Towards an ecosystem-based approach to assess non-target tropical reef fishes

HELENA MOLINA-UREÑA[1,2] and JERALD S. AULT[1]
[1] *RSMAS, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149-1031*
[2] *Escuela de Biología, Universidad de Costa Rica, San José 2060, Costa Rica.*

ABSTRACT

An ecosystem-based approach integrating ontogenetic habitat uses and population dynamics was developed to assess population risks from exploitation and environmental changes on non-target reef fishes. The method employed a combination of fisheries and ecological theory, and a suite of simulation techniques to study South Florida parrotfishes. Recommended steps in this systems approach are: (1) analysis of information gaps for the stocks (or taxon) under consideration, including systematics, biogeography, population dynamics, reproductive ecology, trophodynamics, habitat use, and fisheries catch and fleet dynamics; (2) determination of primary objectives from prioritization of information gap analyses of Step 1; (3) determination of essential fish habitats from integration of stratified sampling design for fisheries-independent surveys and habitat selection theory-based analyses. These length-based analyses include ontogenetic shifts, migrations, and connections between reefs and adjacent habitats subject to fisheries, gear selectivity and catchability; (4) refined estimation of population dynamics and fisheries-specific parameters encompassing life history demographics from empirical data or comparisons to theoretical expectations adapted to local conditions; (5) simulation modeling of a realistic range of fishing scenarios and demographic characteristics using REEFS (Reef fish Equilibrium Exploitation Fisheries Simulator) and size-based mortality estimation (LBAR) to evaluate the efficacy of potential traditional fisheries (e.g., size/bag limits) and spatial (e.g., marine protected areas) management strategies. An example application to the Florida Keys coral reef ecosystem is presented.

KEY WORDS: ecosystem-based management, tropical non-target fisheries, parrotfishes, essential fish habitat

Un Enfoque de Ecosistema para Evaluar Peces de Arrecifes Tropicales Sujetos a Pesca no Dirigida

Se ha desarrollado una metodología de manejo ecosistémico, que integra usos ontogenéticos de hábitat y dinámica poblacional, para evaluar los riesgos de explotación y cambios ambientales en peces de arrecife que no son especies objetivos. Este enfoque utilizó una combinación de teorías ecológicas y pesqueras, y una serie de técnicas de simulación para estudiar los peces loro del Sur de la Florida. Los pasos que se recomiendan en esta metodología son: (1) análisis de vacíos de información para los stocks (o taxon) bajo consideración, incluyendo biosistemática, biogeografía, dinámica poblacional, ecología reproductiva, trofodinámica, uso de hábitat, y dinámica pesquera sobre capturas y esfuerzo; (2) determinación de objetivos primarios al asignar prioridades a las necesidades de información detectadas en el Paso 1; (3) determinación de hábitats esenciales de peces mediante la integración de diseño estratificado de muestreo para datos independientes de pesquerías y análisis basados en teoría de selección de hábitat. Los análisis de tallas incluyen cambios ontogenéticos, migraciones y conexiones entre el arrecife y los hábitats adyacentes sujetos a pesca, selectividad del equipo de colecta, y capturabilidad; (4) estimación refinada de parámetros de dinámica poblacional y pesquera sobre la demografía del ciclo de vida, a partir de datos empíricos o relaciones teóricas adaptadas a las condiciones locales; (5) simulaciones de un ámbito realista de escenarios pesqueros y características demográficas mediante los programas REEFS (Simulador de Explotación Pesquera en Equilibrio de Peces de Arrecife) y LBAR (estimador de mortalidad basado en distribución de tallas) para evaluar la eficacia de estrategias potenciales de manejo tradicionales, ya sean pesqueras (e.g., límites en capturas/tamaños), o espaciales (e.g., áreas marinas protegidas). Se presenta un ejemplo de esta metodología aplicado al ecosistema arrecifal coralino de los Cayos de la Florida.

