In Pursuit of Design Criteria for Marine Fishery Reserves

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ABSTRACT

Marine Fishery Reserves (MFRs) have been identified as efficient instruments to achieve certain fishery conservation and management goals. International interest is growing rapidly and design issues are being discussed. No tested, generally accepted biological/ecological guidelines or principles yet exist which allow managers to designate where a reserve should be placed or the habitats that should be included to achieve MFR goals. If an MFR is large enough, goals will eventually be accomplished simply by returning a significant proportion of shelf area to a state prior to exploitation. The difficulty arises when society elects that an MFR is desirable while fishery exploitation must go on. The MFR design challenge is to minimize the amount of fishing ground set aside while building the biological and social support infrastructures for sustainable, and perhaps greater, fishery production for the long term. In these situations MFRs must be 'small,' at least until positive fishery impacts of the MFR are locally accepted. Data limitation is a fundamental complication affecting MFR design. Detailed information cannot be available for all areas under consideration. A few well studied systems must yield a set of robust principles that can be applied at other locations. The essential unit of management is habitat and the management goal should be to maintain ecological integrity. Self-sustainability requires that the essential structural and functional components of a system are intact. The field of landscape ecology provides a theoretical context within which to view spatially dependent patterns and processes. If habitat is the unit of management, there must be a system of habitat assessment. The selection of habitats and the maintenance of flow among them could be enhanced if there existed a more precise method of categorizing habitats and determining their relative ecological value. Lindeman's (1997) "cross-shelf habitat (CSH)" framework offers a potentially powerful methodology in assessing habitats that considers aspects of ecological distribution and flow to be related to the kind, amount and mix of habitats. CSH assessment methods may allow one to efficiently identify priority areas for inclusion into an MFR. While the approach has only been applied to one area

(Biscayne Bay, Florida), it merits rigorous field testing elsewhere. The time is opportune to attempt quantifying dynamic habitat attributes most relevant to MFR design.

KEY WORDS: Marine fishery reserves, marine habitat classification, marine protected areas

INTRODUCTION

Marine Fishery Reserves and Fishery Management

Fisheries management is now undergoing a major paradigm shift (Roberts 1997). According to this new paradigm, a system of Marine Fishery Reserves (MFRs) is considered a desirable, if not essential, component of any management plan. Within the past decade, MFRs have been identified as perhaps the most efficient instruments to achieve certain fishery management goals, such as (1) establishment of control areas against which to assess the impact of fishing; (2) preservation of intraspecific and interspecific (fish stock) genetic diversity; (3) preservation of spawning stock biomass and age structure; (4) security of recruitment supply; and (5) enhancing neighboring fishing grounds through (fish) emigration (PDT 1990, Roberts and Polunin, 1991, Ballantine, 1995; Bohnsack and Ault, 1996; Pitcher 1997; Roberts *et al.*, 1995; Roberts, 1997).

MFR Design Criteria

No tested, generally accepted biological/ecological guidelines or principles yet exist which allow managers to designate where a reserve should be placed or the habitats that should be included to achieve MFR goals. International interest is growing rapidly and design issues are being discussed (Pitcher, 1997). A set of biological and social "criteria" for selecting "ecological reserves" has been published (Bohnsack In press). These were developed by the National Oceanic and Atmospheric Administration (NOAA) for inclusion in the draft comprehensive management plan for the Florida Keys National Marine Sanctuary, and are summarized here (and abridged; see Bohnsack In press, Table 1, for original, complete text):

Biological Criteria	**Social Criteria**
Use best available science.	Avoid private property.
Include spatially-linked, representative habitats, inshore to offshore.	Use best available science.
	Use straight, recognizable boundaries.
Include representative regions.	Consider proximity to users.

Size MFR for potential ecological integrity.
Provide replicates for effectiveness assessment.

Include centers of biological diversity.
Protect life cycles of critical species.
Consider oceanographic conditions
(for reside species' requirements).

