Development of interdisciplinary criteria to identify priority candidate no-take marine protected areas in Puerto Rico: Integration of ecosystem-based and community-based models

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INDEX

SUMMARY

Chapter 1: Status and magnitude of no-take MPA management issues in Puerto Rico.

There is a need to develop standardized criteria to identify priority candidate no-take marine protected areas (MPAs) in Puerto Rico (PR). There is still scarce information regarding the ecological status of marine fish communities in PR. Also, community-based participatory processes for the decision-making and management of reef fisheries are largely absent in PR. This has resulted in poor management decisions regarding the conservation and restoration of coral reef fisheries. This project provided a quantitative baseline regarding the actual status of coral reef-associated fisheries within Arrecifes La Cordillera Natural Reserve (ALCNR) in northeastern PR and identified the community expectations of and support for the designation of no-take MPAs within the reserve boundaries. We used a holistic approach that employed a set of biophysical and socioeconomic methods as part of a participatory model to develop a set of interdisciplinary criteria necessary for the establishment of priorities for the identification of candidate no-take MPAs. This project was aimed at three objectives: (1) *Quantitatively assess the actual status of coral reef fish communities within ALCNR*. This was accomplished by means of 65 replicate 30 x 4 m belt transect visual censuses to characterize fish communities at seven localities within ALCNR; (2) *Develop a participatory model to involve local fisher communities and other stakeholder groups in a decision-making process aimed at suggesting candidate no-take MPA sites within ALCNR*. This was accomplished using a variety of social science field techniques (including semi-structured interviews, focus groups, and limited, participatory surveys). It allowed us to identify strategies by which to maximize coral reef-associated fisheries protection while enabling public participation; and (3) *Develop an interdisciplinary data matrix using a combination of biological, ecological, regional, impacts, pragmatic, social and economic criteria to rank no-take MPA sites*. This was accomplished by developing a scoring and ranking system for each criterion that allowed us to prioritize candidate no-take MPA sites and facilitated evaluation, discussion and decision-making processes. The results identified areas of convergence between different stakeholder groups, ranked candidate no-take MPA sites, evaluated the preferred methods of public participation within and between community groups, and determined community expectations of no-take MPA benefits and costs. Furthermore, the information gathered contributed in devising and prioritizing strategies by which to maximize coral reef-associated fisheries protection while enabling public participation and maximizing community support for no-take MPAs.

Chapter 2: Characterization of coral reef fish communities.

This project component provided a quantitative baseline regarding the actual status of coral reef fish communities within ALCNR. Data was used to infer the spatial distribution of factors affecting fish communities within the ALCNR. Information was also used, in combination with Geographic Information Systems (GIS), to develop basic mapping products to rank study sites based on reef fish benthic community parameters (Chapter 4). Data was also used, in combination with information obtained from a community-based participatory decision-making model aimed at suggesting candidate no-take MPA sites within ALCNR (Chapter 3), to develop an interdisciplinary data matrix used to rank priority candidate no-take MPA sites (Chapter 4). Coral reef fish communities within ALCNR were

showing unequivocal signs of crisis. Populations of the most significant fishery-targeted species were significantly depleted, apex predators were largely absent from most reefs, the most significant predators were small or medium-sized intermediate predators, and herbivore guilds were dominant across most sites (i.e., abundance, biomass). Several fish functional groups were largely depleted through most of the study sites, particularly in areas subjected to very intense recreational activities, including spearfishing. Piscivore guilds were the most affected. Most grouper (Serranidae), snapper (Lutjanidae), and barracuda (Sphyraenidae) populations were significantly depleted or completely absent at most sites. This pattern was evident also for some grunts (Haemulidae). Further, most individuals of fishery-targeted species observed belonged to smaller size categories. Other significant fishery-targeted groups such as triggerfishes (Balistidae), porcupinefish (Diodontidae), highly-prized species such as Nassau Grouper (*Epinephelus striatus*), or entire genera such as *Mycteroperca* spp. were totally absent during the entire study. Herbivores represented 53% of the total fish abundance in shallow reef zones, and 50% in deeper habitats, while carnivores represented 39% and 28%, respectively. Also, herbivores represented 71% of the total fish biomass in shallow coral reefs, and 55% in deeper zones, while carnivores represented 27% and 43%, respectively. Such trends represent an unequivocal shifting of inverted abundance and biomass pyramids as a result of a long-term intense overfishing of apex predators, and heavy exploitation of primarily carnivorous trophic level fishes. Recreational and artisanal fishing activities across the reserve were poorly managed. Another significant finding was the depauperate condition of many non-targeted taxa such as Grammatidae, Clinidae, Labrisomidae, Chaenopsidae, Blennidae, Monacanthidae, and Tetraodontidae were almost completely depleted or absent from study sites. We suggest that such condition could have been related to the massive coral mortality that followed the unprecedented sea surface warming and mass bleaching that occurred during 2005. Further, benthic communities were also reflecting major recent declines in % coral cover, particularly in the most significant reef-building taxa. This has been largely the result of chronic water quality degradation (i.e., recurrent polluted runoff pulses from the Fajardo coast), variable human recreational impacts (i.e., anchoring), and the massive coral mortality event of 2006 that followed the 2005 unprecedented sea surface warming event and bleaching episode. The actual status of coral reef fish communities within ALCNR is a major cause of concern that requires rapid action to significantly reduce or eliminate consumptive uses through the establishment of a network of small, discrete no-take MPAs.

Chapter 3: Characterization of stakeholder groups.

Fishermen relied on the reserve mainly on a seasonal basis and less so for key, commercial species such as spiny lobster, conch, and yellowtail snapper, that fishermen did not exhibit any direct conflicts with other user groups, that fishermen perceived a long-term decline in key, natural resource conditions in the reserve related to their livelihoods (i.e. commercial fisheries), and that fishermen were generally in favor of a no-take MPA that exists on a de facto basis – the Cayo Icacos to Cayo Lobos (and perhaps Cayo Palomino) – due to the high volume of recreational use within and between those islands. If a no-take MPA is to be implemented using stakeholder participation, the following should be considered: Participation should involve open meetings that allow complete participation, over technical workshops and representative councils; fishermen's views on site location and allowable uses should be included in the information gathering and decision-making process; and, regardless of the governmental agency that would administer the no-take MPA, management should facilitate dialogue among the commercial fishing communities in the region and the PRDNER such that the former may improve trust in the agency.

Concessionaires were comprised of diverse interests, including dive and snorkel operators, catamaran and other large vessel operators, and fishing and other mixed-trip charters. The entire group relies extensively (in many cases, exclusively) on the reserve's coastal and marine resources for its livelihood, and there was a majority view among respondents that the reserve's coral reef and related resources have declined over the past decade or longer. Most concessionaires also identified Cayo Icacos and Cayo Palominos as areas that experience high volumes of use and which are centers of use conflict, particularly from recreational divers and private recreational vessels. Due to these and related factors (i.e., overfishing, water quality decline), over 70% of the concessionaires were in favor of a no-take MPA within the ALCNR. The reserve, as would be designed by most respondents, would exclude commercial and recreational fishing but would allow non-consumptive uses, including diving, snorkeling, and cruising. The areas that were most often identified as candidate sites were those which were the waters around the most heavily visited islands, including Cayo Icacos and Cayo Lobos. Although less popular, concessionaires also identified as Cayo Diablo and Cayo Palominos as islands around which to set up a no-take MPA. Concessionaires believed that reserve designation should involve mainly open meetings that allow all stakeholder groups and the public, while many concessionaires also favored having other forms of public participation, including technical workshops. Finally, concessionaires were more amenable than the commercial fishing group to have PRDNER manage the no-take MPA site, but most still preferred a federal agency, mainly because of the latter's enforcement capability and financial advantage.

Registered vessel operators who visited the ALCNR are prolific boaters, taking five trips per month, each of which lasted over half a day (4.5 hours); thus, they represent a group that is most likely knowledgeable about the region and its resources, if not its designated status. That is, the results also demonstrated that while the operators took a majority, or almost 90%, of their trips to the reserve, over a third of the respondents were unaware of the reserve or its boundaries. If the group were to be engaged in a process to set up a no-take MPA, part of the process would have to involve boater (and, indeed, general public) education on the existence of the reserve and its present boundaries and regulations. The results also determined that a smaller percentage of registered vessel operators (52%), compared to the corresponding percentages of commercial fishermen (80%) and concessionaires (73%) supported a no-take MPA designation. However, this lower support for a no-take MPA may have been a result of the methodology involved, which consisted of a formal, self-administered survey instrument that did not allow for respondents to select the types of uses that could be restricted and choices between designation processes and different management agencies. Notwithstanding those constraints, over 90% of those who did identify a recommended no-take MPA in the reserve selected Cayo Icacos, which was more popular than the adjacent Cayo Lobos and Cayo Palominos, but which together garnered support for closure from over 70% of the registered vessel operators.

It was determined that all stakeholder groups agreed that coral reef conditions in the reserve had declined, as had associated resources such as water quality which affected the health of the coral reefs and fisheries which depended on healthy coral reefs. While the stakeholder groups believed that there were a myriad of causes for the decline, there was general consensus that overfishing (resulting from commercial and recreational fishing) and development (especially as related to coastal and marine tourism, sedimentation, and water quality) had been responsible. The stakeholders mostly accepted the solution of implementing a no-take MPA and may actually have been addressing their concerns over resource decline by identifying the most heavily used areas (the Cayo Icacos-Lobos-Palominos complex) as those which deserve the highest protection. While it is clear that non-consumptive stakeholder groups stand to gain the most by restricting access to all other kinds of uses within a no-take MPA, the study revealed that even consumptive groups such as commercial fishermen, fishing charters, and consumptive dive charters generally did not oppose the implementation of a no-take MPA.

As important as reaching consensus on the location and characteristics of a no-take MPA was the determination of the process to be used to foster public participation in a format that stakeholders considered would be fair and equitable and the identification of the management agency which stakeholders believed would be best positioned to ensure enforcement and management efficacy. While not discussed in any detail in this report, it was found via commercial fishermen and concessionaire interviews that the stakeholder groups held a dim view on public participation; that is, members of both groups often felt that meetings addressing resource management were often poorly advertised and held at hours when they could not attend. Others believed that public participation, while allowed and even promoted, made little difference in influencing the final decisions. However, stakeholders still preferred holding meetings as part of the decision-making process for a no-take MPA instead of other formats, such as technical workshops or representative councils. Finally, in terms of identifying the agency that could best implement a no-take MPA, most stakeholders were in favor of a federal agency, particularly the Fish and Wildlife Service (FWS). It is likely that the FWS was most commonly cited because it is the primary federal, natural resource agency that most stakeholders are aware of in the region, through experiences with the Vieques National Wildlife Refuge and the Culebra National Wildlife Refuge. Thus, at the federal level at least, stakeholders should be made aware of other models, including national parks and, in particular, national marine sanctuaries. Also, there remains the need to better understand and ameliorate the mainly negative views that many stakeholders, and especially commercial fishermen, hold towards PRDNER. Many stakeholders interviewed as part of the study believed that PRDNER did not have the financial or enforcement capacity to manage a no-take MPA. Others felt that the agency was draconian and thus did not foster stakeholder confidence in being fair in the management of a no-take MPA. Finally, a few respondents perceived the agency as having failed to adequately protect the regional natural reserves, including Luis Peña Channel No-take Natural Reserve and ALCNR, and argued that the agency could not handle additional management tasks. These examples are raised here to highlight the pervasive views held by many stakeholders concerning PRDNER and to recommend that any no-take MPA designation process consider improving stakeholder understanding of DRNA objectives, management actions, and accomplishments and an overall rehabilitation of the agency's image in relation to stakeholder trust.

Chapter 4: Geo-spatial rankings of coral reef fish community characteristics and other designation criteria

Overall, SDP ranked as the most significant site for a no-take MPA designation, with a 83.3% combined score. It was followed by DIA with a score of 74.6%, and PLM and LOB, with 73.8%, each one. PLT followed with 69.8%, ICW with 65.1%. ICE scored 45.2%. These results suggest that based on a combination of criteria, three different complexes emerged as potential candidate no-take MPA sites: SDP-DIA complex, PLM-PLT, and LOB-ICE-ICW. SDP-DIA ranked highest under most criteria, but mostly under biological criteria. These sites are located at approximately 10 km off the Fajardo coast and show the lowest density of visitors (see Shivlani, Ch. 3). Distance and strong oceanographic conditions is a major constraint largely reducing recreational activities east of LOB towards DIA. Therefore, biological criteria strongly supports its designation as a no-take MPA. PLM-PLT is an area that also showed a moderately high ranking by a combination of criteria. But also, most stakeholders including 80% of the commercial fishermen, 73% of concessionaires and registered vessel operators, and 52% of private vessel operators (Shivlani, Ch. 3) supported its designation as a no-take MPA due to several reasons. These included proximity, easy access, usually protected conditions at frequented areas, and overfished state. Similar justifications were presented for supporting the designation of ICW-ICE-LOB complex.

There was a strong agreement between stakeholder perceptions of the status of ALCNR's natural resources (i.e., fish communities, benthic communities, water quality, cleanliness, etc.) and empirical data obtained in this study regarding the status of fish communities within the reserve that strongly support the immediate designation of no-take MPAs within ALCNR. Candidate sites include three different island-key complexes: SDP-DIA, PLM-PLT, and ICW-ICE-LOB. With the exception of SDP-DIA, commercial fishermen strongly supported the designation of all other sites. However, some of the fishermen did support its designation. All other stakeholders strongly supported ICW-ICE-LOB, and PLM-PLT, and in a lower degree SDP-DIA. The suggested three sites is a consensus solution based on empirical data and stakeholder perceptions and recommendations.

After careful consideration of empiric evidence regarding the depauperate condition of fish communities within ALCNR, and stakeholders perceptions of the status of the reserve, we strongly recommend PRDNER and NOAA to consider alternative 2 as the preferred option, or alternative 4 as a consensus option. Alternative 2 will definitely provide better protection to critical resources as well as facilitate enforcement of no-take areas. However, it will require stronger efforts to seek full support by fishermen and other user groups that may fully support the designation of smaller areas. This solution would be consistent with the ranking analysis performed in Ch. 4. Alternative 4 adjust better to a consensus model more compatible with the options supported by fishermen and other user groups, while simultaneously protecting overexploited resources by overfishing and recreational activities, as well as protecting critical areas that still support healthier fish populations.

Chapter 5: Final remarks and management recommendations.

This study identified areas of convergence between different stakeholder groups, ranked candidate no-take MPA sites based in multiple criteria, evaluated the preferred methods of public participation within and between community groups, and determined community expectations of no-take MPA benefits and costs. Information gathered contributed to devise and prioritize strategies by which to maximize coral reef-associated fisheries protection while enabling public participation and maximizing community support for no-take MPAs. No-take MPA implementation linked to habitat protection and management can be the most significant tool to recover already depleted fish populations within ALCNR system. We strongly recommend PRDNER and NOAA to consider alternative 2 as the preferred option, or alternative 4 as a consensus option to designate a no-take MPA. Alternative 2 will definitely provide better protection to critical resources, will facilitate enforcement of no-take areas, and would be consistent with the ranking analysis performed in Ch. 4. But alternative 4 adjust better to a consensus model more compatible with the options supported by fishermen and other user groups, while simultaneously protecting overexploited resources by overfishing and recreational activities, as well as protecting critical areas that still support healthier fish populations.

CHAPTER 1

Status and magnitude of no-take MPA management issues in Puerto Rico

(E.A. Hernández-Delgado, M. Shivlani, A.M. Sabat)

Background

The designation and conservation of no-take Marine Protected Areas (MPAs) is one of the top priorities under the National Coral Reef Action Strategy (USCRTF, 2000) and under the Puerto Rico (PR) Local Action Strategy (LAS) plan (PRDNER and USDC, 2003). Currently, there are five no-take MPAs covering only 54.2 km^2 (1.08%) of the PR shelf. These include Canal Luis Peña Natural Reserve, Tres Palmas Marine Reserve, Desecheo Island Marine Reserve, and a 0.5 mile-wide stretch of waters surrounding the north, east and south coast of Mona and Monito Islands (Figure 1.1). The State Chamber Resolution 307 (2000) and Goal #3 of the PR LAS plan (2004) required the designation of 3% of the PR insular shelf as full-time no-take MPAs. Thus, at least another 100 km^2 of shelf bottom must be declared as full-time no-take MPAs to comply with these expectations. The PR LAS plan also established the need to develop criteria to identify priority candidate areas to be designated as no-take MPAs. However, no actions on this direction have been taken so far.

In spite of significant recent research efforts conducted by NOAA/NOS/NCCOS/CCMA Biogeography Branch, the University of Puerto Rico's Coral Reef Ecosystem Studies (CRES) Program, the Caribbean Coral Reef Institute (CCRI), and the PR Department of Natural and Environmental Resources (PRDNER),

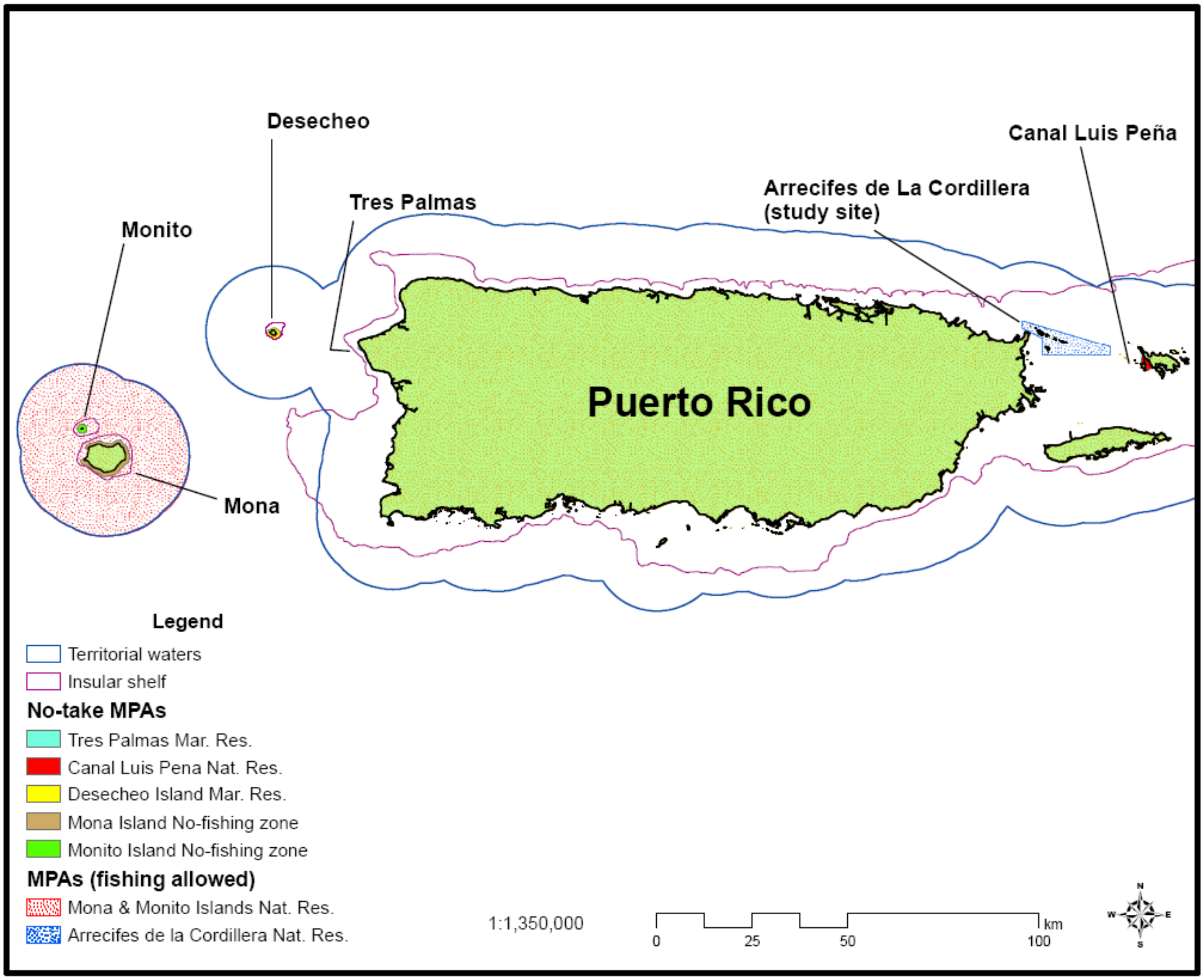

FIGURE 1.1. Distribution of no-take MPAs in Puerto Rico in relation to the study site. Full-time no-take MPAs cover 45.47 km^2 of the insular shelf and are distributed as follows: Mona Island no-fishing zone (28.13 km^2), Monito Island no-fishing zone (4.09 km^2), Desecheo Island (6.10 km^2), Tres Palmas Marine Reserve (0.83 km^2), and Canal Luis Peña Natural Reserve (6.33 km^2). The entire 100% surface area of Desecheo, Tres Palmas, and Canal Luis Peña are full-time no-take MPAs. Mona no-fishing zone represents only 1.80% of the surface area of the Mona and Monitro Island Natural Reserve, while Monito no-fishing zone represents 0.26% of the reserve.

among others, there are still large information gaps concerning the actual ecological status of coral reef fish communities in PR, including Arrecifes La Cordillera Natural Reserve (ALCNR). Recent regional assessments have also identified overfishing as top priority issue through the northeastern Caribbean, including PR (Burke and Maidens, 2004; Hawkins and Roberts, 2004; Paddack et al., 2009). There is limited information regarding the status of coral reef-associated fisheries within ALCNR, but the scant data suggests significant fishing impacts in several locations (Hernández-Delgado, 2000; Hernández-Delgado and Sabat, 2000). The lack of proper resource assessments highlights the need to identify, monitor, and protect critically important fishery resources and targeted populations. Even more importantly from a resource management perspective, community-based participatory processes regarding decision-making and management of reef fisheries remained largely absent in PR until recently. Previous research has shown how the lack of participatory schemes (i.e., public and stakeholder input) on MPA planning, decision-making and management can lead to significant opposition and poor support if any at all, resulting in stakeholder group misperceptions of management goals and objectives, and a poor understanding of community expectations, among others (Fiske, 1992; Suman et al., 1999; McConney et al., 2003; Helvey, 2004).

ALCNR supports important coral reefs, associated ecosystems, and fishery resources (DRNA, 1990a,b; Hernández-Delgado, 2000, 2005; Hernández-Delgado and Sabat, 2000; García-Sais et al., 2003; CSA Group, 2005; Ballantine et al., 2008). It also supports a rapidly expanding coastal and marine tourism industry, which has resulted in significant impacts by recreational activities (i.e., massive charter vessel excursions, boating, anchoring, SCUBA diving, snorkeling), especially consumptive ones such as fishing (Hernández-Delgado, 1992, 1994, 2000, 2005; CSA Group, 2005). Currently, there are no no-take zones within ALCNR, but such zones remain as one of the management options currently under evaluation by the PRDNER. Thus, ALCNR provides a perfect case study to develop interdisciplinary criteria to identify priority candidate no-take MPAs by the novel combination of traditional empiric information regarding the condition of coral reef fish communities and a community-based participatory model.

Recent actions undertaken to address the issues

At the October 2, 2002 US Coral Reef Task Force (USCRTF) meeting in San Juan, NOAA and PRDNER announced five initiatives to strengthen Coral Reef Management in PR. One of these initiatives was strengthening the Natural Reserve system, and ALCNR was one of the identified priority areas. PRDNER has prioritized management actions at ALCNR and already produced a draft management plan which is on its final stage. Further management strengthening efforts at ALCNR include the development of capacity-building of the resource management personnel, habitat characterization surveys, and recreational boating impact surveys, among others.

How did the project fitted into the jurisdiction's strategy to address critical coral reef conservation needs?

The project fitted into the National Coral Reef Action Strategy, building on Action Theme 1, Goal 4 (*To understand social and economic factors*) and Action Theme 2, Goal 5 (*To improve the use of marine protected areas in the coral reef ecosystems*) (USCRTF, 2000). It also complied with one of the priority goals, objectives and projects of the PR LAS plan including: 1) "*identify, designate and implement the*

3% minimum of the insular platform as a no-take marine reserve with respect to the Chamber Resolution 307 and prepare management plans in collaboration with the community for these reserves"; 2) "*establish priorities for potential areas to be designated as no-take marine reserves*"; 3) "*identification and prioritization of indicators and parameters that will serve as priorities for designating no-take marine reserves*"; and 4) "*designate and implement one or more no-take marine reserves based on the ecological importance of the coral reefs in the area to comply with the required 3% designation*" (PRDNER and USDC, 2003).

The project was also consistent with one of the priority NOAA-DNER announcements released at the USCRTF meeting of October 2002, that of facilitating stakeholder participation into management decisions. We also provided baseline information regarding the actual status of ALCNR coral reef-associated fisheries that will contribute to fill up major fishery-independent data gaps, complemented existing long-term coral reef monitoring efforts (i.e., CCRI), and provided important baseline data for the implementation of the recently drafted management plan, thus supporting current PRDNER's ALCNR management plan implementation initiative. This further supports current NOAA's coral reef fisheries monitoring and management efforts through the U.S. Caribbean.

Identification of problems

This project provided a quantitative baseline regarding the actual status of coral reef-associated fisheries within ALCNR and identified the community expectations of and support for the designation of full-time no-take MPAs within ALCNR. It also contributed addressing several no-take MPA management-related problems that are listed below:

- *There is limited information regarding the status of coral reef-associated fish communities within ALCNR*. As part of the PRDNER strategy to implement the recently drafted ALCNR management plan, the development of a baseline data bank regarding the actual status of coral reef fish communities is a paramount priority. We were able to document spatial variation patterns in coral reef-associated fish community structure that contributed to establish the baseline for future long-term monitoring efforts, complementing current efforts conducted by CCRI. It also allowed the identification of threatened and refuge populations of commercially-important species, important fish recruitment sites, critical habitats for sustaining high biodiversity, fish abundance and biomass. Also, in combination with interviews to local artisan fisher associations, we got an insight on current fishery trends.

- *PRDNER needed to fill data gaps identified through the management plan development process for ALCNR*. There was a major data gap regarding the actual status of coral reef-associated fisheries and reef benthic communities within ALCNR. This study provided PRDNER useful baseline information and management recommendations regarding the potential designation of full-time no-take MPAs within ALCNR. This approach allowed ranking the important of surveyed candidate sites under different interdisciplinary criteria. This allowed testing a novel strategy to evaluate candidate no-take MPA sites by combining empirical fish community data and community-based perceptions and recommendations

- *Ecosystem-based coral reef-associated fishery management has been poorly implemented in PR Natural Reserves*. Fishery target species are often used as indicators of compliance and management success in no-take MPAs (Roberts, 1995a). However, this approach has the limitation of ignoring functional roles of fishes at the community and ecosystem levels. It also ignores the functional role that coral reef benthic habitat integrity has on maintaining fish community structure. Functional changes in fish communities often accompany structural changes at the ecosystem level, thus affecting major reef processes such as grazing, predation, competition, food web structure, energy flow and interactions among species (Sobel and Dahlgren, 2004). It could also impair benthic processes such reef accretion and bioerosion (Roberts, 1995b). Top-down fishing effects can result in significant phase shifts in coral reefs benthic community structure (Hughes, 1994; Hawkins and Roberts, 1994), leading to declines in functional redundancy and in ecosystem resilience (Bellwood et al., 2003, 2004). Environmental degradation can also produce bottom-up effects resulting in declining fish biodiversity (Jones et al., 2004) and biomass (Hernández-Delgado et al., 2006). These impacts have been recently magnified by impacts associated to climate change that have resulted in significant fish community phase shifts (Bellwood et al., 2006; Pratchett et al., 2008; Hernández-Delgado et al., in preparation). However, these types of impacts have often been poorly documented due to limited funding or to standard monitoring efforts focused only on a few target species, ignoring ecological changes across the entire fish community. Current large-scale reef crisis (Gardner et al., 2003; Paddack et al., 2009) requires an improved understanding of the ecological processes that underlie reef resilience. Such processes may include phase shifts in coral reef fish and benthic community structure and their relationship to modifications in their functional roles in coral reef ecosystems (Bellwood et al., 2004). In addition, and until very recently, lack of significant public participation in the management cycle (i.e., identification of problems and solutions, planning, decision-making, implementation, monitoring, governance) has been a major concern (McConney et al., 2003). Human uses are a critical issue that deserves major attention during the process of evaluating and designing candidate no-take MPA sites (Salm et al., 2000; NRC, 2001). This project integrated community-based perceptions and empirical ecosystem-based approaches to characterize coral reef fish communities in an effort to obtain an ecosystem-based baseline view of MPA effectiveness, and in an effort to evaluate, rank and recommend potential candidate no-take MPA locations within ALCNR.

- *Community-based participatory processes regarding decision-making and management of reef fisheries have remained largely absent in PR*. Participatory decision-making processes, and conflict mediation and negotiation at the community level can result in rapid and effective natural resource management arrangements with stakeholders support (McConney et al., 2003). It has also been shown that the most effective Caribbean no-take MPAs were those where government shared management responsibilities with local stakeholders (Appeldoorn and Lindeman, 2003). However, community-based participatory management of marine resources is still largely absent in PR. This type of participatory approach is important, especially in light of Coral Reef Law 147 (1999) and Coral Reef Regulations enforced by PRDNER that are still maintaining a top-down approach that lacks adequate public participation in decision-making processes regarding MPA planning and designation. Law 147 states that public comment will be requested by DNER ***after*** reserves are designated and that public hearings will not be conducted unless requested with a strong justification. Such approaches do not foster adequate public participation. This project demonstrated the advantages of using interdisciplinary participatory approaches regarding no-take MPA designation processes and could catalyze a movement to amend the Coral Reef Law to make MPA designation a stronger participatory process.

- *No-take MPA designations in PR require novel interdisciplinary and participatory approaches*. This project provided a novel tool in PR that allowed a full interdisciplinary integration through a participatory model regarding no-take MPA designation decision-making processes. It provided the necessary framework for quantitative parameterization of biological and socio-economic data that will facilitate local stakeholder integration into coral reef management decision-making and will allow PRDNER develop a testable model to characterize and rank other candidate no take MPAs in PR. Such a model can be fully applicable to other natural reserves, as well as to other Caribbean islands. Also, it should provide the baseline to amend existing provisions on the Coral Reef Law that are still maintaining old-fashioned non-functioning top-down approaches to MPA designation that have often lead to conflicts and rejection by community stakeholders (e.g., proposed no-take MPA at Arrecife Turrumote, La Parguera). This approach has also allowed compliance with one of the NOAA-PRDNER 2002 priority announcements during the USCRTF meeting in San Juan (2002) about fostering public participation into decision-making processes regarding coral reef conservation.

- *No-take MPAs in PR have received very limited public support*. Lack of public support can result from poor implementation or total lack of participatory approaches, poor educational, outreach and/or management efforts (e.g., enforcement), that has lead to management failure(8). This project fostered stakeholder involvement into participatory decision-making processes and allowed us to identify points of convergence within different stakeholder groups, and identify and rank candidate no-take MPA sites within ALCNR based on a sort of multi-disciplinary criteria. It also allowed us to evaluate the preferred methods of public participation within and between community groups, and to determine community expectations of no-take MPA benefits and costs. Information gathered using different ecological and social science field techniques contributed in the identification of strategies by which to maximize coral reef-associated fisheries protection while enabling public participation and eventually maximizing community-based support of no-take MPAs. This novel approach in PR was absolutely compatible with PRDNER's long-term conservation and management goals for the ALCNR.

- *There are no standard criteria to designate no-take MPAs in PR*. There have been no uniform scientifically-based approaches in PR to place no-take MPAs and this project allowed us to set an important candidate-MPA evaluation model before other areas are named by PRDNER. This lack of uniformity has lead in the past to the use of various approaches for the identification and designation of no-take MPAs, ranging from nearly bottom-up (e.g., Canal Luis Peña Natural Reserve, Culebra), to top-down decisions (e.g., Mona and Monito islands no-take zones within the Natural Reserve). The legal status of no-take MPAs in PR is also highly variable, ranging from PRDNER's Secretary Administrative Orders enacted under Law No. 278 (1998) (i.e., Canal Luis Peña, Mona, Monito), to legislative designation (i.e., Desecheo, Tres Palmas). Further, decisions regarding no-take MPA designations in PR have often lacked strong baseline ecosystem-based quantitative information regarding the status of fish communities. The novel approach used in this project allowed us evaluate, rank and propose candidate no-take MPAs in PR by using an interdisciplinary approach through the development of a set of biological, ecological, regional, impacts, pragmatic, social and economic criteria to establish priorities for the identification of candidate no-take MPAs within ALCNR using empirical scientific data in combination with public perception data gathering through a participatory model approach.

The aforementioned approach confers a series of benefits and advantages:

- The approach is relatively open-ended and thus allows for a broad discussion on ALCNR management strategies.

- It has provided important baseline biological data and fostered stakeholder and interest group participation in the development of management strategies for the ALCNR.

- The biological sampling approach produced baseline information useful to develop a long-term coral reef fish ecosystem-based long-term monitoring program within ALCNR.

- The community-based approach was targeted at specific user groups, such that it includes a variety of views, including those of consumptive stakeholder groups, non-consumptive stakeholder groups, special interest groups, public interest groups, and others.

- The approach incorporated both qualitative and quantitative aspects of social science in that it used multiple tools such as semi-structured interviews, focus group sessions, as well as participatory surveys, to complete a comprehensive characterization of community and visitor views on ALCNR.

- Finally, it is important to state that this project relied on inputs at various levels and disciplines, and with the expertise of the principal investigators and cooperative linkages that the project fostered, the amount of information collected was maximized and results are applicable to similar areas through the Caribbean.

Consistency with other program's objectives

This project addressed the following GCRC objectives:

- Help preserve, sustain and restore the condition of coral reef ecosystems.
- Develop sound scientific information on the condition of coral reef ecosystems and the threats to such ecosystems.
- Increase public knowledge and awareness of coral reef ecosystems and issues regarding their conservation.
- Promote the wise management and sustainable use of coral reef resources.

This project also addressed Program Priority *d* “Coral reef fisheries management” by carrying out resource assessments and activities that identified, monitored, and helped to protect critically important fisheries habitats and populations. It also addressed Program Priority *c* regarding “Marine Protected Areas and associated management activities” by assessing gaps in the protection of fishery resources in an existing MPA, developing and providing tools for MPA management including models of community-based conservation, policy guidance, evaluating management effectiveness, determining functional linkages among candidate no-take MPA sites, and involving outreach and education efforts designed to strengthen and support community cooperation in conserving coral reef biodiversity. It also addressed Program Priority *g* regarding “Public education and outreach activities” by conducting activities that contributed to raise awareness and understanding of coral reef ecosystems, and by convening public meetings and other activities that addressed the needs of local user groups. Finally, this project addressed Program Priority *a* regarding “Monitoring and assessment of coral reefs or reef resources” by providing baseline information about the status of coral reef fish communities within ALCNR, a high priority MPA for NOAA and PRDNER.

Project objectives

This project was aimed at three objectives:

- *Quantitatively assess the actual status of coral reef fish communities within ALCNR*. This was accomplished by means of 65 replicate 30 x 4 m belt transect visual censuses to characterize fish communities at seven localities within ALCNR.

- *Develop a participatory model to involve local fisher communities and other stakeholder groups in a decision-making process aimed at suggesting candidate no-take MPA sites within ALCNR*. This was accomplished using a variety of social science field techniques (including semi-structured interviews, focus groups, and limited, participatory surveys). It allowed us to identify strategies by which to maximize coral reef-associated fisheries protection while enabling public participation.

- *Develop an interdisciplinary data matrix using a combination of biological, ecological, regional, impacts, pragmatic, social and economic criteria to rank no-take MPA sites*. This was accomplished by developing a scoring and ranking system for each criterion that allowed us to prioritize candidate no-take MPA sites and will facilitate evaluation, discussion and decision-making processes.

CHAPTER 2

Characterization of coral reef fish communities

(E.A. Hernández-Delgado, A.M. Sabat)

Introduction

This project component provided a quantitative baseline regarding the actual status of coral reef fish communities within Arrecifes La Cordillera Natural Reserve (ALCNR) in northeastern PR. The objective of this chapter was to quantitatively assess the actual status of coral reef-associated fish communities within ALCNR. Data was used to infer the spatial distribution of factors affecting fish communities within the ALCNR. Information was also used, in combination with Geographic Information Systems (GIS), to develop basic mapping products to rank study sites based on reef fish benthic community parameters (Chapter 4). Finally, the above ecological data was used, in combination with information obtained from a community-based participatory decision-making model aimed at suggesting candidate no-take MPA sites within ALCNR (Chapter 3), to develop an interdisciplinary data matrix used to rank priority candidate no-take MPA sites (Chapter 5).

Methodology

Study sites

The study was carried out at seven sites within Arrecifes La Cordillera Natural Reserve (ALCNR), which is located just east of Fajardo, in northeastern PR (Figure 2.1). These included

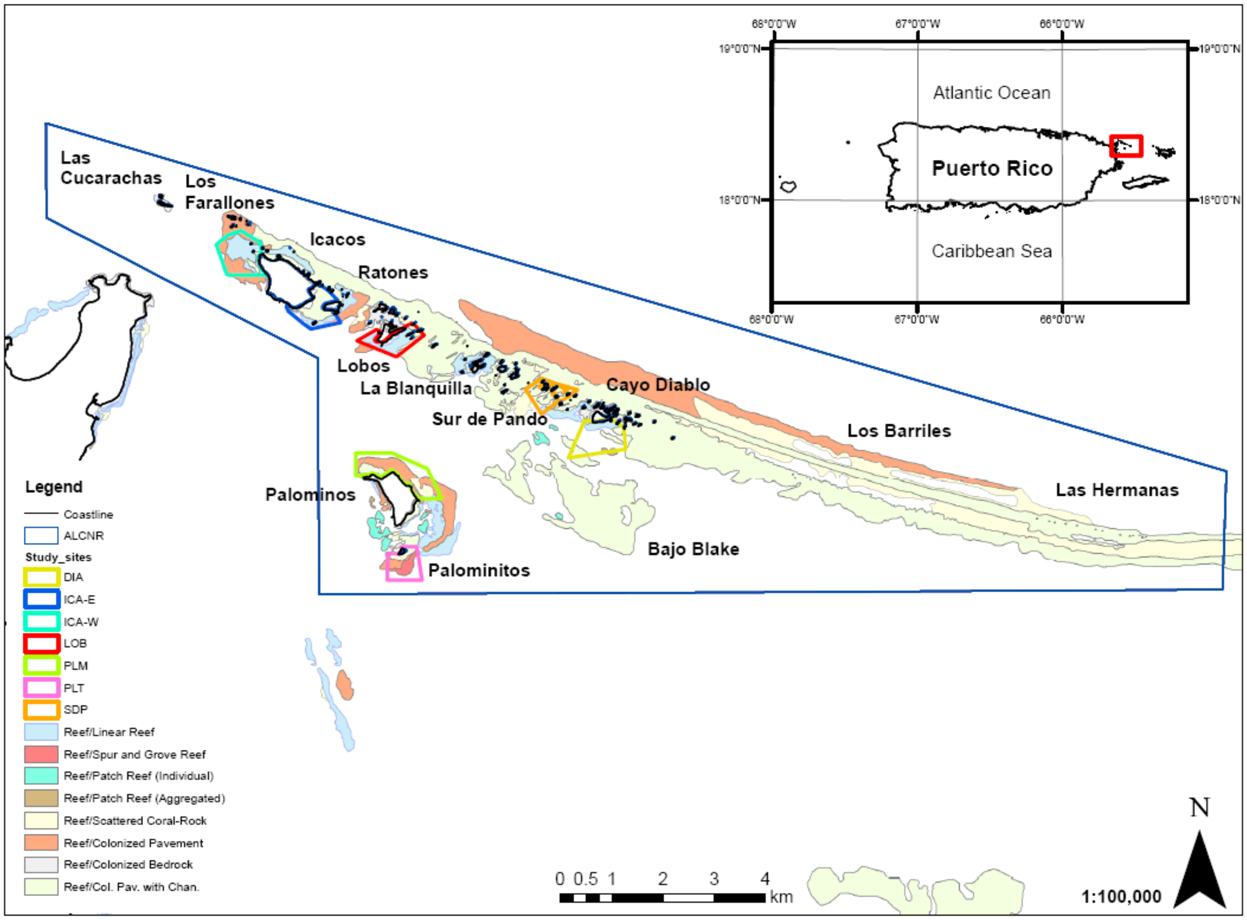

FIGURE 2.1. Study sites at ALCNR.

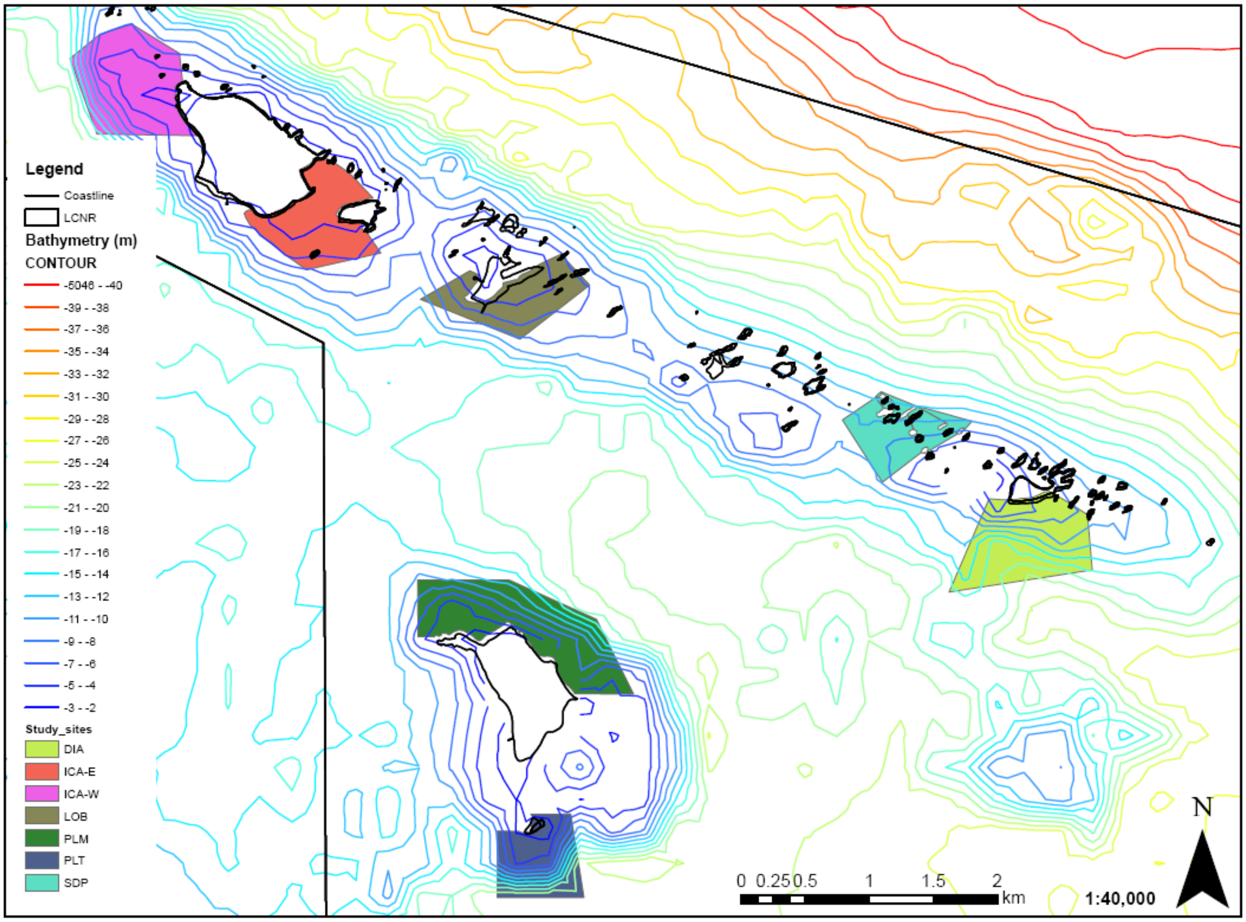

FIGURE 2.2. Bathymetry of study sites.