KEY WORDS: manejo de ecosistemas, pesca incidental, peces loro, hábitat esencial de peces

INTRODUCTION

Ecosystem-based Approach to Fisheries (EAF) is a concept that aims at science-based governance, based on the combination of principles and tools from conventional fisheries management and ecosystem management (Garcia et al. 2003). Ideally, this approach considers all interactions of target stocks with their physical habitat and with other species (*e.g.*, predator, prey, and competitor species), weather and climate effects on their biology and ecology, as well as the effects of fishing on their dynamics and habitat (Department of Commerce 1999). However, this concept is constantly evolving, due in part to the difficulty of turning these principles into operational objectives (Garcia et al. 2003).

On the other hand, few studies have addressed population dynamics, trophodynamics, and habitat use of non-target populations because those species have often been neglected in traditional fisheries management plans. Besides, reliable catch data is usually unavailable for analyses of their fisheries dynamics, unless there are records of incidental captures. Taxonomy, ecology, reproductive biology, and local abundances might be better known on some non-target fish, but those studies do not relate life history patterns to observed population structure and dynamics. Thus, lack of integrated knowledge is pervasive and deters further analyses of the status of this type of populations. The pathway hereby proposed intends to use all available information, with the aim of improving the understanding of different aspects of the life history of species that could be (a) vulnerable to exploitation, and/or (b) important prey items for target fishes.

By developing methods to detect and fill important gaps of information pertaining to non-target, herbivorous fish in a coral reef ecosystem and adjacent habitats, the goal of this study is to build a reliable, more integrated understanding about species that are not actively considered by either fishing or conservation objectives. While developed with Florida populations, this pathway is intended to be useful in different locations around the Wide Caribbean Basin. With respect to the South Florida populations of parrotfishes, two questions were examined: How do these species use habitats in Biscayne Bay and Florida Keys? What are the effects of marine protected areas?

METHODS

A three-step approach is proposed as a viable, integrating alternative designed to detect and prioritize major biological information voids, and to attempt to fill those gaps (Figure 1). Step I is an analysis of information gaps. Step II prioritizes the information within a framework including ecosystem relationships and data gathering opportunities, in order to determine the amount and scope of the studies that can be carried out. Step III consists of the techniques, approaches, and analyses that can be applied to answer the top priorities (Figure 1).

Step I. It consisted of a thorough literature search aimed at obtaining all background necessary for an *a priori* picture about the role of the stock or taxon within the ecosystem, and the population dynamics of this component. The search included: population dynamics, behavior and reproductive strategies, trophodynamics and other ecological relationships (*e.g.*, symbiosis, competition), habitat, biosystematics, taxonomy, biogeography, and evolution. In order to have a more complete picture, especially in the context of shifting baselines, this first step also reviewed information on human activities that may have effects on the studied species, focusing on fisheries dynamics across the geographic range of the Western Atlantic parrotfishes. For this study, the search was restricted to peer-reviewed journals, and government reports. The proposed approach enhances the scope of the search and sharing of information by a network of government agencies, research institutions, non governmental organizations (NGOs), fishermen, and sources of gray literature (*e.g.*, local agency reports, environmental impact studies, theses, etc.). An interdisciplinary team would include other aspects to better characterize the locality of the study and associated watersheds, *e.g.*, hydrographic regimes, pollution issues, urban development, industrial activities, anthropological issues, and tourism pressure.