Include fishery considerations:
dispersal onto fishing grounds; fishing preferences; avoid charterboat areas.
Consider proximity to enforcement and monitoring support facilities.

The NOAA "criteria" reasonably summarize what ought to be considered, during the design process. The next step is to research how these criteria might be realized in different ecological and socioeconomic settings. Note that if an MFR is large enough, its stated goals will eventually be accomplished simply by returning a significant proportion of shelf area to a state prior to exploitation. The difficulty arises when society elects that a MFR is desirable while fishery exploitation must go on. Note also that while the NOAA design criteria (Bohnsack, In press) make good biological and social common sense, they are products of a developed nation for application in a region where commercial fishermen are but one of many interest groups making a livelihood from the coastal sea. We address ourselves to this problem, from primarily a biological perspective, as it pertains to coral reef fishery ecosystems generally.

The MFR design challenge is to minimize the amount of fishing ground set aside while satisfying management goals. In many reef fishery ecosystems, fishing pressure is already high. Displacing fishermen without their agreement is certain to generate fierce opposition, even though an ideal MFR is supposed to render fisheries sustainable over the long term. The challenge translates into how to minimize short term negative impacts on fishing while building the biological and social support infrastructures for sustainable, and perhaps greater, fishery production for the long term. In these situations MFRs must be 'small,' at least until positive fishery impacts of the MFR are locally accepted (Appeldoorn, 1997). There are few success stories with respect to enhancing fishery production. One example of a 'small' MFR adjacent to fishing grounds which are intensively exploited is Apo Island in the central Philippines. From fishing grounds nearby a 25 ha MFR, Russ and Alcala (1996) provide some evidence that, over a 10 year period, densities of predatory fish had increased outside the reserve. They reported that local fishermen felt that yields had increased but, typically, solid production statistics are lacking.

Another challenge where MFR's must be 'small' in order to be locally accepted is that areas suited to one design goal may be widely separated from areas suited to another goal. One area may be known to provide settlement and juvenile habitats whereas another may harbor adults; the former supports recruitment, the latter protects spawning stock biomass. Additionally, some areas probably deserve reserve status occasionally in time; spawning aggregation sites exemplify this. In the real world unfortunately, MFR proposers must make hard choices and know when and when not design goals can be realized.

Data Limitation

Data limitation is a fundamental complication affecting the design of a MFR system. It is clear that detailed information will not, and cannot, be available for all areas under consideration, due to the excessive cost and time involved to accumulate pertinent data. At best, a few well studied systems must yield a set of robust principles that can be applied at other locations with minimal data input. Ballantine (In press, 1997), recognizing this reality, suggested a series of principals for building a network of MFRs: (1) self sustaining - the system should include all structural and functional components necessary to maintain itself; (2) representation - all marine habitats in each biological region should be represented; and (3) replication - all habitats must be replicated. A critical concept embedded within these principals is that the unit of management is not the species or community, but the habitat, and that habitat can be used as a surrogate for demography (Hansen *et al.*, 1992). This result is consistent with current thinking in conservation biology: the essential unit of management is habitat, and that the management goal should be to maintain ecological integrity (Merriam and Wegner, 1992). Self-sustainability requires that the essential structural (species, habitats) and functional (flow of nutrients and species) components of a system are intact. Thus it is necessary not only to have representative habitats; these must be situated so that flows between them are maintained. At present, the ecological functions necessary for reef fish conservation together with maintenance of fishery production have not been systematically categorized.