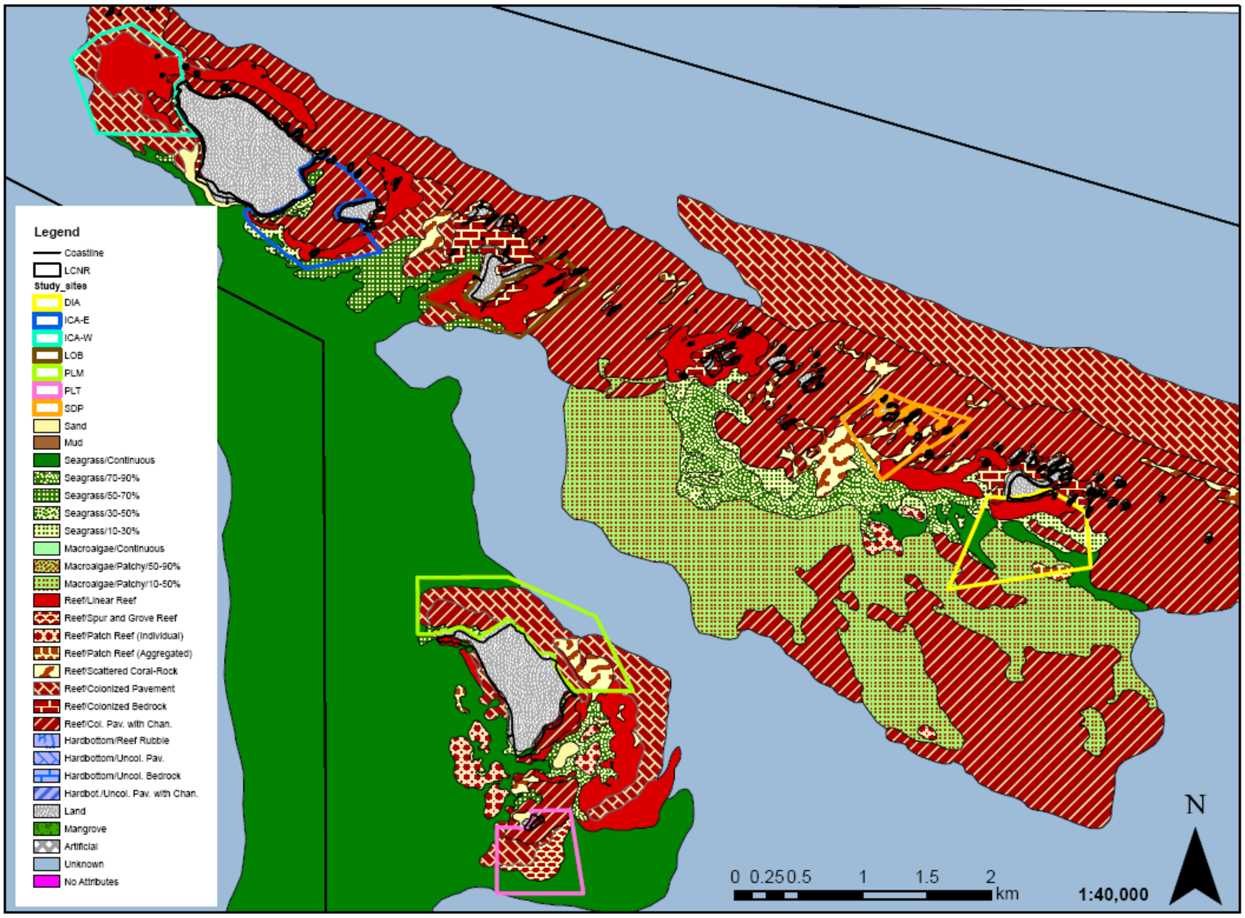

FIGURE 2.3. Benthic categories of candidate no-take MPA sites (based on NOAA, 2001).

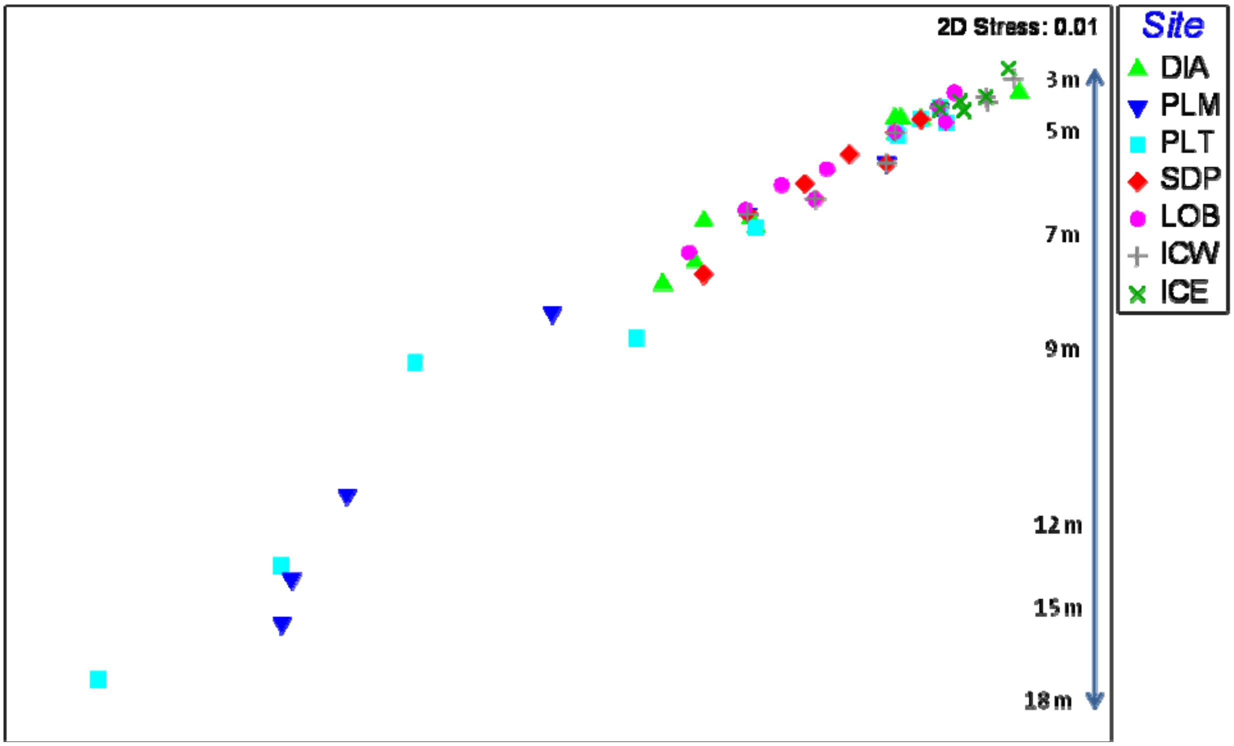

FIGURE 2.4. Multi-dimensional scaling (MDS) plot of depth gradient.

east to west: Cayo Diablo (DIA), Sur de Pando (SDP), Palominos Island (PLM), Palominitos Island (PLT), Cayo Lobos (LOB), Cayo Icacos-east (ICE), and Cayo Icacos-west (ICW). Polygons were identified in areas that included data collection sites, a representative portion of dominant benthic community types at each site, and variable depths. Depths at DIA reached 20 m, 18 m at PLM, 20 m at PLT, although some areas during field surveys reached 27 m, 10-12 m at SDP, 8 m at LOB, 16 m at ICW, and only 6 m at ICE (Figures 2.2 and 2.3).

Data collection

Fish communities were sampled following a two-way factorial design with sites (n=7) and depth zones (n=2) as main factors. Replicate fish censuses (n=5/depth zone) were used as error terms in the model. Data on fish species richness, abundance and size estimates were collected once at each site between 2007 and 2008 along a depth gradient (Figure 2.4) clustered within two depth zones (<5 m, 5-15 m). Sampling avoided winter months to prevent any bias associated to reproductive behavior of some target fish groups during these seasons (Hernández-Delgado et al., 2006). A total of five replicate censuses were conducted per depth zone at each site using haphazard 30 x 4 m belt transects that followed selected depth contours. Fishes were identified to the lowest taxon possible, counted and fork length estimated for each individual (Hawkins & Roberts, 2004). Fish fork length data was used to calculate biomass (Bohnsack & Bannerot, 1986; Bohnsack & Harper, 1988; Bohnsack unpub., 1988). Abundance of individuals from large fish schools was estimated by 10s, 20s, 50s or 100s. Weight-length relationships were calculated by fitting a regression line to the equation: $\log W = \log a + b \log L$, which is equivalent to the equation $W = aL^{b}$, where W is weight in grams, L is length in mm, and *a* and *b* are constants (Bohnsack & Harper, 1988). Basic information of the fish community structure included species richness, abundance, species diversity index (H'n) (Shannon and Weaver, 1948), evenness (J'n) (Pielou, 1966), biomass, and standing stock biomass. Also, this approach provided information about abundance and biomass at the species, family, and subfamily level, and at the trophic functional group level, including herbivore guilds (i.e., non-denuders, browsers, scrapers), carnivore guilds (i.e., generalist, piscivores, planktivores), omnivores and detrivores. It also, provided abundance and biomass data on fishery targeted species guilds. Reef structural complexity is known to have an important influence on fish community structure (Roberts and Ormond, 1987). A 6-point scale was used to characterize a reef structural heterogeneity index (RSHI) as follows: 0= no vertical relief; 1= low and sparse relief; 2= low but widespread relief; 3= moderately complex; 4= very complex with numerous caves and fissures; 5= exceptionally complex with high coral cover and numerous caves and overhangs (Hawkins et al., 1999).

Performance measures of the fish community assessment phase of the project relied on standard species accumulation curves and statistical power analysis, expecting mean power values >0.80 per sampling effort at each sampling station for most of the parameters. This approach allowed us to determine if the number of replicate fish censuses was enough to achieve high statistical power, otherwise allowed us to make adjustments as needed. This study provided a baseline data bank that will be used to launch a future long-term coral reef fish-community monitoring program in ALCNR. It also contributed empirical data to parameterize the interdisciplinary data matrix that helped us score and rank each candidate no-take MPA site within the reserve.

Parametric community data analysis

Several null hypotheses regarding spatial variation patterns in coral reef fish community parameters were tested using a two-way analysis of variance (ANOVA) using sites, and depth zones as main factors (Zar, 1984). Tukey's test was used to compare means (Zar, 1984). No interaction effects were tested due to an unbalanced model as a result of having only one depth zone sampled at ICE. Statistical significance helped us identify significant and critical areas that might require immediate management action. Data on counts were square root-transformed ($X' = \sqrt{X}$; or $X' = \sqrt{(X+0.5)}$ if there are zeros), data on fish abundance and biomass were $\log_{10}$-transformed. Data on proportions were transformed to arcsine-($\sqrt{X}$) (Zar, 1984). Pearson correlation analysis was used to test for significant relationships between fish community parameters, RSHI, and depth.

Multivariate community data analysis

Several null hypotheses regarding spatial variation patterns in coral reef fish community structure at the functional group and the species levels were tested using multivariate statistics. Individual coral reef fish community matrices based in fish species and fish functional group biomass were compiled and imported into PRIMER ecological statistics software package for multivariate analysis (Clarke and Warwick, 2001). Mean proportional data from each site (n=7) and depth zone (n=2) were classified with hierarchical clustering (CLUSTER) using the Bray-Curtis group average linkage method (Bray and Curtis, 1957) and then ordinated using a non-metric multidimensional scaling (MDS) plot (Clarke and Warwick, 2001). Spatial variation patterns were tested using PRIMER's multivariate equivalent of an ANOVA called ANOSIM. Key taxa responsible for spatial variation in community structure between groups of sites and depth zones were determined using SIMPER routine. Principal Component Analysis (PCA) was also used to test for correlations among spatial patterns in fish community structure, RSHI, and depth.

Results

Surveyed habitat characteristics

Study sites were characterized by a gradient of reef benthic spatial heterogeneity. The reef spatial heterogeneity index (RSHI) showed significant differences among sites and between depth zones (Figure 2.5, Table 2.1). With the exception of LOB, RSHI was usually higher in deeper reef zones. It was particularly higher at deeper zones in PLT, both zones at DIA, deeper zones of PLM, and both zones of LOB and ICW. There was a highly significant correlation (r=0.4653, *p*=0.0001) between RSHI and depth that suggested overall increased RSHI with increasing depth (Figure 2.6). When combined in a multi-dimensional scaling (MDS) plot, RSHI and depth formed four evident clusters following an increasing trend in RSHI value with depth (Figure 2.7). The wider the spatial distribution of RSHI points per individual site in the vertical dimension of the MDS plot, the wider the spatial heterogeneity of each reef. The wider the spatial distribution of RSHI points per site in the horizontal dimension of the MDS plot, the stronger the impact of depth.

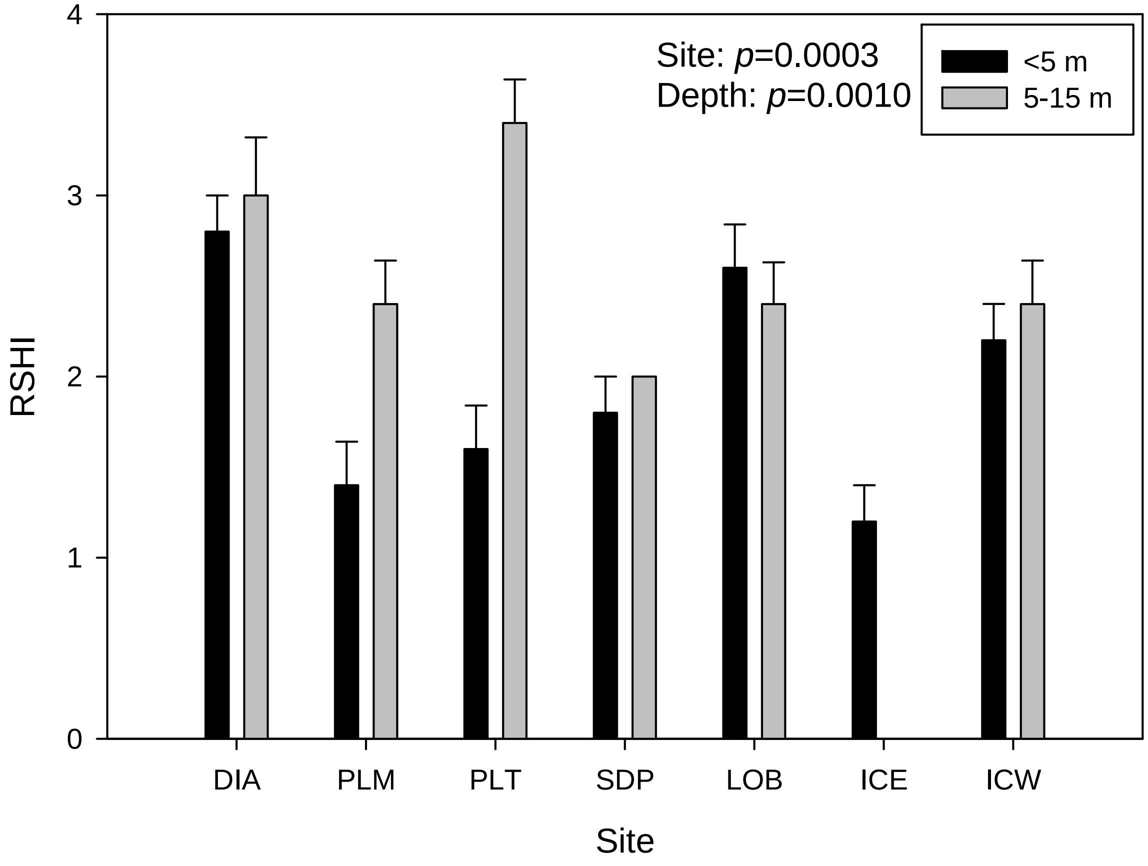

FIGURE 2.5. Mean reef spatial heterogeneity index (RSHI) values (±one standard error).

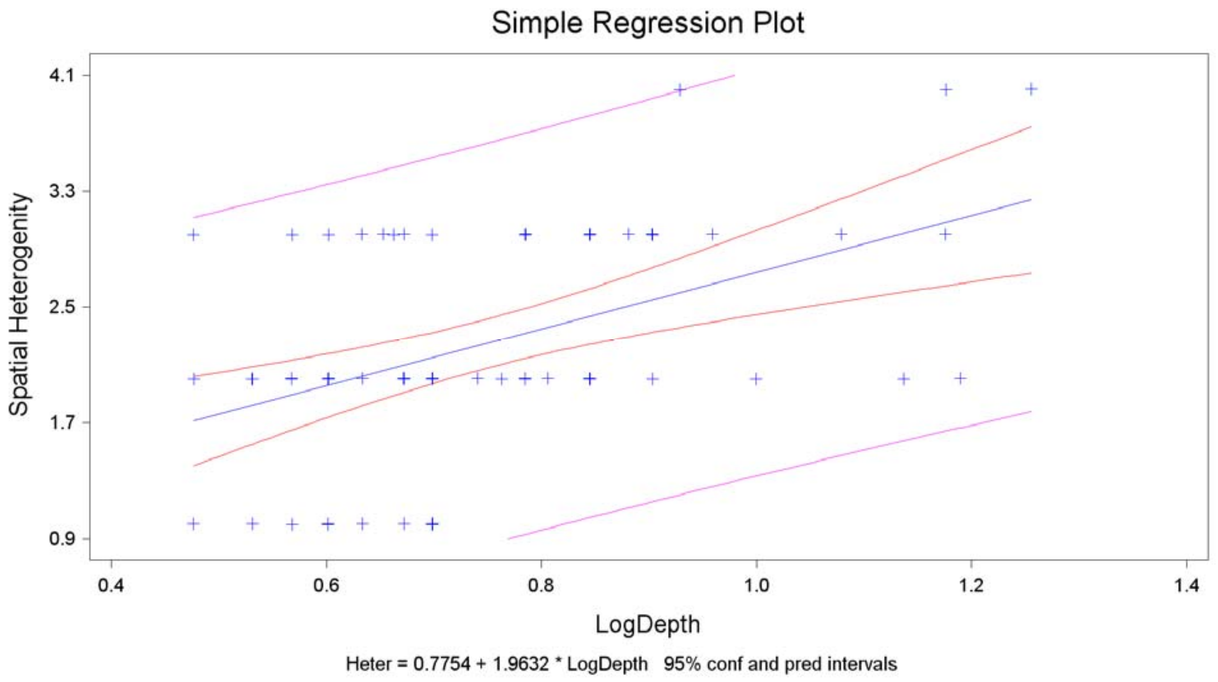

FIGURE 2.6. Linear regression plot of reef benthic spatial heterogeneity index and depth (r=0.4653, *p*=0.0001, d.f. 1,63).

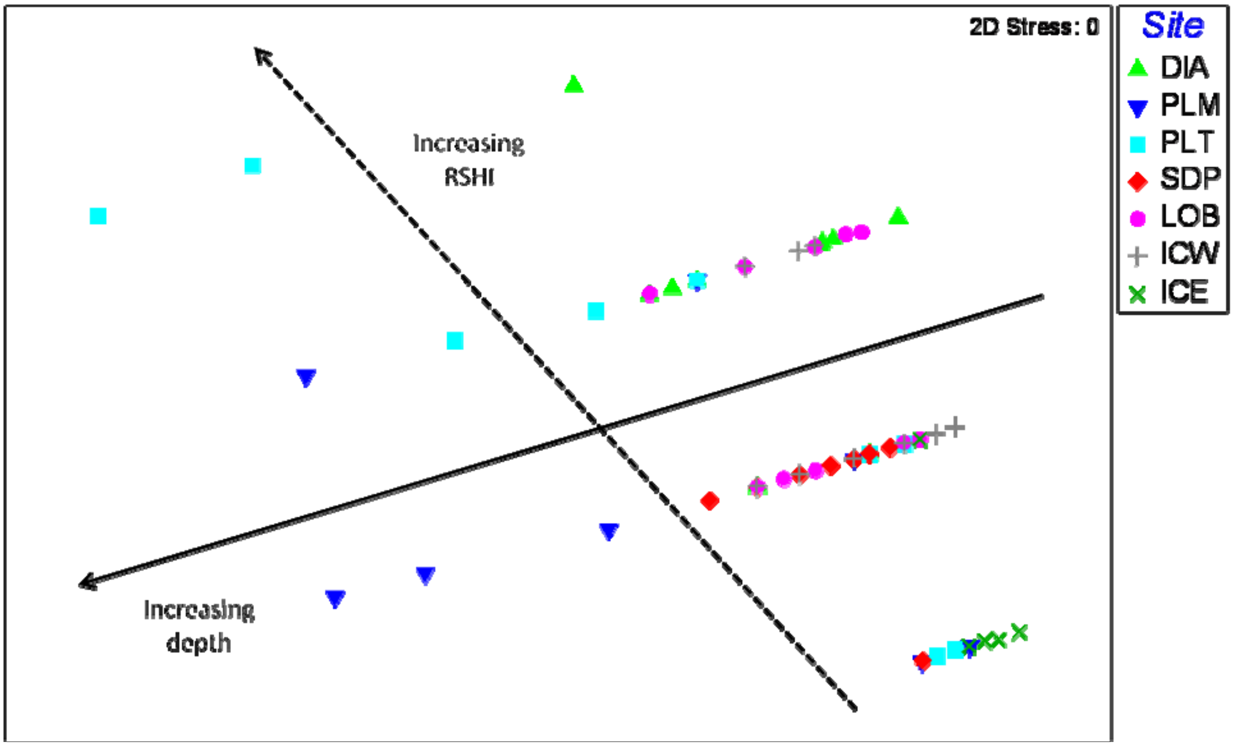

FIGURE 2.7. Multi-dimensional scaling (MDS) plot based on mean reef spatial heterogeneity index (RSHI) values and depth. There were four evident clusters following an increasing trend in RSHI value (from bottom to the top of the plot). There was also a gradient following increasing depth (from right to left of the plot). The wider the spatial distribution of RSHI points per site in the vertical dimension of the MDS plot, the wider the spatial heterogeneity of each reef. The wider the spatial distribution of RSHI points per site in the horizontal dimension of the MDS plot, the stronger the impact of depth.

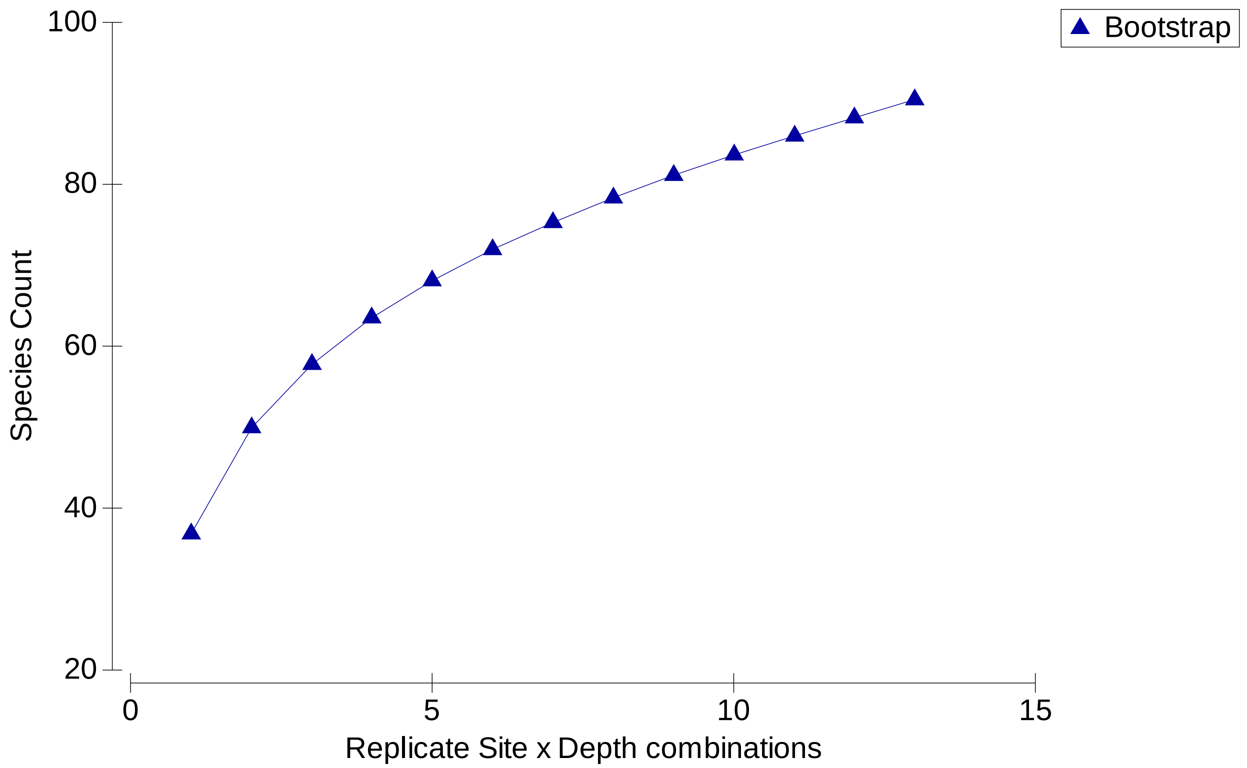

FIGURE 2.8. Cumulative species richness as a function of replicate *Site x Depth* combinations. Analysis based on 5,000 bootstrap replicates.

Fish community characterization

Fish community sampling was considered representative of the most common fish taxa of the ALCNR. A statistical power of 0.8 or higher was obtained for most important fish community parameters (data not shown). Further, a species saturation curve suggests that sampling effort was sufficient to capture the fish biodiversity of ALCNR (Figure 2.8).

TABLE 2.1. Summary results of one-way ANOVA analysis of coral reef fish community parameters among sites (d.f., Site=6; Depth=1; Error=57).

Parameter	**Site *p* value**	**Depth *p* value**
Species richness	0.0036	0.2089
H'n	0.0114	0.0988
J'n	0.0163	0.4470
Abundance (total)	0.0019	0.9432
Total herbivores	0.0174	0.0757
Non-denuders	<0.0001	0.4020
Browsers	<0.0001	0.0009
Scrapers	0.1444	0.3363
Total carnivores	0.0011	0.6475
Generalists	0.0005	0.0325
Piscivores	0.0013	0.1607
Planktivores	0.1129	0.0001
Omnivores	<0.0001	0.2647
Fishery target species	0.0209	0.8096
Biomass (total)	<0.0001	0.5308
Total herbivores	0.0013	0.0527
Non-denuders	0.0673	0.1830
Browsers	0.0032	0.0225
Scrapers	0.0008	0.2660
Total carnivores	<0.0001	0.1366
Generalists	<0.0001	0.1904
Piscivores	<0.0001	0.1318
Planktivores	0.0553	0.0021
Omnivores	0.0020	0.7164
Fishery target species	<0.0001	0.7471
RSHI	0.0003	0.0010

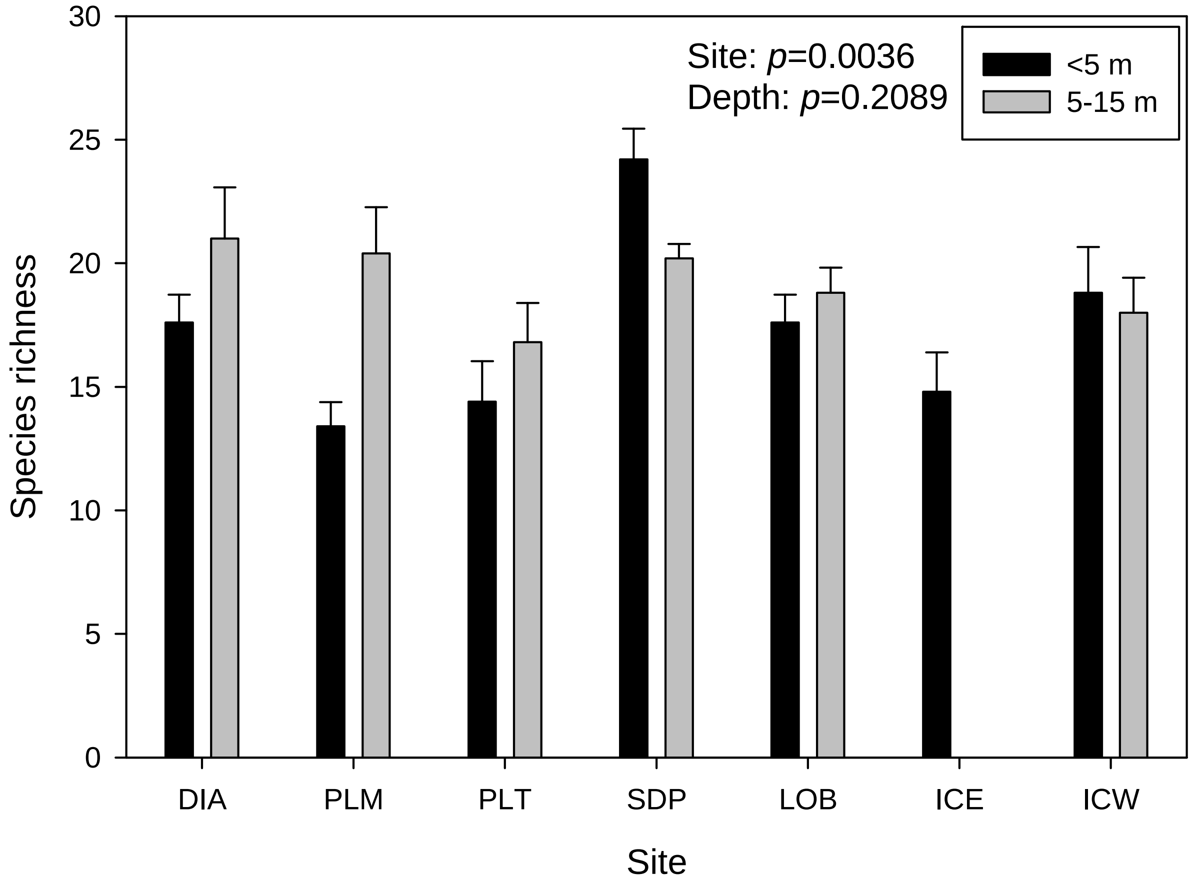

FIGURE 2.9. Mean number of species per count (±one standard error).

Species richness

SDP showed the highest mean fish species richness within ALCNR (Figure 2.9). Fish species richness at shallower depths was significantly higher at SDP with 24.2 species/count, followed by ICW (18.8 species/count), and lowest at PLM with 13 species/count. Each count represented a 120 m^2 belt transect. It was higher at deeper zones in DIA (21), followed by PLM (20.4), and lowest at PLT (16.8). No significant difference was documented between depth zones. There were no deeper zones at ICE.

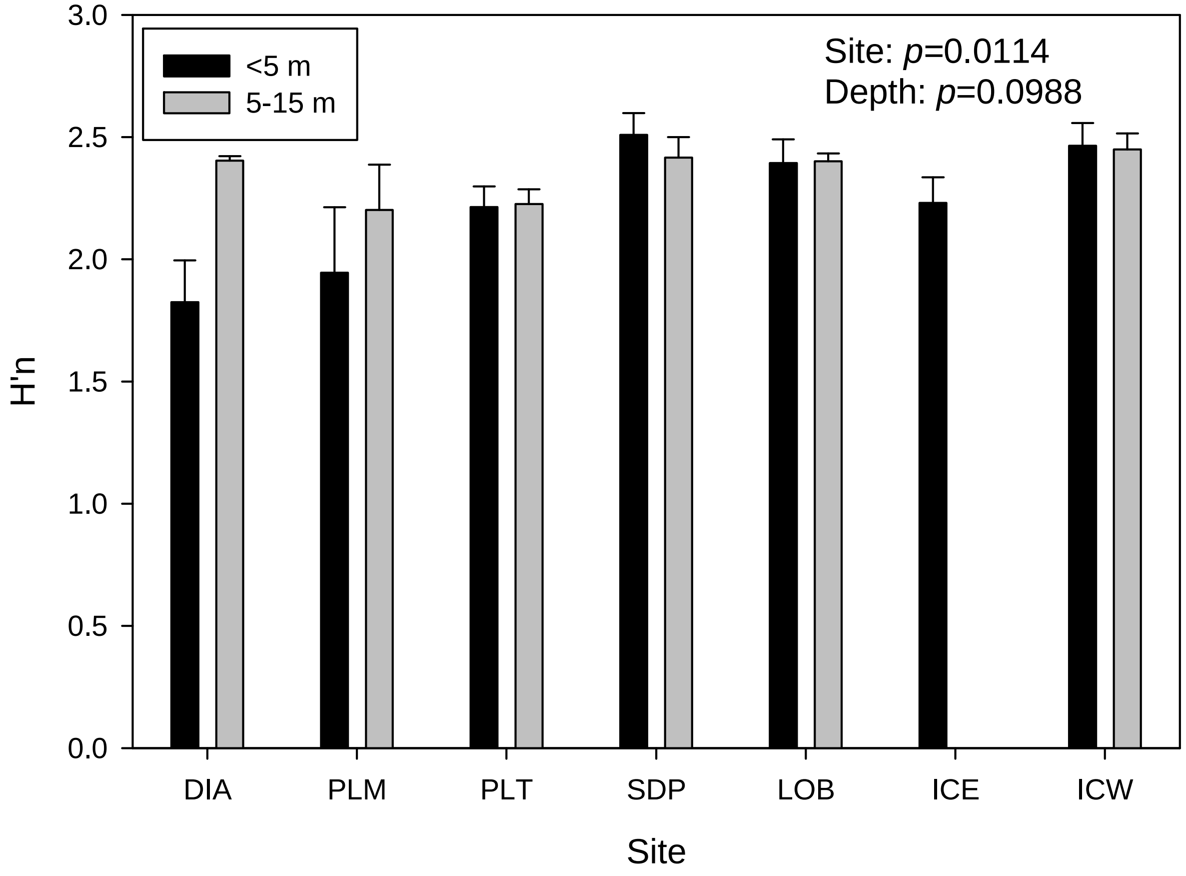

FIGURE 2.10. Mean species diversity index (H'n) per count (±one standard error).

Species diversity index

SDP and ICW showed the highest mean fish species richness within ALCNR (Figure 2.10). H'n at shallower depths was significantly higher at SDP (2.5097), followed by ICW (2.4645), and lowest at DIA with 13 (1.8248). It was higher at deeper zones in ICW (2.4497), followed by SDP (2.4155), and lowest at PLM (2.2015). No significant difference was documented between depth zones. There were no deeper zones at ICE.

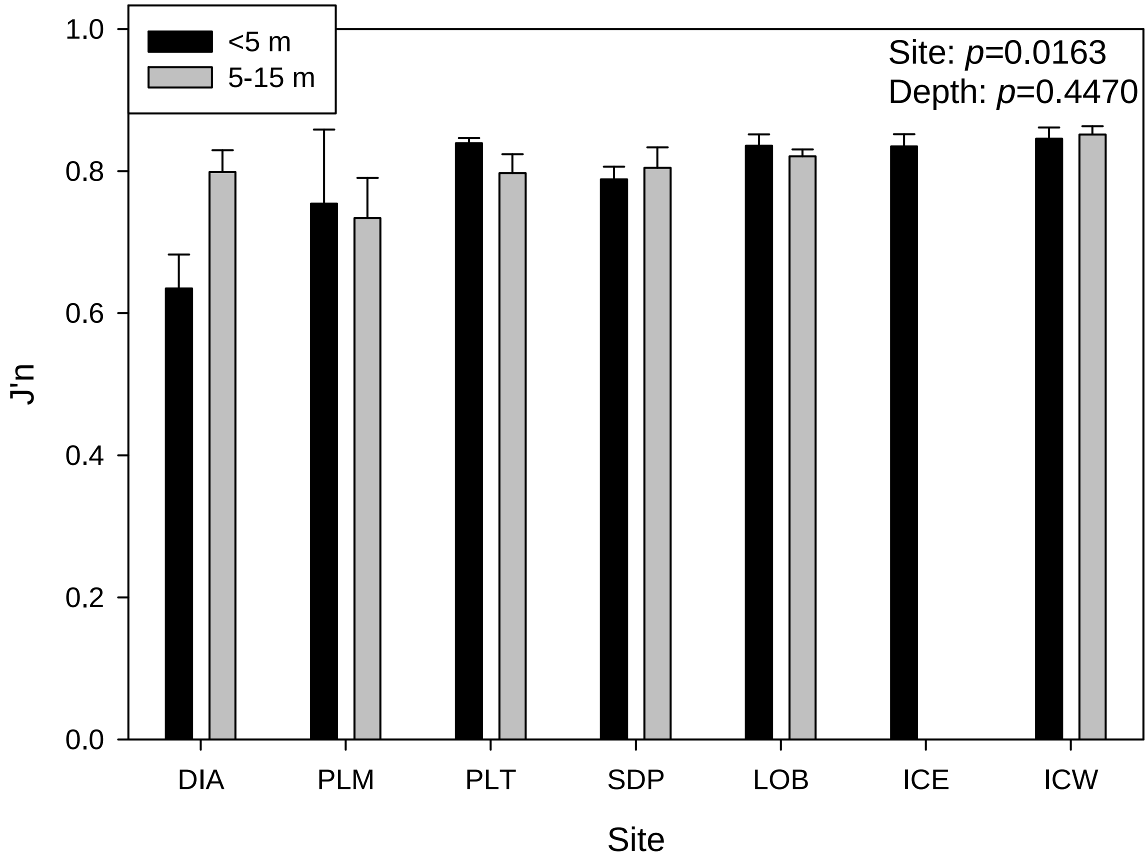

FIGURE 2.11. Mean J'n per sample (±one standard error).

Evenness

ICE, PLT, LOB and ICW showed the highest mean fish species evenness within ALCNR (Figure 2.11). At shallow depths J'n was highest at ICW (0.8457), followed by PLT (0.8392), and lowest at DIA with 13 (0.6347). At deeper zones, it was highest in ICW (0.8512), followed by LOB (0.8208), and lowest at PLM (0.7339). No significant difference was documented between depth zones. There were no deeper zones at ICE.

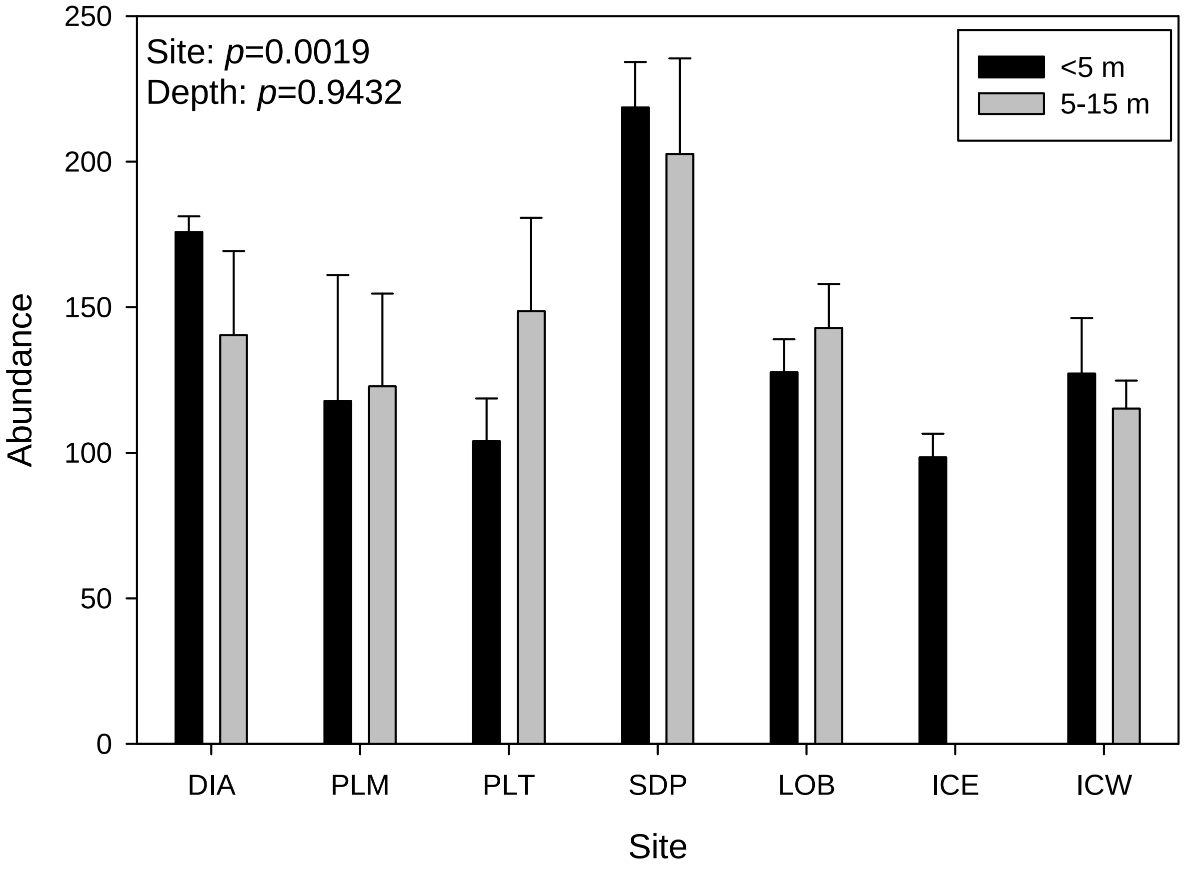

FIGURE 2.12. Mean fish abundance per sample (±one standard error).

Total abundance

SDP showed the highest mean total abundance within ALCNR (Figure 2.12). Abundance at shallower depths was significantly higher at SDP (219 individuals/count), followed by DIA (176 individuals/count), and lowest at ICE (98 individuals/count). Deeper zones showed higher values at SDP (203 individuals/count), followed by PLT (149 individuals/count), and lowest at ICW (115 individuals/count). No significant difference was documented between depth zones. There were no deeper zones at ICE.