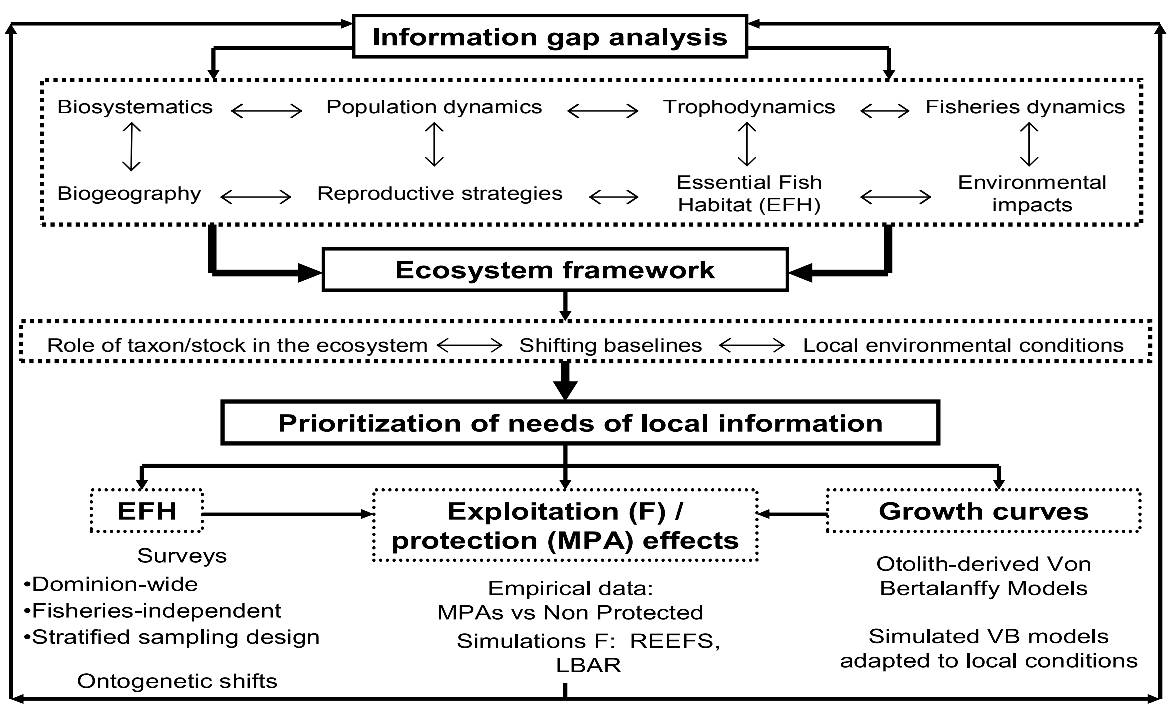

Figure 1. Flowchart of the rationale for prioritizing the need to fill information gaps in an ecosystem-based management of marine resources.

Step II. In order to prioritize the questions that needed answers, and the possibility of addressing them, several aspects were considered. The information available on the role of the stock, taxon, or guild in the ecosystem was analyzed within an integrative framework, considering three aspects: (a) the paradigm of shifting baselines, *i.e.*, because reef ecosystems have been evolving during much longer time scales than the less than five decades of research, standards to assess changes should be based on paleoecological, archaeological, and historical information besides recent empirical data; (b) distinctive local adaptations throughout the geographic range of each species; and (c) type and quality of data available, *i.e.*, data that need to be generated, and possibilities of answering the questions with observed data.

In the case of parrotfishes (Perciformes: Scaridae), the information gap analysis determined that habitat use and feeding modes were tightly related, and this relationship drove the evolution of the family to a certain extent. This taxon is very abundant, frequent, and specious in most Caribbean reefs. Scarids play a major role as bioeroders and grazers, the latter likely being enhanced since the decline of the populations of the sea urchin, *Diadema antillarum*, in the last two decades. This taxon also acts as a trophic link to commercial species, such as groupers, snappers, jacks, and barracudas, as well as marine birds (*e.g.*, cormorant). Small parrotfish species are under predation pressure during the whole life cycle, while the larger species might be most vulnerable at younger developmental stage of their life cycle. The gap analysis also suggested very low fishing mortality from ornamental trade, and lobster fisheries by-catch in South Florida scarids, but very variable fishing pressure elsewhere in the Caribbean Basin. No data was found on the shrimp fishery in Biscayne Bay. Effects of implementation of marine protected areas (MPA) on parrotfishes in the Florida Keys had not been studied on a large scale, while studies from other localities were mostly based on simulations rather than empirical data. Finally, two major projects based on large scale fishery-independent surveys in South Florida, provided an opportunity to examine scarids in adjacent dominions. One study surveyed the seasonal abundances of pink shrimp, *Farfantepenaeus duorarum*, in Biscayne Bay (Diaz 2001), in which by-catch data from bottom trawls was used. The other project consisted of a long term, Keys-wide reef fish visual census by divers in the Florida reef tract.