The Role of Habitat

The field of landscape ecology (Naveh and Lieberman, 1990; Hansen and DiCastri, 1992; Hansson *et al.*, 1995) provides a theoretical context within which to view spatially dependent patterns and processes, such as distribution and migration, that characterize ecological function. In this approach, habitat classification (e.g., Wiens *et al.*, 1993) is defined functionally (e.g., how used by the individual: feeding habitat, nursery habitat, migration corridor, barrier, spawning site) instead of being spatially defined. Landscape ecological theory shows that not only are the amount and distribution of habitat important in regulating ecological flows, but that the context within which a particular habitat occurs is also important (Ims, 1995). Both of these concepts have emerged during recent studies of Caribbean Reef Systems. For fishes, Appeldoorn *et al.* (In press) and Appeldoorn (In press) have shown that movement patterns and rates of dispersal are controlled to a large degree by the distribution of habitat. Habitat context was demonstrated by Beets *et al.* (1997), who showed that fish community structure on tropical reefs was significantly affected by the presence or absence of nearby seagrass beds. Thus, attempts to identify key factors affecting habitat choice and use must account for the possible mix of habitats.

While the emerging discipline of landscape ecology offers promising approaches in MFR design and habitat visualization, important (ecological) functional differences between terrestrial landscapes and ecosystems must be considered. In the latter, the exploitative focus is on harvesting fishes and macroinvertebrates; in the former, at least in forests, the focus is on harvesting or altering the flora. Fishing pressure on predators has been shown to structurally and functionally alter the fishery ecosystem (Parsons ,1992). In coral reef ecosystems many species of fishes and invertebrates are algal grazers and/or chew hard corals. Thus they shape the habitat mix; removals of these or their predators would be expected to influence habitat topology. With respect to functional similarities between coral reef and terrestrial ecosystems, the resemblance to grazing lands is compelling: managing the herbivores (cattle and wild grazers) and their predators shapes the character of the landscape, its productivity of cattle and game, and its species richness.

If habitat is the essential unit of management, there must be a system of habitat assessment. Systems of habitat classification have been used in other aquatic environments (e.g., Hawkins *et al.*, 1993). Ballantine (In press, 1997) suggests that in a data-limited situation, marine topology should be used as a basis for habitat classification, with the three most important variables being degree of wave/current exposure (e.g., sheltered or exposed), depth, and type of substratum (e.g., rocky or soft bottom). In this process, selection of habitats to be included into reserves would not be deterministic, that is, one area of a particular habitat would be considered as good as another. Flow among habitats would be facilitated by the existence of a network of many protected areas, such that as new areas are added, the mean inter-area distance would decline to some ecologically meaningful level. Ballantine (1997) suggested that public support and demand for additional reserve areas are emergent properties of this management approach, even though they may be manifest on a scale of decades.

The selection of habitats and the maintenance of flow among them could be enhanced, and the time frame accelerated, if there existed a more precise method of categorizing habitats and determining their relative ecological value. Cowardin *et al.* (1979) developed a classification system for aquatic habitats ranging from freshwater to saltwater wetlands. Dethier (1994) refined and extended this system to estuarine and marine habitats, explicitly including energy level as a classification factor. Nevertheless, these systems do not account for the context in which a habitat occurs and the spatial scales, with respect to surface area, of habitats are undefined.

For tropical reef fishes, numerous studies have demonstrated a correlation between the distribution of coral reef fishes and aspects of habitat structure on a variety of spatial scales. The most common approach attempts to quantify aspects of the physical environment (e.g., depth, substrate complexity, substrate type, turbidity; cf. Luckhurst and Luckhurst, 1978; Roberts and Ormond, 1987; McCormick, 1994; McGehee, 1994; Friedlander *et al.*, 1995). This approach allows for detection of key factors, but has generally been limited to small spatial scales or to species of little commercial interest. Comparisons across studies using this approach have yielded mixed results (Roberts and Ormond, 1987). In contrast, other studies have divided habitat on the basis of reef geomorphology (e.g., fore reef-back reef, offshore reef-inshore reef, etc.; cf. Kimmel, 1985; Green, 1996; Williams, 1982). This approach recognizes or assumes there exist similarities within zones relative to pertinent variables such as benthic community structure, substrate complexity, slope, water motion, etc., but does not seek to characterize attributes to which fish actually respond. Lastly, it has been argued that fish distribution is regulated largely by physical energy (i.e., water motion) and that there exist discreet energy zones across a reef or series of reefs (Galzin and Legerdre, 1987; McGehee, In press). In addition to the direct effect of water motion on fishes, water motion may act indirectly as a general integrating factor underlying other measurable attributes such as substrate type and complexity. All of the above approaches rely on aspects of habitat structure, and in some way are dependent upon the particular geomorphology of the study area, and as such their spatial scales are fixed. Also, because of the differences in methodological approach, their definitions and terms of reference are usually not comparable. Thus, while it is clear that habitat features are important in controlling the distribution and movements of fishes, no unified approach to habitat assessment has been accepted. Nevertheless, these studies do suggest that such an approach is possible and should include aspects of habitat structure, and the placement of that structure within settings of geomorphology and physical energy.