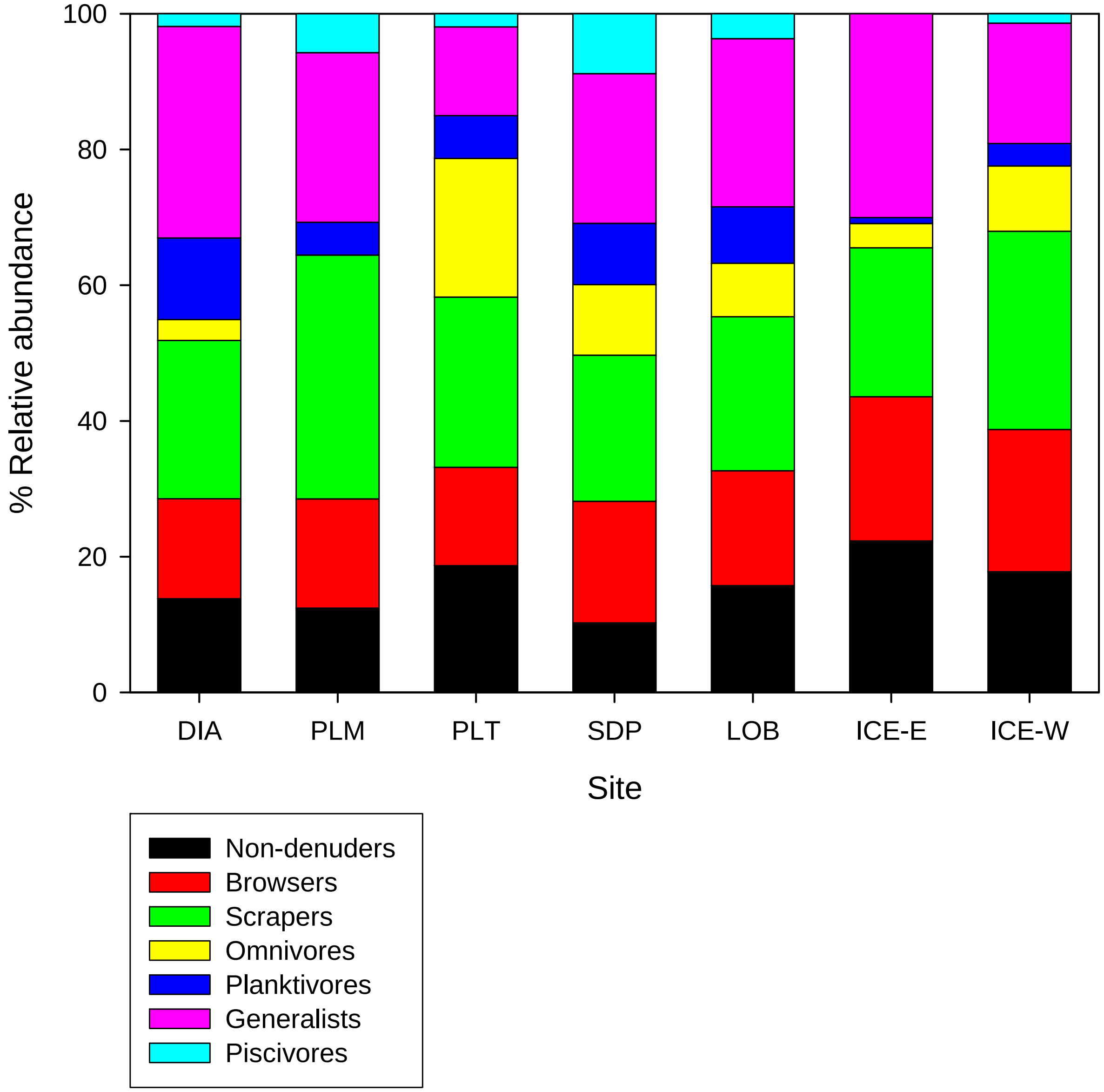

FIGURE 2.13. Mean relative abundance of fish functional groups per study site.

Mean relative abundance of fish functional groups

Each study site showed different reef fish assemblages at the functional group level, but with several consistent patterns (Figure 2.13). Herbivore guilds represented approximately 50 to 65% of the total fish fauna abundance at ALCNR. Overall, scrapers resulted numerically dominant with relative abundance values ranging from 22% at ICE to 36% at PLM. Browsers fluctuated from 15% at PLT to 21% at ICE and ICW. Non-denuders resulted remarkably abundant, ranging from 10% at SDP to 22% at ICE. Omnivores ranged from nearly none at PLM to 20% at PLT. Carnivores were consistently dominated by generalist, followed by planktivores, and a depauperate piscivore guild. Generalist relative abundance values ranged from 13% at PLT to 31% at DIA. Planktivore guilds fluctuated from 0.9% at ICE to 12% at DIA. The low abundance of piscivores was alarming, with the highest value at 9% (SDP), and amean abundance for the entire ALCNR of 3.4%.

Total herbivore abundance

Total herbivore abundance at shallower depths was significantly higher at SDP (100 individuals/count), followed by ICW (81 individuals/count), and lowest at ICE (56 individuals/count) (Figure 2.14a). Deeper zones showed higher values at ICW (86 individuals/count), followed by SDP (83 individuals/count), and lowest at PLM (59 individuals/count). No significant difference was documented between depth zones.

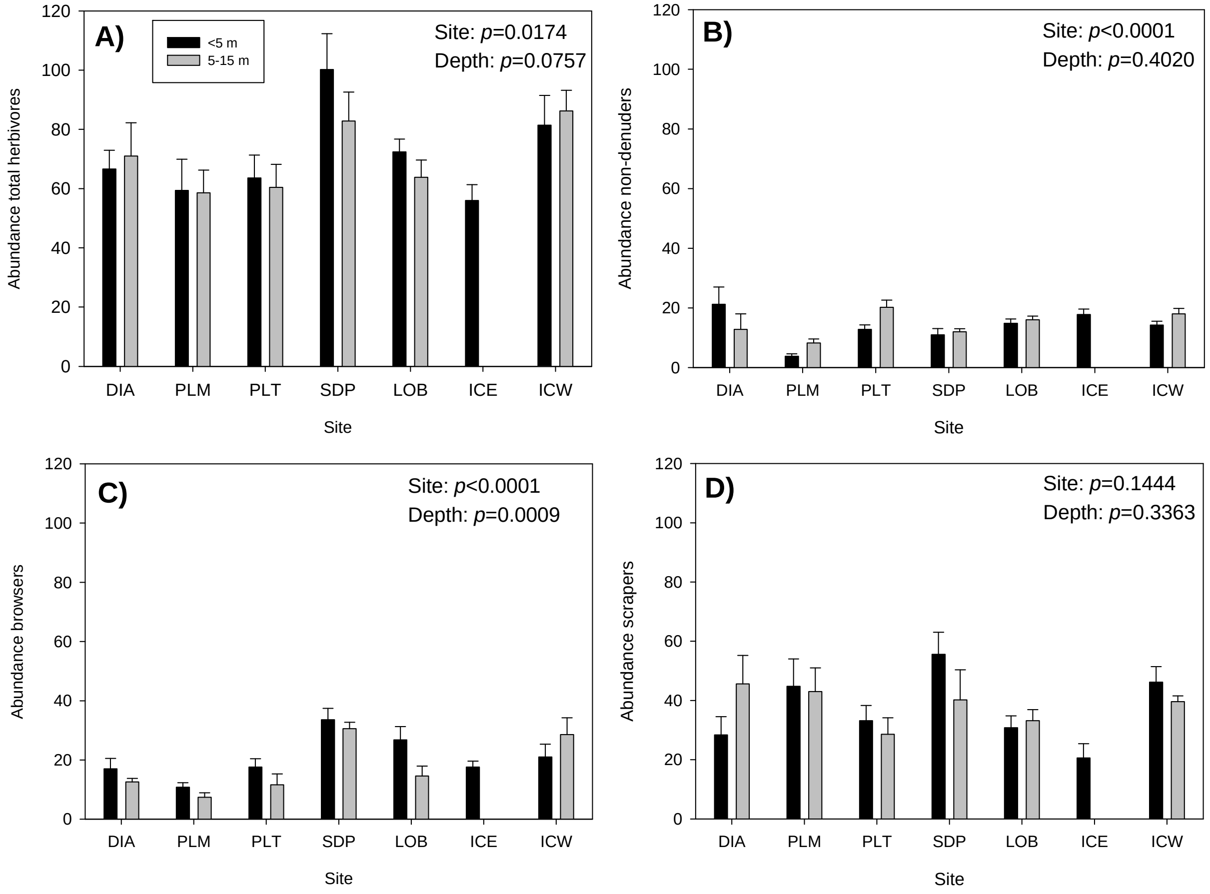

FIGURE 2.14. Mean herbivore abundance per count (±one standard error). From top left: (A) total herbivores; (B) non-denuders (Pomacentridae); (C) browsers (Acanthuridae); and (D) scrapers (Scaridae).

Non-denuder herbivore abundance

Non-denuder herbivore abundance at shallower depths was significantly higher at DIA (21 individuals/count), followed by ICE (18 individuals/count), and lowest at PLM (4 individuals/count) (Figure 14b). Deeper zones showed higher values at PLT (20 individuals/count), followed by ICW (18 individuals/count), and lowest at PLM (8 individuals/count). No significant difference was documented between depth zones.

Browser herbivore abundance

Browser herbivore abundance at shallower depths was significantly higher at SDP (34 individuals/count), followed by LOB (27 individuals/count), and lowest at PLM (10 individuals/count) (Figure 14c). Deeper zones showed higher values at SDP (31 individuals/count), followed by ICW (29 individuals/count), and lowest at PLM (7 individuals/count). Browser abundance was significantly higher at shallower depths.

Scraper herbivore abundance

No significant difference in scraper herbivore abundance was documented among sites or between depth zones. Anyway, abundance at shallower depths was slightly higher at SDP (56 individuals/count), followed by ICW (46 individuals/count), and lowest at ICE (21 individuals/count) (Figure 14d). Deeper zones showed higher values at DIA (46 individuals/count), followed by PLM (43 individuals/count), and lowest at PLT (29 individuals/count).

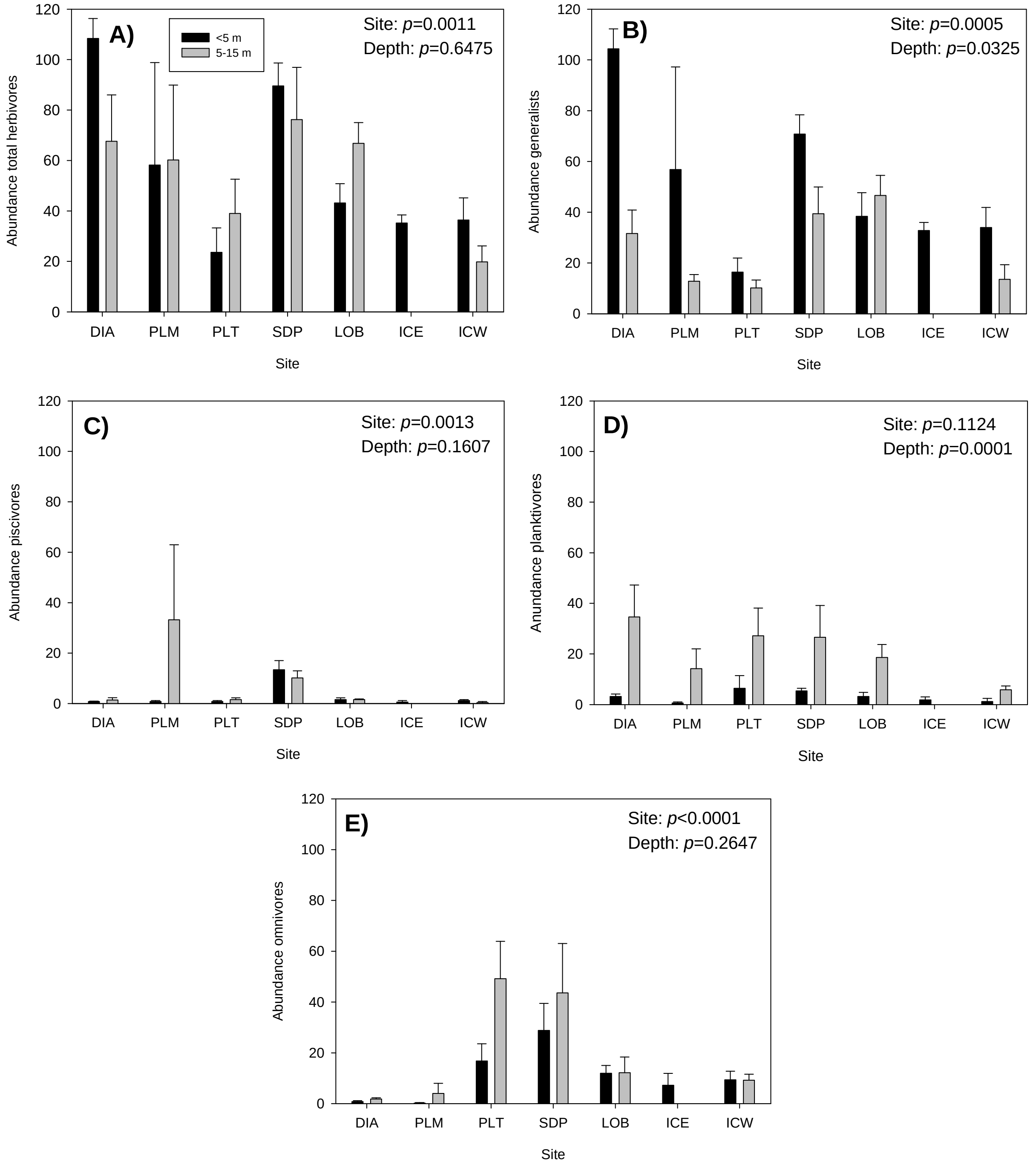

FIGURE 2.15. Mean carnivore abundance per sample (±one standard error). From top left: (A) total carnivores; (B) generalists; (C) piscivores; and (D) planktivores; and (E) omnivores.

Total carnivore abundance

Total carnivore abundance at shallower depths was significantly higher at DIA (108 individuals/count), followed by SDP (90 individuals/count), and lowest at PLT (25 individuals/count) (Figure 2.15a). Total carnivore abundance at deeper zones was higher at SDP (76 individuals/count), followed by DIA (68 individuals/count), and lowest at ICW (20 individuals/count). No significant difference was documented between depth zones.

Generalist carnivore abundance

Generalist carnivore abundance in shallower reefs was significantly higher at DIA (104 individuals/count), followed by SDP (71 individuals/count), and lowest at PLT (16 individuals/count) (Figure 2.15b). Deeper reefs showed a higher abundance at LOB (47 individuals/count), followed by SDP (39 individuals/count), and lowest at PLT (10 individuals/count). Generalist carnivore abundance was significantly higher at shallower depth zones.

Piscivore carnivore abundance

Overall, piscivore abundance was depauperate. Abundances in shallower reefs were significantly higher at SDP (13 individuals/count), largely as a result of the schooling behavior of Bar jack (*Carangoides ruber*) (Figure 2.15c). All other site had less than two individuals/count. Deeper transects showed the highest abundance at PLM (33 individuals/count) also due to a *C. ruber* school at one census, followed by SDP (10 individuals/count). The remaining sites had less than two individuals/count. Difference between depth zones was not significant.

Planktivore carnivore abundance

No significant difference in planktivore abundance was documented among sites. However, abundance at shallower depths was slightly higher at PLT (6 individuals/count), followed by SDP (5 individuals/count), and lowest at PLM (0.6 individuals/count) (Figure 2.15d). Deeper sites showed a higher abundance at DIA (35 individuals/count), followed by PLT (27 individuals/count), and lowest at ICW (6 individuals/count). Planktivore abundance was significantly higher at deeper reef zones.

Omnivore abundance

Omnivore abundances in shallower reef zones was significantly higher at SDP (29 individuals/count), followed by PLT (17 individuals/count), and lowest at PLM (0.2 individuals/count) (Figure 2.15e). Deeper zones showed the highest abundance at PLT (49 individuals/count), followed by SDP (44 individuals/count), and lowest at DIA (1.8 individuals/count). Difference between depth zones was not significant.

Fishery-targeted species abundance

Abundance of fishery-targeted (edible) species in shallower reef zones was significantly higher at SDP (82 individuals/count), followed by ICW (52 individuals/count), and lowest at ICE (29 individuals/count) (Figure 2.16). Deeper reefs zones showed the highest abundance at PLM (80

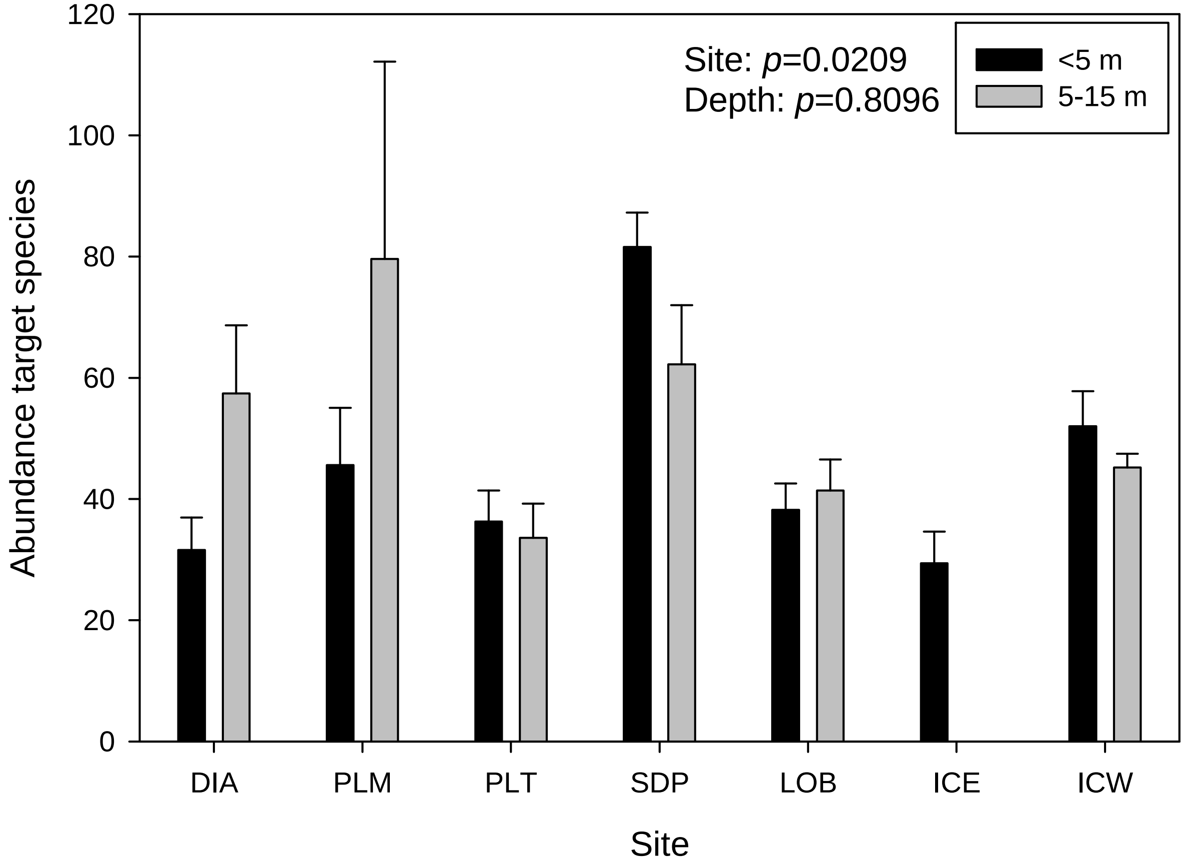

FIGURE 2.16. Mean abundance per sample of fishery-targeted species (±one standard error).

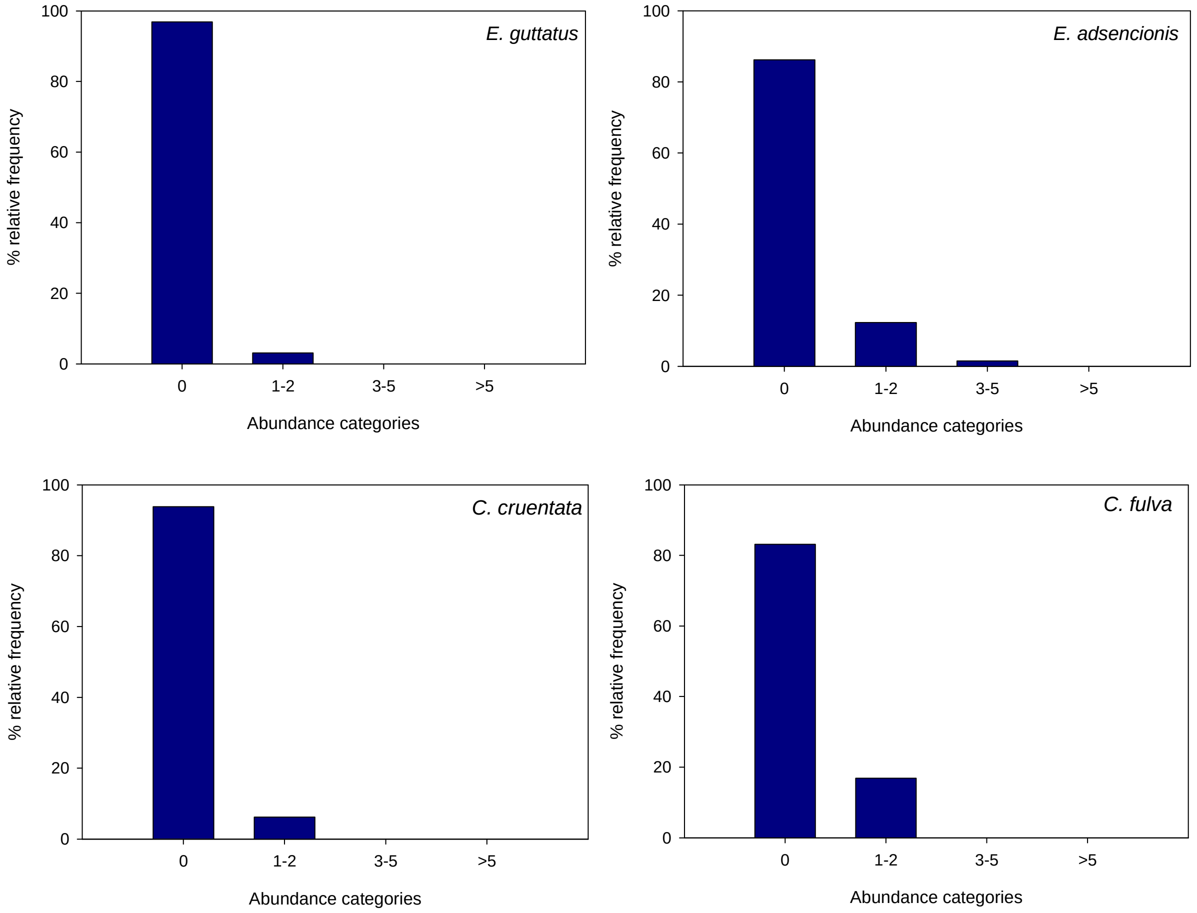

FIGURE 2.17. Abundance category distribution of members of subfamily Epinephelinae across ALCNR. From top left: (A) Red Hind (*Epinephelus guttatus*), (B) Rock Hind (*E. adsencionis*); (C) Graysby (*Cephalopholis cruentata*); and (D) Coney (*C. fulva*).

individuals/count), followed by SDP (62 individuals/count), and lowest at PLT (34 individuals/count). Difference between depth zones was not significant.

Abundance category distribution of members of subfamily Epinephelinae

The spatial distribution of abundance categories of the most significant target species showed unequivocal signs of long-term fishing impacts. In the case of edible grouper species of sub-family Epinephelinae only four species were documented in this study (Figure 2.17). Red

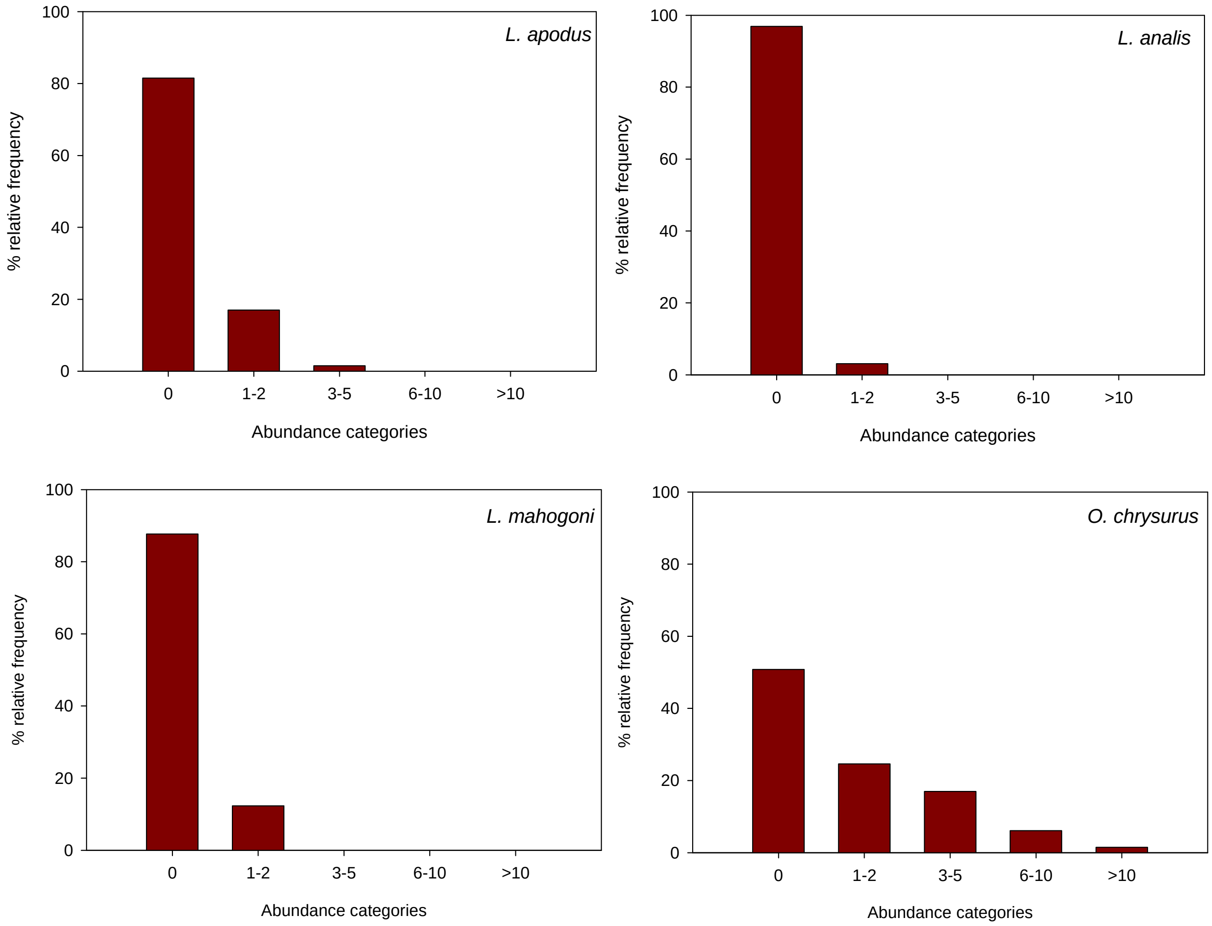

FIGURE 2.18. Abundance category distribution of members of family Lutjanidae across ALCNR. From top left: (A) Schoolmaster (*Lutjanus apodus*), (B) Mutton Snapper (*L. analis*); (C) Mahogany Snapper (*L. mahogoi*), and (D) Yellowtail snapper (*Ocyurus chrysurus*).

hind grouper (*Epinephelus guttatus*) was absent in 97% of the visual census transects (N=65). Only 1-2 individuals were observed in the remaining 3% of the counts. Rock hind (*E. adsencionis*) was absent in 86% of the counts, with 1-2 individuals present 12% of the time, and 3-5 individuals only 2% of the time. Graysby (*Cephalopholis cruentata*) was absent in 94% of the counts, with 1-2 individuals present in 6% of instances. Coney (*C. fulva*) was not present 83% of the time, with the remaining 17% constituted by densities of less than two individuals per count.

Abundance category distribution of members of family Lutjanidae

Lutjanid targeted populations were also relatively low (Figure 2.18). Schoolmaster (*Lutjanus apodus*) was absent in 82% of the visual census transects, with 1-2 individuals observed in 16% of the counts, and 3-5 individuals in 1% of the counts. Mutton Snapper (*L. analis*) was absent in 97% of the counts, with 1-2 individuals present in the remaining 3% of the time. Mahogany Snapper (*L. mahogoni*) was absent 88% of the time, with 1-2 individuals present in the remaining 12% of the counts. Yellowtail Snapper (*Ocyurus chrysurus*) was the most abundant of Lutjanids, not present in 51% of the counts, but with 1-2 individuals/count 25% of the time, 3-5 individuals 17%, 6-10 individuals 6%, and >10 individuals 1% of the time.

Abundance category distribution of members of family Haemulidae

Smallmouth grunt (*Haemulon chrysargyreum*) was absent in 80% of the visual counts, with 3-5 individuals observed 14% of the time, and 6-10 individuals in the remaining 6% of the counts (Figure 19). White grunt (*H. plumieri*) was absent 83% of the time, with 1-2 individuals present in the remaining 17% of the censuses. Caesar grunt (*H. carbonarium*) was absent in 91% of the counts, with 1-2 individuals present in the remaining 9%. French Grunt (*H. flavolineatum*) was the most abundant of Haemulids, not present in 63% of the counts, but with 1-2 individuals/count 15.5% of the time, 3-5 individuals 15.5%, and 6-10 individuals in the remaining 6% of the cases.

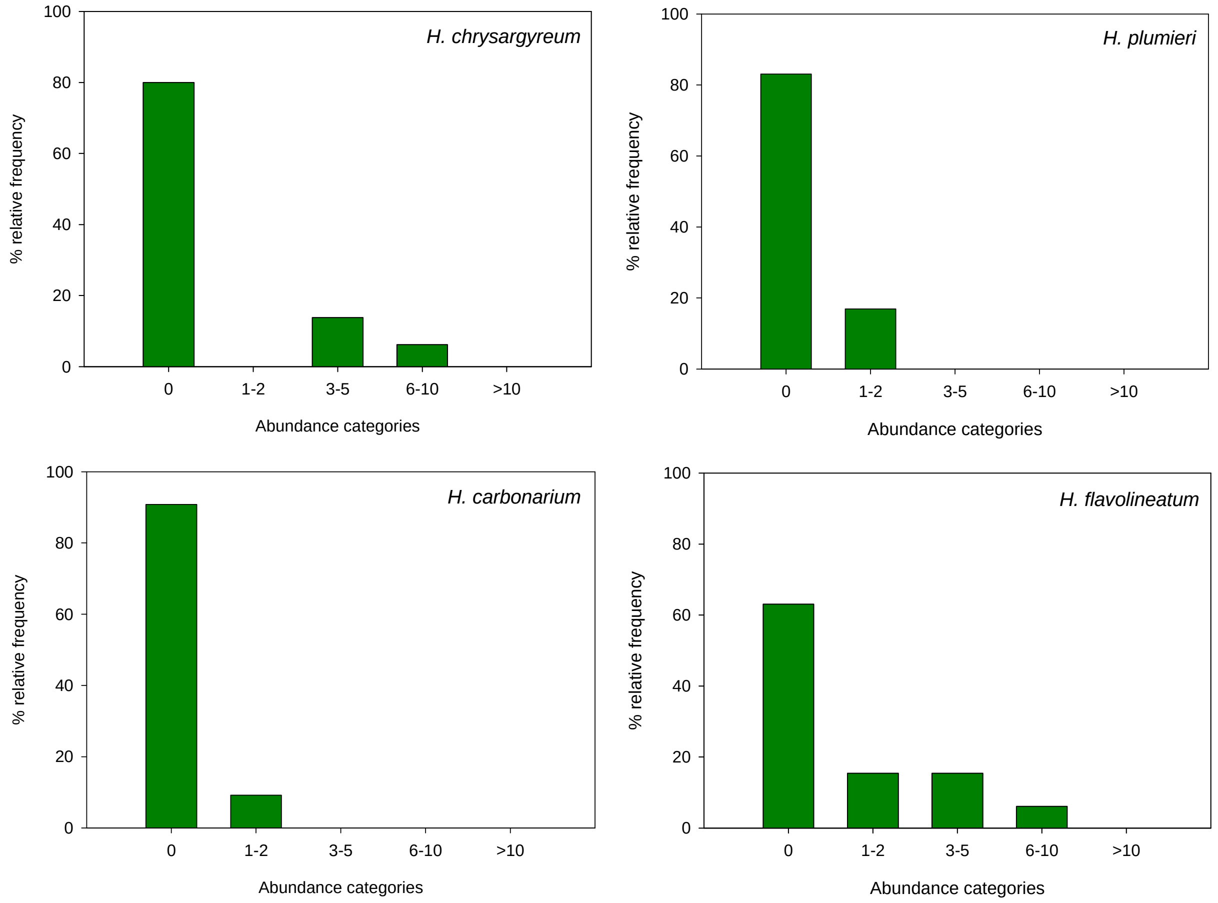

FIGURE 2.19. Abundance category distribution of members of family Haemulidae across ALCNR. From top left: (A) Smallmouth grunt (*Haemulon chrysargyreum*); (B) White Grunt (*H. plumieri*); (C) Caesar grunt (*H. carbonarium*); and (D) French Grunt (*H. flavolineatum*).

Abundance category distribution of members of family Scaridae

Scarids are one of the most important fishery target groups and showed large variation in the abundance category distribution depending on the species (Figure 2.20). Yellowtail parrotfish (*Sparisoma rubripinne*) was absent in 83% of the visual counts, with 1-5 individuals 12% of the time, and 6-10 individuals observed in the remaining 5% of the time. Stoplight parrotfish (*Sp. viride*) was one of the most abundant Scarids, absent only in 3% of the time, with

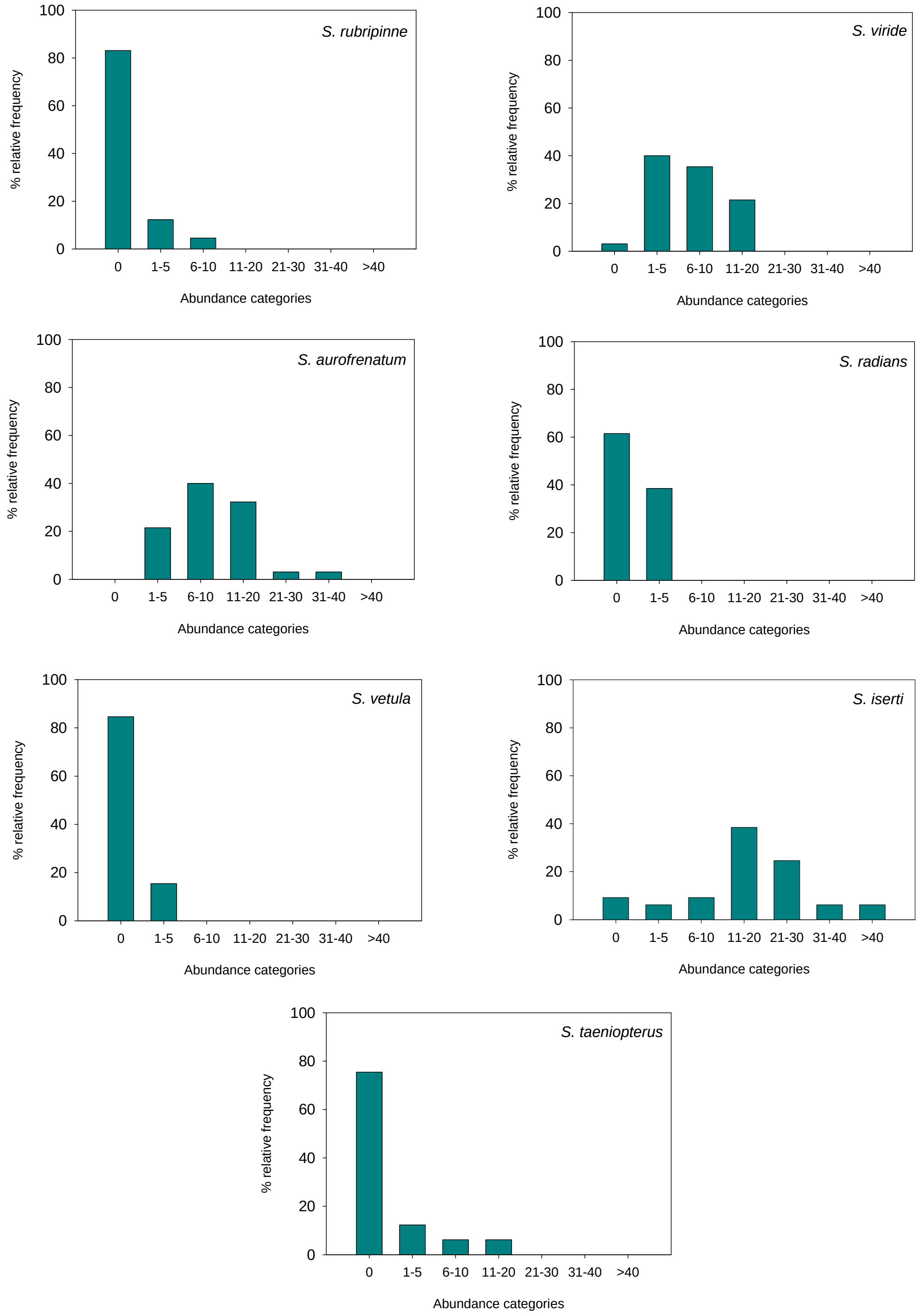

FIGURE 2.20. Abundance category distribution of members of family Scaridae across ALCNR. From top left: (A) Yellowtail parrotfish (*Sparisoma rubripinne*); (B) Stoplight parrotfish (*Sp. viride*); (C) Redband parrotfish (*Sp. aurofrenatum*); (D) Bucktooth parrotfish (*Sp. radians*); (E) Queen parrotfish (*Scarus vetula*); (F) Striped parrotfish (*Sc. iserti*); and (G) Princess parrotfish (*Sc. taeniopterus*).

1-5 individuals present in 40% of the counts, 6-10 individuals present 25% of the time, and 11-20individuals 22% of the time. Redband parrotfish (*Sp. aurofrenatum*) was present in all fish counts, with 1-5 individuals present in 22% of the counts, 6-10 individuals 40%, 11-20 individuals 32% of the time, 21-30 individuals 3%, and 31-40 individuals 3% of the time. Bucktooth parrotfish (*Sp. radians*) was not present in 62% of the counts, with 1-2 individuals/count 38% of the time. Queen parrotfish (*Scarus vetula*) was not present in 85% of the counts, with 1-2 individuals/count 15% of the time. Striped parrotfish (*Sc. iserti*) was another abundant Scarid, absent in 9% of the counts, with 1-5 individuals present in 6% of the counts, 6-10 individuals 9%, 11-20 individuals 39% of the time, 21-30 individuals 25%, 31-40 individuals 6%, and >40 individuals 6% of the time. However, most of these were juvenile individuals. Princess parrotfish (*Sc. taeniopterus*) was absent in 76% of the counts, with 1-5 individuals present 12% of the time, 6-10 individuals 6%, and 11-20 individuals in 6% of the counts.

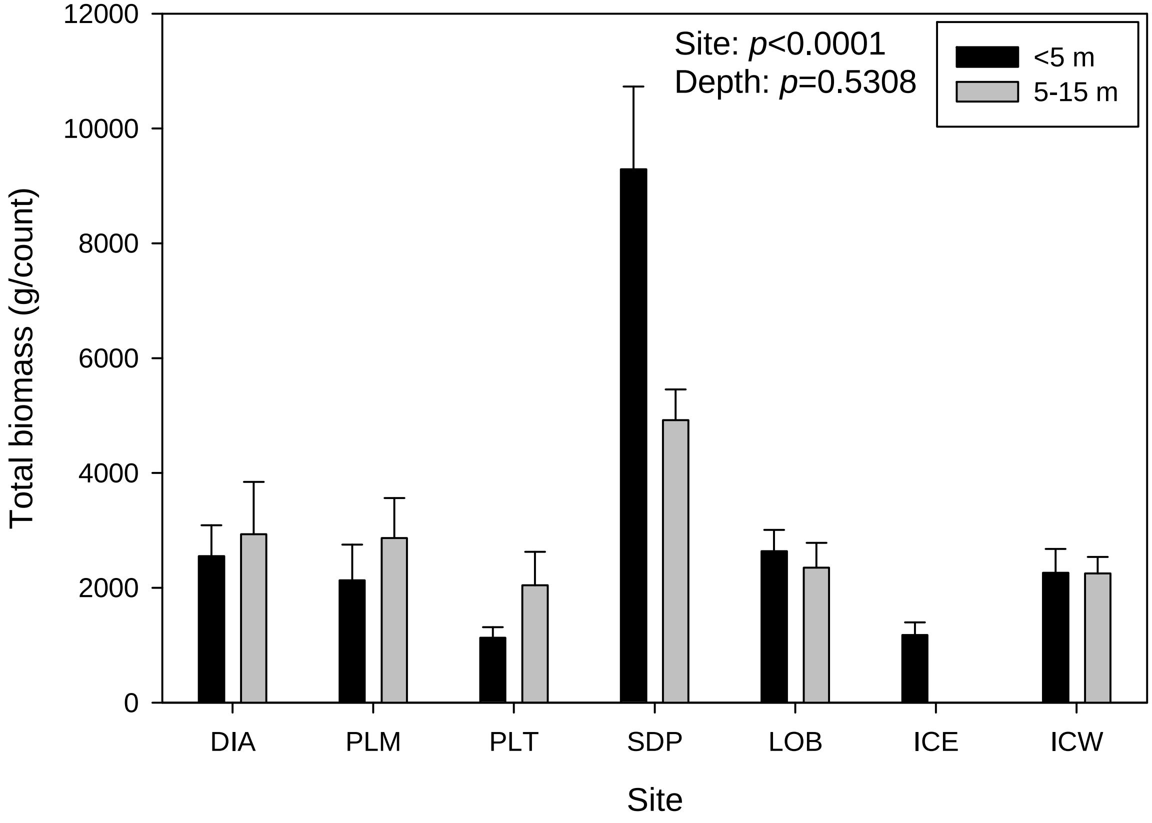

FIGURE 2.21. Mean fish biomass per sample (±one standard error).

Total biomass

SDP showed the highest mean total biomass within ALCNR (Figure 2. 21). Biomass at shallower depths was significantly higher at SDP (9,290 g/count), followed by LOB (2,639 g/count), and lowest at PLT (1,131 g/count). Deeper zones showed significantly higher values at SDP (4,922 g/count), followed by DIA (2,933 g/count), and lowest at PLT (2,045 g/count).

