitat category boundaries, additional records were created such that numbers of fishes were allocated in proportion to the subdivided areas of the polygon. The total surface area of the habitat types was included and used to calculate density of the species' total length classes for each habitat type in the transect. This generates a length frequency distribution of densities for each habitat type for each transect.

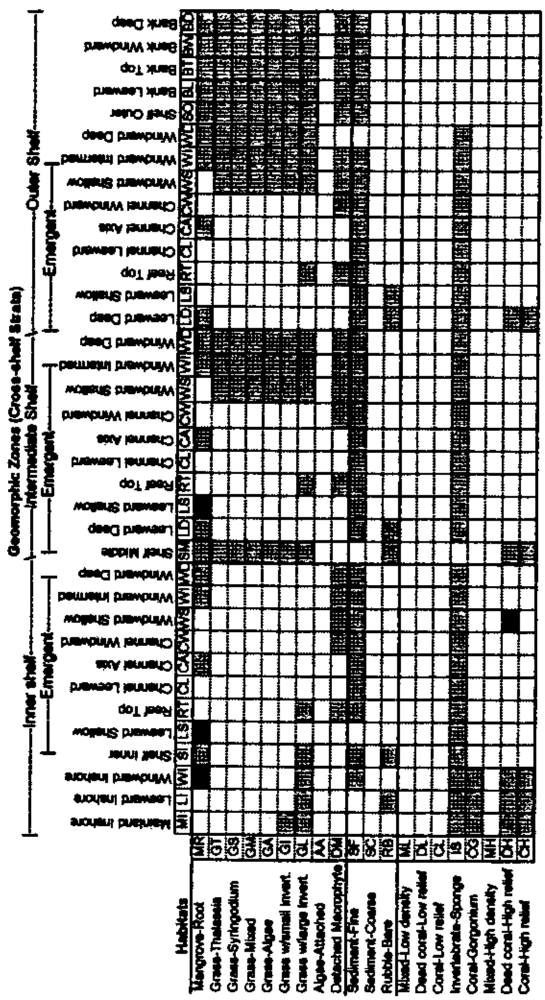


Figure 1. Preliminary cross-shelf habitat matrix for La Parguera, southwest Puerto Rico. Mnemonic acronyms denote habitat types (rows) and geomorphic zones (columns) as modified from Lindeman et al. (1998). Crosshatched cells indicate structural habitat types (Mangrove Root, Dead Coral-High Relief) and geomorphic zones (Windward Inshore–Inner Shelf, Leeward Shallow–Inner Shelf, Windward Shallow–Inner Shelf, and Leeward Shallow Intermediate Shelf)emphasized in the present study. Shaded cells indicate combinations of habitats and geomorphic zones that are absent from the system.

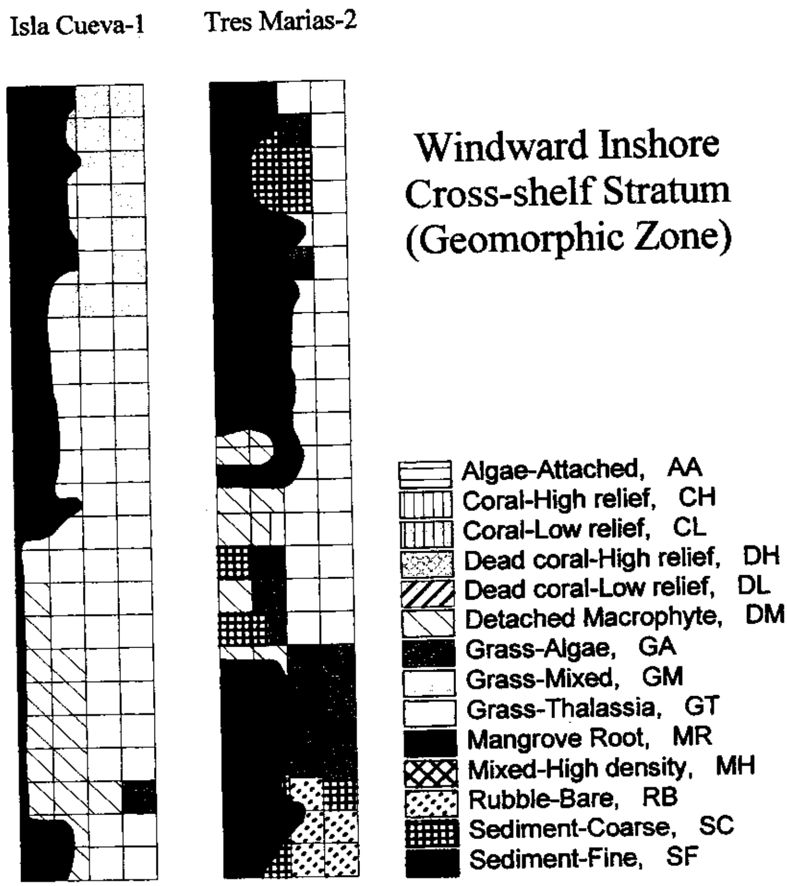
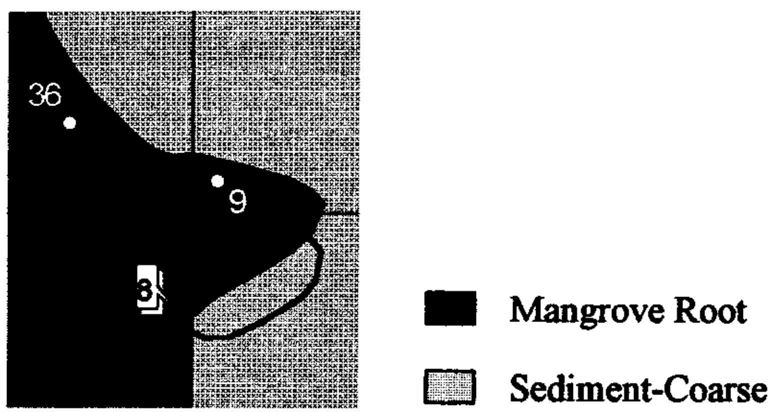