Table 1. Length –weight, and length-length relationships for South Florida parrotfish populations.

Species		*Sc. iseri*	*Sp. aurofrenatum*	*Sp. chrysopterum*	*Sp. viride*	*N. usta*	*Sp. radians*
n		82	7	105	53	42	12
Size range (TL)		2.0, 14.3	4.6, 22.4	5.9, 35.1	4.3, 39.8	5.5, 19.2	4.1, 15.8
W-TL:							
R^2		0.980	0.993	0.997	0.990	0.990	0.998
	α	0.0126	0.0128	0.0152	0.0226	0.0069	0.0122
	β	3.1426	3.0857	3.0274	2.9298	3.3046	3.1414
95CI(β) Lower, Upper		2.946, 3.340	N/A	2.970, 3.085	N/A	3.222, 3.387	3.083, 3.200
SL-TL							
	β_o	-0.0273	+0.4179	-0.2932	+1.0818	-0.0445	+0.0928
	β_1	0.8411	0.7882	0.7916	0.749	0.8037	0.7894
R^2		0.940	0.997	0.990	0.994	0.995	0.998

W=weight, TL=total length, FL= fork length, SL=standard length.α

and β are parameters in the equation W= α*(TL)$^{\beta}$. The growth is isometric when the 95% confidence interval (95CI) of the β estimate contains the value 3.0.

β_o and β_1 are parameters in the equation SL= $\beta_o + \beta_1$*TL. Parameters for *Sp. aurofrenatum* and *Sp. viride* were calculated from unpublished data generously provided by Michelle Paddack, Simon Fraser University, 2004.

Step III. Given the information gaps and the data gathering opportunities, two major objectives were selected as priorities:

To determine ontogenetic habitat uses by parrotfishes in Biscayne Bay and the Florida Keys.

To evaluate the effects of habitat protection in the Florida Keys on parrotfishes.

Sampling design

Habitat use was studied in two domains, a coastal bay and a reef tract. Biscayne Bay was surveyed with nighttime bottom trawls at 983 stations during 8 cruises between 1996 and 2000, with a sampling unit of 600 m^2. The sampling design followed a simple stratified random scheme customized for pink shrimp, based on 9 strata defined by three attributes: substrate type, distance from shore, and depth. The Florida Keys reef fish visual censuses (RVC) were conducted from 1997 to 2001, on a 2-stage stratified random design, with 12 strata defined by distance from shore, depth, and protection level. The sampling unit was of 177 m^2. Species and total length (TL, cm) were recorded for each fish collected or observed, as well as habitat attributes in a spatial-explicit database. In order to determine ontogenetic changes, total length was used as proxy for life stage, by grouping size classes that utilized strata in similar manners. When necessary, length-to-length relationships obtained empirically or from the literature were used to convert between total and standard length. Isometric growth was tested with the 95% confidence interval method (Can et al. 2002).