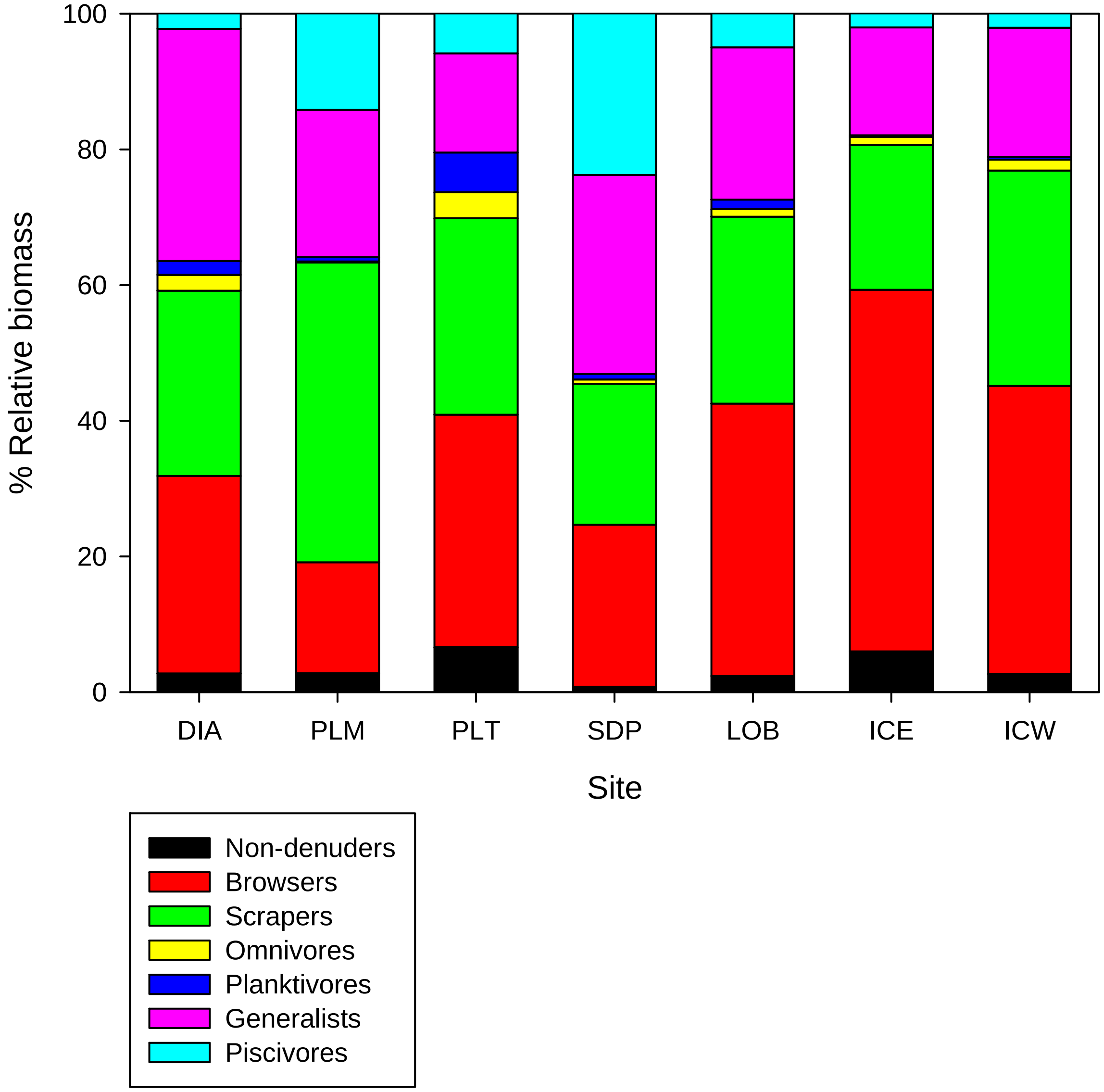

FIGURE 2.22. Mean relative biomass of fish functional groups per study site.

Mean relative biomass of fish functional groups

Reef fish assemblages at the functional group level showed significant differences among sites, but also with some consistent patterns (Figure 2.22). Herbivore guilds represented approximately 47 to 80% of the total fish fauna biomass at ALCNR. Overall, browsers and scrapers were the dominant guilds, with browser relative biomass values ranging from 16% at PLM to 53% at ICE, and scrapers from 20% at SDP to 44% at PLM. Non-denuders ranged from 0.8% at SDP to 6% at ICE. Omnivores ranged from 0.15% at PLM to 4% at PLT. Biomass of carnivore guilds were consistently dominated by generalist guilds, followed by piscivore and planktivore guilds. Generalist relative biomass values ranged from 15% at PLT to 34% at DIA. Planktivore guilds fluctuated from 0.25% at ICE to 6% at PLT. Relative piscivore biomass was overall alarmingly low, ranging from 2% at ICE to 24% at SDP. Mean value of piscivore relative biomass for the entire ALCNR was 7.9%. Such low values suggest strong fishing impacts.

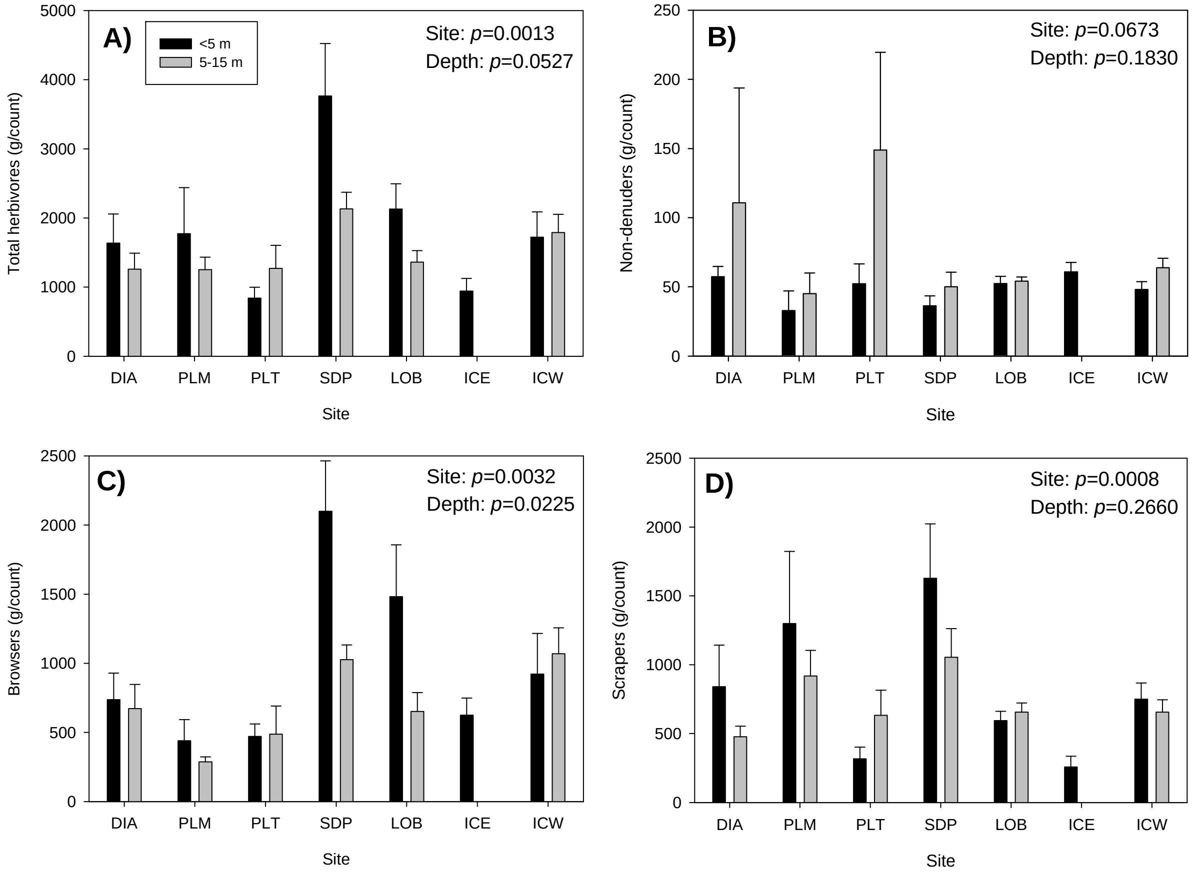

FIGURE 2.23. Mean herbivore biomass per sample (±one standard error).

Total herbivore biomass

Total herbivore biomass at shallower depths was significantly higher at SDP (3,764 g/count), followed by LOB (2,129 g/count), and lowest at PLT (840 g/count) (Figure 2.23a). Deeper zones showed significantly higher values at SDP (2,131 g/count), followed by ICW (1,788 g/count), and lowest at PLM (1,250 g/count). Difference documented between depth zones was barely short of significance.

Non-denuder herbivore biomass

No significant difference in non-denuder herbivore biomass was observed. However, higher biomass in shallower depths was documented at ICE (61 g/count), followed by DIA (57 g/count), and lowest at PLM (33 g/count) (Figure 2.23b). Deeper zones showed higher values at PLT (149 g/count), followed by DIA (111 g/count), and lowest at PLM (45 g/count). No significant difference was documented between depth zones.

Browser herbivore biomass

Browser herbivore biomass at shallower depths was significantly higher at SDP (2,099 g/count), followed by LOB (1,482 g/count), and lowest at PLM (439 g/count) (Figure 2.23c). Deeper zones showed significantly higher values at ICW (1,068 g/count), followed by SDP (1,026 g/count), and lowest at PLM (287 g/count). Browser biomass was significantly higher at shallower depths.

Scraper herbivore biomass

Scraper herbivore biomass at shallower depths was significantly higher at SDP (1,628 g/count), followed by PLM (1,299 g/count), and lowest at ICE (258 g/count) (Figure 2.24d). Deeper zones showed significantly higher values at SDP (1,055 g/count), followed by PLM (918 g/count), and lowest at DIA (477 g/count).

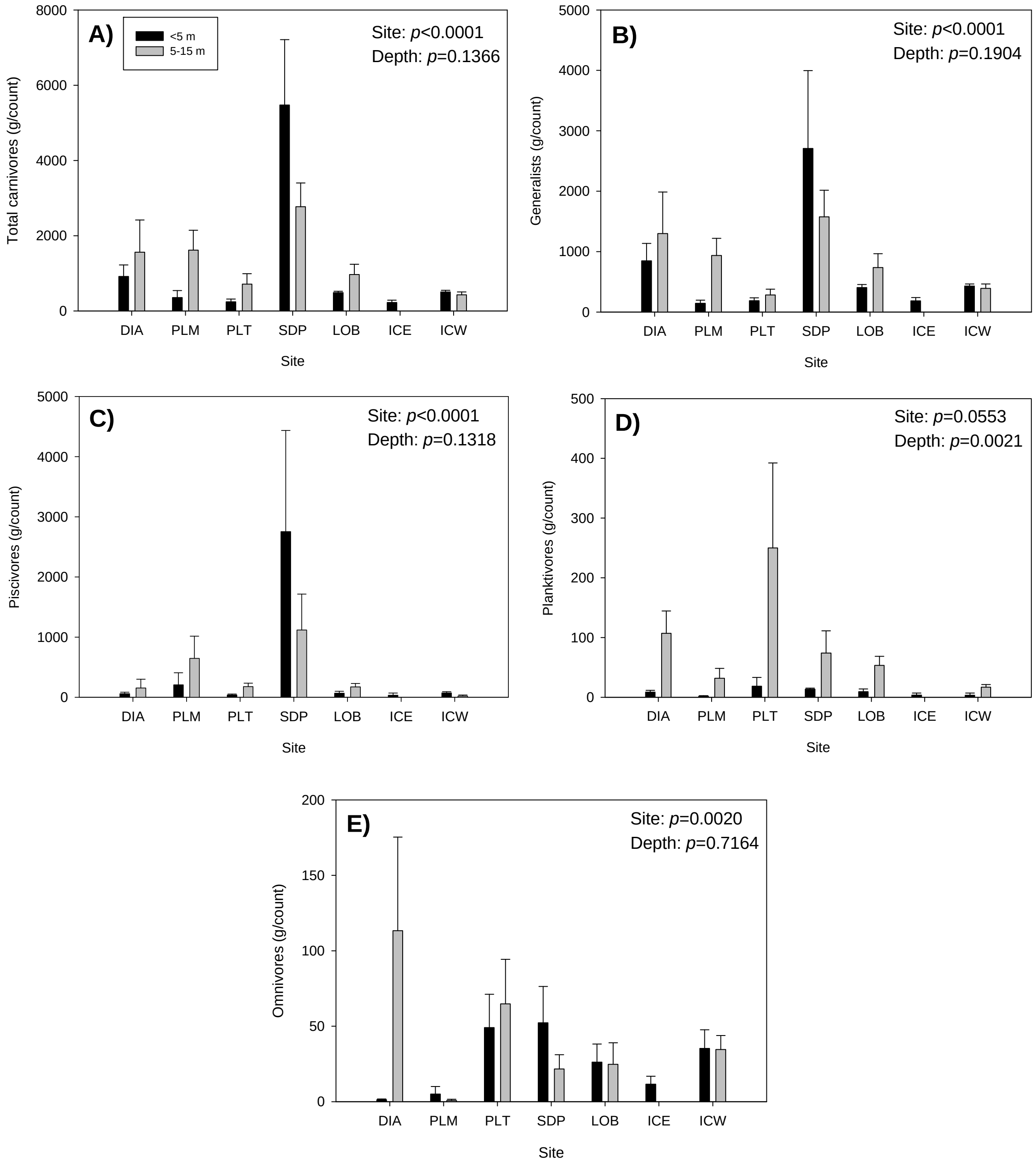

FIGURE 2.25. Mean carnivore biomass per sample (±one standard error). From top left: (A) total carnivores; (B) generalists; (C) piscivores; and (D) planktivores; and (E) omnivores.

Total carnivore biomass

Total carnivore biomass at shallower depths was significantly higher at SDP (5,474 g/count), followed in the distance by DIA (915 g/count), and lowest at ICE (221 g/count) (Figure 2.25a). Total carnivore biomass at deeper zones was also significantly higher at SDP (2,770 g/count), followed by PLM (1,615 g/count), and lowest at ICW (427 g/count). No significant difference was documented between depth zones.

Generalist carnivore biomass

Generalist carnivore biomass in shallower reefs was significantly higher at SDP (2,708 g/count), followed by DIA (847 g/count), and lowest at PLM (144 g/count) (Figure 2.25b). Deeper reefs showed a significantly higher biomass at SDP (1,577 g/count), followed by DIA (1,299 g/count), and lowest at PLT (282 g/count). No significant difference was documented between depth zones.

Piscivore carnivore biomass

Overall, piscivore biomass was alarmingly low. Biomass in shallower reefs were significantly higher at SDP (2,753 g/count), followed at the distance by PLM (208 g/count), and lowest at ICE (35 g/count) (Figure 2.25c). Deeper reefs showed a significantly higher biomass at SDP (1,118 g/count), followed by PLM (647 g/count), and lowest at ICW (19 g/count). Peak biomass values at SDP were the combined result of the presence of a moderate school of *C. ruber*, and of two large barracudas (*Sphyraena barracuda*). Peak values at deeper zones of PLM were also due to the presence of a moderate school of *C. ruber*. No significant difference was documented between depth zones.

Planktivore carnivore biomass

No significant difference in planktivore biomass was documented among sites. However, biomass at shallower depths was slightly higher at PLT (19 g/count), followed by SDP (14 g/count), and lowest at PLM (2 g/count) (Figure 2.25d). Deeper reefs showed a higher biomass at PLT (250 g/count), followed by DIA (107 g/count), and lowest at ICW (17 g/count). Planktivore biomass was significantly higher at deeper reef zones.

Omnivore biomass

Omnivore biomass in shallower reef zones was significantly higher at SDP (52 g/count), followed by PLT (49 g/count), and lowest at DIA (1 g/count) (Figure 2.25e). Deeper reefs showed significantly higher biomass at DIA (113 g/count), followed by PLT (65 g/count), and lowest at PLM (22 g/count). Difference between depth zones was not significant.

Fishery-targeted species standing stock biomass (SSB)

SSB of fishery-targeted (edible) species in shallower reef zones was significantly higher at SDP (50 g/m^2), followed by PLM (13 g/m^2), and lowest at ICE (3 g/m^2) (Figure 2.26). Deeper reefs showed the highest SSB at SDP (30 g/m^2), followed by PLM (20 g/m^2), and lowest at ICW (8 g/m^2). Difference between depth zones was not significant.

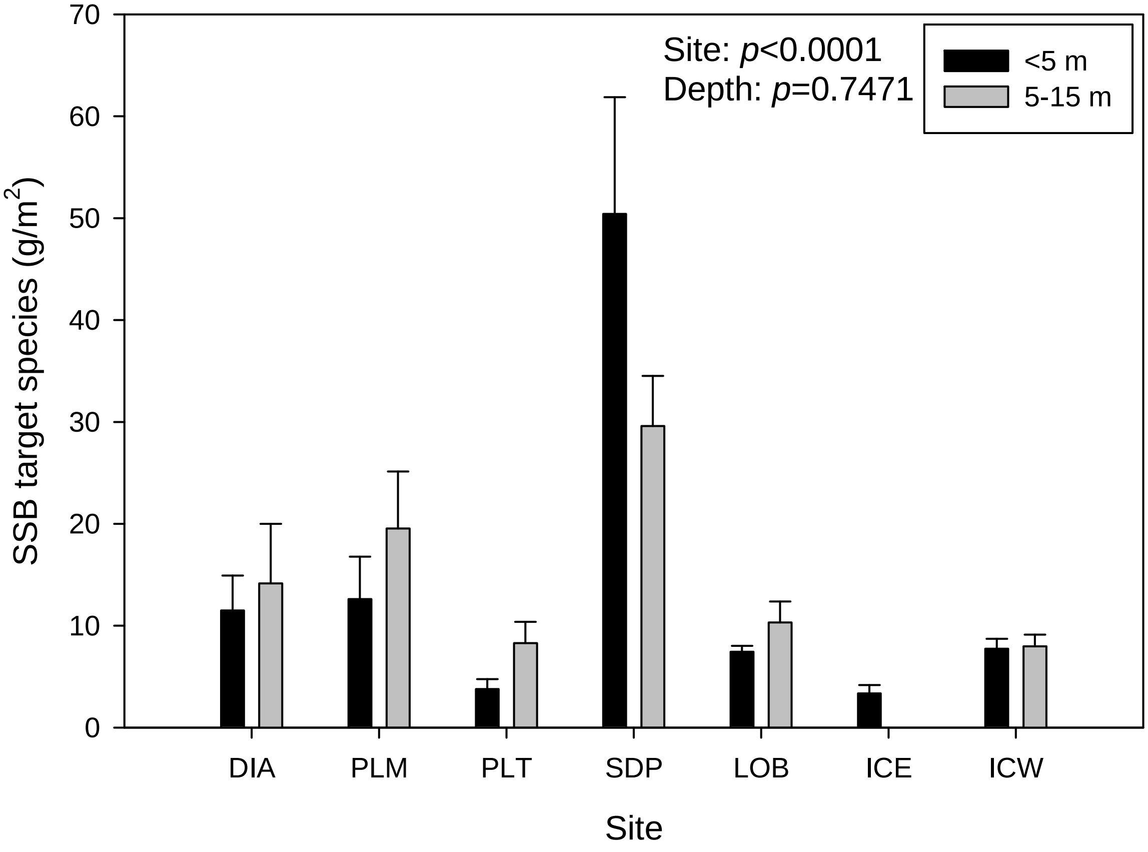

FIGURE 2.26. Mean standing stock biomass (SSB) per square meter of fishery-targeted species (±one standard error).

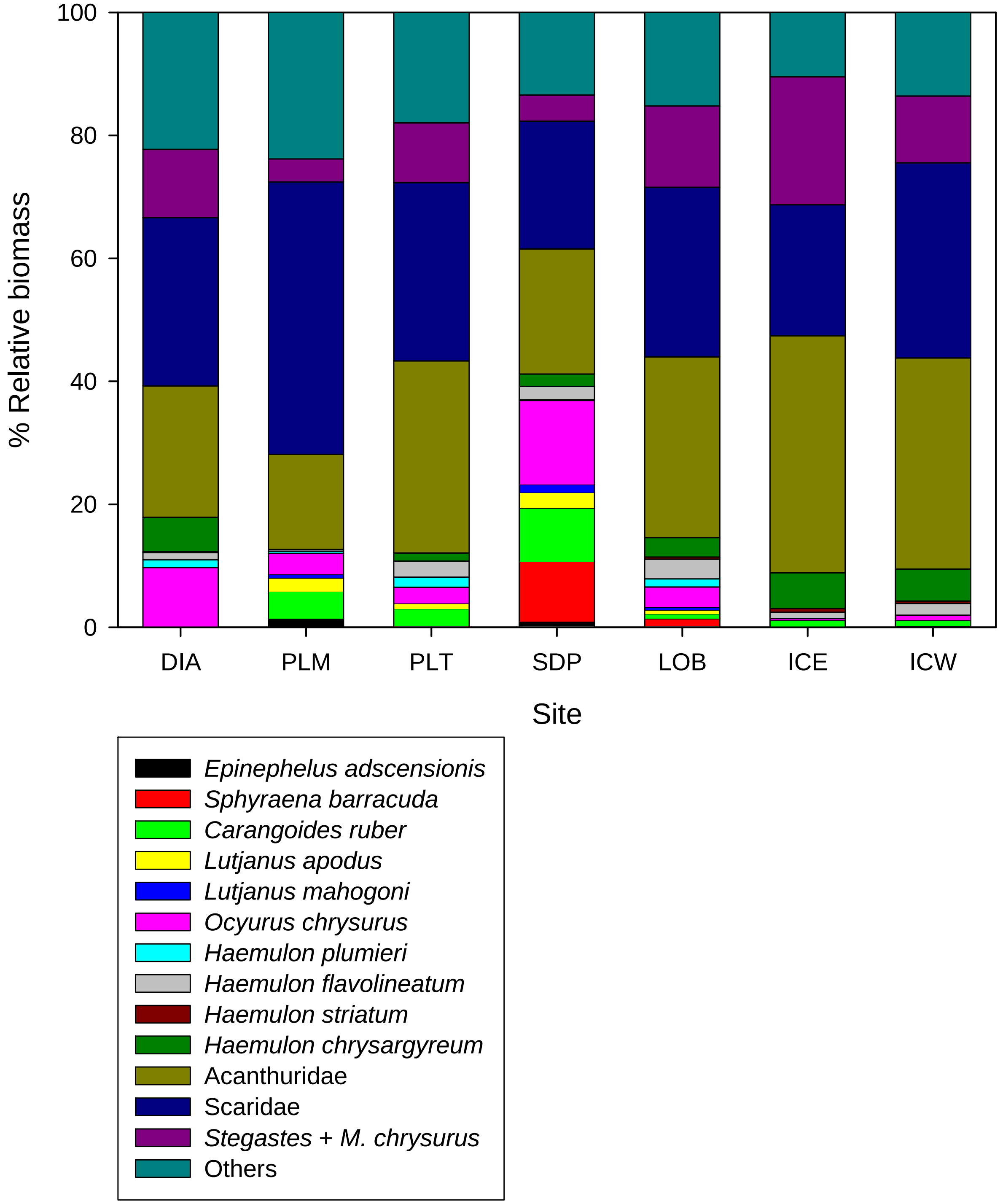

FIGURE 2.27. Percent relative biomass of significant taxa per site.

Relative biomass of significant taxa

The relative biomass of assemblages of selected significant fish taxa showed remarkable differences among sites, but some patterns were consistently evident (Figure 2.27). Overall, herbivores were largely dominant with 67% of the total biomass through the entire study, total herbivore relative biomass ranged from as low as 45% at SDP to 81% at ICE. Acanthuridae and Scaridae were the dominant guilds, with acanthurids ranging from 15% at PLM to 39% at ICE, and scarids from 21% at SDP to 44% at PLM. The guild formed by territorial damselfishes (*Stegastes* spp. + *Microspathodon chrysurus*) ranged from 4% at PLM to 21% at ICE.

Overall, total carnivores of the selected taxa represented only 17% of the total fish biomass of ALCNR. Rock hind (*Epinephelus adscensionis*) constituted only 0.4% of the documented fish biomass, ranging from 1.4% at PLM to absent at DIA and ICE. Barracudas (*Sphyraena barracuda*) represented 1.6% of the total fish biomass, and represented 10% of the fish biomass at SDP and only 1% at LOB. Elsewhere, it was absent. Bar jack (*Carangoides ruber*), a pelagic piscivore, represented 2.7% of the total fish biomass, ranging from 9% at SDP to absent at DIA. Schoolmaster (*Lutjanus apodus*) represented only 0.9% of the biomass, and ranged from 2.6% at SDP to totally absent at DIA, ICE, and ICW. Mahogany snapper (*L. mahogoni*) constituted only 0.3% of the fish biomass of ALCNR. It ranged from 1% at SDP to absent at DIA, PLT, ICE, and ICW. Yellowtail snapper (*Ocyurus chrysurus*) represented nearly 5% of the fish biomass, with ranges from 14% at SDP to 0.3% at ICE.

A depauperate 0.7% of the total fish biomass was constituted by the White Grunt (*Haemulon plumieri*), which ranged from nearly 2% at PLT to absent at ICE and ICW. French Grunt (*H. flavolineatum*) represented nearly 2% of the total fish biomass, fluctuating from 3% at SDP to 0.3% at PLM. Striped grunt (*H. striatum*) constituted approximately 0.2% of the biomass, and showed fluctuations from 0.6% at ICE to absent at PLM, PLT and SDP. This species shows preferences for seagrass habitats or seagrass-reef transition zones. None of these habitats were present at the sampled sites at these three locations. The smallmouth grunt (*H. chrysargyreum*) constituted 3.3% of the entire fish biomass, ranging from 6% at ICE to absent at PLM. The remaining taxa clustered under “Others” represented nearly 17% of the total biomass, and ranged from 11% at ICE to 24% at PLM.

Catastrophic decline of non-targeted fish taxa

A dramatic decline or nearly total collapse has occurred in many non-targeted fish species or even in entire families, particularly in coral dwellers such as members of family Gobiidae. Cleaning gobies were absent from most surveyed coral reefs after the unprecedented sea surface warming and massive coral bleaching event of year 2005. This was followed by an unprecedented coral mortality event that caused significant a significant loss in % living tissue cover in large reef-building taxa, mostly in the star coral complex species *Montastraea* spp. (this will be documented in a separate technical report). Only a single individual of the cleaning goby (*Gobiosoma genie*) was documented at one of the transects at PLM, representing 0.00000009% of the total fish biomass at ALCNR. Other small-sized cryptic taxa such as members of Grammatidae, Clinidae, Labrisomidae, Chaenopsidae, Blennidae, Tetraodontidae, and Monacanthidae showed extremely low abundance or were absent from surveyed sites.

Multivariate analysis of fish community structure at the species level

Multivariate analyses were conducted using fish biomass. There were significant differences in fish community structure among sites, between depth zones, as well as a highly significant site x depth interaction effect (Table 2.2). With the exception of the pairwise combination between LOB and ICW, all combinations among sites showed significant differences. A total of 38.1% of the pairwise combinations resulted overlapping but clearly different (Table 2.3). A similar proportion resulted overlapping but partially different. An additional 19% resulted barely separable at all, and 4.8% non-separable.

TABLE 2.2. Results of a one-way ANOSIM test of fish community structure based on fish species biomass. Analysis based on 5000 permutations.

Factors	Global R	Significance
Global test		
Site	0.370	0.0002
Depth	0.264	0.0002
Site x Depth	0.259	0.0380

TABLE 2.3. Pairwise ANOSIM test comparisons among study sites. Analysis based on fish species biomass. The R statistic represents pairs of sites that are well separated (R>0.75, blue), overlapping but clearly different (R= 0.50 -0.75, green), overlapping but partially different (R=0.25-0.50, yellow), barely separable at all (R=0.25-0.10, red), or non-separable (R<0.10, lavender). Number in parentheses represents statistical significance level (*p*).

Site	DIA	PLM	PLT	SDP	LOB	ICE	ICW
DIA	-						
PLM	0.23 (0.0050)	-					
PLT	0.36 (0.0010)	0.49 (0.0006)	-				
SDP	0.51 (0.0004)	0.58 (0.0004)	0.50 (0.0006)	-			
LOB	0.23 (0.0020)	0.63 (0.0002)	0.37 (0.0006)	0.40 (0.0002)	-		
ICE	0.32 (0.0002)	0.70 (0.0002)	0.40 (0.0002)	0.56 (0.0002)	0.19 (0.0320)	-	
ICW	0.20 (0.0240)	0.60 (0.0080)	0.33 (0.0480)	0.66 (0.0080)	0.10 (0.1750)	0.28 (0.0160)	-

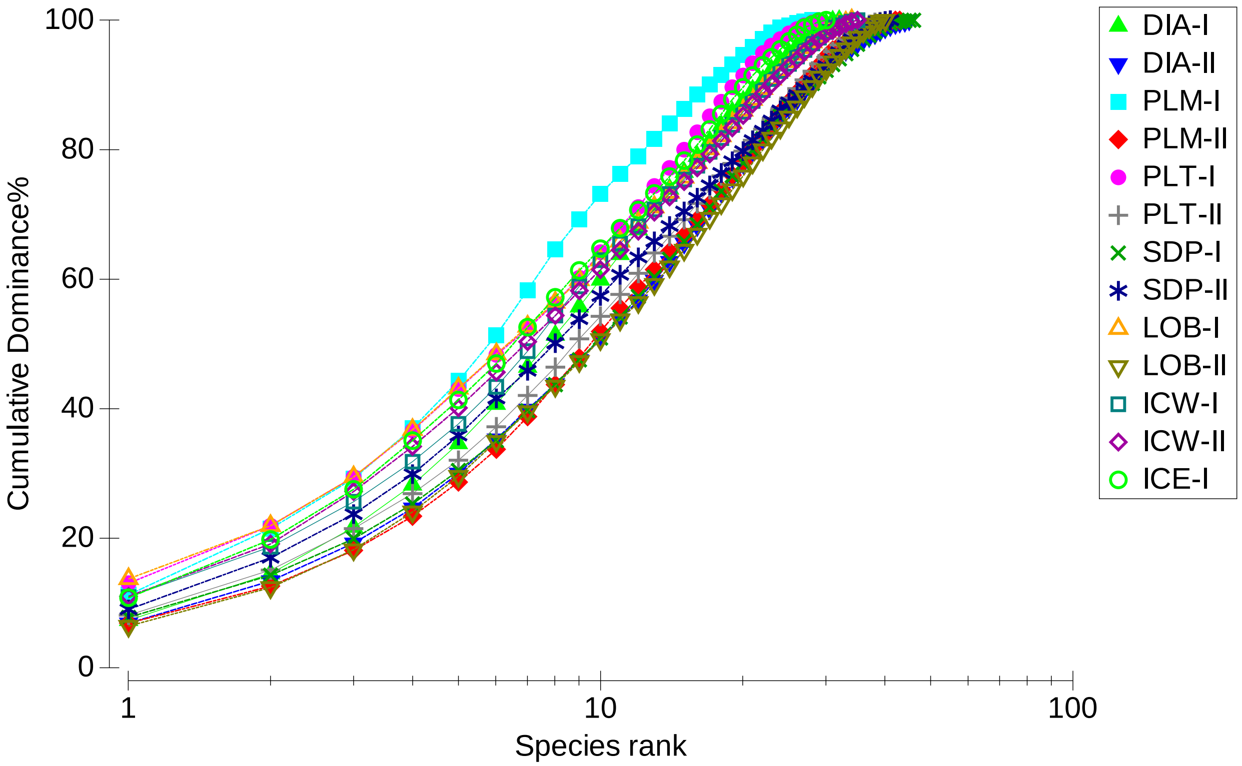

FIGURE 2.28. Species rank dominance plot based on fish biomass.

Species rank dominance

Fish species rank dominance analysis suggested that depauperate sites characterized by having lower species richness and lower fish abundance (i.e., PLM-I, PLT-I, ICE, ICW-I, ICW-II) rapidly reached higher % cumulative dominance in comparison to habitats with richer and denser fish fauna (Figure 2.28). The wider the distance among curves, the higher is the difference in fish community structure among sites. This difference can be the combined result of factors such as variable RSHI, depth and fishing pressure.

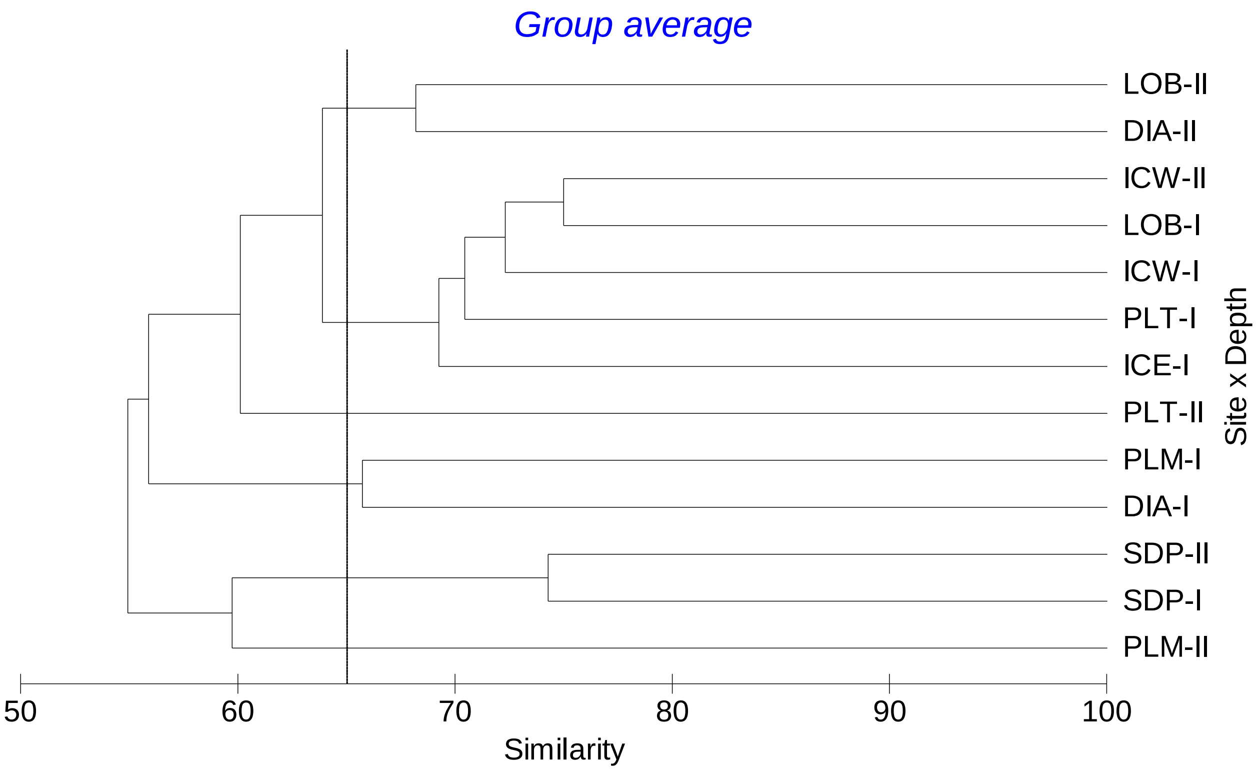

FIGURE 2.29. Cluster analysis of fish community structure based on species biomass. Vertical bar shows 65% cutoff level. Fish communities organized within six different clusters based on the 65% similarity cutoff level. Acronyms are explained in the Methodology section. Depth zones: I (<5 m); II (5-15 m).

Ordination analysis of fish communities at the species level

Fish communities were ordinated first using a cluster analysis (Figure 2.29), followed by a multi-dimensional scaling analysis (Figure 2.30). Fish communities organized within six different clusters based on the 65% similarity cutoff level. The two clusters composed by SDP-I and SDP-II, and PLM-II were characterized by having the largest presence of piscivore guilds, principally moderate schools of Bar jack (*Carangoides ruber*), and Great barracudas (*Sphyraena barracuda*), as well as other species. PLT-II formed a separated cluster due to the abundance of

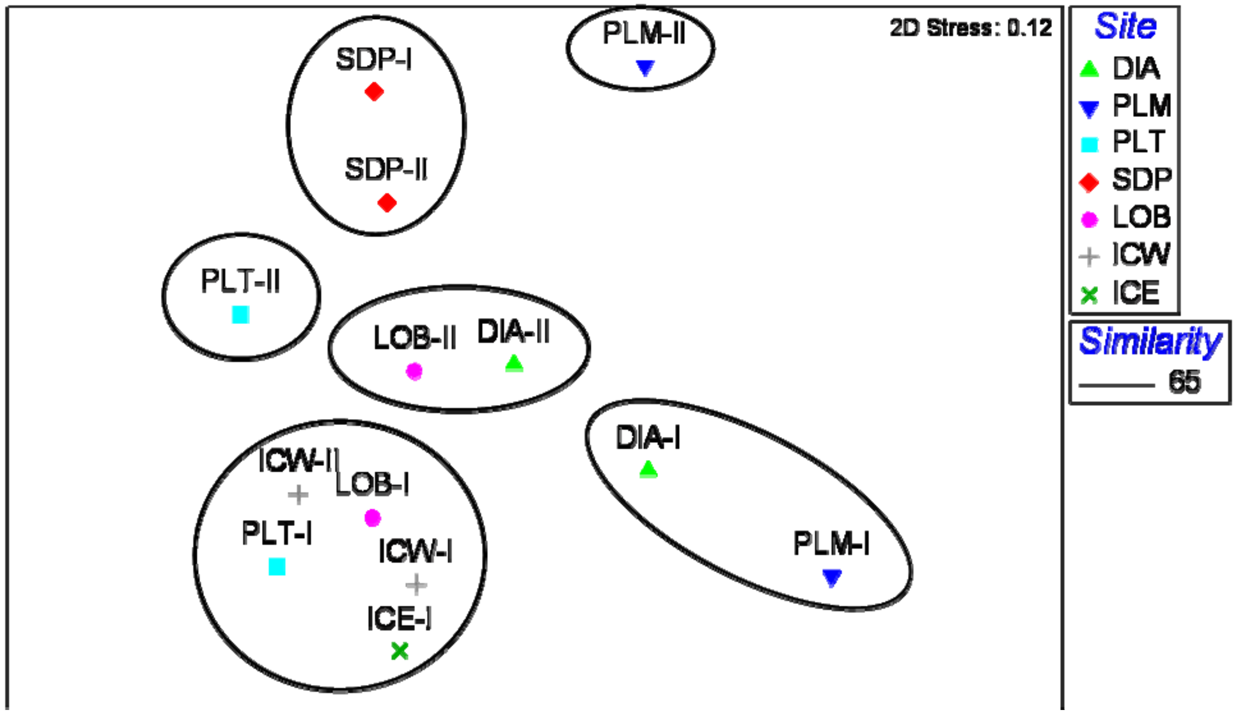

FIGURE 2.30. Multi-dimensional scaling (MDS) plot of fish community structure based on species biomass. Fish communities organized within six different clusters based on the 65% similarity cutoff level. Acronyms are explained in the Methodology section. Depth zones: I (<5 m); II (5-15 m).

planktivore species. LOB-II and DIA-II organized in a fourth separate cluster due to the highest similarity of their abundant planktivore guilds, and their herbivore guilds, mostly damselfishes (*Stegastes* spp. + *Microspathodon chrysurus*), and their generalist carnivore guilds. DIA-I and PLM-I formed a separate cluster as a result of their depauperate herbvivore fauna. The remaining sites clustered together as a result of their overall depleted fish communities.

Spatial patterns of biomass distribution of selected fishery-targeted species

Bubble plots derived from MDS analysis were used to discriminate spatial patterns of biomass distribution of selected fishery-targeted species across ALCNR. Most edible grouper species (subfamily Epinephelinae) showed skewed geographical distributions favoring reefs located farther offshore and usually deeper habitats (Figure 2.31). Otherwise, some species were completely absent for sites which are known to be significant recreational spearfishing spots. Red Hind (*Epinephelus guttatus*) was only present at SDP, representing only 15% of the habitats sampled. Graysby (*Cephalopholis cruentata*) was present only at deeper PLT habitats, representing 8% of the habitats. Although Rock Hind (*E. adsencionis*) and Coney (*C. fulva*) were present across 46% and 54% of the sites, respectively, their higher mean biomass values were attained at farther and deeper habitats, away from the most significant recreational fishing pressure.

This pattern was fairly similar for snappers (Lutjanidae) (Figure 2.32). Schoolmaster (*Lutjanus apodus*) was only present in 38% of the surveyed sites, mostly habitats less frequented by recreational spearfishers. Mutton Snapper (*L. analis*) was present in 15% of the habitats, Mahogany Snapper (*L. mahogoni*) in 31% of the habitats, and Yellowtail Snapper (*Ocyurus chrysurus*) across all sites. However, larger biomass values were observed at farther and deeper sites.

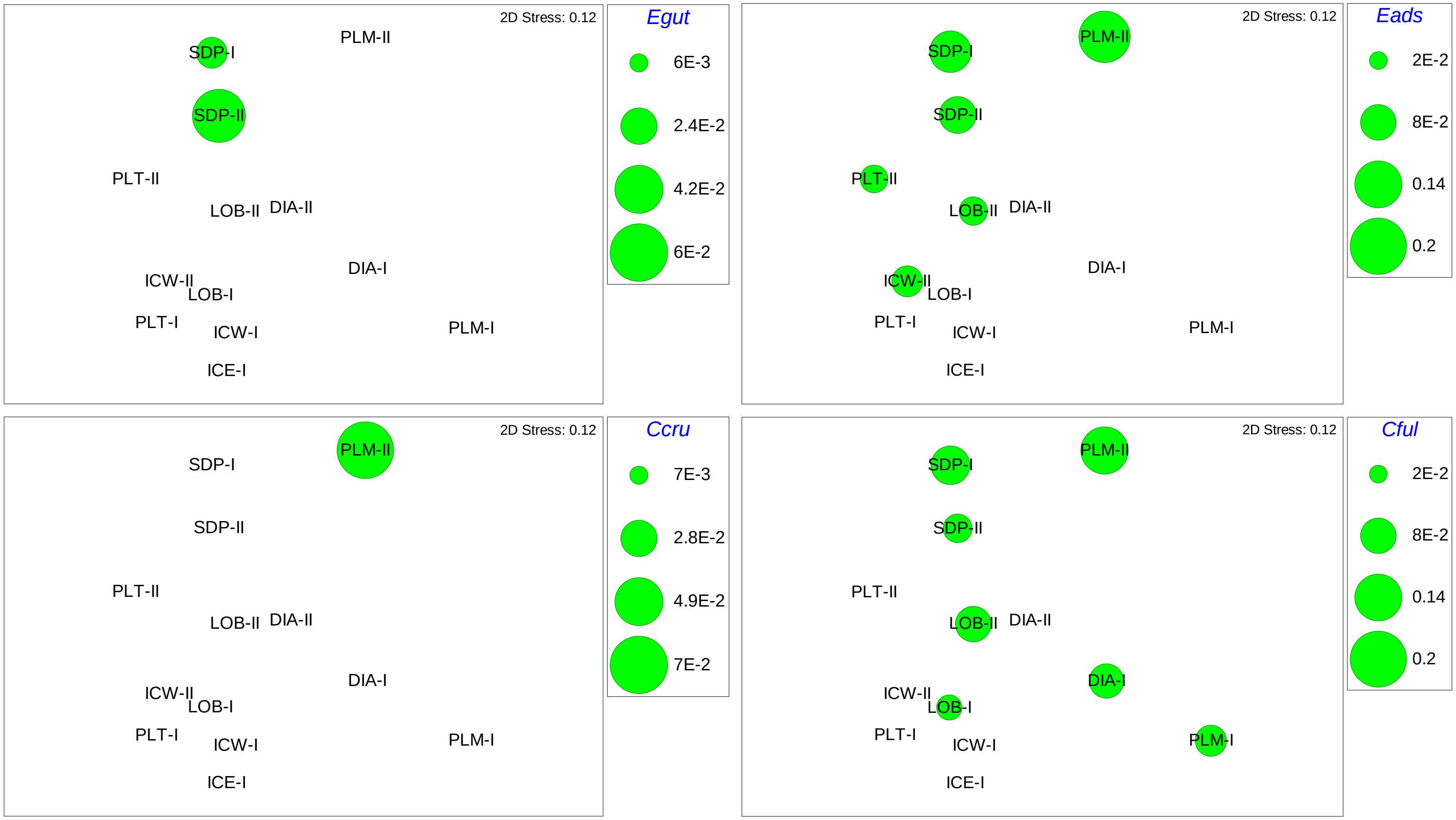

FIGURE 2.31. Bubble plot analysis of Epinephelinae subfamily spatial distribution based on biomass. From top left: (A) Red Hind (*Epinephelus guttatus*), (B) Rock Hind (*E. adsencionis*); (C) Graysby (*Cephalopholis cruentata*); and (D) Coney (*C. fulva*).