Figure 2. Habitat maps for two transects within the windward inshore cross-shelf stratum, La Parguera. Grid cells are 1m2. Legend key includes habitat types shown in this figure and in Figure 4.

Leeward Shallow Cross-shelf Stratum
Las Pelotas - 6



Location Code	Species	N	Total Length (cm)
8	Hfla	5	8 - 12
8	Hfla	2	8 - 12
9	Sbar	1	25
36	Asax	1	3
36	Asax	1	1

Figure 3. Examples of how fish positions on mapped transects were delimited using either discrete points or polygon areas. The figure illustrates the interface between a red mangrove drop root canopy and sediment halo within a leeward shallow geomorphic zone of the inner shelf at Las Pelotas, La Parguera, July 1998.

RESULTS

To date, we have conducted 67 transects at the following sites in the La Parguera area: Isla Cueva - 10, N of Tres Marias – 10, Collado - 10, Las Pelotas – 9, Enrique – 6, La Gata – 6, Laurel – 4, San Cristobal – 4, Margarita – 4, W of El Palo – 4 (several transect examples are shown in Figure 4). These transects occurred within a total of seven geomorphic zones and included 18 structural habitat types. These data are under analysis and the following summaries employ only a small subset.

Size classes of the grunt species examined here were not uniformly distributed among either structural habitats or geomorphic zones. Ontogenetic differences in the density of French grunts among differing habitats were suggested by the preliminary results. For example, a bimodal size class distribution was observed when densities were compared between mangrove roots of windward inshore transects and dead coral of high relief within a windward shallow geomorphic zone (Figure 5). The latter cross-shelf habitat, used by older life stages, was positioned further seaward on the shelf. A bimodal pattern was seen among size classes of the bluestriped grunt but densities for the smaller fish within the windward inshore transects were clearly lower, in contrast to the French grunt case (Figure 5).

A preliminary examination of differential habitat use of the same structural habitat (mangrove roots) within differing geomorphic zones across the shelf is given in Figure 6. In the French grunt, these data suggest early life stages occurred closer to the mainland than older stages. The rarity of censused life stages under 9 cm TL made comparisons less distinct in bluestriped grunts. In all habitats and cross-shelf strata examined here, French grunts were 2-10 times more abundant than bluestriped grunts (Figures 5 and 6).

DISCUSSION

Recent initiatives to identify essential fish habitats and to design fishery reserve boundaries are complimentary because optimal reserve design logically implies that boundaries include habitats essential to stock production and sustainability. Therefore, habitats used during juvenile migrations (Appeldoorn et al. 1997) and at settlement and spawning (Lindeman et al. in press) should be protected from fishing gear impacts and coastal construction activities. Since the spawning areas of many species are discrete from settlement areas, spatial frameworks that can stratify comparisons of fish abundance among diverse structural habitat types and geomorphic zones may have utility in the cross-shelf positioning of marine reserve boundaries.