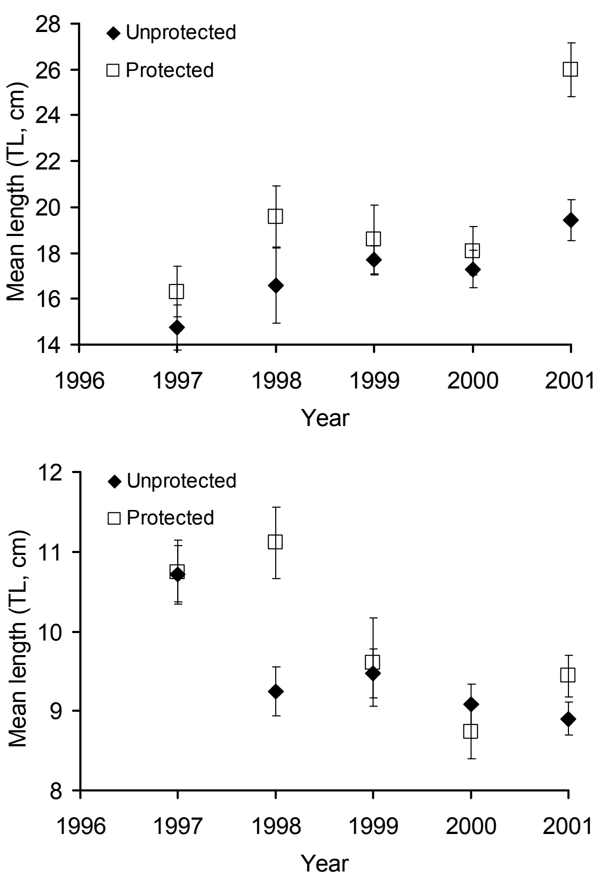

Figure 2. Observed mean length ± 95% confidence intervals of *Sp. chrysopterum* (upper panel) and *Sp. aurofrenatum* (lower panel) populations, in non-protected and protected reefs of the Florida Keys.

Three measures of habitat affinity were applied by domain, species, lifestage, cruise or year (Manly et al. 1993): (1) *probability of use of a habitat unit in stratum h*, $p(use)_h$, calculated as the proportion of habitat units occupied by at least one fish; (2) *per unit amount of use*, PUA, based on the comparison of the stratum-specific density against the overall mean density in each dominion, where densities higher than average indicated higher amount of use of a given habitat; and (3) *relative population amount of use*, p(P) vs. p(A), computed as a statistical comparison of population proportion against habitat proportion of the total area of the domain.

The short-term effect of habitat protection was measured with four endpoints that compared inside- and outside-MPA samples in the Florida Keys: size structure (Chi-square tests, χ^2, α=0.05), mean length (point estimates with 95% confidence intervals), maximum length observed, and recruitment trends (density of 4-12 cm TL size classes). The term "recruit" hereby refers to the individual of year class 0, *i.e.*, up to ~12 cm due to the fast early rates of body growth in parrotfishes (cf. Choat and Robertson 2002), assumed to have 100% probability of being observed by the diver (≥4 cm TL).

RESULTS AND DISCUSSION

In the Biscayne Bay trawls, the three most abundant scarids were *Sparisoma chrysopterum* (Redtail parrotfish), *Nicholsina usta* (Emerald parrotfish), and *S. radians* (Bucktooth parrotfish), ranking among the top 24 of a total of 177 species sampled. Little has changed in the relative abundance of those three species, even 20+ years after the fish trap ban (cf. Campos 1985), and despite the continuous removal as by-catch by the shrimp fisheries.

Four lifestages (juvenile phase, JP; subadult, SP; initial phase, IP; and terminal phase, TP) were determined for the scarids. Within-bay habitat use by the three top parrotfishes showed similar patterns: an affinity for seagrass, and use of barebottom substrates driven by the availability of these habitats. The outcome of the habitat affinity analysis suggested a dual use of seagrass habitats and ocean waters by *N. usta*. This parrotfish has its own reproductive population in Biscayne Bay with very little exchange with the adjacent reefs, and probable uses offshore (18-50 m depth) waters as habitat for adult phases. This population remains in the bay mostly during the wet, warm months (summer, fall), and a considerable portion of the population leaves this domain in winter and spring. A prolonged influx of new recruits into the bay likely reflected a protracted spawning activity, although the actual spawning grounds of *N. usta* have not been determined. A progressive expansion onto nearby substrates associated with growth was observed, but no sharp ontogenetic within-bay habitat shifts were detected. Because of gear selectivity towards smaller fish, the fate of the older individuals >20 cm TL is unknown. In order to clarify whether the bay acts as nursery grounds for open water populations of *N. usta*, or constitutes a lifelong habitat, it is recommended to obtain trawl samples from ocean waters 20-100 m depth off the South Florida coast. The results also suggested little exchange between the Florida Keys and bay populations of *S. radians*. However, given its reported preference for seagrass, mangrove and sandy substrates, its avoidance of high rugosity reefs (Nagelkerken et al. 2000, Gratwicke and Speight 2005), and its permanent territorialism (Marconato and Shapiro 1996), it seems likely that the whole life cycle may take place within each dominion.