FIGURE 2.32. Bubble plot analysis of Lutjanidae family spatial distribution based on biomass. From top left: (A) Schoolmaster (*Lutjanus apodus*), (B) Mutton Snapper (*L. analis*); (C) Mahogany Snapper (*L. mahogoni*); and (D) Yellowtail Snapper (*Ocyurus chrysurus*).

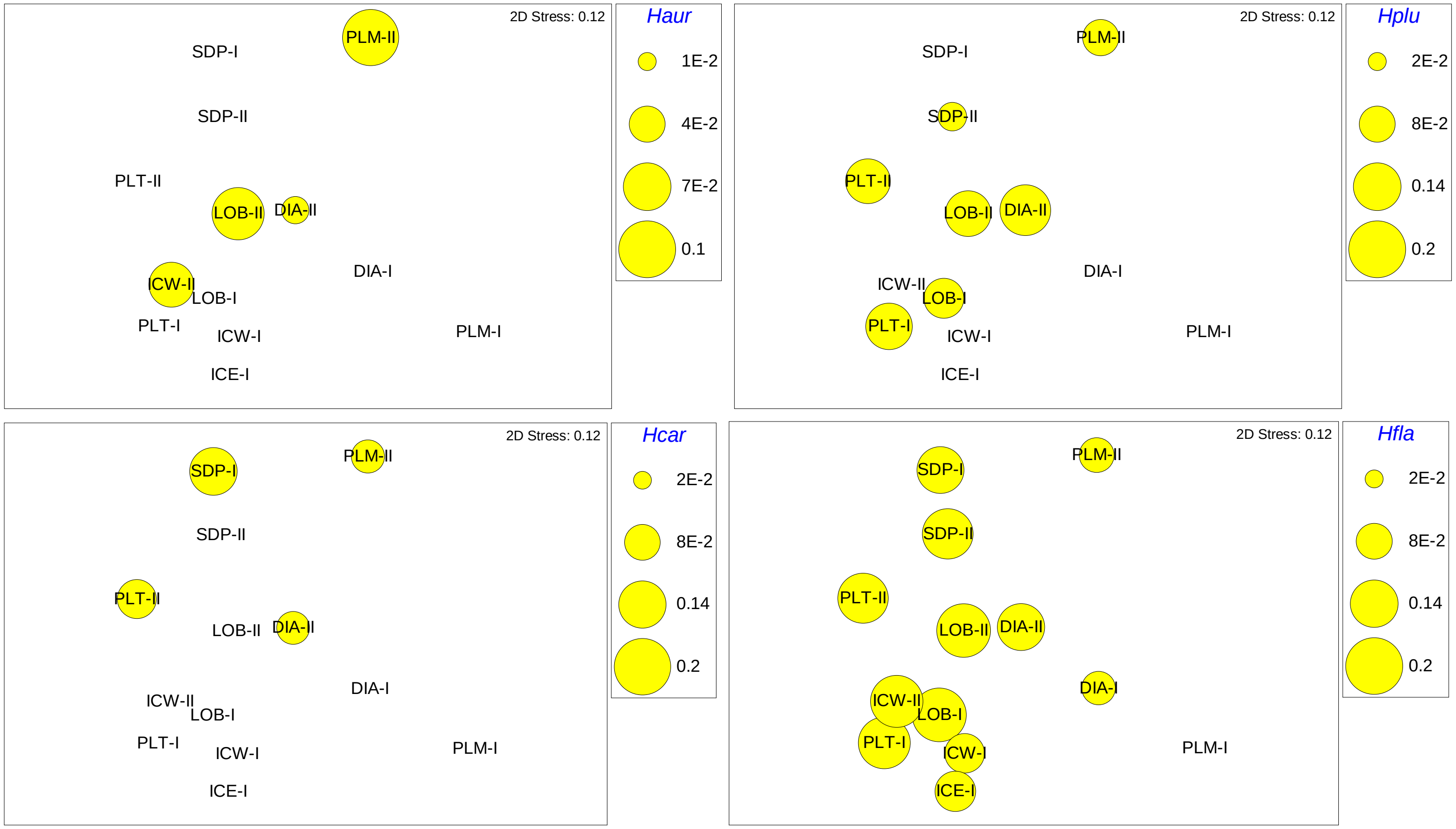

FIGURE 2.33. Bubble plot analysis of Haemulidae family spatial distribution based on biomass. From top left: (A) Tomtate (*Haemulon aurolineatum*), (B) White Grunt (*H. plumieri*); (C) Caesar Grunt (*H. carbonarium*); and (D) French Grunt (*H. flavolineatum*).

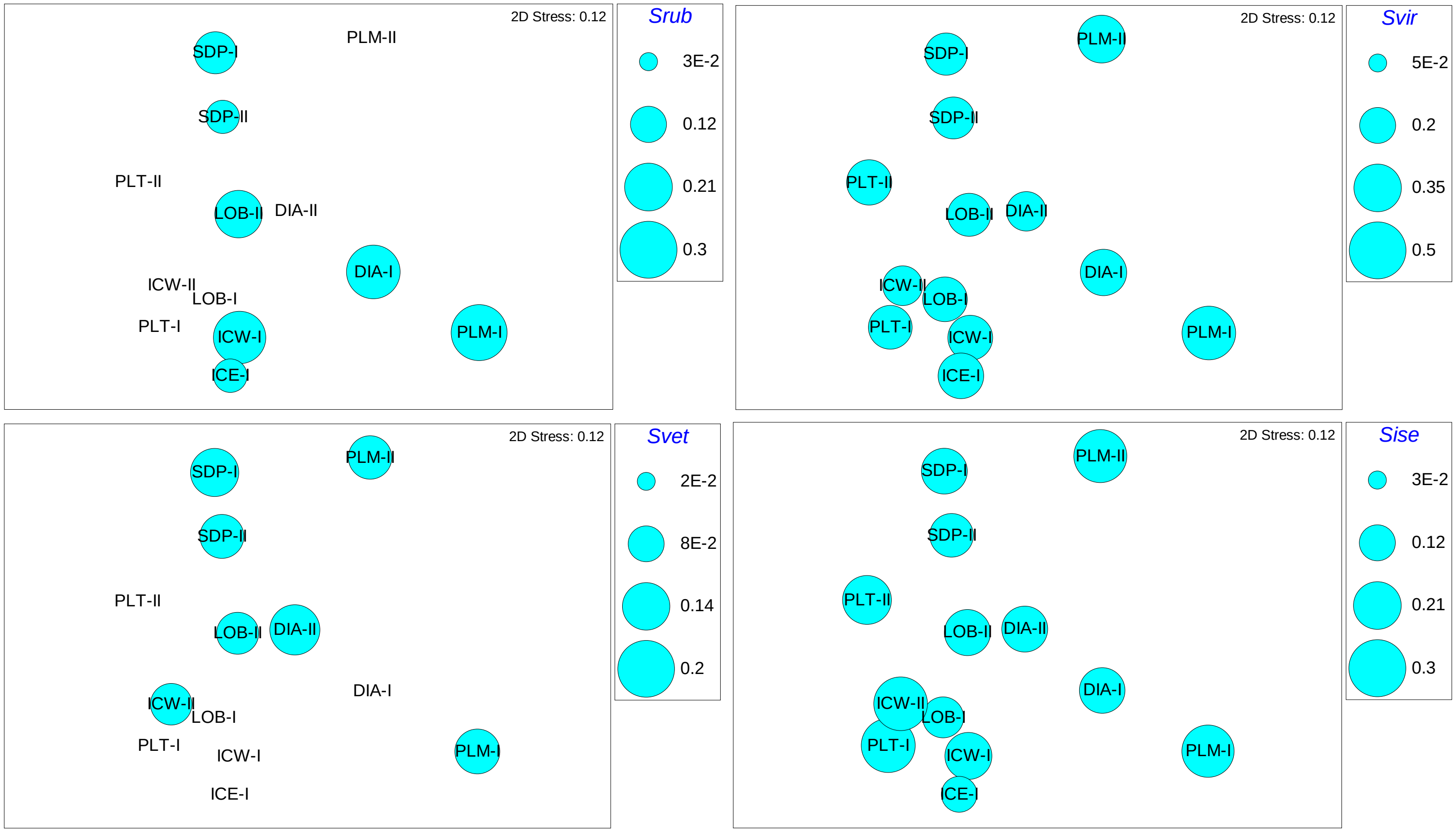

FIGURE 2.34. Bubble plot analysis of Scaridae family spatial distribution based on biomass. From top left: (A) Yellowtail parrotfish (*Sparisoma rubripinne*), (B) Stoplight Parrotfish (*Sp. viride*); (C) Queen Parrotfish (*Scarus vetula*); and (D) Striped Parrotfish (*Sc. iserti*).

FIGURE 2.35. Bubble plot analysis of selected fish species spatial distribution based on biomass. From top left: (A) Great Barracuda (*Sphyraena barracuda*), (B) Hogfish (*Lachnolaimus maximus*); (C) Cleaning Goby (*Gobiosoma genie*); and (D) Sharpnose Puffer (*Canthigaster rostrata*).

Spatial patterns were less evident for ubiquitous taxa such as grunts (Haemulidae) (Figure 2.33). However, Tomtate (*Haemulon aurolineatum*) and Caesar Grunt (*H. carbonarium*) were present in 31% of surveyed sites, respectively. White Grunt (*H. plumieri*) was present in 54% of the sites, while French Grunt (*H. flavolineatum*) was present at 92% of the sites. But mean biomass values overall resulted rather low, suggesting possible fishing impacts. Similarly, spatial patterns were not that evident in parrotfishes (Scaridae) (Figure 2.34). Yellowtail parrotfish (*Sparisoma rubripinne*) and Queen Parrotfish (*Scarus vetula*) were present in 54% of the surveyed sites, respectively. But the ubiquitous Stoplight Parrotfish (*Sp. viride*) and Striped Parrotfish (*Sc. iserti*) were present across all sites. Lack of spatial biomass patterns in scarids is a reflection of the abundance of juvenile individuals for most of the species, which could possibly reflect that juveniles are ignored by fishers.

Spatial biomass patterns of other selected fish species show very strong spatial gradient effects (Figure 2.35). Important fishery-targeted species such as the Great Barracuda (*Sphyraena barracuda*) and Hogfish (*Lachnolaimus maximus*), were present in 23% and 8% of the sites, respectively. Observations for each of these species were based on a single individual per site. Entire non-targeted taxa were very rare or completely absent from surveyed sites. For instance, only a single individual of the Cleaning Goby (*Gobiosoma genie*) was documented through the entire study. Similarly, only isolated observations of the Sharpnose Puffer (*Canthigaster rostrata*) were made at three separate sites.

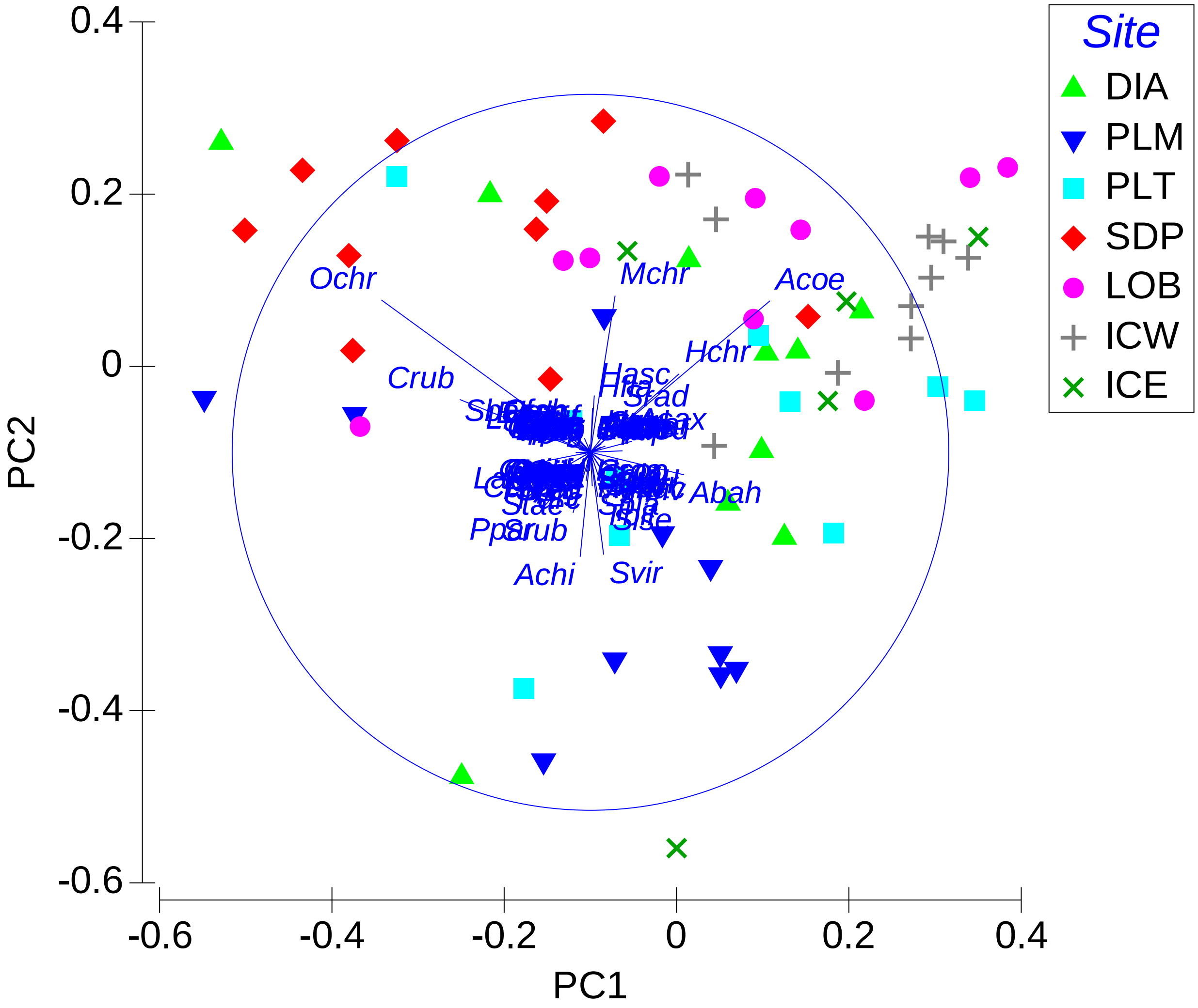

FIGURE 2.36. Principal component analysis of fish functional groups.

Principal component analysis

Principal component analysis (PCA) based on fish biomass was used to identify which species better explained the observed spatial patterns of fish community structure (Figure 2.36). Yellowtail snapper (*Ocyurus chrysurus*) was the most significant factor influencing community structure at SDP, while Yellowtail damselfish (*Microspathodon chrysurus*) did so at LOB. Blue tang (*Acanthurus coeruleus*) was a significant determinant of community structure at shallow sites of LOB and DIA, as well as for most of ICE and ICW. Stoplight parrotfish (*Sparisoma viride*) resulted a moderate determinant of fish community structure at PLM. Planktivore Sargeant Major (*Abudefduf saxatilis*) was a moderate predictor at PLT.

SIMPER tests of indicator species

SIMPER routine analysis showed which species were dominant at each site based on mean biomass values. Herbivores were the dominant taxa overall, with very few exceptions (Tables 2.4 and 2.5). *Sparisoma aurofrenatum*, *Acanthurus coeruleus* and *Ocyurus chrysurus* constituted 30% of the total biomass at DIA. Herbivore guilds composed of *S. viride*, *S. aurofrenatum*, and *A. coeruleus* constituted 39% of the total biomass at PLM. Similarly, herbivores *A. bahianus*, *S. aurofrenatum*, and *S. viride* conformed 34% of the biomass at PLT. A total of 26% of the total fish biomass were dominated by *A. coeruleus*, *O. chrysurus*, *Sphyraena barracuda* at SDP. Herbivores *S. aurofrenatum*, *Microspathodon chrysurus*, and *A. coeruleus* explained 29% of fish biomass at LOB, while *A. bahianus*, *M. chrysurus*, and *Sp. viride* explained 27% of the biomass at ICE. Similarly, *A. coeruleus*, *S. aurofrenatum*, and *A. bahianus* constituted 35% of the biomass at ICW. Cumulative species abundance per site ranged from 23 at PLM and ICW to 31 at SDP (Table 2.4). A remarkably consistent 63 to 67% of the total species pool constituted 90% of the biomass at each site, with the exception of PLM (57%).

Eight species explained differences in fish community structure among sites (Table 2.5). *Sphyraena barracuda* explained differences between SDP and the remaining sites (29% of the

TABLE 2.4. SIMPER routine cumulative percent of the three dominant species of each site (based on SIMPER analysis using biomass).

Site	**Fish species**	**Cumulative %**	**Species contributing 90% of the total fish biomass**
DIA	*Sparisoma aurofrenatum, Acanthurus coeruleus, Ocyurus chrysurus*	30.08	15/24 (62.5%)
PLM	*S. viride, S. aurofrenatum, A. coeruleus*	39.04	13/23 (56.5%)
PLT	*A. bahianus, S. aurofrenatum, S. viride*	33.67	16/24 (66.7%)
SDP	*A. coeruleus, O. chrysurus, Sphyraena barracuda*	26.03	20/31 (64.5%)
LOB	*S. aurofrenatum, Microspathodon chrysurus, A. coeruleus*	28.54	18/27 (66.7%)
ICE	*A. bahianus, M. chrysurus, S. viride*	27.27	20/30 (66.7%)
ICW	*A. coeruleus, S. aurofrenatum, A. bahianus*	35.30	15/23 (65.2%)

TABLE 2.5. Species indicating differences between sites (based on SIMPER analysis using biomass).

Sites	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**
DIA	-					
PLM	*M. chrysurus*					
PLT	*P. paru*	*S. taeniopterus*				
SDP	*S. barracuda*	*S. barracuda*	*S. barracuda*			
LOB	*H. chrysargyreum*	*M. chrysurus*	*M. chrysurus*	*S. barracuda*		
ICE	*O. chrysurus*	*M. chrysurus*	*M. chrysurus*	*S. barracuda*	*A. chirurgus*	
ICW	*O. chrysurus*	*H. chrysargyreum*	*H. chrysargyreum*	*S. barracuda*	*A. coeruleus*	*A. chirurgus*

total combinations). Territorial Yellowtail damselfish (*M. chrysurus*) explained differences in community structure in 24% of the time. Smallmouth grunt (*Haemulon chrysargyreum*) explained community variation patterns among sites 14% of the time. Yellowtail snapper (*Ocyurus chrysurus*) and Doctorfish (*Acanthurus chirirgus*) did so 10% of the time, respectively. French angelfish (*Pomacanthus paru*), Princess parrotfish (*Scarus taeniopterus*), and Blue Tang (*A. coeruleus*) explained fish community differences among sites 5% of time, each one respectively.

Multivariate analysis of fish community structure at the functional group level

Multivariate analyses were also conducted using fish biomass at the fish functional group level. There were significant differences in fish community structure among sites, and between depth zones, but no significant site x depth interaction effects were documented (Table 2.6). All combinations among sites showed significant differences (Table 2.7). DIA and PLT resulted well separated, representing 5% of the total site combinations. A total of 24% of the pairwise combinations resulted overlapping but clearly different, while 62% of the combinations resulted overlapping but partially different. An additional 10% resulted non-separable at all.

Ordination analysis of fish communities at the functional group level

Fish communities were also ordinate at the functional group level, first using a cluster analysis (Figure 2.37), followed by a MDS analysis (Figure 2.38). Fish communities organized within five different clusters based on the 87.5% similarity cutoff level. There was cluster

TABLE 2.6. Results of a one-way ANOSIM test of fish community structure based on fish functional group biomass. Analysis based on 5000 permutations. NS= Not significant ($p>0.0500$).

Factors	Global R	Significance
Global test		
Site	0.430	0.0002
Depth	0.451	0.0002
Site x Depth	0.245	0.0780 NS

TABLE 2.7. Pairwise ANOSIM test comparisons among study sites. Analysis based on fish functional group biomass. The R statistic represents pairs of sites that are well separated (R>0.75, blue), overlapping but clearly different (R= 0.50 -0.75, green), overlapping but partially different (R=0.25-0.50, yellow), barely separable at all (R=0.25-0.10, red), or non-separable (R<0.10, lavender). Number in parentheses represent statistical significance level (*p*).

Site	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
DIA	-						
PLM	0.37 (0.0020)	-					
PLT	0.84 (0.0006)	0.42 (0.0004)	-				
SDP	0.68 (0.0006)	0.40 (0.0010)	0.40 (0.0060)	-			
LOB	0.42 (0.0010)	0.41 (0.0007)	0.38 (0.0050)	0.28 (0.0080)	-		
ICE	0.55 (0.0080)	0.38 (0.0320)	0.30 (0.0560)	0.64 (0.0160)	0.02 (0.5320)	-	
ICW	0.68 (0.0010)	0.43 (0.0010)	0.35 (0.0060)	0.60 (0.0006)	0.38 (0.0060)	0.20 (0.0710)	-

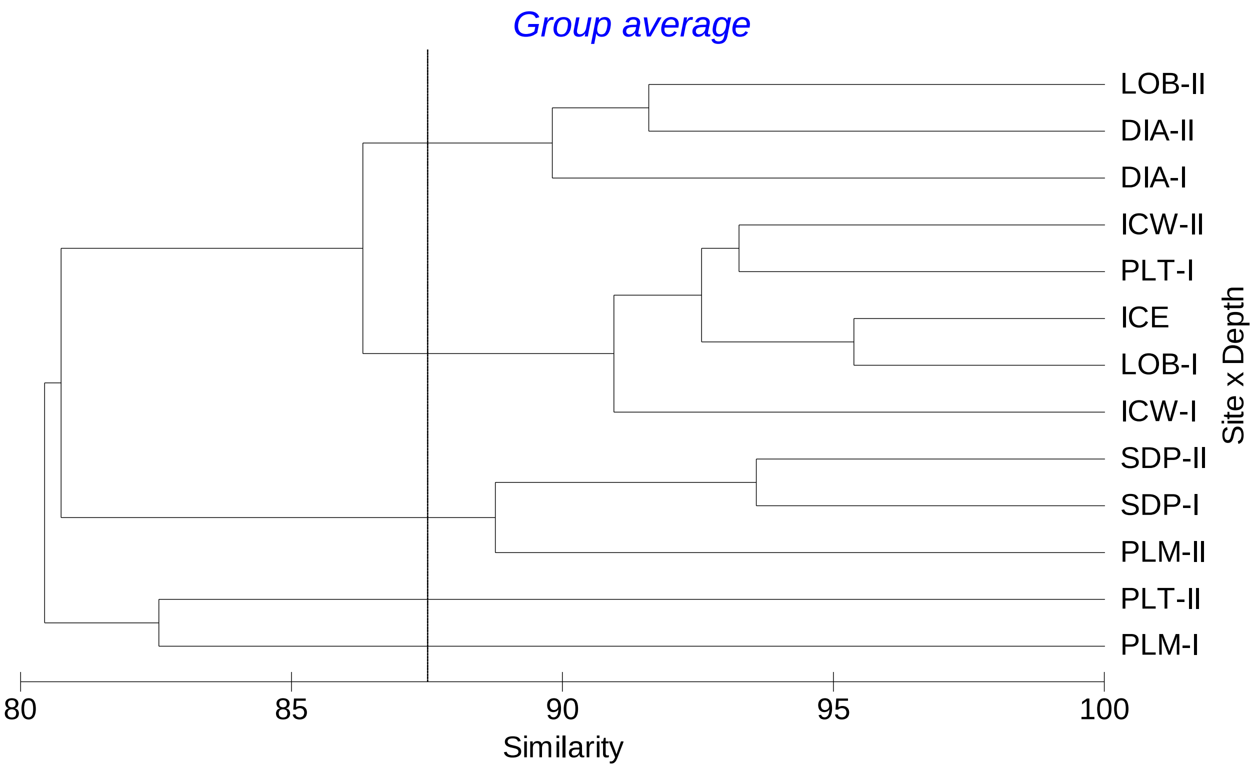

FIGURE 2.37. Cluster analysis of fish community structure based on functional group biomass. Vertical bar shows 87.5% cutoff level. Fish communities organized within five different clusters based on the 87.5% similarity cutoff level. Acronyms are explained in the Methodology section. Depth zones: I (<5 m); II (5-15 m).

composed by SDP-I, SDP-II, and PLM-II that was characterized by having the largest presence of piscivore guilds, principally moderate schools of Bar jack (*Carangoides ruber*), a few large individuals of the Great barracudas (*Sphyraena barracuda*), as well as other species. PLT-II formed a separated cluster due to the abundance of planktivore species. LOB-II, DIA-I, and DIA-II organized in a second cluster due to the highest similarity of their planktivore and herbivore guilds. PLM-I and PLT-II formed individual clusters also as a result of their depauperate herbvivore fauna. The remaining sites clustered together as a result of their overall depleted fish communities.

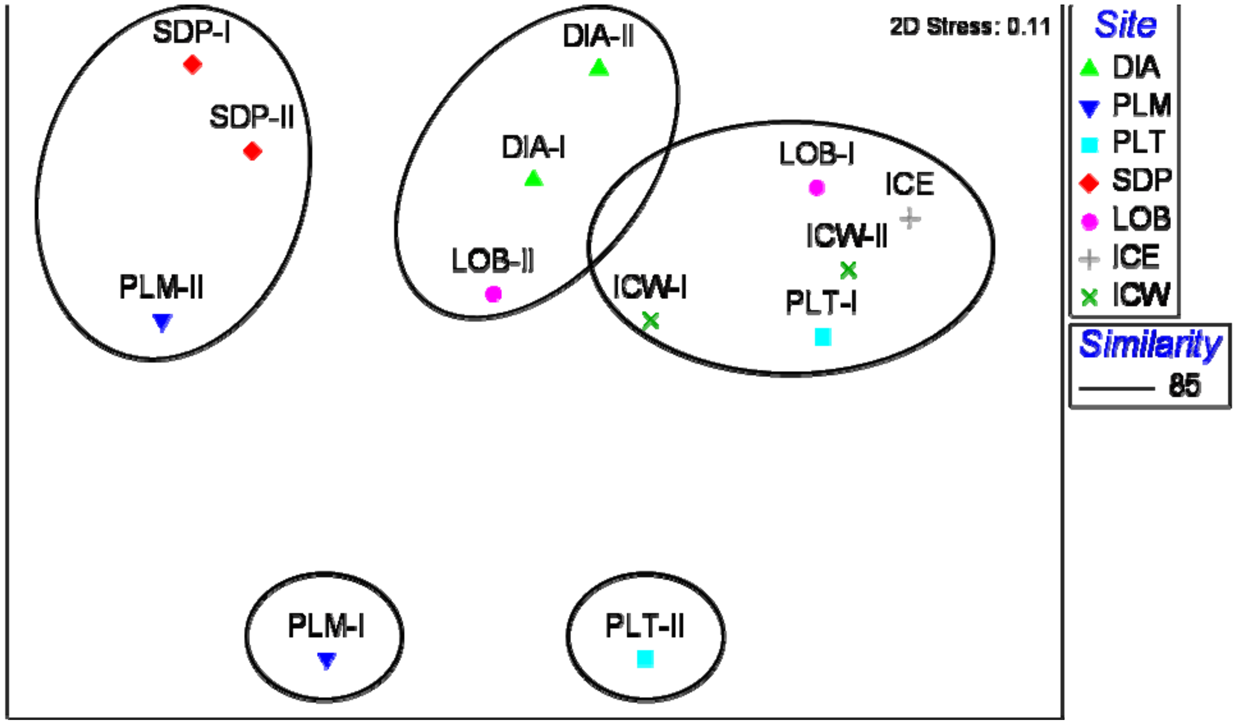

FIGURE 2.38. Multi-dimensional scaling (MDS) plot of fish community structure based on functional group biomass. Fish communities organized within six different clusters based on the 85% similarity cutoff level. Acronyms are explained in the Methodology section. Depth zones: I (<5 m); II (5-15 m).

Spatial patterns of biomass distribution of functional groups

Bubble plots derived from MDS analysis were similarly used to discriminate spatial patterns of biomass distribution of functional groups. Non-denuder and browser herbivores were dominant (Figure 2.39) at coral reefs known to be depleted of piscivores (Figure 2.40). Scrapers were distributed on a nearly similar magnitude across all sites with few exceptions. Generalist carnivore biomass was higher on reefs located farther from areas subjected to recreational

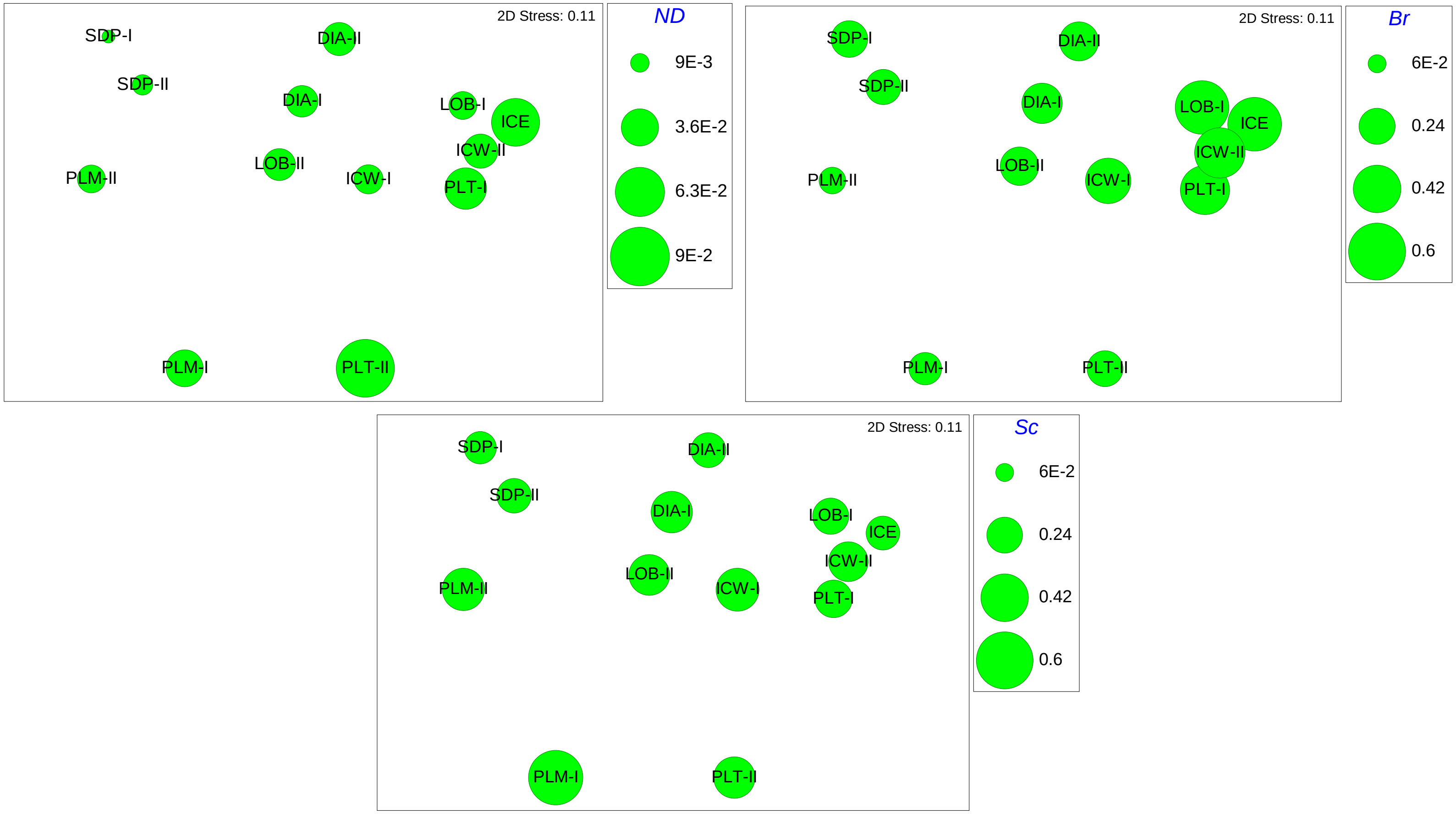

FIGURE 2.39. Bubble plot analysis of herbivore functional groups spatial distribution based on biomass. From top left: (A) Non-denuders (Pomacentridae), (B) Browsers (Acanthuridae); and (C) Scrapers (Serranidae).

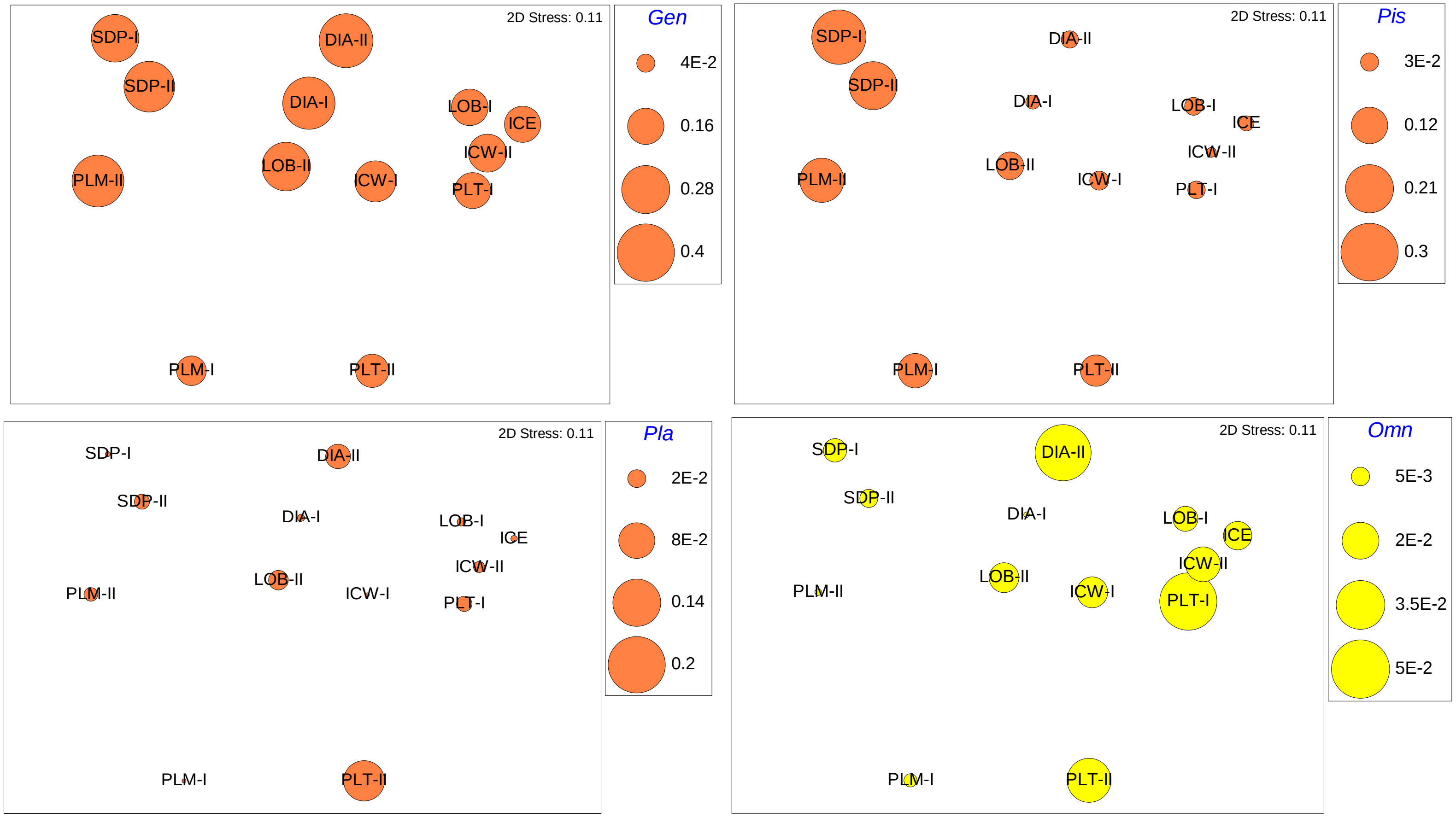

FIGURE 2.40. Bubble plot analysis of carnivore functional groups spatial distribution based on biomass. From top left: (A) Generalists, (B) Piscivores; (C) Planktivores; and (D) Omnivores.

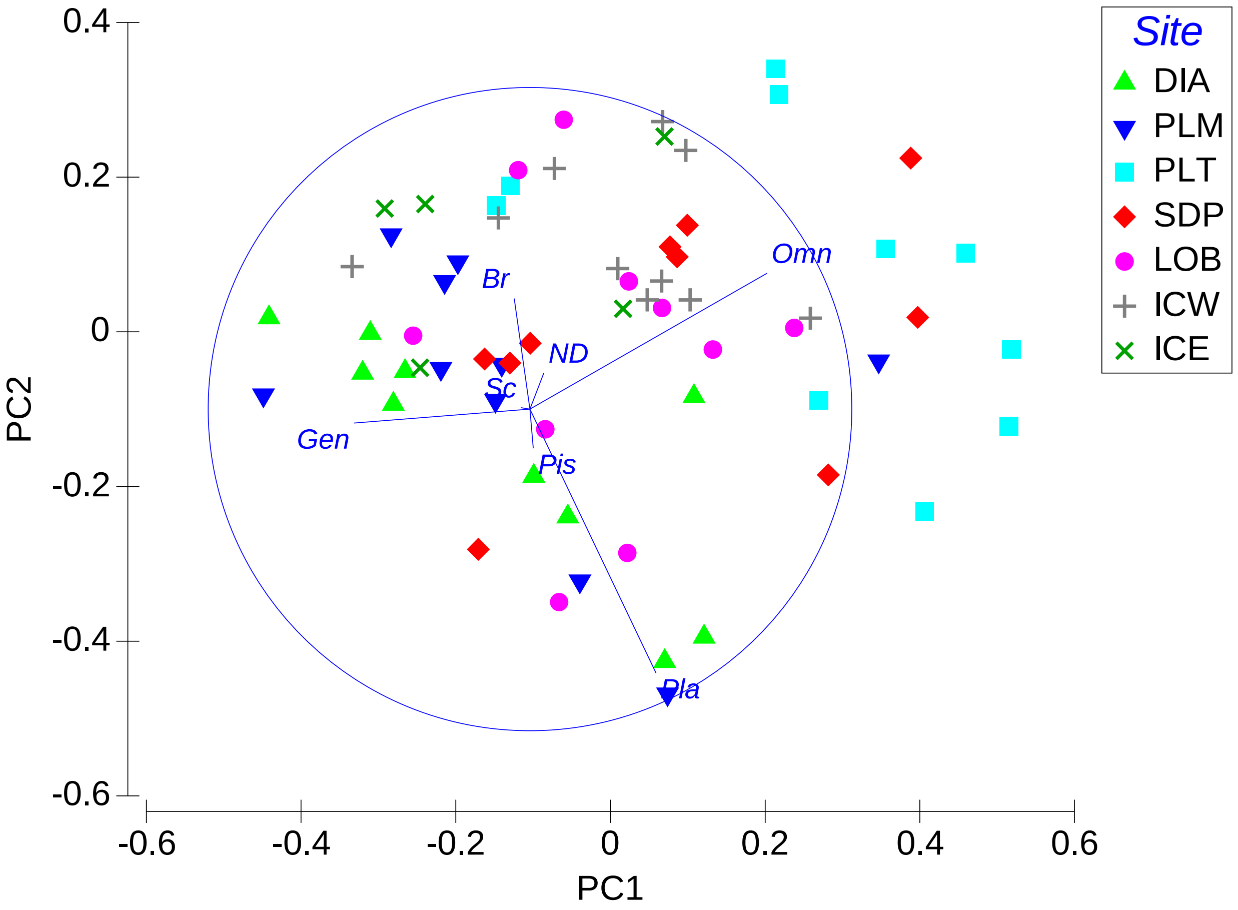

FIGURE 2.41. Principal component analysis of fish functional groups.

spearfishing pressure. Planktivores were dominant in coral reefs located farther offshore, particularly on deeper habitats. Omnivores were also more abundant on reefs with depleted piscivore populations.

Principal component analysis

Principal component analysis (PCA) based on fish functional group biomass was used to identify which group better explained the observed spatial patterns of fish community structure

(Figure 2.41). Planktivores were a very strong factor influencing fish community structure at deepwater DIA, PLM and LOB sites. Omnivores explained most of the community structure at PLT, LOB, ICW, and shallow SDP sites. Browsers resulted significant factors in explaining community structure at shallow ICE, ICW, PLT, and LOB sites. Generalists were more significant in explaining fish community structure at DIA and SDP. Scrapers are a poor predictor of community structure at SDP and PLM, as well as non-denuders at SDP, ICE, and ICW. Similarly, piscivores were poor predictors overall.

SIMPER tests of indicator functional groups

SIMPER tests also showed which functional groups were dominant at each site based on mean biomass values. As previously shown, herbivores were the dominant taxa overall, with very limited exceptions (Table 2.8). Browsers were the dominant functional group at LOB, ICE, and ICW, while scrapers did it at PLM and PLT. Generalist carnivores did it DIA and SDP. Browsers were always among the top three dominant functional groups across all sites, while scrapers and generalist carnivores did it at six out of the seven sites. Piscivores ranked third at SDP and at PLM, with mean relative biomass of 22 and 18%, respectively. Elsewhere, piscivore biomass barely reached 9% at LOB, 8% at PLT, 7% at DIA, 5% at ICW, and 2% at ICE.