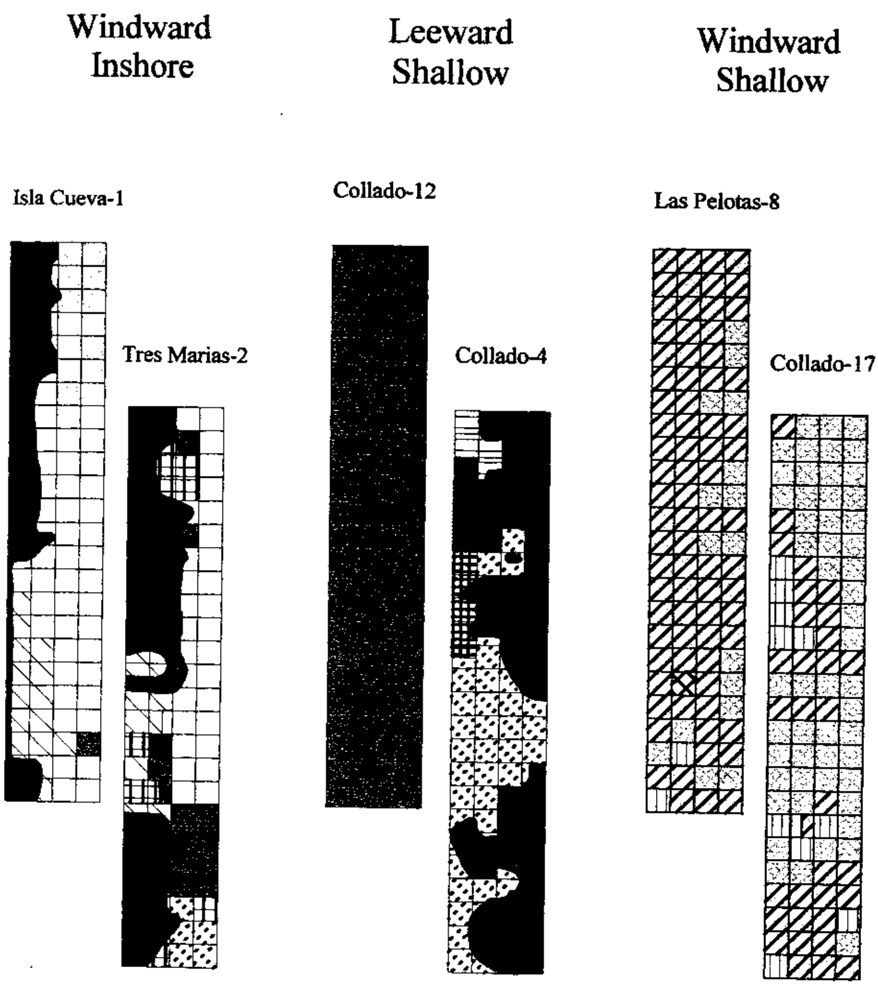


Figure 4. Habitat maps for six transects within three cross-shelf strata of the inner shelf of La Parguera. The key for habitat types is given in Figure 2.