Habitat Assessment

Lindeman (1997), building on the earlier work of Cowardin *et al.* (1979) and Dethier (1994), has attempted to standardize definitions of habitats (including spatial scales) and put these within a frame of reference considering cross-shelf geomorphology in an attempt to produce a tractable assessment system useful for identifying critical habitats, ontogenetic transitions, sampling strata, etc. In Lindeman's system, a matrix is formed by categorizing areas by geomorphology (depth, distance from shore, current/wave exposure) and by benthic substratum (hard-soft, dominant vegetation or invertebrate cover). This approach inherently recognizes the importance of context in habitat function, e.g., an offshore reef is different from an inshore reef. The resulting cross-shelf habitat matrix allows for fine-scale description of habitat structure and use. Examples are presented in Figure 1 through Figure 3. Comparison of Figure 1 and Figure 2 shows how the use of habitat can be described and distinguished for two grunt congeners with similar ecological distributions. The comparison shows how the Spanish grunt is distributed slightly further offshore relative to the smallmouth grunt. Furthermore, each matrix shows how the habitat is used by different life history stages, thus clearly identifying, for example, nursery areas versus adult habitat (i.e., the matrix identifies some functional properties of habitat and indicates in which direction there will be probable flow of individuals). Figure 3 illustrates two important advantages of the matrix. First, the habitats identified in a matrix can be superimposed on a spatial map to show the relative abundance and distribution of habitats in an area. Thus, rare habitats are identified, and the mix of habitats is shown. The latter is important for identifying areas where ecological flows among habitats may be enhanced due to close proximity. Second, the 15 habitats represented in Figure 3 are formed by pooling 19 substratum categories (defined at a finer scale) into three. Thus, the matrix method is flexible and can still provide useful information when data are limited in quality or amount.

The arguments above may be summarized as follows. There is an immediate need for developing a system of marine fishery reserves in tropical reef areas. Implementation will necessarily proceed in a data-limited environment and initial efforts will likely be on a small scale. Data limitation can partially be overcome by (a) using well studied systems to develop robust guidelines that can be applied elsewhere, and (b) by using habitat as a proxy representation of ecological structure and function. This approach also focuses on maintaining ecological integrity. However, in order to manage habitat to maintain ecological structure and function it is necessary to (a) define what aspects of structure and function are important in maintaining production and integrity, (b) define the specific mechanisms responsible for ecosystem function, and (c) relate these to specific kind, amount and mix of habitats. Lindeman's (1997) "cross-shelf habitat (CSH)" framework offers a potentially powerful methodology in assessing habitats that considers aspects of ecological distribution and flow to be related to the kind, amount and mix of habitats. Thus, CSH assessment methods may allow one to efficiently identify priority areas for inclusion into an MFR or MFR system. The approach has only been applied to one area (Biscayne Bay, Florida) and its general utility, although promising, has not been tested elsewhere.