Five out of seven functional groups (71%) explained differences in fish community structure among sites (Table 2.9). Browsers constituted 33% of the observed variations among sites. Piscivores explained variation patterns among study sites 29% of the time. Generalists and

TABLE 2.8. SIMPER routine cumulative percent of the three dominant functional group of each site (based on SIMPER analysis using biomass).

Site	Functional group	Cumulative %
DIA	Generalists, Browsers, Scrapers	80.92
PLM	Scrapers, Browsers, Piscivores	70.61
PLT	Scrapers, Browsers, Generalists	67.11
SDP	Generalists, Browsers, Piscivores	70.30
LOB	Browsers, Scraper, Generalists	74.92
ICE	Browsers, Scraper, Generalists	90.92
ICW	Browsers, Scraper, Generalists	80.12

TABLE 2.9. Functional groups indicating differences between sites (based on SIMPER analysis using biomass).

Sites	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**
DIA	-					
PLM	Piscivores					
PLT	Generalists	Browsers				
SDP	Piscivores	Scrapers	Piscivores			
LOB	Generalists	Browsers	Planktivores	Piscivores		
ICE	Browsers	Browsers	Planktivores	Piscivores	Browsers	
ICW	Generalists	Browsers	Planktivores	Piscivores	Browsers	Scrapers

planktivores explained variation patterns among study sites 14% of the time, respectively. Scrapers did it 10% of the time.

Discussion

Coral reefs in crisis

Coral reef fish communities within ALCNR were showing unequivocal signs of crisis. Results were largely consistent with direct impacts of apex predator extraction and indirect impacts on lower trophic level assemblages similar to the findings of DeMartini et al. (2008). Populations of the most significant fishery-targeted species were significantly depleted, apex predators were largely absent from most reefs, the most significant predators were small or medium-sized intermediate predators, and herbivore guilds were dominant across most sites (i.e., abundance, biomass). Recreational and artisanal fishing activities across the reserve were poorly managed. Further, benthic communities were also reflecting major recent declines in % coral cover, particularly in the most significant reef-building taxa. Benthic community decline has been largely the result of chronic water quality degradation (i.e., recurrent polluted runoff pulses from the Fajardo coast), variable human recreational impacts (i.e., anchoring), and the massive coral mortality event of 2006 that followed the 2005 unprecedented sea surface warming event and bleaching episode. This combination of factors has also indirectly resulted in major depletion of non-tagerted cryptic, small-sized reef dweller fish species.

Reefs are in worldwide crisis as a result of complex, historical, and synergistic interactions among local-scale anthropogenic-driven factors, including fishing, and regional- or global-scale climatic factors (Jackson, 2001; Gardner et al., 2003; Pandolfi et al., 2003; Buddemeier et al., 2004). Increasing human populations and economic demands can produce direct and indirect chronic and acute stresses that may result in chronic coastal pollution, and recurrent pulses of sediment- and nutrient-laden runoff that may threaten coral reefs, often in combination with chronic indirect fishing impacts, and regional- or global-scale factors such as rising sea surface temperature (SSTs) (Hughes, 1994; Hoegh-Guldberg, 1999; Birkeland, 2004; Hawkins and Roberts, 2004; Aronson and Precht, 2006; Newman et al., 2006; Miller et al., 2006; Hoegh-Guldberg et al., 2007; Lesser, 2007; Whelan et al., 2007). The cumulative and synergistic impact of these factors may result in a long-term significant habitat structure modification or loss, with often a sharp threshold in habitat availability that could potentially result in local extirpation of species or extinctions (Travis et al., 2003). It is suggested that the long-term combination of local anthropogenic-driven habitat loss and large-scale rising SST, with long-term fishing impacts, might result in a major phase shift in coral reef fish assemblages, therefore resulting in significant indirect modifications of habitat structure and function (McClanahan and Muthiga, 1998; Jackson, 2001).

Top-down fishing impacts

Long-term impacts of fishing, essential fish habitat loss, and climate change might have had significant combined and cumulative negative impacts on ALCNR fish community structure.

Several fish functional groups were largely depleted through most of the study sites, particularly in areas subjected to very intense recreational activities, including spearfishing. Piscivore guilds were the most affected. Most grouper (Serranidae), snapper (Lutjanidae), and barracuda (Sphyraenidae) populations were significantly depleted or completely absent at most sites. This pattern was evident also for some grunts (Haemulidae). Further, most individuals of fishery-targeted species observed belonged to smaller size categories. Other significant fishery-targeted groups such as triggerfishes (Balistidae), porcupinefish (Diodontidae), highly-prized species such as Nassau Grouper (*Epinephelus striatus*), or entire genera such as *Mycteroperca* spp. were totally absent during the entire study. These observations were consistent with local artisanal fishers perception about the fisheries conditions within ALCNR where they largely avoided fishing within the reserve due to its limited abundance of target species and competition/conflicts with other user groups (Shivlani, Ch. 3). Observations were also consistent with with previous studies of fishing impacts elsewhere across different systems (Jennings and Polunin, 1996; Friedlander and DeMartini, 2002; Scheffer et al., 2005; DeMartini et al., 2008; Götz et al., 2008).

Another significant finding was the depauperate condition of many non-targeted taxa such as Grammatidae, Clinidae, Labrisomidae, Chaenopsidae, Blennidae, Monacanthidae, and Tetraodontidae were almost completely depleted or absent from study sites. We suggest that such condition could have been related to the massive coral mortality that followed the unprecedented sea surface warming and mass bleaching that occurred during 2005. Responses to different local or regional variables are family-specific or species-specific, depending on the factor. Fishing impacts can have a direct negative impact over fishery-targeted taxa (Roberts, 1995b; Götz et al., 2008), and even on the entire fish community trophic structure (Friedlander and DeMartini, 2002; Valentine and Heck, 2005; DeMartini et al., 2008). Reef environmental degradation (i.e., water quality decline, % coral cover decline) can affect a wider number of groups, including non-targeted species such as planktivores (Jones et al., 2004). Regional or global factors such as high SSTs, recurrent bleaching and coral declines can affect most groups as well (Pratchett et al., 2008).

Fishing impacts can have profound persistent ecological effects on ecosystem dynamics of coral reefs and other marine habitats (Roberts, 1995b; Daskalov, 2002). Impacts have been documented across multiple spatial and temporal scales (Jackson, 1997, Jackson et al. 2001; Pauly et al. 2002). Often in combination with other human disturbances such as eutrophication, sedimentation, and disease outbreaks, fishing could indirectly trigger long-term phase shifts in the community structure of both fish and benthic communities (Hughes, 1994; Hawkins and Roberts, 2004). It can also have profound effects at the ecosystem level that may include declines in the abundance and biomass of large animals, some of them undergoing extinction (Jackson, 2001). Fishing can produce cascade effects negatively impacting the abundance of marine fish populations (Pinnegar et al., 2000; Carr et al., 2002), and age of maturity, size structure, sex ratio and genetic diversity of exploited species (Sobel and Dahlgren, 2004; Götz et al., 2008). Fishing down the food web can indirectly affect marine biodiversity (Roberts, 1995b; Bohnsack and Ault, 1996) and ecosystem productivity (Daskalov, 2002). It can also have paramount long-term impacts on functional cross-habitat connectivity, ecosystem functions, and resilience and as a result of bycatch, habitat degradation, and by altering biological interactions (Carr et al., 2002), ecosystems structure and function, and reducing the ability of reefs to recover from disturbance (Roberts, 1995b; Sobel and Dahlgren, 2004).

Biomass pyramid and functional connectivity impacts

Previous studies showed that carnivores were the most abundant trophic group and showed higher biomass than herbivores in coral reefs (Goldman and Talbot, 1976; Grigg et al., 1984). This pattern followed a classical inverted pyramid trophic structure. Under natural conditions, long-term sustainability of large predator populations might have relied on the productivity of multiple habitats beyond coral reefs to meet their nutritional needs (Valentine and Heck, 2005), as well as in significant cross-habitat connectivity. Where abundant, predators might have represented significant mobile links for transferring energy and nutrients across habitat boundaries. Intense top-down overfishing impacts may result in a permanent shifting of the classical inverted biomass pyramid towards dominance by herbivore guilds (Jennings and Polunin, 1996; Friedlander and DeMartini, 2002). Fishing down the food web will lead to a sustained relaxation of top-down control by apex predators leading to phase shifts favoring dominance by lower trophic guilds (Pauly et al., 1998; Pinnegar et al., 2000), often leading to local extirpation of species (Christensen and Pauly, 1997), and to alterations of cross-habitat energy exchange (Valentine et al., 2007). Reversing such shifting trends at the ecosystem level is very difficult (Pitcher, 2001), specially in systems with low functional redundancy such as

Caribbean coral reefs (Bellwood et al., 2004). Further, these trends can make ecosystems more vulnerable to other sources of anthropogenic stress (Jackson, 2001).

In this study, herbivores represented 53% of the total fish abundance in shallow reef zones, and 50% in deeper habitats, while carnivores represented 39% and 28%, respectively. Also, herbivores represented 71% of the total fish biomass in shallow coral reefs, and 55% in deeper zones, while carnivores represented 27% and 43%, respectively. Such trends represent an unequivocal long-term intense overfishing impact of apex predators, and heavy exploitation of primarily carnivorous trophic level fishes, as suggested by previous studies (Jennings and Polunin, 1996; Friedlander and DeMartini, 2002; DeMartini et al., 2008).

Bottom-up habitat degradation impacts

One key aspect across most of LCNR has been its recent significant coral decline, currently being documented by Hernández-Delgado et al. (unpub. data). Preliminary findings suggest declines in the order of more than 50% coral cover within the last decade. We suggest that, in addition to overfishing impacts, major phase shifts in benthic community composition have indirectly contributed to fish community declines. Carpenter et al. (1981) showed that there were strong positive correlations between living coral cover and species diversity, and fish abundance. Gladfelter and Gladfelter (1978), Carpenter et al. (1981), and Galzin et al. (1994) also found that fish biomass increased with structural heterogeneity of reef substrate. Doherty et al. (1997) found that a catastrophic loss of coral cover on the Great Barrier Reef caused a great reduction in fish recruitment, suggesting that any significant change in benthic community composition may also affect fish community structure. Jones et al. (2004) found significant declines in fish biodiversity, particularly in cryptic, non-target reef dwellers following a long-term benthic community decline. However, little is still known about the direct and indirect functional ecological impacts of declining fish populations on factors such as settlement, recruitment, survival, tissue regeneration and bioerosion rates of reef-building corals, processes which are vital for structuring and maintaining coral reef benthic communities and for maintaining ecosystem resiliency. According to Bohnsack (1993), this lack of studies becomes a problem due to the absence of long-term monitoring studies on coral reef fish populations, multi-disciplinary studies on reef problems, experimental studies, valid scientific controls (i.e., no-take MPAs), and because sometimes fishing impacts could be masked by other anthropogenic factors (i.e. water quality decline).

Water quality degradation in the Fajardo area has been a historical concern for coral reef conservation (Mckenzie and Benton, 1972; Goenaga and Cintrón, 1979; Hernández-Delgado, 2000, 2005). Figure 42 shows an ALCNR aerial image showing evidence of complex localized gyre currents as reflected by water turbidity “cloud” patterns. Local gyres can be important to foster self-recruitment within ALCNR’s boundaries. But at the same time they can “trap” and carry out highly turbid, sewage-polluted coastal waters coming from the Fajardo River mouth, from regional and private sewage treatment facilities, from several private marinas, and from

FIGURE 42. Modification of aerial image of ALCNR showing evidence of complex localized gyre currents as reflected by water turbidity “cloud” patterns. Local gyres can be important to foster self-recruitment within reserve’s boundaries. But a the same time they can carry out highly turbid, sewage-polluted coastal waters coming from the Fajardo River mouth towards offshore islands, even farther east and north than Cayo Diablo (source: http://www8.nos.noaa.gov/biogeo_public/aerial/viewer.aspx?source=usvi&id=5418). Photo technical information: ID: 5418; Flight Line ID: PR 48-002; Roll#: 99ACN29; Spot#: 200-812; Date: 28-NOV-1999; Time: 13:51:07GMT; Latitude: 18.3680067; Longitude: -65.560367; Height ASL (meters): 7344; Azimuth (degrees): 93.1; Nominal Scale: 1: 48,000; Upper-right Lat (min): -3.13; Upper-right Long (min): 2.96.

variable non-point sources countercurrent towards offshore islands, even farther east and north than Cayo Diablo. This may often result in dramatic drops in visibility, from approximately 10-20 m to about 5 m or less, during episodes of turbid counterflows, even at depths of 20 to 30 m (Hernández-Delgado, pers. obs.). With time, turbid, polluted counterflow pulses have become more recurrent, becoming a major concern for fish communities due to long-term habitat quality decline. Water quality decline is also a major concern for commercial fishermen. Most fishermen believed that coral reefs had declined in the reserve over their tenure, as had water quality and, most importantly, fish abundance (Shivlani, Ch. 3).

Climate change-related impacts on fish communities

An unprecedented sea surface warming event occurred through the northeastern Caribbean during 2005, with temperatures reaching up to 33.1°C at shallow reef zones, and 31.8°C at 27 m depths at ALCNR (Hernández-Delgado, unpub. data). This event caused a massive coral bleaching episode in September 2005 that lasted for several months. This event caused major bleaching in 82 cnidarian species, including 48 scleractinians species, impacting 30 to 85% of the coral colonies within ALCNR, depending on the site and water circulation patterns (Hernandez-Delgado et al., 2006). This prolonged bleaching resulted in a major pattern of coral mortality, mostly impacting large reef-building species such as *Montastraea annularis*, *M. faveolata*, *Diploria* spp., *Siderastrea siderea*, and *Acropora cervicornis*, among others. Such decline triggered a rapid and significant phase shift in fish species community composition, as reflected by a significant loss of many fish taxa, mostly cryptic, small-sized, non-target reef dwellers, including cleaning gobies *Gobiosoma* spp. This study showed that these groups were still largely absent across the reserve. We suggest that sea surface warming has also indirectly contributed to current fish declines.

Rising SST and massive coral bleaching are known to negatively impact several aspects of the biology of coral reef fishes. These impacts may in turn cascade upwards and impinge further impacts on fish assemblages. Roessig et al. (2004) reported significant alterations in the physiology of fishes following increased exposure to warm temperatures. Bevelhimer and Bennet (2000) observed alterations in immune system functions. Mora and Ospina (2001) documented a decrease in fecundity. The relationship between altered fish physiology and its consequence in community structural phase shifts still remains largely unknown, but Lough (1998) and Pratchett et al. (2006) reported a major phase shift in Great Barrier Reef stressed out chaetodontid fish assemblages following bleaching-related coral mortality. Bleaching-related coral mortalities also resulted in decreased fish abundance and recruitment rates (Booth and Beretta, 2002), and caused significant species composition phase shifts (Williams 1986; Parker and Dixon, 1998; Spalding and Jarvis, 2002; Pratchett et al. 2008). These responses have been documented from Indo-Pacific reef habitats, but no documentation of these impacts on fish communities exists from Atlantic coral reefs, with the exception of studies by Hernández-Delgado et al. (in preparation) from Culebra Island.

Populations of most non-targeted taxa, particularly rare living-coral dwellers, were very rare or totally absent from surveyed reefs. This suggests that possibly a combination of mechanisms associated to increased SSTs, followed by benthic habitat modification (i.e., post-bleaching-related mortality) caused the observed changes in non-target fish assemblages. Similar effects have been previously documented in the Pacific (Parker and Dixon 1998; Spalding and Jarvis, 1992; Munday, 2004), and in Culebra Island (Hernández-Delgado et al., in preparation). Pratchett et al. (2008) suggested that coral loss following prolonged SST and mass bleaching events has the greatest and most immediate impact on fish taxa that depend on living corals for food or shelter. Further, this may also have long-term negative impacts on fish taxa that rely on reef topographic complexity and living coral for recruitment (Booth and Beretta, 2002), thus producing significant fish community phase shifts (Bellwood et al., 2006; Wilson et al., 2006, 2008). Secondary long-term impacts following coral mortality (i.e., bioerosion) can prevent fish community recovery (Garpe et al., 2006). Climate change has also been documented to produce variable sub-lethal effects that may affect fish physiology (Nakano et al., 2004; Roessig et al., 2004), may alter the nutritional value of remnant coral-prey (Pratchett et al., 2004), may alter fish bathymetric, latitudinal and seasonal distribution patterns (Dulvy et al., 2008; Henriques et al., 2008), and may potentially affect the sustainability of local fisheries in the future. Therefore, under an imminent climate change scenario, no-take MPAs may become even more important tools to buffer climate change-related impacts in the near future.

Recent lessons learned from Culebra

Hernández-Delgado et al. (in preparation) related the spatio-temporal changes in the structure of a fish community in Culebra Island, PR, which is located less than 20 km east of ALCNR, to local-scale anthropogenic-driven factors, and to a regional-scale high sea surface temperature (SST) and a massive coral bleaching event. Visual censuses were used to estimate fish abundance, biomass and species composition at three sites (control, boundary and core) before and for six years after the designation of a no-take MPA, the Canal Luis Peña Natural Reserve. The control (outside the MPA) and core (within the MPA) sites were characterized by better water quality (i.e., lower impacts by runoff pulses). Water quality at the boundary site was inferior to that of the control and core sites due to its proximity to the main population center in Culebra. Before the MPA designation, recreational and artisanal fishing activities occurred at the three sites. After the designation, only the core site experienced a reduction, but not a total cessation, in fishing activities.

MPA designation was followed by a significant and rapid increase in species richness, total abundance and biomass of most functional groups, including piscivores and fishery-targeted species at the core site. Subsequently, poaching caused a significant fish decline. There was a fish community collapse at the boundary site as a result of fishing displacement and water quality degradation which resulted in lower abundances of planktivores and piscivores relative to the core and control sites. There was an increase in fish abundance and biomass at the control site contributed mostly by non-denuder herbivores. In 2005 a high SST and mass bleaching event caused a widespread fish community collapse, impacting both fishery-targeted and non-targeted taxa. Fish species richness declined by factors exceeding 50% at all sites, regardless of its condition. Further sampling between 2006 and 2008 has shown that although some fish functional groups show no significant declines associated to coral mortality, most non-targeted, small-sized reef dwellers have extensively declined all over. Similarly, piscivore guilds have largely declined as well. Hernández-Delgado et al. (in preparation) concluded that

MPAs can be effective management tools with respect to local-scale anthropogenic effects, but they offer no safeguard against regional-scale impacts such as high SST events, particularly if there are concurrent significant management failure impacts.

Arrecifes de La Cordillera vs. No-take Canal Luis Peña

In spite of recurrent poaching at the Canal Luis Peña no-take Natural Reserve (CLPNR) (Hernández-Delgado et al., 2006) and the significant benthic community phase shift that followed post-bleaching coral mortality in 2006, overall fish biomass per count (120 m^2) at ALCNR resulted overall lower than in CLPNR. Mean total biomass at ALCNR was 3,026 g/count in shallow reef zones, and 2,895 g/count at deeper zones. Recent data from CLPNR suggests counts still exceeding 5,000 g/count at each depth zone (Hernández-Delgado et al., in preparation). Similarly, piscivore biomass at ALCNR averaged only 455 g/count at shallow reef zones and 382 g/count at deeper reef zones. Piscivore biomass at CLPNR reached values of 800 to 4,000 g/count. Even control reefs outside the no take CLPNR (i.e., Punta Soldado, Culebra) showed higher total and piscivore biomass than ALCNR, suggesting the overfished status of ALCNR.

The no-take MPA alternative

The actual status of coral reef fish communities within ALCNR is a major cause of concern that requires rapid action to significantly reduce or eliminate consumptive uses through the establishment of a network of small, discrete no-take MPAs. No-take MPAs have become a successful tool to help rebuild overexploited fish populations (Roberts and Polunin, 1993, 1994;

Polunin and Roberts, 1994; Roberts et al., 2001; Friedlander et al., 2002; Gell and Roberts, 2002; Halpern and Warner, 2002; Tupper and Rudd, 2002). They can also contribute to improve nearby open fisheries (McClanahan and Mangi, 2000; Goñi et al., 2008). MPAs have also been suggested to regulate the ecosystem functions of harvested stocks, their prey and coral reef ecosystem resilience (Hughes et al., 2003, 2007), and as one of the most critical tools to restore declining coral reefs, particularly under a global climate change scenario (Aronson and Precht, 2006). Full-time MPA implementation linked to habitat protection and management has been pointed out as critical to developing whole ecosystem protection to threatened habitats and populations (Appeldoorn and Lindeman, 2003; Duval et al., 2004). Fish community recovery within fully-protected no-take MPAs has been more successful when compared to partially-protected MPAs (Lester and Halpern, 2008). But when full protection is removed or significantly lacking there is an immediate decline in fish density and biomass as a result of rapid fishing impacts (Russ and Alcala, 2003; Ferraris et al., 2005). Poaching impacts within fully-protected no-take MPAs can have similar impacts. Non-compliance usually results in illegal harvesting activities that can offset MPA benefits (Kritzer, 2004), can dissipate the potential benefits of fishery management regulations (Gigliotti and Taylor, 1990), and undermines community support (Coleman et al., 2004). Therefore, given the significantly overfished condition of ALCNR full-time no-take MPA designation is recommended for selected locations (discussed in Chapters 3 and 5).

The effectiveness of full-time no-take MPAs as buffers or refuges against regional- or global-scale climatic impacts still remains to be tested. Their role in protecting fish biodiversity in degrading environments might be of limited value in the near future if we cannot confront the increasingly negative impacts of local human-driven stresses and of regional and/or global-scale sources of coral mortality (McClanahan, 2002; Aronson and Precht, 2006). The interaction between local-scale and regional-scale stressors is not well understood. For example, would a high SST event followed by massive bleaching and coral mortality have the same impact in a healthy coral reef fish community as in a reef already impacted by overfishing and/or poor water quality? Does high diversity and abundance increase the resilience of a coral reef fish community to regional-scale stressors such as high SST events, or on the other hand make it more susceptible? These are just examples of questions that remain to be answered. However, no-take MPAs, in combination with integrated coastal and adaptive management, are definitely one of the paramount management tools to help in the short-term rebuild depleted fishery stocks within ALCNR and in the long-term buffer climate change-related impacts. Failure of success of no-take MPA designation may depend on the impact of external stressors and on institutional management capability (Jameson et al., 2002). In this case, it will depend on the ability of PRDNER to address key management issues (i.e., enforcement, improve regulation of recreational activities), and on the ability of PRDNER, and other PR state regulatory agencies to address other key environmental issues beyond the ALCNR boundaries (i.e., land use patterns, coastal development, sewage treatment, and non-point source pollution).

Literature cited

Appeldoorn, R.S., & K.C. Lindeman. 2003. A Caribbean-wide survey of no-take marine reserves: spatial, coverage and attributes of effectiveness. *Gulf Caribb. Res*. Suppl. 2003:1-16.

Aronson, R.B., & W.F. Precht. 2006. Conservation, precaution, and Caribbean reefs. *Coral Reefs* 25:441-450.

Ballantine, D.L., R.S. Appeldoorn, P. Yoshioka, E. Weil, R. Armstrong, J.R. García, E. Otero, F. Pagán, C. Sherman, E.A. Hernández-Delgado, A. Bruckner, & C. Lilyestrom. 2008. Biology and ecology of Puerto Rican coral reefs. 375-406. In, B.M. Riegl & R.E. Dodge (eds.), *Coral Reefs of the World, Vol. I. Coral Reefs of the USA*, Springer-Science + Business Media B.V. 803pp.

Bellwood, D.R., A.S. Hoey, & J.H. Choat. 2003. Limited functional redundancy in high diversity systems: resilience and ecosystem function on coral reefs. *Ecol. Lett*. 6:281-285.

Bellwood, D.R., T.P. Hughes, C. Folke, & M. Nyström. 2004. Confronting the coral reef crisis. *Nature*. 429: 827-833.

Bellwood, D.R., A.S. Hoey, J.L. Ackerman, & M. Depczynski. 2006. Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. *Global Change Biol.* 12:1587-1594.

Bohnsack, J.A., & S.P. Bannerot. 1986. A stationary census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. 15 pp.

Bohnsack, J.A., & D.E. Harper. 1988. Length-weight relationships of selected marine reef fishes from the Southeastern United States and the Caribbean. NOAA Technical Memorandum NMFS-SEFC-215. 31 pp.

Bohnsack, J.A. Unpublished manuscript. Biomass calculation update. Fishes added or estimated after NOAA Technical Memorandum NMFS-SEFC-215, Reviewed March 21, 1996. 2 pp.

Booth, D.J., & G.A. Beretta. 2002. Changes in a fish assemblage after a coral bleaching event. *Mar. Ecol. Progr. Ser.* 245:205-212.

Bray, J.R., & J.T. Curtis 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr*. 27:325-349.

Buddemeier, R.W., J.A. Kleypas, & R.B. Aronson. 2004. Coral reefs and climate change: Potential contributions of climate change to stresses on coral reef ecosystems. Pew Center on Global Climate Change, 1-44.

Burke, L, & J. Maidens 2004. Reefs at Risk in the Caribbean. WRI, Washington, DC.

Carr, M.H., T.W. Anderson, & M.A. Hixon. 2002. Biodiversity, population regulation, and the stability of coral-reef fish communities. *Proc. Natl. Acad. Sci. USA* 99:11241-11245.

Christensen, V., & D. Pauly. 1997. Changes in models of aquatic ecosystems approaching carrying capacity. *Ecol. Appl*. 8:104-109.

Clarke, K.R., & R.M. Warwick. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd Ed. PRIMER-E, Ltd., Plymouth Marine Laboratory, UK.

Coleman, F.C., P.B. Baker, & C.C. Koenig. 2004. A review of Gulf of Mexico marine protected areas: success, failures, and lessons learned. *Fisheries* 29:10-21.

CSA Group, Inc. 2005. Evaluación, delimitación y análisis de los usos en los habitáculos marinos dentro de la Reserva Natural Arrecifes de La Cordillera. Informe técnico sometido al Departamento de Recursos Naturales y Ambientales, San Juan, PR. 125 pp.

Daskalov, G.M. 2002. Overfishing drives a trophic cascade in the Black Sea. *Mar. Ecol. Progr. Ser*. 225:53-63.

DeMartini, E.E., A.M. Friedlander, S.A. Sandin, & E. Sala. 2008. Differences in fish-assemblage structure between fished and unfished atolls in the northern Line Islands, central Pacific. *Mar. Ecol. Progr. Ser*. 365:199-215.

Departamento de Recursos Naturales y Ambientales. 1990a. Programa de Manejo de la Zona Costanera, Plan de Manejo de la Reserva Natural Arrecifes La Cordillera. 99 pp.

Departamento de Recursos Naturales y Ambientales. 1990b. Programa de Manejo de la Zona Costanera, Suplemento Técnico al Plan de Manejo de la Reserva Natural Arrecifes La Cordillera. 274 pp.

Dulvy, N.K., S.I. Rogers, S. Jennings, V. Stelzenmüller, S. Dye, & H.R. Skjoldal. 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. *J. Appl. Ecol.* 45:1029-1039.

Duval, M.A., D.N. Rader, & K.C. Lindeman. 2004. Linking habitat protection and marine protected area programs to conserve coral reefs and associated back reef habitats. *Bull. Mar. Sci.* 75:321-324.

Ferraris, J., D. Pelletier, M. Kulbicki, & C. Chauvert. 2005. Assessing the impact of removing reserve status on the Abore Reef fish assemblage in New Caledonia. *Mar. Ecol. Progr. Ser.* 292:271-286.

Fiske, S.J. 1992. Sociocultural Aspects of Establishing Marine Protected Areas. *Ocean Coast. Mgmt*. 17:25-46.

Friedlander, A.M., & E.E. DeMartini. 2002. Contrasts in density, size, and biomass of reef fishes between the northern and the main Hawaiian islands: the effects of fishing down apex predators. *Mar. Ecol. Progr. Ser.* 230:253-264.

García, J.R., J. Morelock, R. Castro, C. Goenaga, & E. Hernández. 2003. Puerto Rican reefs: Research synthesis, present threats and management perspectives. 111-130. In, J. Cortés (ed.), *Latin American Coral Reefs*. Elsevier Publ., Amsterdam, Holland. 497 pp.

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant, & A.R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. *Science* 301:958-960.

Garpe, K.C., S.A.S. Yahya, U. Lindhal, & M.C. Öhman. 2006. Long-term effects of the 1998 coral bleaching event on reef fish assemblages. *Mar. Ecol. Progr. Ser.* 315:237-247.

Gell, F.R., & C.M. Roberts. 2002. The fishery effects of marine reserves and fishery closures. WWF-US, Washington, DC. 89 pp.

Gigliotti, L.M., & W.W. Taylor. 1990. The effect of illegal harvest on recreational fisheries. *N. Am. J. Fish. Mgmt*. 10:106-110.

Goldman, B., & F.H. Talbot. 1976. Aspects of the ecology of coral reef fishes. In: O.A. Jones & R. Endean (eds.), *Biology and Geology of Coral Reefs*, Vol. III. Academic Press, N.Y. 125-163.

Goñi, R., S. Adlerstein, D. Alvarez-Berastegui, A. Forcada, O. Reñones, G. Criquet, S. Polti, G. Cadiou, C. Valle, P. Lenfant, P. Bonhomme, A. Pérez-Ruzafa, J.L. Sánchez-Lizaso, J.A. García-Charton, G. Bernard, V. Stelzenmüller, & S. Planes. 2008. Spillover from six western Mediterranean marine protected areas: evidence from artisanal fisheries. *Mar. Ecol. Progr. Ser.* 366:159-174.

Götz, A., S.E. Kerwath, C.G. Attwood, & W.H.H. Sauer. 2008. Effects of fishing on population structure and life history of roman *Chrysoblephus laticeps* (Sparidae). *Mar. Ecol. Progr. Ser.* 362:245-259.

Grigg, R.W., J.J. Polovina, & M.J. Atkinson. 1984. Model of coral reef ecosystem. III. Resource limitation, community regulation, fisheries yield and resource management. *Coral Reefs*. 2:23-27.

Halpern, B.S., & R.S. Warner. 2002. Marine reserves have rapid and lasting effects. *Ecol. Lett.* 5:361-366.

Hawkins, J.P., & C.M. Robets. 2004. Effects of artisanal fishing on Caribbean coral reefs. *Conserv. Biol*. 18:215-226.

Helvey, M. 2004. Seeking Consensus on Designing Marine Protected Areas: Keeping the Fishing Community Engaged. *Coast. Mgmt*. 32:173-190.

Henriques, M., E.J. Gonçalves, & V.C. Almada. 2007. Rapid shifts in a marine fish assemblage follow fluctuations in winter sea conditions. *Mar. Ecol. Progr. Ser.* 340:259-270.

Hernández-Delgado, E.A. 1992. Coral reef status of northeastern and eastern Puerto Rican waters: Recommendations for long-term monitoring, restoration and a coral reef management plan. Submitted to the Caribbean Fishery Management Council, Hato Rey, P.R., December 1, 1992. 87 pp.

Hernández-Delgado, E.A. 1994. Preliminary inventory of the coral reef systems and hard ground communities from Arrecifes La Cordillera Natural Reserve, Puerto Rico. Submitted to Project Reefkeeper, Miami, FL. 10 pp. March 3, 1994.

Hernández-Delgado, E.A. 2000. Effects of anthropogenic stress gradients in the structure of coral reef fish and epibenthic communities. Unpublished Ph.D. Dissertation, Dept. Biology, University of Puerto Rico, San Juan, P.R. 330 pp.

Hernández-Delgado, E.A. 2005. Historia natural, caracterización, distribución y estado actual de los arrecifes de coral Puerto Rico. 281-356. *In*, R.L. Joglar (Ed.), *Biodiversidad de Puerto Rico: Vertebrados Terrestres y Ecosistemas. Serie Historia Natural*. Editorial Instituto de Cultura Puertorriqueña, San Juan, PR. 563 pp.

Hernández Delgado, E.A., & A.M. Sabat. 2000. Ecological status of essential fish habitats through an anthropogenic environmental stress gradient in Puerto Rican coral reefs. *Proc. Gulf Caribb. Fish. Inst*. 51:457-470.

Hernández-Delgado, E.A., B.J. Rosado-Matías, & A.M. Sabat. 2006. Management failures and coral decline threatens fish functional groups recovery patterns in the Luis Peña Channel No-Take Natural Reserve, Culebra Island, PR. *Proc. Gulf Caribb. Fish. Inst*. 57:577-605.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. *Mar. Freshw. Res.* 50:839-866.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi, & M.E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318:1737-1742.

Hughes, T.P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science*. 265:1547-1550.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Carr, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nyström, S.R. Palumbi, J.M. Pandolfi, B. Rosen, & J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* 301:929-933.

Hughes, T.P., D.R. Bellwood, C.D. Folke, L.J. McCook, & J.M. Pandolfi. 2007. No-take areas, herbivory and coral reef resilience. *TREE.* 22:1-3.

Jackson, J.B.C. 1997. Reefs since Columbus. *Coral Reefs* 16, Suppl.:S23-S32.

Jackson, J.B.C. 2001. What was natural in the coastal oceans? *Proc. Ntnl. Acad. Sci. USA.* 98: 5411-5418.

Jackson, J.B.C., M.X. Kirby, W.H. Berger, K.A. Bjorndal, L.W. Botsford, B.L. Bourque, C.B. Lange, H.S. Lenihan, J.S. Pandolfi, C.H. Peterson, R.S. Steneck, M.J. Tegner, & R.R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293:629-638.

Jameson, S.C., M.H. Tupper, & J.M. Ridley. 2002. The three screen doors: Can marine "protected" areas be effective? *Mar. Poll. Bull.* 44:1177-1183.

Jennings, S., & N.V.C. Polunin. 1996. Effects of fishing effort and catch rates upon the structure and biomass of Fijian reef fish communities. *J. Appl. Ecol.* 33:400-412.

Jones, G.P., M.I. McCormick, M. Srinivasan, & J.V. Eagle. 2004. Coral decline threatens fish biodiversity in marine reserves. *Proc. Nat. Acad. Sci. USA*. 101:8251-8253.

Kritzer, J.P. 2004. Effects of noncompliance on the success of alternative designs of marine protected-area networks for conservation and fisheries management. *Conserv. Biol.* 18:1021-1031.

Lesser, M.P. 2007. Coral reef bleaching and global climate change: Can corals survive the next century? *Proc. Natnl. Acad. Sci. USA.* 104:5259-5260.

Lester, S.E., & B.S. Halpern. 2008. Biological responses in marine no-take reserves versus partially protected areas. *Mar. Ecol. Progr. Ser.* 367:49-56.

Lough, J.M. 1998. Coastal climate of northwest Australia and comparisons with the Great Barrier Reef: 1960 to 1992. *Coral Reefs* 17:351-367.

McClanahan, T.R. 2002. The near future of coral reefs. *Environ. Conserv.* 29:460-483.

McClanahan, T.R., & S. Mangi. 2000. Spillover of exploitable fishes from a marine park and its effects on the adjacent fishery. *Ecol. Appl.* 10:1792-1805.

McClanahan, T.R., & N. Muthiga. 1998. An ecological shift in a remote coral atoll of Belize over 25 years. *Environ. Conserv.* 25:122-130.

McConney, P., R. Pomeroy, & R. Mahon. 2003. Guidelines for coastal resource co-management in the Caribbean: communicating the concepts and conditions that favour success. CCA/CERMES/MRAG. 55 pp.

Miller, J., R. Waara, E. Muller, & C. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality on reef in US Virgin Islands. *Coral Reefs* 25:418.

Nakano, K., A. Takemura, S. Nakamura, Y. Nakano, & G.K. Iwama. 2004. Changes in the celular and organismal stress responses of the subtropical fish, the Indo-Pacific sergeant, *Abudefduf vaigiensis*, due to the 1997-1998 El Niño/Southern Oscillation. *Environ. Biol. Fishes* 70:321-329.

Paddack, M.J., J.D. Reynolds, C. Aguilar, R.S. Appeldoorn, J. Beets, E.W. Burkett, P.M. Chittaro, K. Clarke, R. Esteves, A.C. Fonseca, G.E. Forrester, A.M. Friedlander, J. García-Sais, G. González-Sansón, L.K.B. Jordan, D.B. McClellan, M.W. Miller, P.P. Molloy, P.J. Mumby, I. Nagelkerken, M. Nemeth, R. Navas-Camacho, J. Pitt, N.V.C. Polunin, M.C. Reyes-Nivia, D.R. Robertson, A. Rodríguez-Ramírez, E. Salas, I.D. Williams, C.L. Wormald, A.R. Watkinson, & I.M. Côté. Recent region-wide declines in Caribbean reef fish abundance. *Curr. Biol*. 19:1-6. DOI 10.1016/j.cub.2009.02.041.

Parker, R.O., & R.L. Dixon. 1998. Changes in a North Carolina reef fish community after 15 years of intense fishing – global warming implications. *Trans. Amer. Fish. Soc*. 127:908-920.

Pauly, D., V. Christensen, J. Dalsgaaard, R. Froese, & F. Torres, Jr. 1998. Fishing down marine food webs. *Science*. 279:860-863.

Pauly, D., V. Christensen, S. Guenette, T.J. Pitcher, U.R. Sumaila, C.J. Walters, R. Watson, & D. Zelle. 2002. Towards sustainability in world fisheries. *Nature*. 418:689-695.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. *J. Theor. Biol*. 13:131-144.

Pinnegar, J.K., N.V.C. Polunin, P. Francour, F. Badalamenti, R. Chemello, M.-L. Harmelin-Vivien, B. Hereu, M. Milazzo, M. Zabala, G. D'Anna, & C. Pipitone. 2000. Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. *Environ. Conserv*. 27:179-200.

Pitcher, T.J. 2001. Rebuilding ecosystems as a new goal for fisheries management: reconstructing the past to salvage the future. *Ecol. Appl*. 11:601-617.

Polunin, N.V.C., & C.M. Roberts. 1993. Greater biomass and value of target coral-reef fishes in two small Caribbean marine reserves. *Mar. Ecol. Progr. Ser.* 103:25-34.

Pratchett, M.S., S.K. Wilson, & A.H. Baird. 2006. Declines in the abundance of *Chaetodon* butterflyfishes following extensive coral depletion. *J. Fish Biol*. 69:1269-1280.

Puerto Rico Department of Natural and Environmental Resources, & United States Department of Commerce. 2003. Puerto Rico Progress Report on Draft Local Action Strategies. PRDNER/NOAA. Sept. 12, 2003. 66 p.

Roberts, C.M., 1995a. Rapid build-up of fish biomass in a Caribbean marine. *Conserv. Biol*. 9:815-826.

Roberts, C.M., 1995b. Effects of fishing on the ecosystem structure of coral reefs. *Conserv. Biol*. 9:988-995.

Roberts, C.M., J.A. Bohnsack, F. Gell, J.P. Hawkins, & R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. *Science* 294:1920-1923.

Roberts, C.M., & N.V.C. Polunin. 1993. Marine reserves: simple solutions to managing complex fisheries. *AMBIO* 22:363-368.

Roberts, C.M., & N.V.C. Polunin. (1994) Hol-Chan: demonstrating that marine reserves can be remarkably effective. *Coral Reefs* 13:90.

Roessig, J.M., C.M. Woodley, J.J. Cech, Jr., & L.J. Hansen. 2004. Effects of global climate change on marine and estuarine fishes and fisheries. *Rev. Fish Biol. Fisheries* 14:251-275.

Russ, G.R., & A.C. Alcalá. 2003. Marine reserves: rates and patterns of recovery and decline of predatory fish, 1983-2000. *Ecol. Appl.* 13:1153-1565.

Salm, R.V., J.R. Clark, & E. Siirila. 2000. Marine and Coastal Protected Areas, A Guide for Planners and Managers, 3rd Ed. IUCN, Gland, Switzerland. 370 pp.

Shannon, C.E., & W. Weaver. 1948. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, IL. 117 pp.

Scheffer, M., S. Carpenter, & B. de Young. 2005. Cascading effects of overfishing marine systems. *TREE*. 20:579-581.

Sobel, J. & C. Dahlgren. 2004. *Marine Reserves, A Guide to Science, Design, and Use*. Island Press, Washington, D.C. 383 pp.

Spalding, M.D., & G.E. Jarvis. 2002. The impact of the 1998 coral mortality on reef fish communities in the Seychelles. *Mar. Poll. Bull.* 44:309-321.

Suman, D.O., & M.P. Shivlani. 1998. Characterization of the commercial dive operator industry in the Florida Keys National Marine Sanctuary. Florida Sea Grant Technical Paper-103.

Suman, D. O., M. P. Shivlani, & J. W. Milon. 1999. Perceptions and attitudes regarding marine reserves: A comparison of stakeholder groups in the Florida Keys National Marine Sanctuary. *Ocean Coast. Mgmt*. 42:1019-1040.

Travis, J.M.J. 2003. Climate change and habitat destruction: a deadly anthropogenic cocktail. *Proc. Biol. Sci.* 270:467-473.

Tupper, M., & M.A. Rudd. 2002. Species-specific impacts of a small marine reserve on reef fish production and fishing productivity in the Turks and Caicos Islands. *Environ. Conserv.* 29:484-492.

United States Coral Reef Task Force. 2000. The National Action Plan to Conserve Coral Reefs. Washington, DC. 34 p.

United States National Oceanic and Atmospheric Administration. National Ocean Service. National Centers for Coastal Ocean Science Biogeography Program. 2001. Benthic habitats of Puerto Rico and the U.S. Virgin Islands. CD ROM, NOAA, Silver Spring, MD.

Valentine, J.F., & K.L. Heck, Jr. 2005. Perspective review of the impacts of overfishing on coral reef food web linkages. *Coral Reefs* 24:209-213.

Valentine, J.F., K.L. Heck, Jr., D. Blackmon, M.E. Goecker, J. Christian, R.M. Kroutil, K.D. Kirsch, B.J. Peterson, M. Beck, & M.A. Vanderklift. 2007. Food web interactions along seagrasses-coral reef boundaries: effects of piscivore reductions on cross-habitat energy exchange. *Mar. Ecol. Progr. Ser*. 333:37-50.

Whelan, K.R.T., J. Miller, O. Sánchez, & M. Patterson. 2007. Impact of the 2005 coral bleaching event on *Porites porites* and *Colpophyllia natans* at Tektike Reef, US Virgin Islands. *Coral Reefs* 26:689-693.

Williams, D.M. 1986. Temporal variation in the structure of reef slope fish communities (central Great Reef Barrier): short term effects of *Acanthaster planci* infestation. *Mar. Ecol. Progr. Ser.* 28:157-164.

Zar, J.H. 1984. Biostatistical Analysis, 2nd Ed. Prentice-Hall, Inc., Englewood Cliffs, N.J. 718 pp.

CHAPTER 3

Characterization of stakeholder groups in the Arrecifes La Cordillera Natural Reserve

(M. Shivlani)

Introduction

In support of establishing standardized criteria to identify priority candidate no-take marine protected area (MPA) sites in Arrecifes La Cordillera Natural Reserve (ALCNR), the present study focused on the identification of stakeholder expectations of and support for no-take MPAs within the reserve. To develop a participatory model that involved four types of stakeholders – commercial fishermen, dive and snorkel operators, water-based operators, and recreational boaters – the study characterized stakeholder uses within the reserve, views on resource conditions, and preferred management mechanisms, including no-take MPA candidate sites, modes of participation, and management agency.