In the Florida Keys, the most abundant parrotfishes in the RVC were *Scarus iseri* (Striped parrotfish), *Sparisoma aurofrenatum* (Redband parrotfish), *S. viride* (Stoplight parrotfish), and *S. chrysopterum*. Parameter of weight-to-length (W-L) and length-to-length (L-L) relationships of South Florida scarids are presented in Table 1. No differences in W-L curves were found among lifestages (ANCOVA, $P > 0.05$). The 95% confidence intervals of the parameter b for the pooled regression equation indicated that both *S. iseri* and *S. chrysopterum* displayed an overall isometric growth ($b = 3.0$), while *N. usta* and *S. radians* displayed a small positive allometry (≤ 3.2). Results for *S. chrysopterum* and *S. radians* agreed with observations from the Lesser Antilles by Bouchon-Navaro *et al.* (2006).

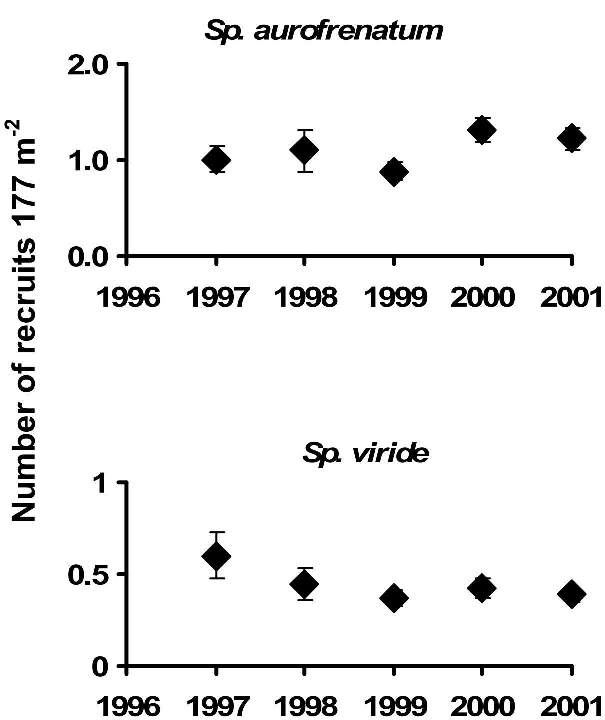

Figure 3. Recruit density

These parrotfish populations showed an onshore-to-offshore ontogenetic pattern, in which the smaller individuals occupied the near shore reefs, expanding to mid-shelf, offshore and fore reefs as the fish grew, usually in proportions driven by substrate availability. The exceptions were *S. iseri* (IPs, 4-11 cm TL), which showed active affinity for non-protected near shore strata, and *S. viride* (SP, 4-11 cm TL) that preferred non-protected reefs across the shelf. TPs concentrated in fore reefs ≥ 6 m deep. Indirect evidence suggested a seagrass-reef connection for *S. chrysopterum*, in which an influx of young IPs (TL ≥ 12 cm), leaving the bay via Safety Valve, may enter the Florida reefs along mid-shelf strata. Firstly, only few JPs of this species were observed in the reef areas, suggesting settlement grounds other than reefs. Secondly, the timing of a change in tail shape from truncated to concave in *S. chrysopterum* (at ~9-11 cm TL), which may indicate an ecomorphological adaptation for longer sustained swimming ability, coincided with the lifestage seemingly emigrating from the bay waters onto the reef habitats. Finally, an apparent reversal of the ontogenetic pattern was observed towards the middle of the shelf, which might reflect the influx of younger individuals from offshore waters.