Smallmouth grunt
Haemulon chrysargyreum

Habitat Categories	Structural Habitat Types	Cross-shelf Strata Depth (m) 0-1	1-2	> 2	1-2	0-1	> 2	0-2	2-10	10-20	> 20
		Mainland			Leeward			Windward			
		Inshore ↓	Subtidal ↓	Basin Axis	Subtidal ↓	Inshore ↓	Channel Axis	Inshore ↓	Subtidal ↓	Mid-Shelf	Outer Shelf
Trees	Mangrove - Red			■	2	2	■	2	■	■	■
	Eroded Trees			■			■		■	■	■
Grasses and Algae	Grass - Thalassia										■
	Grass - Syringodium										■
	Grass - Halodule									■	■
	Grass - Mixed (>1 species)										■
	Grass - Algae										■
	Algae - Attached										
	Detached Macrophytes										
	Detatched Drift macrophytes										■
Sediments	Sediments - Fine										
	Sediments - Coarse										
Hard Bottom; Invertebrates	Exposed Hardbottom	■			1 2	1 2	1 2	1 2	1234	3 4	4
	Mixed - Low density inverts.	■			1 2	1 2	1 2	1 2	1234	3 4	4
	Corals - Low relief genera	■			1 2	■	1 2	1 2	1234	3 4	4
	Invert. - Phragmatopoma reef	■	■	■	■	■	1 2	1 2	1234	■	■
	Invert. - Miscellaneous				1 2	1 2	1 2	1 2	1234	3 4	4
	Invert. - Sponges							■			
	Corals - Gorgonians	■				■		■			
	Mixed - High density inverts.	■			1 2	1 2	1 2	1 2	1234	3 4	4
	Corals - High relief genera	■	■	■	■	■	■	■	■	3 4	4

Figure 1. Estimated occurrence of four life history stages of smallmouth grunt, *Haemulon chrysargyreum,* across the Biscayne Bay shelf area of southeast Florida. 1: newly settled (0.7-2 cm SL); 2: early juvenile (2-5 cm SL); 3: juvenile (5-15 cm SL); 4: adult (>15 cm SL). Structural habitat types absent from specific cross-shelf strata are shaded.

Spanish grunt
Haemulon macrostomum

Cross-shelf Strata

		Depth (m)									
		0-1	1-2	> 2	1-2	0-1	> 2	0-2	2-10	10-20	> 20
		Mainland			Leeward			Windward			
Habitat Categories	Structural Habitat Types	Inshore ↓	Subtidal ↓	Basin Axis	Subtidal ↓	Inshore ↓	Channel Axis	Inshore ↓	Subtidal ↓	Mid-Shelf	Outer Shelf
Trees	Mangrove - Red			■			■		■	■	■
	Eroded Trees			■			■		■	■	■
Grasses and Algae	Grass - Thalassia										■
	Grass - Syringodium										■
	Grass - Halodule									■	■
	Grass - Mixed (>1 species)										■
	Grass - Algae										■
	Algae - Attached										
	Detached Macrophytes										
	Detatched Drift macrophytes										■
Sediments	Sediments - Fine										
	Sediments - Coarse										
Hard Bottom; Invertebrates	Exposed Hardbottom	■						1 2	123	1234	4
	Mixed - Low density inverts.	■						1 2	123	1234	4
	Corals - Low relief genera	■				■		1 2	123	1234	4
	Invert. - Phragmatopoma reef	■	■	■	■	■		1 2	123	■	■
	Invert. - Miscellaneous							1 2	123	1234	4
	Invert. - Sponges							■			
	Corals - Gorgonians	■				■		■			
	Mixed - High density Inverts.	■						1 2	123	1234	4
	Corals - High relief genera	■	■	■	■	■	■	■	■	1234	4

Figure 2. Estimated occurrence of four life history stages of Spanish grunt, *Haemulon macrostomum*, across the Biscayne Bay shelf area of southeast Florida. 1: newly settled (0.7-2 cm SL); 2: early juvenile (2-5 cm SL); 3: juvenile (5-15 cm SL); 4: adult (>15 cm SL). Structural habitat types absent from specific cross-shelf strata are shaded.