The human dimension of no-take MPAs.

Literature concerning the human dimensions of no-take MPAs has demonstrated both the need to consider human uses in MPA management processes (Bunce et al., 1999; Kelleher, 1999; Salm et al., 2000; NRC, 2001) and to incorporate public participation at the various stages of the MPA cycle, from designation (Suman et al., 1999; Weible, 2008) to reassessment and monitoring (Thomas J. Murray & Associates, 2007; Day, 2008; Shivlani et al., 2008). Uses and concerns, when left unidentified, can undermine the effectiveness of no-take MPAs, manifested as incomplete characterizations of socioeconomic uses (Suman et al., 1999), inter-group conflicts (Helvey, 2004; Weible et al., 2004; Weible, 2008), and mistrust of management intentions or processes (Valdés-Pizzini, 1990; NAPA, 2000). Conversely, when human dimensions are integrated into the decision-making process in no-take MPA designation stage and throughout the management process, MPAs often perform to their expectations rather than being relegated as 'paper parks'. Successful no-take MPA designation approaches, such as that used for the designation of the Dry Tortugas Ecological Reserve in the Florida Keys National Marine Sanctuary (Delaney, 2003), are those that accept stakeholder knowledge, acknowledge stakeholder concerns, and engage stakeholder participation in a transparent and consensus-building process.

MPAs in Puerto Rico.

As of 2006, the Commonwealth of Puerto Rico had a total of 37 MPAs designated under a diverse series of Commonwealth and US federal directives, and most of these had been implemented via a top-down approach with limited public participation (Aguilar-Perera et al., 2006). Of the 37, there are three federally designated, seasonal no-take zones off western Puerto Rico that prohibit fishing for three months each year (50 CFR 622.33), and there are two no-fishing reserves established by the Puerto Rico Department of Natural and Environmental Resources (PRDNER) (Aguilar-Perera et al., 2006; CIEL, 2008a; CIEL, 2008b). All other MPAs in Puerto Rico are largely multiple-use areas, in that the MPAs allow a majority of consumptive and non-consumptive uses, subject to either Commonwealth (ex. fishery regulations) or US federal regulations (ex., protected species regulations).

Arrecifes La Cordillera Natural Reserve.

Designated in January 1980, the 10,083 hectare ALCNR is an example of a multiple-use MPA (Aguilar-Perera et al., 2006). Importantly, excluded from the designation of the reserve are the very popular islands of Lobos and Palomino, of which the latter is an important beach destination for guests staying at the Hotel Conquistador on the mainland. The reserve allows commercial and recreational fishing activities as regulated under Commonwealth fishery laws, pleasure boating, and other recreational uses (CEA, 2007). Commercial operators, defined as those operators who take out clients to recreate within the reserve, may only utilize the reserve as concessionaires, by registering with the PRDNER and paying an annual concessionaire fee (CEA, 2007). The main uses within the reserve are commercial fishing, snorkeling, diving, beach visits to the most popular island beaches, and cruising. The primary stakeholders are commercial fishermen, water-based operators (that take out their clients on fishing, diving, snorkeling, and beach trips), and vessel operators (that undertake many of the same activities as do the clients of water-based operators). Secondary stakeholders consist of marinas and related infrastructure operators, lodging establishments, and other businesses dependent on the region’s coastal tourism industry.

While the islands (cayos) of Icacos, Palominos, Palominitos, and Lobos in the reserve are very important tourist destinations, adjacent coastal habitats such as sea grasses and patch and coral reefs are also popular snorkeling and diving centers and, in some cases, serve as commercial and recreational fishing sites. Large catamarans that can accommodate 50 or more visitors per trip compete with smaller charter operators and recreational vessels for access to the islands and marine habitats. Use occurs year-round, with visitation peaking for local tourism from April to August and non-resident tourism from November to March (CEA, 2007). As a result of the use intensity, the reserve's resources (and its coral reef ecosystem in particular) face significant threats; these include recreation-based impacts such as vessel groundings, anchor damage and propeller scarring and snorkeler and diver induced coral reef impacts (i.e., touching or breaking corals), as well as fishery effects on the integrity of the coral reef ecosystem. To this must be added terrestrial threats such as sedimentation impacts from coastal construction on the mainland, other land-based sources of pollution (i.e., runoff from marinas, roads, etc.), and proposals to develop Cayos Lobos and Palominos, among others (CEA, 2007).

Because of its wealth of coastal and marine resources, including important coral reef systems and reef fisheries, and its extensive commercial and especially recreational uses, ALCNR represented an excellent site to establish standardized criteria to identify candidate no-take zones. The stakeholder characterization approach applied was developed to (1) characterize the types of uses that occur within the reserve, the frequency of each use type, and the use patterns of each use type, (2) ascertain stakeholder views on resource conditions, trends, and use conflicts, and (3) evaluate stakeholder preferences towards no-take MPAs within the reserve, including their preference for candidate sites, the type and amount of public participation desired in establishing candidate sites, and government agencies that should manage the candidate sites.

Methodology

A participatory model.

The methodology in the study proposal called for the development of a participatory model to involve local fisher communities and other stakeholder groups in a decision-making process aimed at suggesting no-take MPA sites within ALCNR. This was achieved by conducting semi-structured interviews or focus group meeting with key informants from each stakeholder group. The stakeholder groups identified in the study proposal consisted of those that participated in consumptive activities, such as fishing, and those that participated in non-consumptive activities, as related to recreation. These groups consisted of the regional commercial fishing industry, charter fishing operations, dive and snorkel operations, pleasure (mixed) trip charters, water transportation services, private vessel operators (i.e., recreational vessels), and related, land-based businesses.

Initial interviews conducted in June 2007 with ALCNR personnel, commercial fishermen, water-based operators, and land-based businesses as part of a pilot/scoping session, as well as results from a similar study conducted in Vieques (Shivlani, 2007), led to the decision that land-based businesses would not be included as part of the study. Land-based businesses (i.e., hotel personnel, marina representatives, and watersports rental operators) generally did not provide opinions on candidate no-take MPA sites, with those interviewed often agreeing that they did not have the necessary knowledge to form an informed view. Also, as stated above, a similar study examining stakeholder preferences for coastal and marine protection strategies in Vieques determined that a majority of lodging operators and other land-based businesses were unable to identify trends in coastal and marine resource conditions and that their views on MPAs were shaped more by their perceptions on how MPAs would affect access than address resource protection. Finally, there were very few lodging establishments and services operations identified in the immediate region that could participate in the study; for example, the region had only four lodging establishments that could be interviewed (and of which personnel from two of the establishments stated that they did not have the background to complete an interview).

The four main groups identified as part of the scoping session were commercial fishing operations, dive charters, pleasure (mixed) trip charters, and private vessel operators. Of these groups, the dive charters and the pleasure trip charters were concessionaires that were permitted to take clients to the reserve and who paid an annual concession and a per-head fee; thus, these two groups represented the total population of reserve, water-based operators. In terms of commercial fishing effort, the main port identified for the region was Fajardo, with a few commercial fishermen from Ceiba (Playa de Los Machos) fishing in the reserve. Otherwise, commercial fishermen from ports north and south of Fajardo generally did not fish within the reserve. Finally, while private vessel operators using the reserve originated from many parts of the island, and in particular from the San Juan area, the ports of Fajardo and Ceiba (Puerto del Rey) represented important embarkation points for recreational vessels (Shivlani, 2008).

Stakeholder surveys.

The approaches adopted for each of the groups varied. Key informants among commercial fishermen, identified via previous research in the area (Agar et al., 2008), discussion with the villa pesquera fishery leaders, and with assistance from the PRDNER's Fisheries Research Laboratory field data collector (León, personal communication), were selected for each "villa pesquera" (fish house) in the Fajardo and Ceiba area. Additional interviews were conducted with commercial fishermen from adjacent ports (Luquillo to Río Grande to the north, and Patillas to the south) to ensure that those communities did not fish within the reserve. With concessionaires, ALCNR personnel provided the names and locations of all dive and pleasure trip charters authorized to take out clients into the reserve, and these were located mainly in two marinas: Villa Marina in Fajardo and Puerto del Rey in Ceiba. Unlike as with the key informant approach used for commercial fishermen, a census approach was adopted for reserve concessionaires. With both commercial fishermen and reserve concessionaires, semi-structured interviews were utilized in conjunction with a specific survey instrument. That was, respondents were interviewed on particular issues related to candidate no-take sites, their views on MPA managements, and their preferences towards management authority via open-ended questions, but use pattern and resource trend information was collected using a formal survey instrument. To sample the large population of private vessel operators, a self-administered intercept survey was developed that was passed out by personnel working at the

Puerto del Rey vessel registration office to vessel operators either registering a vessel or renewing a registration. The office was selected because most of the vessels that register at the office operate in eastern Puerto Rico, of which many visit the reserve (Horta, personal communication).

Commercial fishermen were interviewed using both a survey instrument and open-ended questions from August 2007 to June 2008 in three fish houses in Fajardo and one in Ceiba. Similarly, dive operations and pleasure trip charters were interviewed using both a survey instrument and open-ended questions, and that survey session lasted from August 2007 to November 2008. Finally, the Puerto del Rey vessel registration office passed out vessel operator surveys from September 2007 to February 2008, or a six-month session.

Results

Results for each group are presented separately, except for dive operations and pleasure trip charters which are considered together as concessionaires under a single section in which the results are nevertheless discussed separately where relevant.

Commercial fishermen.

A total of 12 commercial fishermen who were identified as key informants in four fish houses across the region were interviewed as part of the study. These fishermen included individuals who were or had served as fishery leaders, had almost two decades of fishing experience within and around the reserve, and represented a variety of species and gear types.

Fishermen were informed of the study objectives and asked to provide information that they believed was representative for both their fish house and for the commercial fishermen in the region, including information on fisheries in which the respondents did not participate but on which they were knowledgeable. Thus, while the fishermen interviewed did describe their fishing behavior, they also did so for their fish house and region.

Respondents in all the fishing communities interviewed, from Río Grande to the northeast through Playa de los Machos, Ceiba, to the southeast (and interviews with fishermen from another study in Naguabo, Palmas del Mar, and Patillas), agreed that the fishing effort within the ALCNR emanated mainly from the communities of Fajardo and Ceiba. Fishermen from communities northwest of Fajardo tended to fish further north and northeast and those from communities to the south of Ceiba focused their effort to the south and east. Importantly, even those fishermen from the communities of Fajardo and Ceiba that fished the reserve, effort within the reserve were described as both sporadic and seasonal. These two aspects of generalized fishing patterns are discussed in greater detail.

Sporadic fishing effort in the reserve is best defined as infrequent and spatially diverse fishing profiles. Fishermen did not identify specific fishing grounds that they targeted within the reserve or general fishing areas that they used on a consistent basis. The possible exception to this pattern was the fishing behavior exhibited by a few commercial divers. Respondents in the Fajardo area identified limited commercial diving, especially for spiny lobster, within the reserve. Other valuable species, such as queen conch and fin fish, were targeted mainly in regions south and east of the reserve and particularly off the islands of Culebra and Vieques.

When asked why fishermen did not use the reserve more frequently, fishermen from ports to the north and south of the reserve stated distance as the main impediment. Fishermen from Fajardo ports who did report using the reserve did not do so on a consistent basis because of the limited abundance of target species within the reserve and competition/conflicts with other user groups. In terms of limited abundance, fishermen stated that the reserve did not contain many good fishing grounds, either due to overfishing (or use from other stakeholder groups) or nearshore pollution. The exception to fisheries abundance was the seasonal occurrence of migratory species, such as king mackerel (sierra) found along the deeper water off the reserve's islands. These fishers also reported targeting reef fish such as yellowtail snapper (*Ocyurus chrysurus*) in parts of the reserve on a seasonal basis.

It is important to note that while fishermen did not use the reserve as frequently as they did other areas, a majority of the fishermen interviewed (over 80%) reported fishing within the reserve.

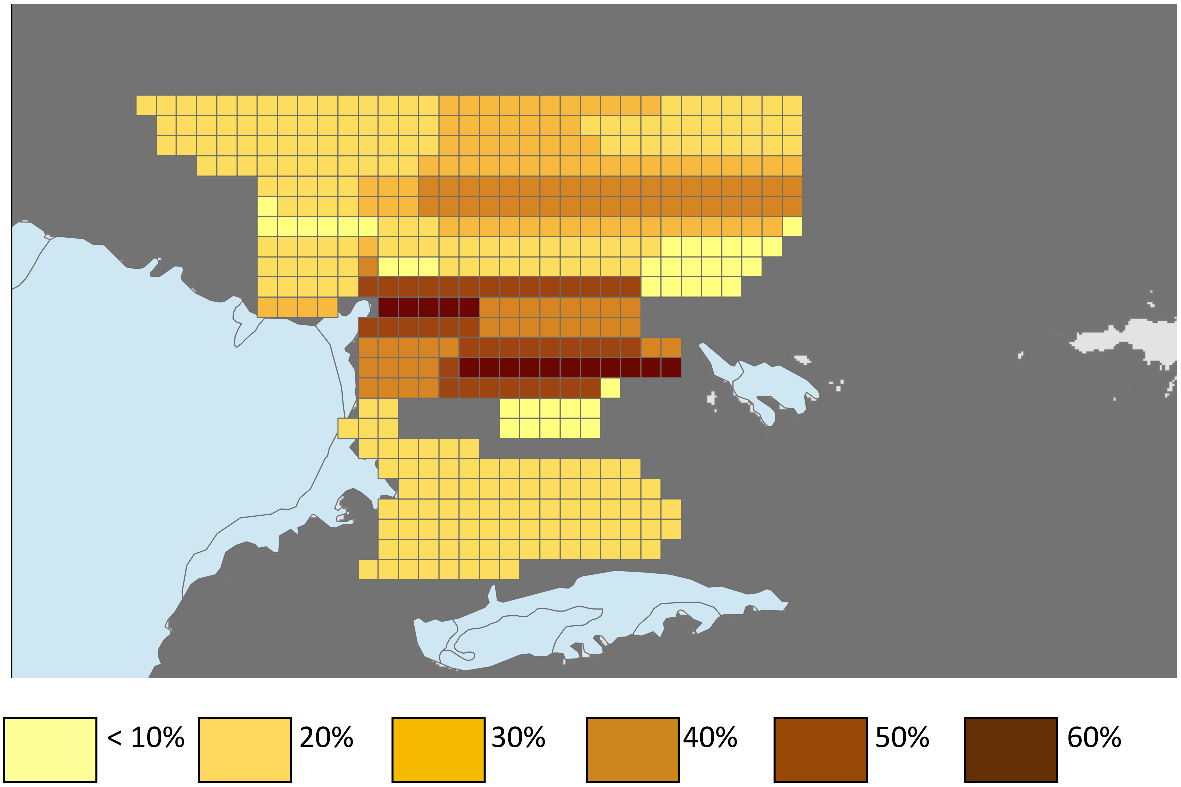

FIGURE 3.1: Commercial fishing in the Arrecifes La Cordillera Natural Reserve area.

As shown in Figure 3.1, most of the fishermen interviewed (60%) in the fish houses in northeastern Puerto Rico (from the ports of Fajardo and Ceiba) reported fishing within the reserve. Use was spread especially to the north of the reserve, for species such as spiny lobster, reef fish, and pelagics. Other fishermen targeted the area southeast of the reserve (but these were mostly fishermen from Ceiba). In terms of species, fishermen identified individual areas within and around the reserve that represented important fishing grounds. Species-area linkages were generally determined by depth and habitat, but some linkages were also based on seasonal hydrodynamics (i.e., winter and spring current conditions). Respondents in the Fajardo area identified the region. As shown in Figure 3.2 (which depicts fishing grounds drawn in maps by fishermen), respondents identified the area between Isleta Marina and Cayo Palominos (directly east off Fajardo) as an important, seasonal fishing ground for king mackerel (sierra). Fishermen also targeted it on the eastern boundary of the reserve, along Pasaje de Barriles. Line fishing, the dominant gear type used for fin fish (although several fishermen reported using fish traps as well), was utilized in deeper water (30 feet or greater) and mostly to the north and east of the reserve. Finally, as previously stated, fishermen identified shallower and more limited areas (i.e., seagrass and reef habitats within the reserve) for spiny lobster and conch fishing, both of which were targeted using dive gear or via free diving. Two respondents added that the reserve is a good location for free diving because of its overall shallow depth, but they (and others in the region) did not use the reserve frequently, opting instead to dive for spiny lobster and conch in deeper water using dive gear.

When asked about use conflicts within the reserve which might necessitate a spatial solution (i.e,. a no-take MPA), the respondents generally did not report having conflicts with their own or other stakeholder groups. The group that was most often cited as generating problems was the recreational fishing community. A smaller number of fishermen felt that divers, both commercial and sport divers, created conflicts by poaching, damaging resources, and disregarding the use of safety flags. However, although fishermen perceived high levels of competition, especially along the nearby islands of Icacos, Lobos, and Palominos, most did not believe that this resulted in inter or intra-group conflict. Similarly, when told to rank social conditions within the reserve, the respondents ranked ‘the level of space available’ as being unchanged since when they first started using the area.

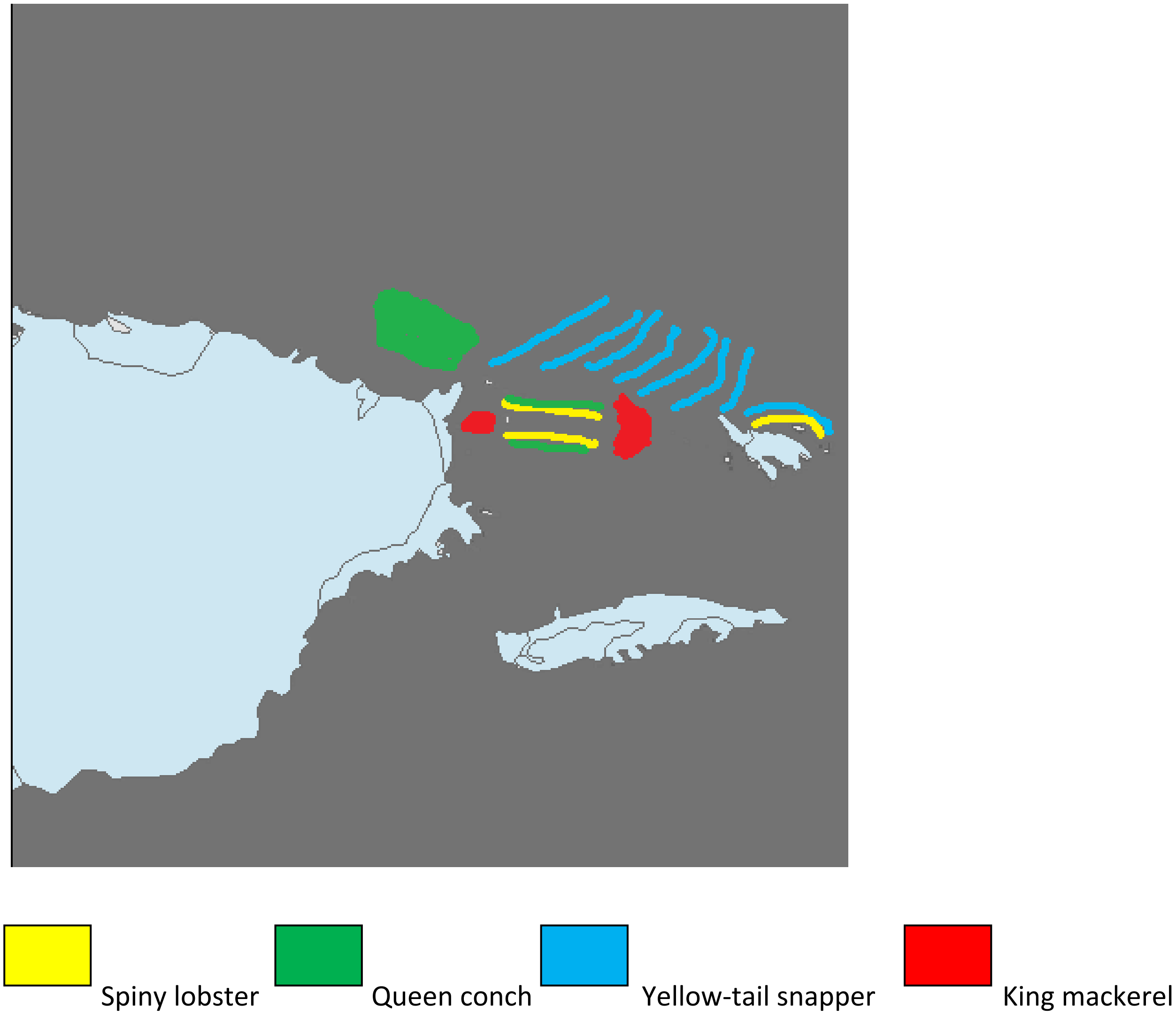

FIGURE 3.2: Fishing grounds by species in the Arrecifes La Cordillera Natural Reserve area.

Natural resource conditions, particularly those related to fisheries, were less favorably ranked. Most fishermen believed that coral reefs had declined in the reserve over their tenure, as had water quality and, most importantly, fish abundance. While one respondent argued that the lowered fish abundance was a cyclical phenomenon, most of the fishermen interviewed felt that overfishing by all stakeholder groups had impacted fisheries in the reserve.

Finally, several fishermen complained about recreational use within the reserve. The issue was not, as previously stated, related to use conflicts; rather, these fishermen felt that recreational use needed to be further regulated to manage reserve resources. Fishermen ranked cleanliness as having declined in the reserve, and several added that recreational users often left trash and dumped debris. Others pointed to recreational snorkelers and divers, who damaged the corals and other marine resources and who scared away commercially important fish.

Of the total of 12 fishermen interviewed, only four initially were in favor of establishing a no-take MPA within the ALCNR. But, that opinion changed when fishermen were offered the opportunity to (a) decide on the types of uses that would be allowed within the no-take MPA, (b) determine the type of process that should be used to establish the no-take MPA, (c) select the governmental agency that would be charged with administering the no-take MPA, and (d) pick the location of the no-take MPA. Based on those conditions, over 80% of the fishermen stated that they would favor the establishment of a no-take MPA; however, as expected, the model, location, and management type varied across respondents. Only 20% of the respondents agreed that all uses should be eliminated from a no-take MPA, whereas 30% preferred prohibiting only recreational fishing; importantly, 50% believed that all fishing should be disallowed. When asked about the process that should be used, a majority (50%) were in favor of having direct representation via meetings to which all stakeholders would be allowed. Only 30% felt that workshops, where technical information is disseminated and where stakeholders can participate in information gathering and zone development issues, would be the best process. There was slightly more support for representative councils or meetings, to which members of stakeholder groups would represent stakeholder interests. It is important to note that fishermen preferred direct representation over the other forms of participation, as they may have perceived the meeting format as providing them the most leverage among the three process types. Finally, 80% of the fishermen favored having the federal government manage a no-take MPA, although the respondents were all made aware (and most were anyway) that the reserve is managed by the PRDNER. Fishermen, especially those interviewed in the Las Croabas area, held a deep mistrust of PRDNER, which they blamed for their inability to take out passengers to the reserve as part-time charters, increased fisheries regulations, and incompetence. While this view was less strongly expressed by fishermen in other ports, these fishermen also did not trust the PRDNER to manage the no-take MPA. Only one fisherman felt that DRNA could be assigned that task and only if the no-take MPA were co-managed by the fishing community and PRDNER.

Figure 3.3 shows the areas picked as candidate no-take MPAs by the fishermen interviewed. Only a few fishermen preferred to designate the entire reserve as a no-take MPA; most were in favor of closing smaller, discrete areas within the reserve. Among the areas that were most popular were those closest to Fajardo, and these included the waters surrounding Cayo Icacos, Cayo Lobos, and Cayo Palominos. Several fishermen felt that because these areas were already crowded with water operators and recreational vessels, the waters could be protected from

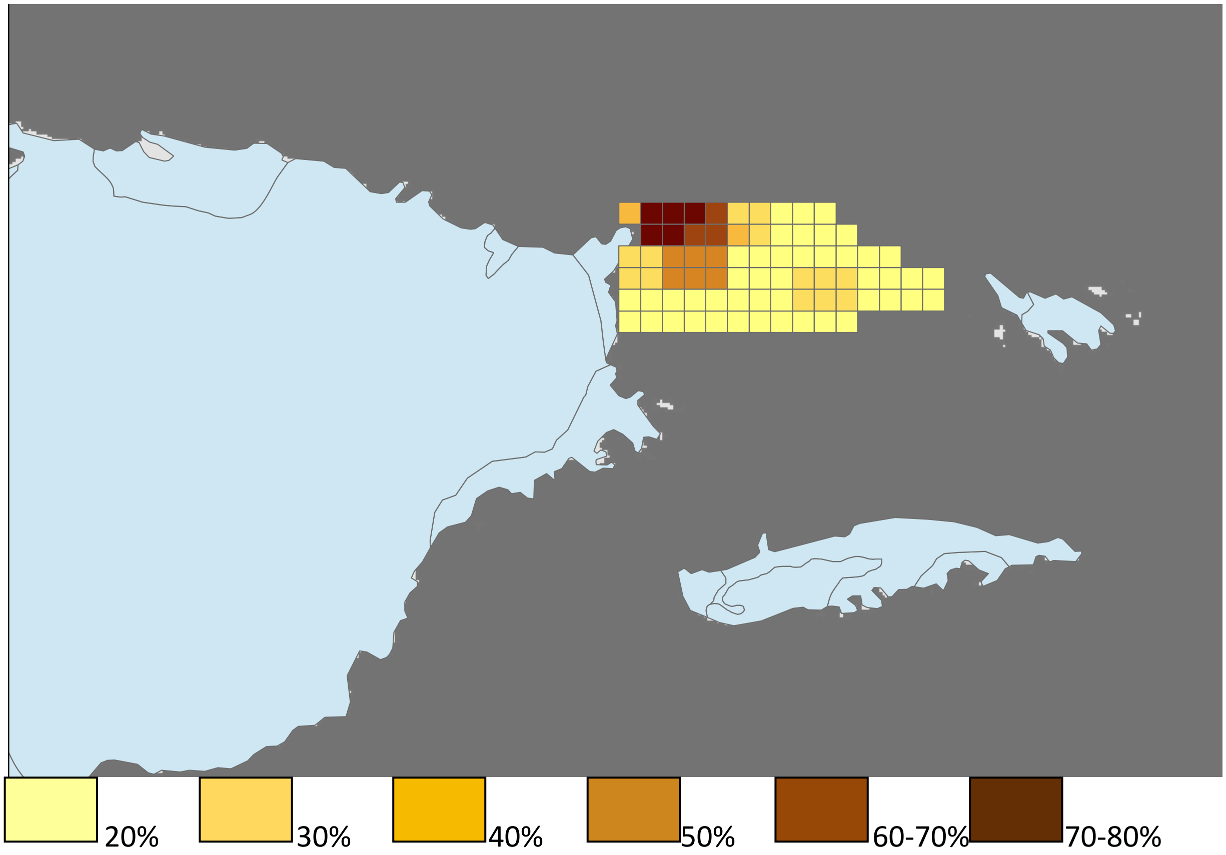

FIGURE 3.3: Commercial fishermen preferred no-take MPA sites in the Arrecifes La Cordillera Natural Reserve.

consumptive uses to a depth of 60 to 80 feet. Others preferred to only close the waters surrounding the northern Cayo Icacos to Cayo Lobos.

Thus, in terms of overall conclusions for commercial fishermen that both use and represent the fishing communities adjacent to the ALCNR, the results showed that fishermen relied on the reserve mainly on a seasonal basis and less so for key, commercial species such as spiny lobster, conch, and yellowtail snapper, that fishermen did not exhibit any direct conflicts with other user groups, that fishermen perceived a long-term decline in key, natural resource conditions in the reserve related to their livelihoods (i.e. commercial fisheries), and that fishermen were generally in favor of a no-take MPA that exists on a de facto basis – the Cayo Icacos to Cayo Lobos (and perhaps Cayo Palominos) – due to the high volume of recreational use within and between those islands. If a no-take MPA is to be implemented using stakeholder participation, the following should be considered: Participation should involve open meetings that allow complete participation, over technical workshops and representative councils; fishermen's views on site location and allowable uses should be included in the information gathering and decision-making process; and, regardless of the governmental agency that would administer the no-take MPA, management should facilitate dialogue among the commercial fishing communities in the region and the PRDNER such that the former may improve trust in the agency.

Concessionaires

As part of the study, a total of 25 water-based operations, consisting of dive and snorkel operators and pleasure (or mixed) trip charters, were identified that took trips from Luquillo to Ceiba. After contacting each operation, it was determined that 17 operated as concessionaires within the ALCNR. From August 2007 to November 2008, 16 of the concessionaires were interviewed using a formal survey instrument and open-ended questions.

Operators' experience within the reserve varied considerably. Unlike the commercial fishermen who, as a stakeholder group, had been fishing in the region for an average of almost two decades, the average tenure for concessionaires was 12 years, which varied broadly across individual operations. Some operations have existed for 25 years but others had less than two years of experience.

Also unlike commercial fishermen who operated small vessels in the region (see, for instance, Agar et al., 2008), concessionaires generally operated large and sometimes multiple vessels (average = 1.6 vessels per operation; SD = 0.95) that held an average of 22 passengers (SD = 20). There were two types of vessel fleets that operated in the reserve. The larger vessel type was the catamaran that could hold between 45-80 passengers, and the smaller vessel type held 20 or fewer passengers, including the so-called six-pack operations that carried six or fewer passengers. Smaller vessels were often used for divers, and the six operations that reported taking dive trips held an average of 13 divers/trip (SD = 9.2), compared to the 29 snorkelers on average held by the snorkel and pleasure trip operators (SD = 23; n = 14). The average number of visitors taken per trip by the entire sample was 16.8 (SD = 12.5; n = 14). Dive charters took out fewer clients than did snorkel or pleasure trip operators, where the snorkel operators averaged 10.2 snorkelers (SD = 6.23; n = 5) per trip and the pleasure trip operators averaged 16.8 clients (SD = 12.5; n = 14) per trip.

Concessionaires operating large catamarans offered pleasure (or mixed) trips which included a cruise to one of the reserve islands followed by a beach visit and snorkeling. The smaller charters took fishing trips or other mixed trips further off the ‘beaten track’ further east in the reserve and Culebra. Dive operations offered only dive and snorkel trips. Finally, water taxis transported tourists to and from the islands but on occasion did take snorkel trips. Importantly, only 19% of the concessionaires took consumptive activities such as line fishing or spear fishing, and of that percentage, all the concessionaires also took other types of trips (i.e., these charters did not rely exclusively on fishing). Also, none of the fishing charters interviewed reported line fishing within the reserve on a consistent basis; only one respondent stated that he would occasionally fish in the eastern half of the reserve but that the location was not important and could be easily substituted by an area outside the reserve. By contrast, 88% and 75% of the concessionaires reported taking snorkeling trips and beach visits within the reserve, respectively. A smaller total, or 38%, used the reserve for dive trips.

Catamaran operators all reported having a similar, relatively inflexible itinerary in the reserve. They either cruise to Cayo Icacos followed by a trip to Cayo Lobos or to Cayo Palominos and Cayo Palominitos, based on wind conditions. The former itinerary is the preferred one and would occur if there were no wind or a northerly flow (the route marked A in Figure 3.4), and the latter itinerary is used if the wind were blowing from the south (the route marked B in Figure 5). Other factors that operators noted as affecting the locations selected included the number of mooring buoys available at a site, safety conditions, fuel costs, and travel speeds. Dive operations were more flexible, and they would tend to shift locations based on the number of users per site, wind conditions, and water clarity.

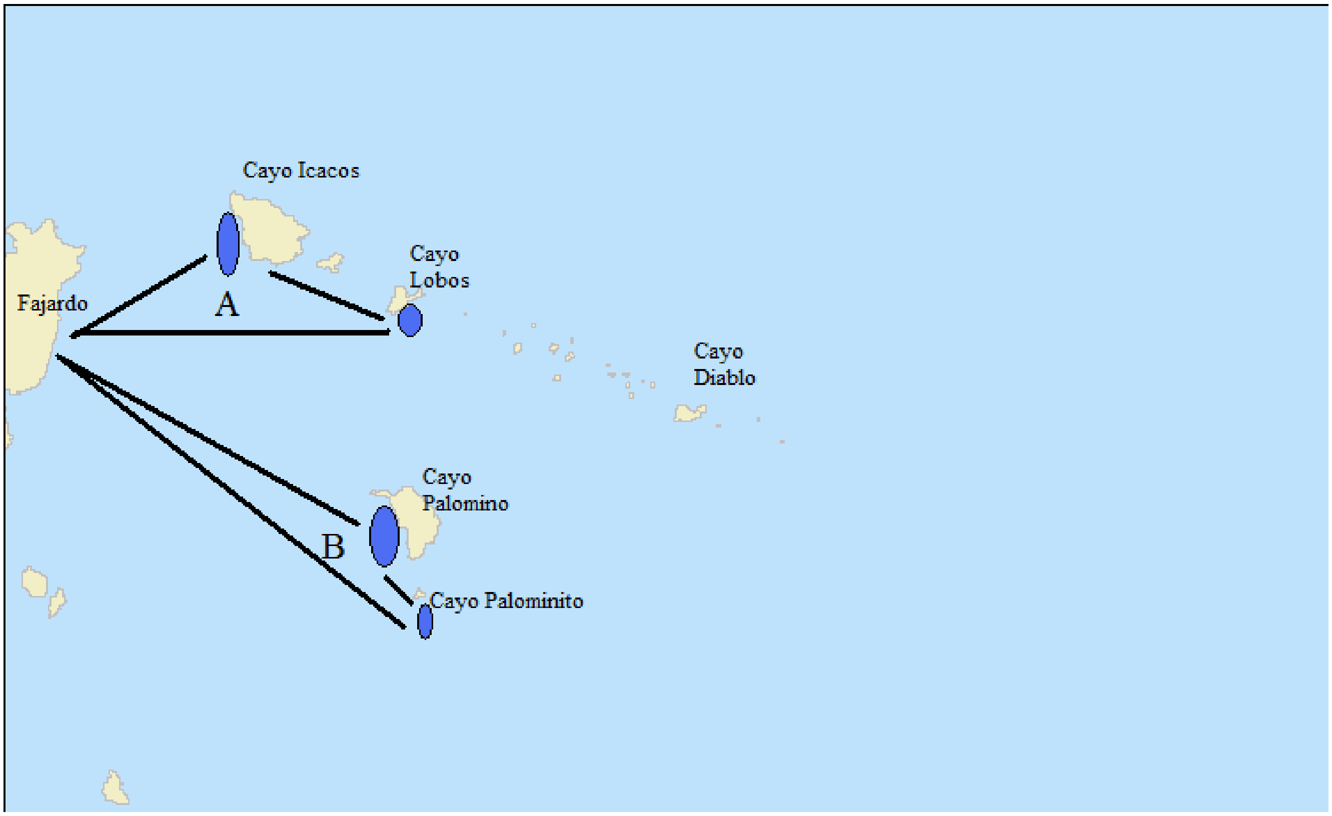

FIGURE 3.4: Catamaran use within the Arrecifes La Cordillera Natural Reserve area.

Also as shown in Figure 3.4, cataramans (and other vessels that visit the islands denoted along the two routes) use distinct sectors of each island. That is, catamarans generally moor along the southeastern side of Cayo Icacos, where they permit their passengers to snorkel and visit the beach. From there, the catamarans cruise to the neighboring Cayo Lobos, where they permit snorkeling on the southwestern and southeastern sides. If route B is taken, then the trip consists of snorkeling off the beach and a beach trip at Cayo Palominos and a cruise to Cayo Palominitos. Only a few catamaran operators reported taking occasional trips to Cayo Diablo, with a majority of the trips being taken via routes A or B.

Among the dive operators, use profiles were somewhat shifted to the east, with the eastern side of Cayo Diablo serving as an important destination. Most of the dive operators, and all of the smaller pleasure or mixed trip charters, reported taking weekly or on-demand trips to Culebra. But, use along the eastern side of the reserve was less commonly reported by either dive or mixed trip charters. Both groups instead still relied on the main islands near Fajardo, including the waters off Cayo Lobos and Cayo Palominos.

In terms of use conflicts, the concessionaires reported few inter or intra-group conflicts. The average ranking for conflict (on a scale from 1 to 4, where 1 represented most conflict and 4 represented no conflict) was highest with sport divers (mean = 3.0; SD = 1.4) and recreational boaters (mean = 2.85; SD = 1.1). By contrast, concessionaires reported lower, average rankings for conflicts with recreational fishers (mean = 3.4; SD = 1.2) and members of their own group (mean = 3.9; SD = 0.3). Several respondents felt that sport divers occasionally represented a danger to their clients with their spearguns, and that some recreational boaters did not obey navigational rules and were discourteous to other vessels. When asked to identify areas of use conflict within the reserve, a majority of the concessionaires pointed to Cayo Icacos and Cayo Palominos. Cayo Icacos was often identified due to the high volume of recreational vessels the island attracts for its beach and snorkeling area, and which many operators felt was poorly maintained (i.e., filled with trash after major holidays). Similarly, respondents believed that the area around Cayo Palominos becomes very crowded with concessionaire and private vessels, leaving little room for their clients to recreate and conditions dangerous for navigation. By contrast, none of the concessionaires interviewed identified areas east of Cayo Palominos as presenting a use conflict, suggesting a strong correlation between use intensity and user conflict within the western sector of the reserve.

Like commercial fishermen, concessionaires believed that coral reef conditions (mean = 3.9; SD = 1.2), fish abundances (mean = 3.5; SD = 1.3), and water quality (mean = 3.2; SD = 0.7) had declined since when they had been operating in the reserve (on a scale from 1 to 5, where 1 = improved and 5 = declined). Concessionaires felt that factors such as anchor damage, vessel groundings, and overfishing had contributed to the decline in coral reef conditions but generally did not blame a single group; instead, the consensus among operators was that the reserve has been impacted by a variety of stressors, including fishing, recreation, and development.

When asked if they would favor the establishment of a no-take MPA within the reserve, 11 of 15 concessionaires, or 73%, agreed. Of the 27% who were against the establishment of a no-take MPA, only one allowed consumptive trips. The others were against the establishment of a no-take MPA for different reasons that were less related to their economic interests, including concerns about the effectiveness of such a reserve (given the bad experience of the Luis Pena Channel No-Take Marine Reserve in Culebra), fears over the government closing all uses within the no-take MPA over time, and concerns for other stakeholder groups that might be affected by the closure. However, the results showed a strong majority support among both the dive operators and mixed trip charters to close part of the ALCNR as a no-take MPA.

Of the 11 concessionaires who provided a location for the no-take MPA within the reserve, 82% preferred Cayo Icacos, followed by 73% in favor of Cayo Lobos (Figure 3.5). It should be noted, however, that most of the respondents in favor of Cayo Lobos also selected Cayo Icacos, as they felt that because both islands are used together, they should be both protected as a single unit. Interestingly, 55% called for the designation of Cayo Diablo, which was higher than the 45% who favored Cayo Palominos and Cayo Palominitos. This may be in part due to the fact that many concessionaires knew that Cayo Palominos is a private island, although its coastal and marine resources are part of the reserve (CEA, 2007). Finally, 27% of the respondents called for closing the entire reserve as a no-take MPA.

Among those in favor of establishing a no-take MPA, all of the concessionaires (n = 11) believed that commercial diving should be prohibited within the reserve, compared to 92% who wanted a similar prohibition for trap and line fishing, and 75% who favored restricting all recreational line fishing. As might be expected by the stakeholders' economic interests, only 33% of the respondents called for the prohibition of sport diving and snorkeling or boating in the no-take MPA. Most of the concessionaires instead perceived these activities as consistent with the objectives of no-take MPAs.

As per the process to be used for establishing a no-take MPA, most concessionaires – like commercial fishermen – preferred using open meetings; however, several felt that meetings, workshops, and representative councils should all be utilized. Workshops were more popular than representative councils, the latter of which the respondents viewed as too far removed to

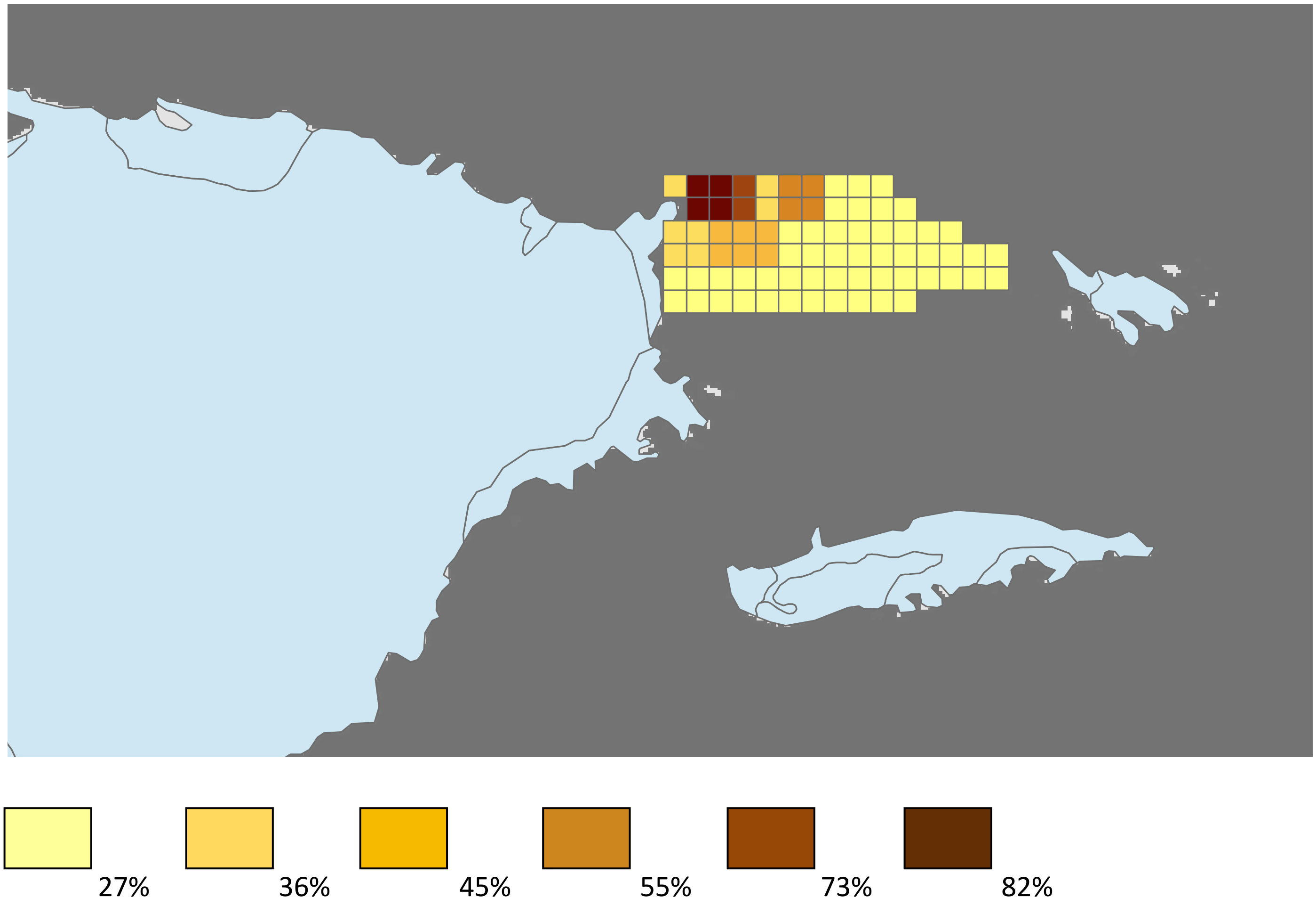

FIGURE 3.5. Concessionaires’ preferred no-take MPA sites in the Arrecifes La Cordillera Natural Reserve.

fully represent their interests. As shown, concessionaires are comprised of a diversity of dive operators, mixed trip operators, and fishing charters, and they represent a variety of large, medium and small-sized operations. Thus, representative councils would most likely not include all interests and were thus most likely least preferred.