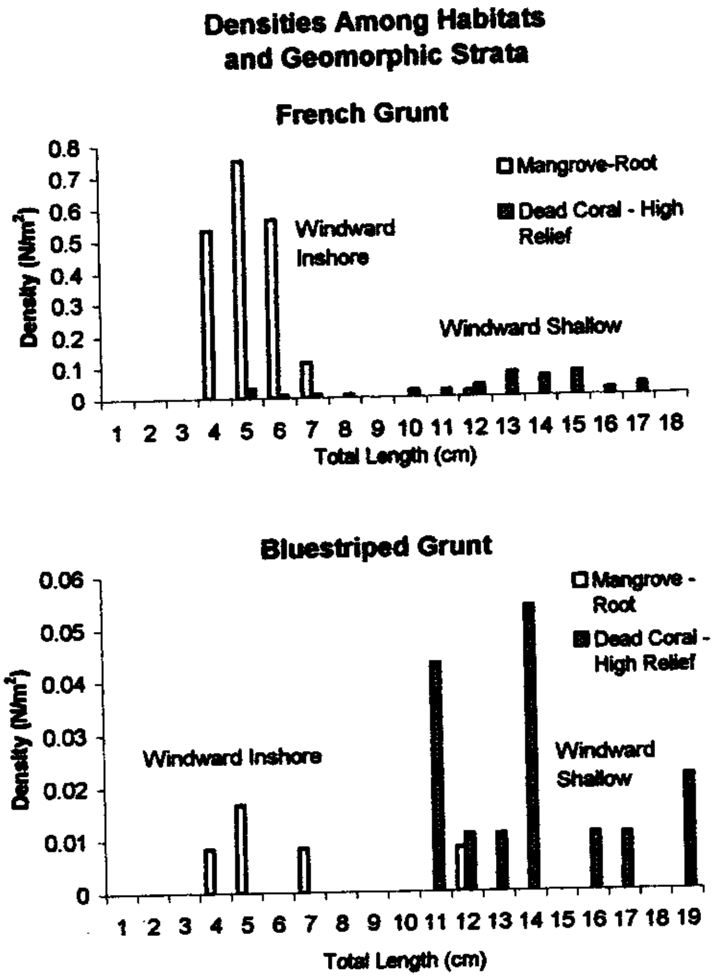
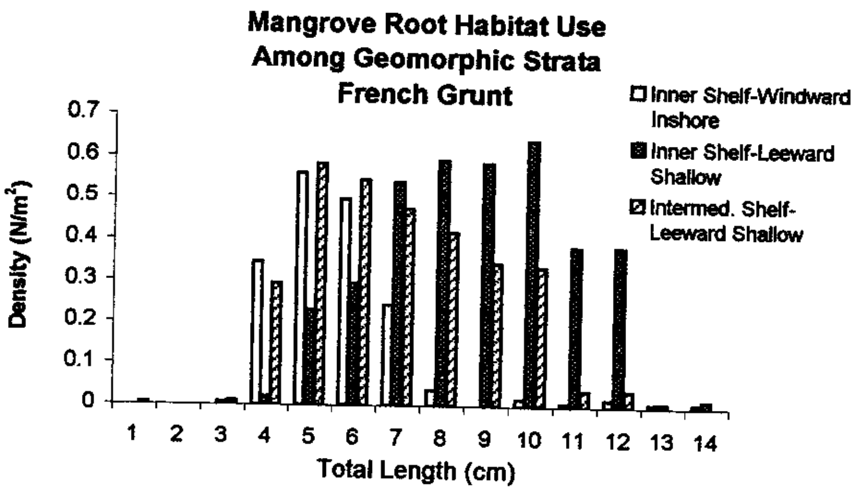


Figure 5. Densities of French grunt and bluestriped grunt size classes in mangrove root and dead coral-high relief habitats from windward inshore and windward shallow geomorphic zones of the inner shelf, respectively. Data for each of the two cross-shelf habitat combinations are pooled from two transects conducted in November-December, 1998.



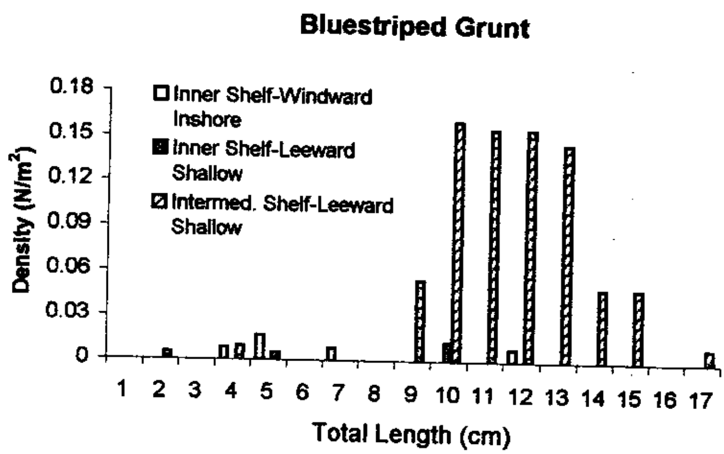


Figure 6. Densities of French and bluestriped grunt size classes from mangrove root habitats among three geomorphic strata. Data were collected in November-December 1998, and were pooled from three, four, and four transects per stratum, respectively.

Our approach builds upon preliminary applications of cross-shelf habitat frameworks by incorporating density estimates by size-class. Based on data availability, these density estimates may be collapsed or expanded among habitat types and geomorphic zones to assess variations in distribution among key spatial scales or to derive biomass estimates for mapped areas (Appeldoorn et al., in press). Preliminary analyses focused on mangrove root and dead coral habitats and showed potential ontogenetic habitat shifts among structures and depth zones (Figure 5). French grunts were more abundant in visual surveys of mangrove habitats than bluestriped grunts (Figure 6), a pattern also seen in the La Parguera area by Rooker and Dennis (1991). This contrasts with visual surveys and trapping in northeast Florida Bay, where bluestriped grunts dominated haemulid abundances, while French grunts were absent (Ley et al. 1999). Abundance estimates of haemulid early life stages within other combinations of habitat and geomorphic zones defined by cross-shelf habitat matrices are available (e.g., Lindeman and Snyder 1999). Comparisons of cross-shelf habitat use patterns that can be stratified according to data availability are underway among several geographic regions.