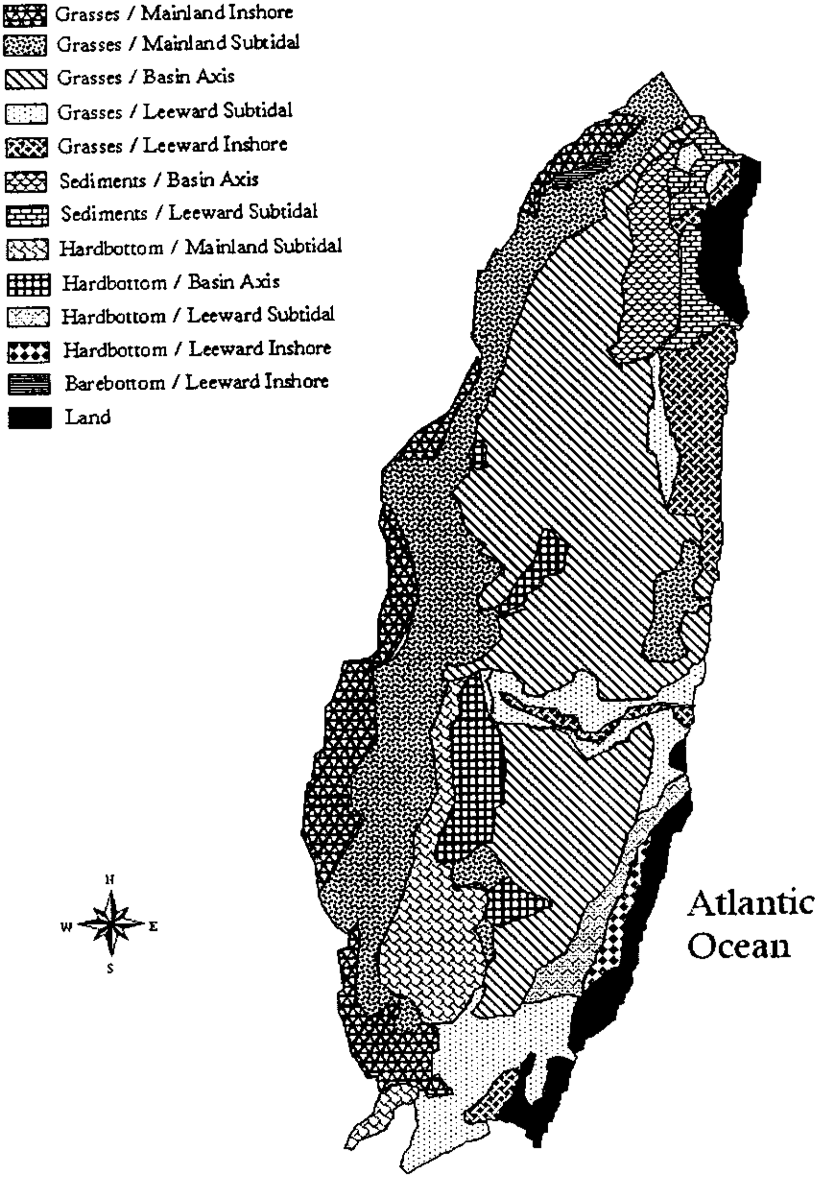

Figure 3. Example of a cross-shelf habitat framework for Biscayne Bay (redrawn from Lindeman, 1997). Three structural habitat types (grasses, sediments, and hardbottom) are combined with five cross-shelf strata (mainland inshore [0-1 m]; mainland subtidal [1-2 m]; basin axis [>2 m]; leeward subtidal [1-2 m]; leeward inshore [0-1 m]).

It is clear that a generally accepted, efficient, and robust habitat assessment system for coral reef fishery ecosystems is required for the design and siting of MFRs, especially where commercial fishing is intense. The CSH framework, as presented here, is worth rigorous field testing. The time is opportune to attempt quantifying dynamic habitat attributes (cf. Appeldoorn 1997) most relevant to MFR design.