Regarding effects of habitat protection, size structures of *S. iseri, S. aurofrenatum*, and *S. viride* did not differ significantly between protected and unprotected reefs in the Florida Keys (χ^2 P>0.10). However, distributions of *S. chrysopterum* varied with protection status (χ^2 P<0.01), with larger modal sizes inside protected areas (Figure 3). No-take areas tend to protect high rugosity reefs, whereas this parrotfish have more affinity for seagrass, hard bottom, and rubble substrates, especially during its early developmental stages. Non-significant differences of mean lengths and observed maximum lengths between protected and unprotected reefs were more common (*e.g.*, Figure 2). Effects on recruitment were not detectable within the first five years of MPA implementation (Figure 3).

CONCLUSIONS

This study is unique because South Florida parrotfish populations present an extraordinary opportunity for the holistic approach on fisheries management. This research has provided medium and large scale analyses of temporal and spatial patterns of habitat use within and among an adjacent seagrass embayment and a coral reef by South Florida scarids. In Biscayne Bay, the results demonstrated the importance of seagrass beds as settlement, recruitment, and nursery areas for parrotfish; seasonal movements were also detected. In the Florida Keys, there was evidence of ontogenetic shifts from inshore to offshore habitats, and annual variability of abundance and distribution of fish. By following the only species with significant presence in both sampling domains, the results suggested a role of Biscayne Bay as source of juveniles and subadults of *S. chrysopterum* to the Florida reef tract.

LITERATURE CITED

Bouchon-Navaro, Y., C. Bouchon, D. Kopp and M. Louis. 2006. Weight-length relationships for 50 fish species collected in seagrass beds of the Lesser Antilles. *Journal of Applied Ichthyology* **22**: 322–324.

Campos, W.L. 1985. Distribution patterns of juvenile epibenthic fish in South Biscayne Bay, Florida. M.S. Thesis. University of Miami, Marine Biology. Miami, Florida USA. 109 pp.

Can, F., N. Basusta and M. Cekic. 2002. Weight-length relationships for selected fish species for the small-scale fisheries off the south coast of Iskenderun Bay. *Turkish Journal of Veterinary and Animal Science* **26**: 1181-1183.

Choat, J.H. and D.R. Robertson. 2002. Age-based studies on coral reef fishes *In*: Sale, P.F. (ed.). *Coral reef fishes: dynamics and diversity in a complex ecosystem*. Academic Press. pp. 57-80.

Department of Commerce, U.S. 1999. Ecosystem-based fishery management. A report to Congress from the Ecosystem Principles Advisory Panel. National Marine Fisheries Service, NOAA. 54 pp.

Diaz, G. 2001. *Population Dynamics and Assessment of Pink Shrimp (Farfantepenaeus duorarum) in Subtropical Nursery Grounds*. Ph.D. Dissertation. University of Miami, Rosenstiel School of Marine and Atmospheric Science. Miami, Florida USA. 175 pp.

Garcia, S.M., A. Zerbi, C. Aliaume, T. Do Chi and G. Lasserre. 2003. *The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook.* FAO, Rome, Italy. 71 pp.

Gratwicke, B. and M.R. Speight. 2005. The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. *Journal of Fish Biology* **66**(3): 650-667.

Manly, B., L. McDonald and D. Thomas. 1993. *Resource Selection by Animals*. Chapman & Hall, Great Britain. 177 pp.

Marconato, A. and D.Y. Shapiro. 1996. Sperm allocation, sperm production and fertilization rates in the bucktooth parrotfish. *Animal Behavior* **52**(5): 971-980.

Nagelkerken, I., M. Dorenbosch, W.C.E.P. Verberk, E. Cocheret de la Moriniere and G. van der Velde. 2000. Importance of shallow-water biotopes of a Caribbean bay for juvenile coral reef fishes: patterns in biotope association, community structure and spatial distribution. *Marine Ecology Progress Series* **202**: 175-192.