As fishery reserves become increasingly accepted management tools, research efforts are shifting in part from rationale for justification to guidelines for actual design (Recksiek and Appeldoorn, 1998). As reserves are ideally configured in interconnected networks (Roberts et al. 1995), broad design criteria can benefit from standardized spatial frameworks. In addition, a variety of new approaches that take advantage of advanced modeling and visualization tools have applications to both essential fish habitat identification (Rubec et al. 1999, Ault et al. 1999) and marine reserve design (Meester 2000). The hybridization of geographically standardized spatial frameworks and new analytic tools will yield practical methods for designing fishery reserves that protect both key habitats and essential demersal life stages.

ACKNOWLEDGMENTS

This project was funded by the University of Puerto Rico Sea Grant Program (R-31-1-98). We thank the faculty and students who worked together for several days during the summer of 1998 at the Isla Magueyes field station to identify the structural habitat categories and geomorphic zones used to assemble a cross-shelf habitat framework for the La Parguera area. We also thank Jerry Ault, Graciela Garcia-Moliner, Matt Kendall, Joe Kimmel, and Mark Monaco for their input on these issues.

LITERATURE CITED

Appeldoorn R.S., C.W. Recksiek, R.L. Hill, F.E. Pagan, G.D. Dennis. 1997. Marine protected areas and reef fish movements: the role of habitat in controlling ontogenetic migration. *Proc. 8th Int. Coral Reef Symp.* **2**: 1917-1922.

Appeldoorn, R.S., K. Foley, E. Molina, and C.W. Recksiek. Benthic mapping from fish and habitat transect data using GIS technology. *Proc. Gulf Carib. Fish. Inst.* Vol. **52**. In Press.

Ault, J.S., J. Luo, S.G. Smith, J.E. Serafy, J. D. Wang, R. Humston, and G. Diaz. 1999. A spatial dynamic multistock production model. *Can. J. Fish. Aquat. Sci.* **56**:1-22.

Ley, J.A., C.C. McIvor, and C.L. Montague. 1999. Fishes in mangrove prop-root habitats of northeastern Florida Bay: distinct assemblages across an estuarine gradient. *Estuar. Coast. Shelf Sci.* **48**:701-723.

Lindeman, K.C., G.A. Diaz, J.E. Serafy and J.S. Ault. 1998. A spatial framework for assessing cross-shelf habitat use among newly settled grunts and snappers. *Proc. Gulf Caribb. Fish. Inst.* **50**:385-416.

Lindeman, K.C. and D.B. Snyder. 1999. Nearshore hardbottom fishes of southeast Florida and effects of habitat burial caused by dredging. *Fish. Bull.* **97**(3):508-525.

Lindeman, K.C., R. Pugliese, G.T. Waugh, and J.S. Ault. Developmental patterns within a multispecies reef fishery: management applications for essential fish habitats and protected areas. *Bull. Mar. Sci.* In Press.

Meester, G.A. 2000. *A mathematical programming and simulation-based approach to determining critical factors in the design of optimal marine reserve plans for reef fish.* Ph.D. Dissertation. Univ. of Miami, Coral Gables, FL.

Recksiek, C.W., and R.S. Appeldoorn. 1998. In pursuit of design criteria for marine fishery reserves. *Proc. Gulf Carib. Fish. Inst.* **50**:372-384.

Roberts, C., W.J. Ballantine, C.D. Buxton, P. Dayton, L.B. Crowder, W. Milon, M.K. Orbach, D. Pauly, and J. Trexler. 1995. Review of the use of marine fishery reserves in the U.S. Southeastern Atlantic. *NOAA Tech. Mem.* NMFS-SEFSC-376, 31 pp.

Rooker, J., and C.W. Recksiek. 1992. The effects of training with fish models in estimating lengths of fish underwater. *Proc. Gulf Carib. Fish. Inst.* **41**:321-331.

Rooker, J.R. and G.D. Dennis. 1991. Diel, lunar and seasonal changes in a mangrove fish assemblage off southwestern Puerto Rico. *Bull. Mar. Sci.* **49**(3):684-698.

Rubec, P.J., J.C. W. Bexley, H. Norris, M.S. Coyne, M.E. Monaco, S.G. Smith, and J.S. Ault. 1999. Suitability modeling to delineate habitats essential for sustainable fisheries. *Amer. Fish. Soc. Symp.* **22**:108-133