ACKNOWLEDGMENTS

This report and its presentation were sponsored by the University of Puerto Rico Office of Sea Grant (Project R/FA-06-3-94). This investigation was supported by the Department of Fisheries, Animal, and Veterinary Science, University of Rhode Island, the Rhode Island Agricultural Experiment Station, and the Department of Marine Sciences, University of Puerto Rico. This is Contribution 3563 of the Rhode Island Agricultural Experiment Station.

LITERATURE CITED

Appeldoorn, R.S. 1997. Dispersal rates of commercial important coral reef fishes: what do tagging studies tell us about potential emigration from marine reserves? *Proc. Gulf Carib. Fish. Inst.* **49**:54 - 63.

Appeldoorn, R.S. 1997. Critical habitat assemblages for the design of marine fishery reserves (Abstract). Page 11 in: Pitcher, T.J., (ed.) *The design and monitoring of marine reserves.* University of British Columbia. Fisheries Centre Res. Rep. **5**(1).

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

Ballantine, W.J. 1995. The New Zealand experience with 'no-take' marine reserves. Pages C15-C31 in: C. Roberts, W.J. Ballantine, C.D. Buxtohn, P. Dayton, L.B. Crowder, W. Milon, M.K. Orbach, D. Pauly, J. Trexler (eds.) *Review of the use of marine fishery reserves in the U.S. Southeastern Atlantic.* NOAA Tech. Mem. NMFS-SEFSC-376. 31 p.

Ballantine, W.J. 'No-take' marine reserve networks support fisheries. *Proc. 2nd World Fisheries Congress* (Brisbane). In press.

Ballantine, W.J. 1997. Design principles for systems of 'no-take' marine reserves. (Abstract). In: Pitcher, T.J., (ed.) *The design and monitoring of marine reserves. University of British Columbia. Fisheries Centre Res. Rep.* 5(1):4 - 5.

Beets, J.P., L.K. Muehlstein, R. Boulon. 1997. *Some mechanisms of fisheries enhancement in marine fisheries reserves (MFRs): interactions between* *coral reefs and seagrasses.*. Univ. Puerto Rico Sea Grant Program.

Bohnsack, J.A. Consensus development and the use of marine reserves in the Florida Keys. *Proc. 8th Int. Coral Reef Symp.* In press.

Bohnsack, J.A., J.S. Ault. 1996. Management strategies to conserve marine biodiversity. *Oceanography* **9**:73 - 82.

Cowardin, L.M., V. Carter, F.C. Golet, E.T. LaRoe. 1979. *Classification of wetlands and deepwater habitats of the United States*. U.S. Fish Wildl. Serv. FWS/OBS-79/31. 103 p.

Dethier, M.N. 1994. Classifying marine and estuarine natural communities: an alternative to the Cowardin system. *Nat. Areas Jour.* **12**:90 - 100.

Friedlander, A.M., R.C. DeFelice, J.D. Parrish, J.L. Frederick. 1995. *Habitat resources and recreational fish populations at Hanalei Bay, Kauai*. Rept. Hawaii Dept. Land Nat. Res., Div. Aquat. Res. 296 p.

Galzin, R., P. Legerdre. 1987. The fish communities of a coral reef transect. *Pac. Sci.* **41**:158 - 165.

Green, A.L. 1996. Spatial, temporal and ontogenetic patterns of habitat use by coral reef fishes (Family Labridae). *Mar. Ecol. Prog. Ser.* **133**:1 - 11.

Hansen, A.J., F. DiCastri (eds.). 1992. *Landscape boundaries. Consequences for biotic diversity and ecological flows.* Springer-Verlag, NY. 452 p.

Hansen, A., D.L. Urban, B. Marks. 1992. Avian community dynamics: the interplay of landscape trajectories and species life histories. Pages 170-193 in: A.J. Hansen, F. DiCastri (eds.) *Landscape boundaries. Consequences for biotic diversity and ecological flows*. Springer-Verlag, NY. 45 p.

Hansson, L., L. Fahrig, and G. Merriam (eds.). 1995. *Mosaic landscapes and ecological processes.* Chapman and Hall, London. 356 p.

Hawkins, C.P., J.L. Kershner, P.A. Bisson, M.D. Bryant, L.M. Decker, S.V. Gregory, D.A. McCullough, C.K. Verton, G.H. Reeves, R.J. Steedman, M.K. Young. 1993. A hierarchiacal approach to classifying stream habitat features. *Fisheries* **18**:3 - 12.

Ims, R.A. 1995. Movement patterns related to spatial structures. Pages 85-109 in: L. Hansson, L. Fahrig, and G. Merriam (eds.) *Mosaic landscapes and ecological processes.* Chapman and Hall, London. 356 p.

Kimmel, J.J. 1985. *A characterization of Puerto Rican fish assemblages.* Ph.D. Dissertation. Univ. of Puerto Rico, Mayaguez, Puerto Rico. 106 p.

Lindeman, K.C. 1997. *Development of grunts and snappers of southeast Florida: cross-shelf distributions and effects of beach management alternatives.* Ph.D. Dissertation. University of Miami, Miami, FL. 419 p.

Luckhurst, B.E., K. Luckhurst. 1978. Analysis of the influence of substrate variables on coral reef communities. *Mar. Biol.* **49**:317 - 323.

McCormick, M.I. 1994. Comparison of field methods for measuring surface topography and their associations with a tropical reef fish assemblage. *Mar. Ecol. Prog. Ser.* **112**:87 - 96.

McGehee, M.A. 1994. Correspondence between assemblages of coral reef fishes and gradients of water motion, depth, and substrate size off Puerto Rico. *Mar. Ecol. Prog. Ser.* **105**:243 - 255.

McGehee, M.A. Correspondence between distributions of coral reef organisms and water motion measured by metal corrosion rates. *Proc. 8th Int. Coral Reef Symp.* In Press.

Merriam, G., J. Wegner. 1992. Local extinctions, habitat fragmentation, and ecotones. Pages 150 - 169 in: A.J. Hansen, F. DiCastri (eds.) *Landscape boundaries. Consequences for biotic diversity and ecological flows.* Springer-Verlag, NY. 452 p.

Naveh, Z., A.S. Lieberman. 1990. *Landscape ecology. Theory and Applications.* Springer Verlag, NY. 356 p.

Parsons, T.R. 1992. The removal of marine predators by fisheris and the impact of trophic structure. *Mar. Pollut. Bull.* **25**(1-4):51 - 53.

Pitcher, T.J. 1997. The design and monitoring of marine reserves - introduction to the issues. In: Pitcher, T.J., (ed.) *The design and monitoring of marine reserves. University of British Columbia. Fisheries Centre Res. Rep.* **5**(1). 47 p.

Plan Development Team (PDT). 1990. The potential of marine fishery reserves for reef fish management in the U.S. Southern Atlantic. *NOAA Tech. Mem.* NMFS-SEFSC-261. 40 p.

Roberts, C.M. 1997. Ecological advice for the global fisheries crisis. *TREE* **12**:35 - 38.

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

Roberts, C.M., R.F.G. Ormond. 1987. Habitat complexity and coral reef fish diversity and abundance on Red Sea fringing reefs. *Mar. Ecol. Prog. Ser.* **41**:1 - 8.

Roberts, C.M., N.V.C. Polunin. 1991. Are marine reserves effective in management of reef fisheries? *Rev. Fish. Biol. Fish.* **1**:65 - 91.

Russ, G.R., A.C. Alcala. 1996. Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. *Mar. Ecol. Prog. Ser.* **132**:1 - 9.

Wiens, J.A., N.C. Stenseth, B. Van Horne, R.A. Ims. 1993. Ecological mechanisms and landscape ecology. *Oikos* **66**:369 - 380.

Williams, D. MCB. 1982. Patterns in the distribution of fish communities across the central Great Barrier Reef. *Coral Reefs* **1**:35 - 43.