Finally, concessionaires showed more support for PRDNER as the agency to be charged to manage the no-take MPA than did their fishermen counterparts. Almost 40% of the operators who answered the question concerning the agency that they would like to see manage the reserve felt that PRDNER, either by itself or in collaboration with a federal agency, should be put in charge. Many of these respondents felt that PRDNER was the logical choice due to the agency's management of the present reserve and due to its experience with marine protected areas. A majority of the concessionaires nevertheless felt that a federal agency, such as the Fish and Wildlife Service which was cited by several respondents, should manage the no-take MPA. Many of these concessionaires believed that only federal agencies possessed the necessary funding to adequately manage and effectively enforce the no-take MPA; these operators often related the need for additional mooring buoys which they argued that PRDNER had not been able to provide thus far for the reserve, as well as their views on the ineffectiveness of PRDNER in enforcing regulations within the reserve.

In terms of overall conclusions on the concessionaire stakeholder group, the results showed the group as comprised of diverse interests, including dive and snorkel operators, catamaran and other large vessel operators, and fishing and other mixed-trip charters. The entire group relies extensively (in many cases, exclusively) on the reserve's coastal and marine resources for its livelihood, and there was a majority view among respondents that the reserve's coral reef and related resources have declined over the past decade or longer. Most concessionaires also identified Cayo Icacos and Cayo Palominos as areas that experience high volumes of use and which are centers of use conflict, particularly from recreational divers and private recreational vessels. Due to these and related factors (i.e., overfishing, water quality decline), over 70% of the concessionaires were in favor of a no-take MPA within the ALCNR. The reserve, as would be designed by most respondents, would exclude commercial and recreational fishing but would allow non-consumptive uses, including diving, snorkeling, and cruising. The areas that were most often identified as candidate sites were those which were the waters around the most heavily visited islands, including Cayo Icacos and Cayo Lobos. Although less popular, concessionaires also identified as Cayo Diablo and Cayo Palominos as islands around which to set up a no-take MPA. Concessionaires believed that reserve designation should involve mainly open meetings that allow all stakeholder groups and the public, while many concessionaires also favored having other forms of public participation, including technical workshops. Finally, concessionaires were more amenable than the commercial fishing group to have PRDNER manage the no-take MPA site, but most still preferred a federal agency, mainly because of the latter's enforcement capability and financial advantage.

Private vessel operators

A total of 102 private vessel operators completed a survey instrument provided to them during a visit to the Puerto del Rey vessel registration office over a survey session that lasted six months, from September 2007 to February 2008. While the sample size was limited, the boaters who did participate in the survey provided extensive use information and views on MPA management relevant to the study. Moreover, because the survey targeted mainly those vessel operators who embark from the northeastern Puerto Rico coast, the sample contained a large percentage of respondents (72%; n = 73) who reported operating in the reserve and surrounding areas. The following results relate to the subsample of respondents who operated within and were knowledgeable about the reserve.

Vessel operators who visited the reserve represented over a decade of experience (mean = 11-15 years (4.1); SD = 1.6) and took an average of 2.1 weekday trips (SD = 1.5) and 3.0 weekend day trips (SD = 1.9) per month. Trips averaged 4.5 hours (SD = 2.6), suggesting that the operators took almost half-day trips once every two weeks on weekdays and three weekend days out of the month.

The most popular activity as ranked by the respondents was visiting beaches in the reserve (mean = 2.6 on a scale from 1-5, where 1 is always and 5 is never; SD = 1.7), followed by cruising (mean = 2.9; SD = 1.7), visiting the islands (mean = 3.1; SD = 1.7), and swimming (mean = 3.2; SD = 1.6). Vessel operators ranked snorkeling (mean = 3.6; SD = 1.4) and diving (mean = 4.5; SD = 0.9) as less important activities, suggesting that they did not often participate in in-water recreation (apart from swimming). In terms of consumptive activities, line fishing (mean = 3.3; SD = 1.6) was more popular than spearfishing (mean = 4.7; SD = 0.9), again most likely related to the respondents' lower rates of participation in in-water activities. As per activities within the reserve, over half of the vessel operators stated that they visited reserve beaches, 41% reported cruising along the reserve, 37% reported swimming, and 33% reported visiting one or more of the reserve islands. Fewer listed fishing (26%) or diving (11%). These use profiles, when considered with the activity rankings, show that water-based activities such as fishing, diving, and snorkeling were less important to vessel operators than were land-based ones, such as beach recreation and island visitation. These profiles suggest that private vessel operators may prefer or be more concerned about the land or coastal-based location, attributes, and regulations of a no-take MPA (if any) than its marine components (ex. fisheries potential, benthic habitats, etc.).

When asked if they had heard of the ALCNR prior to the survey, over a third (36%) of the vessel operators stated that they did not previously know about the reserve. It should be noted as well that two thirds of the respondents reported having visited the reserve in the previous year. These findings suggest that a considerable proportion of private vessel operators may not be aware that they are operating within a marine protected area which, especially if modified to include a no-take MPA, must take measures to improve awareness.

The most popular destinations within the reserve were Cayo Palominos (92%) and Cayo Icacos (81%). By contrast, only over a third had visited Cayo Lobos (36%) and a fifth (21%) to Cayo Diablo. As with the concessionaires, it appears that vessel operator visitation was inversely related to the distance from port, where the closest islands were most often visited. If the reserve is considered as a single destination compared to other areas visited in the region, it is clear that the reserve was still the most important destination for those vessel operators who listed it as one of many destinations. Figure 4.6 (taken from Shivlani, 2008) shows the relative importance of various destinations in eastern Puerto Rico.

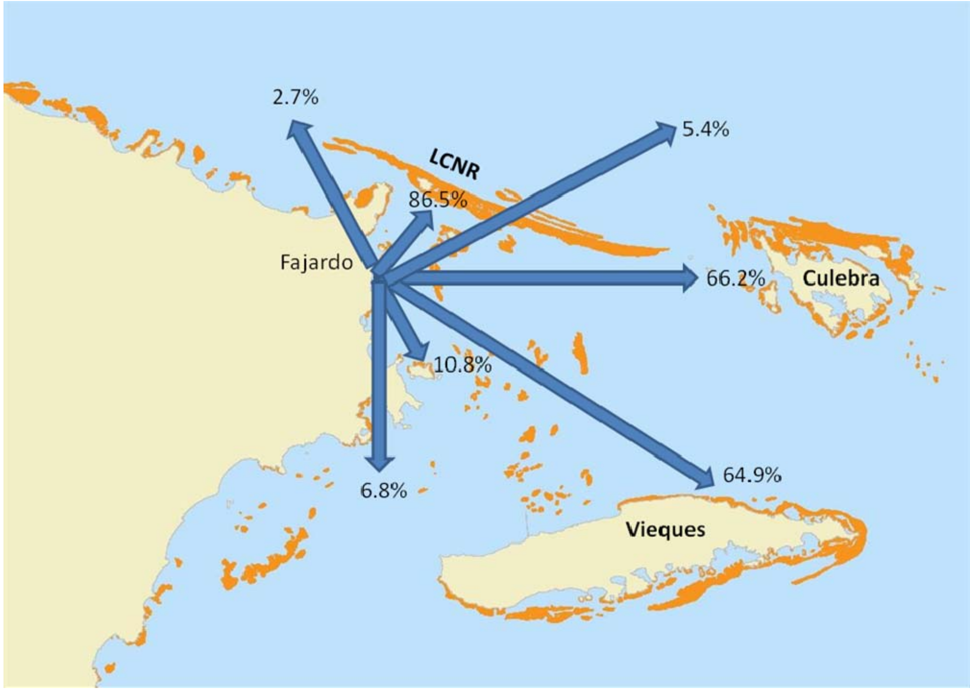

FIGURE 3.6. Private vessel use profiles in the Arrecifes La Cordillera Natural Reserve and other destinations (Shivlani, 2008).

As shown in Figure 3.6, 87.5% of the private vessel operators reported using the reserve. This was much higher than the rates of visitation to the next two popular destinations: The islands of Culebra (66%) and Vieques (65%). Other destinations to the north, northeast, and south were less popular, accounting for 11% of the respondents. Interestingly, when visitation profiles for the island of Culebra were considered in more detail, it was determined a majority of the vessel operators who traveled to the island, or 19%, visited the Luis Peña Channel no-take Natural Reserve, a no-take MPA located off western Culebra (CIEL, 2007). It should be noted that use profiles within the Luis Peña No-take Channel Reserve prior to designation are not well known (but see Hernández-Delgado et al., 2003, and Hernández-Delgado, 2004); thus, the reserve area may have been equally popular prior to its designation. Nevertheless, the possibility of increased vessel traffic and recreational use following the implementation of a no-take MPA in ALCNR should be considered (i.e., by characterizing baseline use, as has been done for other MPAs (see, for instance, Shivlani and Suman (2000) for a baseline characterization of dive operator use in the Florida Keys National Marine Sanctuary, NOAA's (2000) baseline characterization of use within the Dry Tortugas Ecological Reserve)).

Just fewer than 52% of the respondents who visited the reserve were in favor of implementing a no-take MPA in the ALCNR, compared to 49% of the entire sample. Thus, there was slightly higher support among those vessel operators who visited the reserve than others who did not. Because the vessel operator survey was self administered, there was no opportunity to ask follow-up questions as with the other stakeholder groups on why respondents did not support a no-take MPA. However, almost 70% of the vessel operators who visited the reserve and who were in favor of a no-take MPA provided a preferred site.

As shown in Figure 3.7, a majority of the registered vessel operators who used the ALCNR preferred no-take MPA sites within the proximity of the most frequently used islands, namely Cayo Icacos, Cayo Lobos, Cayo Palominos, and to a certain extent, Cayo Diablo. Among these sites, the most popular was the area around Cayo Icacos, which 92% of the respondents listed as their preferred site. There was lower support for the adjacent Cayo Lobos, which nevertheless over 70% of the operators listed as a preferred site. Forty percent of the respondents supported closing the entire reserve.

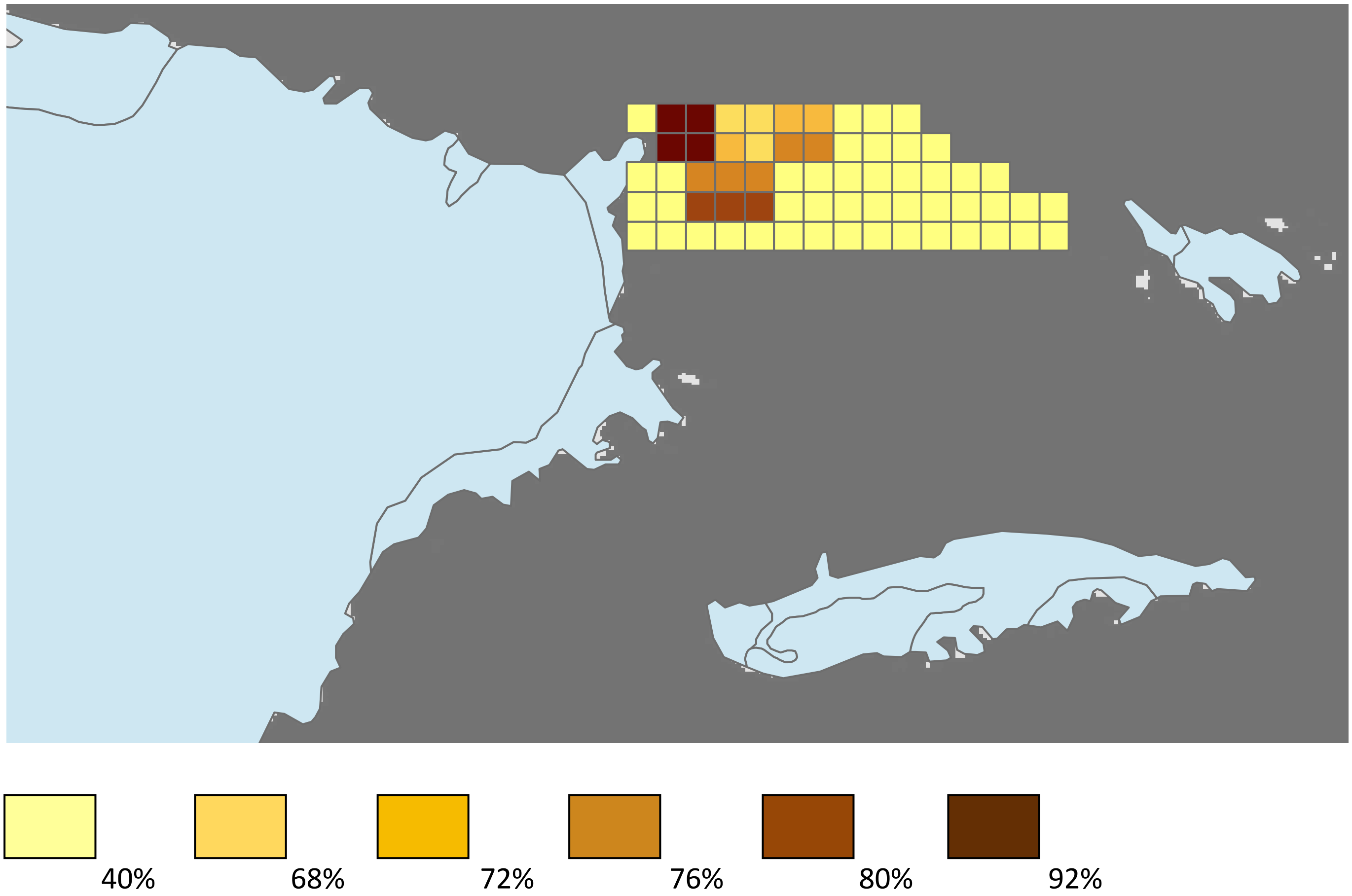

FIGURE 3.7. Registered vessel operator preferred no-take MPA sites in the Arrecifes La Cordillera Natural Reserve

In terms of overall conclusions on the registered vessel operator stakeholder group, the study results indicated that operators who visited the ALCNR are prolific boaters, taking five trips per month, each of which lasted over half a day (4.5 hours); thus, they represent a group that is most likely knowledgeable about the region and its resources, if not its designated status. That is, the results also demonstrated that while the operators took a majority, or almost 90%, of their trips to the reserve, over a third of the respondents were unaware of the reserve or its boundaries. If the group were to be engaged in a process to set up a no-take

MPA, part of the process would have to involve boater (and, indeed, general public) education on the existence of the reserve and its present boundaries and regulations. The results also determined that a smaller percentage of registered vessel operators (52%), compared to the corresponding percentages of commercial fishermen (80%) and concessionaires (73%) supported a no-take MPA designation. However, this lower support for a no-take MPA may have been a result of the methodology involved, which consisted of a formal, self-administered survey instrument that did not allow for respondents to select the types of uses that could be restricted and choices between designation processes and different management agencies. Notwithstanding those constraints, over 90% of those who did identify a recommended no-take MPA in the reserve selected Cayo Icacos, which was more popular than the adjacent Cayo Lobos and Cayo Palominos, but which together garnered support for closure from over 70% of the registered vessel operators.

Conclusions

The study characterized the four, main stakeholder groups in the ALCNR, in terms of use patterns and frequencies, views on resource conditions, trends, and use conflicts, and their preferences towards no-take MPAs within the reserve. Please refer to Table 3.1 at the end of this section for an inter-stakeholder group characterization comparison.

While representative sampling was not used for the commercial fishing industry and the registered vessel operator population, the methodologies adopted for both groups (key informant interviews for commercial fishermen and periodic, self-administered surveys for vessel operators) served to obtain overall views held by members of both groups on the ALCNR and the potential designation of no-take MPAs within the reserve. Dive operators and pleasure or mixed-trip charters were sampled using a census survey of concessionaires. With each group, the focus of the study was to obtain a general understanding on how its members interact with the reserve and its resources, the members' views on how well the reserve is currently managed (i.e., views on use conflicts and resource conditions) to correlate that perception to the demand (or at least, acceptance) of further protection in the form of a no-take MPA, and the preferred location and desired management conditions of the no-take MPA.

It was determined that all stakeholder groups (with the exception of registered vessel operators, who were not asked the questions due to the length of the self-administered survey) agreed that coral reef conditions in the reserve had declined, as had associated resources such as water quality which affected the health of the coral reefs and fisheries which depended on healthy coral reefs. While the stakeholder groups believed that there were a myriad of causes for the decline, there was general consensus that overfishing (resulting from commercial and recreational fishing) and development (especially as related to coastal and marine tourism, sedimentation, and water quality) had been responsible. The stakeholders mostly accepted the solution of implementing a no-take MPA and may actually have been addressing their concerns over resource decline by identifying the most heavily used areas (the Cayo Icacos-Lobos-Palominos complex) as those which deserve the highest protection. While it is clear that non-consumptive stakeholder groups stand to gain the most by restricting access to all other kinds of uses within a no-take MPA, the study revealed that even consumptive groups such as commercial fishermen, fishing charters, and consumptive dive charters generally did not oppose the implementation of a no-take MPA.

As important as reaching consensus on the location and characteristics of a no-take MPA was the determination of the process to be used to foster public participation in a format that stakeholders considered would be fair and equitable and the identification of the management agency which stakeholders believed would be best positioned to ensure enforcement and management efficacy. While not discussed in any detail in this report, it was found via commercial fishermen and concessionaire interviews that the stakeholder groups held a dim view on public participation; that is, members of both groups often felt that meetings addressing resource management were often poorly advertised and held at hours when they could not attend. Others believed that public participation, while allowed and even promoted, made little difference in influencing the final decisions. However, stakeholders still preferred holding meetings as part of the decision-making process for a no-take MPA instead of other formats, such as technical workshops or representative councils.

Finally, in terms of identifying the agency that could best implement a no-take MPA, most stakeholders were in favor of a federal agency, particularly the Fish and Wildlife Service (FWS). It is likely that the FWS was most commonly cited because it is the primary federal, natural resource agency that most stakeholders are aware of in the region, through experiences with the Vieques National Wildlife Refuge and the Culebra National Wildlife Refuge. Thus, at the federal level at least, stakeholders should be made aware of other models, including national parks and, in particular, national marine sanctuaries. Also, there remains the need to better understand and ameliorate the mainly negative views that many stakeholders, and especially commercial fishermen, hold towards PRDNER. Many stakeholders interviewed as part of the study believed that PRDNER did not have the financial or enforcement capacity to manage a no-take MPA. Others felt that the agency was draconian and thus did not foster stakeholder confidence in being fair in the management of a no-take MPA. Finally, a few respondents perceived the agency as having failed to adequately protect the regional natural reserves, including Luis Peña Channel No-take Natural Reserve and ALCNR, and argued that the agency could not handle additional management tasks. These examples are raised here to highlight the pervasive views held by many stakeholders concerning PRDNER and to recommend that any no-take MPA designation process consider improving stakeholder understanding of DRNA objectives, management actions, and accomplishments and an overall rehabilitation of the agency’s image in relation to stakeholder trust.

TABLE 3.1. Comparison of stakeholder characteristics and views towards no-take MPA designation and management

Group	Interaction with the reserve	Reliance on reserve	Main activity in reserve	Views on resource conditions	Views on no-take MPA	MPA location	Preferred process	Preferred management agency
1. Commercial fishermen	Consumptive, extractive	Moderate to minimal	Diving, line fishing, some trap fishing	Declining	80% support	Icacos, Lobos	Meetings	Federal
2. Dive charters	Mostly non-consumptive	High	Diving off islands and coral reefs	Declining	73% support	Icacos, Diablo	Meetings, technical workshops	Federal
3. Mixed trip charters	Mostly non-consumptive	High	Pleasure trips to nearby islands	Declining	73% support	Icacos	Meetings, technical workshops	Federal
4. Registered vessel operators	Mixture of consumptive and non-consumptive	Moderate to high	Pleasure trips to nearby islands	N/A	52% support	Icacos	Need for awareness, education within group	N/A

Literature cited

Agar, J. J., J.R. Waters, M. Valdés-Pizzini, M. Shivlani, T. Murray, J.E. Kirkley, & D. Suman. 2008. U.S. Caribbean fish trap fishery socioeconomic study. *Bull. Mar. Sci.* 82:315-331.

Aguilar-Perera, A., M. Schärer, & M. Valdes-Pizzini. 2006. Marine protected areas in Puerto Rico: Historical and current perspectives. *Ocean Coast. Mgmt*. 49:961-975.

Bunce, L., K. Gustavson, J. Williams, & M. Miller. 1999. The human side of reef management: a case study analysis of the socioeconomic framework of Montego Bay Marine Park. *Coral Reefs* 18 (4): 369-380.

Centro Interdisciplinario de Estudios del Litoral (CIEL). 2008a. Plan de Manejo de la Reserva Natural Canal de Luis Peña. Mayagüez, Puerto Rico: CIEL/Universidad de Puerto Rico en Mayagüez.

Centro Interdisciplinario de Estudios del Litoral (CIEL). 2008b. *Plan de Manejo de la Reserva Marina Tres Palmas, Rincón, Puerto Rico.* Mayagüez, Puerto Rico: CIEL/Universidad de Puerto Rico en Mayagüez.

Consultores Educativos Ambientales (CEA). 2007. *Plan de Manejo de la Reserva Natural Arrecifes de Cordillera, Fajardo.* Humacao, Puerto Rico: CEA.

Day, J. 2008. The need and practice of monitoring, evaluating and adapting marine planning and management—lessons from the Great Barrier Reef. *Mar. Policy* 32:823– 831.

Delaney, J. M. 2003. Community capacity building in the designation of the Tortugas Ecological Reserve. *Gulf Caribb. Res.* 14:163–169.

Helvey, M. 2004. Seeking consensus on designing marine protected areas: Keeping the fishing community engaged. *Coast. Mgmt.* 32:173-190.

Hernández-Delgado, E.A. 2004. Análisis de los usos históricos, actuales y recomendados de la Reserva Natural del Canal Luis Peña, Culebra, P.R. Informe Técnico sometido a la Autoridad de Conservación y Desarrollo de Culebra, Culebra, PR. 77 pp.

Hernández-Delgado, E.A., M.T. Vázquez, A. Díaz, X. Rentas, J.C. López, K. Cortés, A.F. Rainford, D. Colón, A. López, A. Rodríguez , G. Hernández, I. Navarro, J. Gómez, M. González, S. Hernández 2003. Suplemento técnico al Plan de Manejo de la Reserva Natural del Canal Luis Peña, Culebra, Puerto Rico. III. Usos históricos, actuales y valor arqueológico del Canal Luis Peña. Informe sometido al Departamento de Recursos Naturales y Ambientales. San Juan, PR. 30 de agosto de 2003. 45 pp.

Kelleher, G. 1999. *Guidelines for marine protected areas*. Gland, Switzerland: IUCN.

National Academy of Public Administration (NAPA). 2000. *Protecting our National Marine Sanctuaries: A report by the Center for the Economy and the Environment*. Washington, DC: NAPA.

National Oceanic and Atmospheric Administration (NOAA). 2000. *Final Supplemental Environmental Impact Statement/Final Supplemental Management Plan for the Tortugas Ecological Reserve*. Silver Spring, MD: SRD/OCRM/NOS/NOAA.

National Research Council (NRC). 2001. *Marine protected areas: Tools for sustaining marine ecosystems.* Washington, DC: National Academy Press.

Salm, R.V., J. Clark, & E. Siirila. 2000. *Marine and coastal protected areas: A guide for planners and managers. 3rd Ed*. Washington DC: IUCN.

Shivlani, M. 2007. *Community studies to determine the feasibility and expectations of marine protected area (MPA) management in Vieques, Puerto Rico.* Report completed in support of NOAA Coral Reef Conservation Grant NA04NMF4630335.

Shivlani, M. 2008. *Characterization of stakeholder uses in marine protected areas in support of establishing limits of acceptable change: Five case studies in the coastal and marine natural reserve system of Puerto Rico.* Unpublished manuscript.

Shivlani, M., Leeworthy V.R., Murray, T.J., Suman, D.O., and F. Tonioli. 2008. *Knowledge, attitudes and perceptions of management strategies and regulations of the Florida Keys National Marine Sanctuary by commercial fishers, dive operators, and environmental group members: A baseline characterization and 10-year comparison*. Silver Spring, MD: NOAA/Office of National Marine Sanctuaries. Marine Sanctuaries Conservation Series ONMS-08-06.

Shivlani, M.P., & D.O. Suman. 2000. Dive operator use patterns in the designated no take zones within the Florida Keys National Marine Sanctuary. *Environ. Mgmt.* 25:647-659.

Suman, D.O.,M.P. Shivlani, & J.W. Milon. 1999. Perceptions and attitudes regarding marine reserves: A comparison of stakeholder groups in the Florida Keys National Marine Sanctuary. *Ocean and Coastal Management* 42: 1019-1040.

Thomas J. Murray & Associates. 2007. *Socio-economic baseline development: Florida Keys National Marine Sanctuary, fishing years 1998-2006.* World Wide Web document. URL: http://marineeconomics.noaa.gov/SocmonFK/Comm_Fish_Panels_Years_7-8.pdf.

Valdés-Pizzini, M. 1990. Fishermen associations in Puerto Rico: Praxis and discourse in the politics of fishing. *Human Org.* 49 (2): 164-173.

Weible, C. M. 2008. Caught in a maelstrom: Implementing California marine protected areas. *Coastal Management* 36:350-373.

Weible, C., P.A. Sabatier, & M. Lubell. 2004. A comparison of a collaborative and top-down approach to the use of science in policy: Establishing marine protected areas in California. *The Policy Stud. J.* 32: 187-207.

CHAPTER 4

Geo-spatial rankings of coral reef fish community characteristics and other designation criteria

(E.A. Hernández-Delgado, A.M. Sabat)

Introduction

No-take MPA designation in PR in the past has relied on limited quantitative information regarding the condition of coral reef fish communities, and usually with poor geo-spatial resolution, and limited evaluations of other designation criteria. Further, incorporation of user surveys to test perceptions have had very limited value in previous local MPA designations in the past. The first objective of this phase of the study was to apply geographic information system (GIS)-based tools to rank all seven study sites based on different coral reef fish community parameters. This information was then used, in combination with information obtained from the literature (Almy and Carrión-Torres, 1963; McKenzie and Benton, 1972; Goenaga and Vicente, 1990; Goenaga and Boulon, 1992; Hernández-Delgado, 1992, 1994a,b; 2000, 2005; Hernández-Delgado et al., 1996; Hernández-Delgado and Sabat, 1998; García-Saís et al. 2003, 2008; CSA, 2005; DRNA, 2007; Ballantine et al., 2008), information documented by Shivlani (Ch. 3) regarding user perceptions, and in combination with MPA ranking criteria of Salm et al. (2000), to develop a multi-criteria data matrix to evaluate and recommend candidate no-take MPAs within ALCNR. The final objective was to use all information to develop a multi-criteria ranking system to help NOAA and PRDNER identify, evaluate and designate candidate no-take MPA areas.

Methodology

Apply GIS-based tools to fish community characterization.

GIS-based tools (ArcView 9.3, ESRI Corp.) were applied to the entire fish community data set (Hernández-Delgado and Sabat, Chapter 2) to geo-spatially rank study sites. This approach allowed facilitation of data interpretation, which could in turn be a useful tool for managers, and allowed rapid ranking of potential candidate no-take MPA sites within ALCNR based on different fish community quantitative biological criteria. Briefly, data distribution patterns were used to create different categories per parameter. Categories were then used to create spatial rankings of each site and projected in a GIS map layer over the reserve's map.

Develop a multi-criteria data matrix to evaluate candidate no-take MPA sites.

An interdisciplinary data matrix using a combination of biological, ecological, regional, impacts, pragmatic, social and economic criteria was developed to rank priority candidate no-take MPA sites within ALCNR. Most of the proposed criteria definitions were based on or modified after Salm et al. (2000). Information was obtained from literature reviews (see listed references in the Introduction section), field surveys (Hernández-Delgado, unpub. data), interviews with different persons, and other sources. Information was also obtained from Shivlani (Chapter 3). A 2-point scale was used to score each criteria based on the rankings of each parameter (i.e., fish biomass) as follows: 0= Low priority site (lower 33% ranking); 1= Moderate priority site (middle 33-66% ranking); 2= Highly recommended site (upper 66-100%

ranking). Candidate no-take MPA sites within ALCNR were ranked according to the global scores from the matrix based on different criteria. Criteria used are described below.

Biological criteria (based in comparisons among sites): These criteria were based on a wide variety of fish community parameters obtained from Hernández-Delgado and Sabat (Chapter 3), and included the following: 1) Fish species richness; 2) H'n; 3) J'n; 4) Total fish abundance; 5) Total herbivore abundance; 6) Non-denuder abundance; 7) Browser abundance; 8) Scraper abundance; 9) Omnivore abundance; 10) Total carnivore abundance; 11) Generalists abundance; 12) Planktivore abundance; 13) Piscivore abundance; 14) Fishery target abundance; 15) Total biomass; 16) Total herbivore biomass; 17) Non-denuder biomass; 18) Browser biomass; 19) Scraper biomass; 20) Omnivore biomass; 21) Total carnivore biomass; 22) Generalists biomass; 23) Planktivore biomass; 24) Piscivore biomass; 25) Fishery target biomass; and 26) Reef substrate heterogeneity index (RSHI). Absolute values of each single parameter were individually ranked and classified in several ranking categories. GIS was applied to the final data sets to produce spatial ranking maps to visually aid in the ranking analysis process.

Ecological criteria: 1) *Biodiversity* – variety or richness of ecosystems, habitats, communities and species. Information was obtained from the literature (Almy and Carrión-Torres, 1963; McKenzie and Benton, 1972; Hernández-Delgado and Sabat, 1998; Hernández-Delgado, 2000), from NOAA (2001) and from Hernández-Delgado (unpub. data). Rankings were made based on coral and fish species richness, as well as based on habitat diversity as documented within selected polygons with information obtained from NOAA benthic habitat mapping products; 2) *Naturalness* – lack of disturbance or degradation. This was based on personal observations regarding the presence or absence of anthropogenic disturbance signals (i.e., overfishing, sedimentation, turbidity, anchoring, excessive SCUBA diving, rapidly declining coral cover, known pollution, etc.); 3) *Dependency* – degree to which a species depends on an area; degree to which an ecosystem depends on ecological processes occurring in the area. This criteria was based on the known or expected connectivity value of each of the habitats that were evaluated for any given species. In this case, we used groupers (Serranidae) and Staghorn coral (*Acropora cervicornis*) as model taxa; 4) *Representativeness* – degree to which an area represents a habitat type, ecological process, biological community, geological feature or other natural characteristic. This was based on personal observations across all sites and the identification of each feature; 5) *Uniqueness* – whether an area is "one of a kind" (i.e., habitats of endangered or rare species). This was based on personal observations across all sites and comparison to other known sites across the immediate region; 6) *Integrity* – degree to which an area is a functional unit; an effective, self-sustaining ecological entity. This was based on personal observations across all sites and the identification of features such as availability of a wide diversity of microhabitats, abundance of large coral colonies, open substrates devoid of macroalgae and sediment open to recruitment, abundant juvenile corals, etc.; 7) *Productivity* – degree to which the productive processes within an area contribute benefits to species or to humans. This was based in the ability of any given site to contribute to the sustainability of local fisheries either as a nursery ground or as an important historical fishing ground; 8) *Ecological status of benthic communities* – status of dominant benthic categories. This information was based on other ongoing studies by Hernández-Delgado (unpub. data) based in current long-term monitoring efforts and extensive surveys across many sites that have allowed to produce benthic habitat characterizations; and 9) *Connectivity to other reefs* – degree to which an area is physically connected to other areas or species are connected to other areas via surface currents. This was also based on previous knowledge about physical connectivity and sea surface current patterns. It also relied on extensive conversations with local fishermen to fine tune previous information regarding sea surface localized currents patterns.

Regional criteria: 1) *Regional significance* – degree to which an area represents a characteristic of the region; and 2) *Sub-regional significance* – degree to which an area fills a gap in the network of protected areas from the sub-regional perspective. This analysis was based on previous knowledge of the relevant literature and of existing MPA networks across the northeastern Caribbean region (i.e., biodiversity information available from different sources, including http://www.reefbase.org).

Impacts criteria: 1) *Vulnerability* – area's susceptibility to degradation by natural events or the activities of people; 2) *Degree of threat* – present and potential threats from direct exploitation and development projects; and 3) *Evident overfishing effects* – area showing signs of low fish abundance, small size classes, low predator populations, impacts of fishing gear, etc. Scores were based on ranks obtained during this study, in combination with previous knowledge of the authors, and the available literature (Almy and Carrión-Torres, 1963; McKenzie and Benton, 1972; Goenaga and Vicente, 1990; Goenaga and Boulon, 1992; Hernández-Delgado, 1992, 1994a,b; 2000, 2005; Hernández-Delgado et al., 1996; Hernández-Delgado and Sabat, 1998; García-Saís et al. 2003, 2008; CSA, 2005; DRNA, 2007; Ballantine et al., 2008).

Pragmatic criteria: 1) *Urgency* – degree to which immediate action must be taken and values within the area be transformed or lost; 2) *Size* – degree to which various habitats need to be included in the protected area as integrated ecological unit; 3) *Effectiveness* – feasibility of implementing a management program; 4) *Opportunism* – degree to which existing conditions or actions already under way or a ground swell of popular support may justify further action; 5) *Availability* – degree to which the area can be managed satisfactorily; and 6) *Restorability* – degree to which an area may be returned to its former natural state, increase in productivity or value to important species and processes. Pragmatic criteria scores were based in previous knowledge by authors and also in different interviews with DNER personnel.

Economic criteria: 1) *Importance to species* – degree to which certain commercially important species depend on an area; 2) *Importance to fisheries* – number of dependent fishermen and/or size of the fishery yield; degree to which an area plays an important link to fisheries; 3) *Nature of threats* – extent to which changes in use patterns threaten the overall value; 4) *Economic benefits* – degree to which protection will affect the local economy in the long term; and 5) *Tourism* – existing or potential value of an area to tourism activities. Scoring of economic criteria was dependent on a combination of user's perceptions, opinions and experience by

DNER personnel, and on previous knowledge and experience by the authors. In addition, important recent data was obtained from CSA (2005) and DRNA (2007).

<u>Social criteria</u>: 1) *Social acceptance* – degree to which the support of local people is assured; 2) *Recreation* – degree to which the area is, or could be used for recreation; 3) *Culture* – religious, historic, artistic, or other cultural value of the site; 4) *Aesthetics* – a seascape, landscape, or other area of exceptional scenic beauty; 5) *Conflicts of interest* – degree to which area protection would affect the activities of local residents (i.e., artisanal fishermen); 6) *Safety* – degree of danger to people from strong currents, surf, submerged obstacles, waves, and other hazards; 7) *Accessibility* – the ease of access across sea; 8) *Research and education* – degree to which an area represents various ecological characteristics and can serve for research and demonstration of management and scientific methods; 9) *Public awareness* – degree to which monitoring, research, education, or training the area can contribute knowledge and appreciation of the importance of conservation of marine resources; 10) *Conflict and compatibility* – degree to which an area may help to resolve conflicts between natural resource values and human activities, or the degree to which compatibility between them may be enhanced; and 11) *Benchmark* – degree to which the area may serve as a “control site” for scientific research (i.e., a largely undisturbed site in which natural processes can proceed without manipulation and which can be used to measure changes elsewhere).

Scoring of social criteria was similarly dependent on a combination of user's perceptions, opinions and experience by DNER personnel, and on previous knowledge and experience by the authors, and from CSA (2005) and DRNA (2007).

Acronyms used for study sites.

Acronyms of study sites are used as follows: east to west: Cayo Diablo (DIA), Sur de Pando (SDP), Palominos Island (PLM), Palominitos Island (PLT), Cayo Lobos (LOB), Cayo Icacos-east (ICE), and Cayo Icacos-west (ICW).

Results

Geo-spatial rankings of candidate no-take sites based on biological criteria.

Table 4.1 summarizes geo-spatial rankings of study sites based on fish community parameters. Overall, SDP ranked highest in biological criteria with a score of 84.6%, followed by DIA (53.8%), and PLM and LOB (51.9%, respectively). Considering all fish community parameters, SDP received a high ranking in 73% of the parameters. LOB and ICE received a moderate ranking in 88% of the parameters each one, while DIA did it in 69% of the parameters. PLT and ICW received a low ranking in 35% of the parameters each one. These results suggest that, based on biological rankings, the SDP-DIA complex ranked highest as a no-take MPA candidate, followed by PLM and LOB. Figures 4.1 to 4.25 represent the geo-spatial patterns of the most significant benthic parameters which were summarized in Table 4.1.

TABLE 4.1. Biological criteria ranking analysis of candidate no-take MPA sites based on fish community parameter ranking scores*.

Criteria	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
Species richness	1	1	1	2	1	0	1
Species diversity index (H’n)	1	1	1	2	2	0	2
Evenness (J’n)	1	1	2	1	2	0	2
Total abundance	1	1	1	2	1	0	1
Total herbivores	1	1	1	2	1	0	2
Non-denuders	1	2	1	0	1	0	1
Browsers	1	0	1	2	1	1	1
Scrapers	1	2	1	2	1	0	2
Omnivores	0	0	2	2	1	0	0
Total carnivores	2	1	0	2	1	0	0
Generalists	2	1	0	1	1	1	1
Planktivores	2	1	2	2	1	0	0
Piscivores	0	2	0	1	0	0	0
Fishery target species	1	2	1	2	1	0	1
Total biomass	1	1	0	2	1	0	1
Total herbivores	1	1	1	2	1	0	1
Non-denuders	1	2	0	2	1	2	1
Browsers	0	0	1	2	1	0	1
Scrapers	1	1	0	2	1	0	1
Omnivores	2	1	1	1	1	0	1
Total carnivores	1	1	0	2	1	0	0
Generalists	1	1	0	2	1	0	0
Planktivores	1	0	2	1	1	0	0
Piscivores	1	1	1	2	1	0	0
Fishery target species	2	1	2	1	1	0	1
Reef structural heterogeneity index	1	1	0	2	1	0	0
Cumulative points	**28**	**27**	**22**	**44**	**27**	**4**	**21**
Final score	**53.8**	**51.9**	**42.3**	**84.6**	**51.9**	**7.7**	**40.4**

*Rank scores: 0= Low ranking; 1= Moderate ranking; 2= High ranking. Total maximum score was 52 cumulative points.

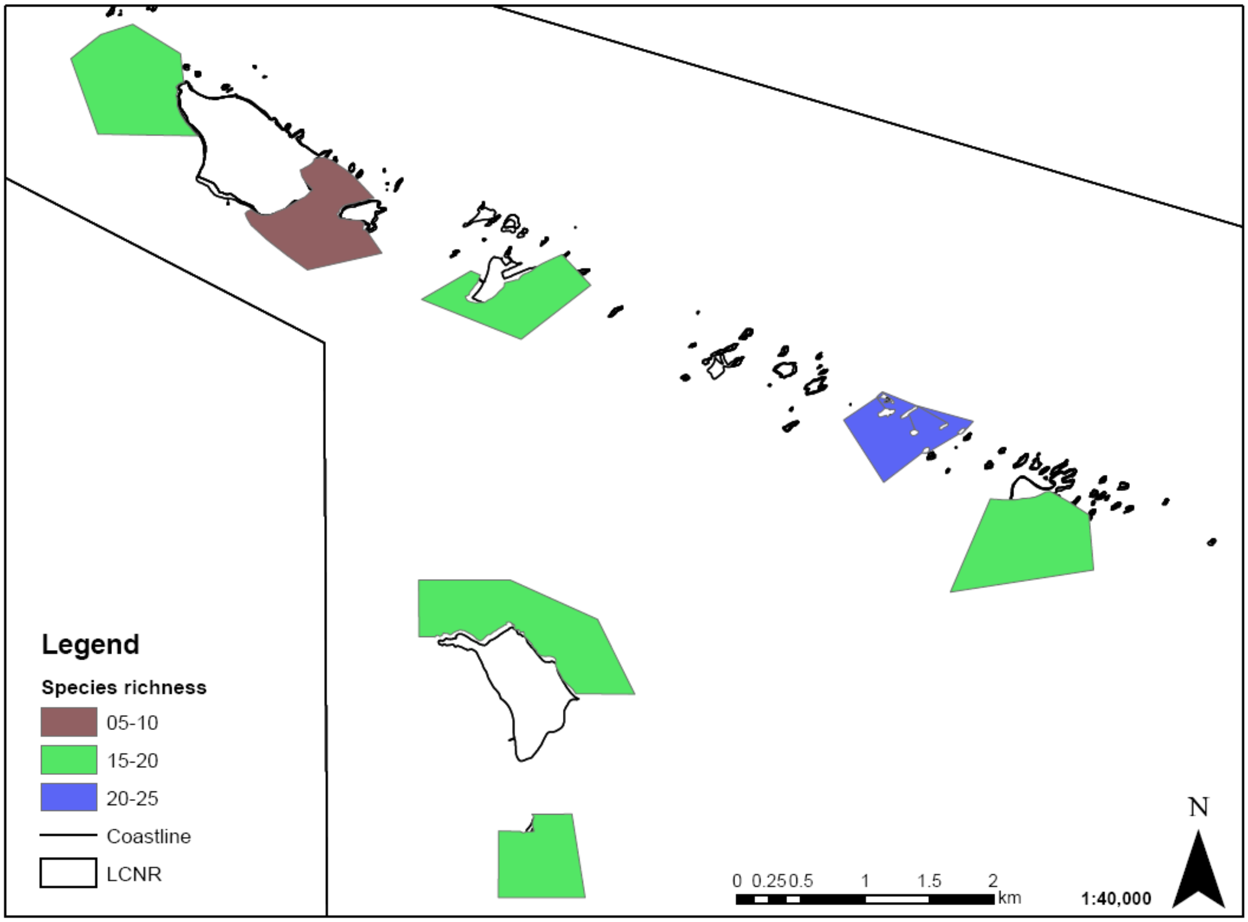

FIGURE 4.1. Spatial rankings of species richness per sample.

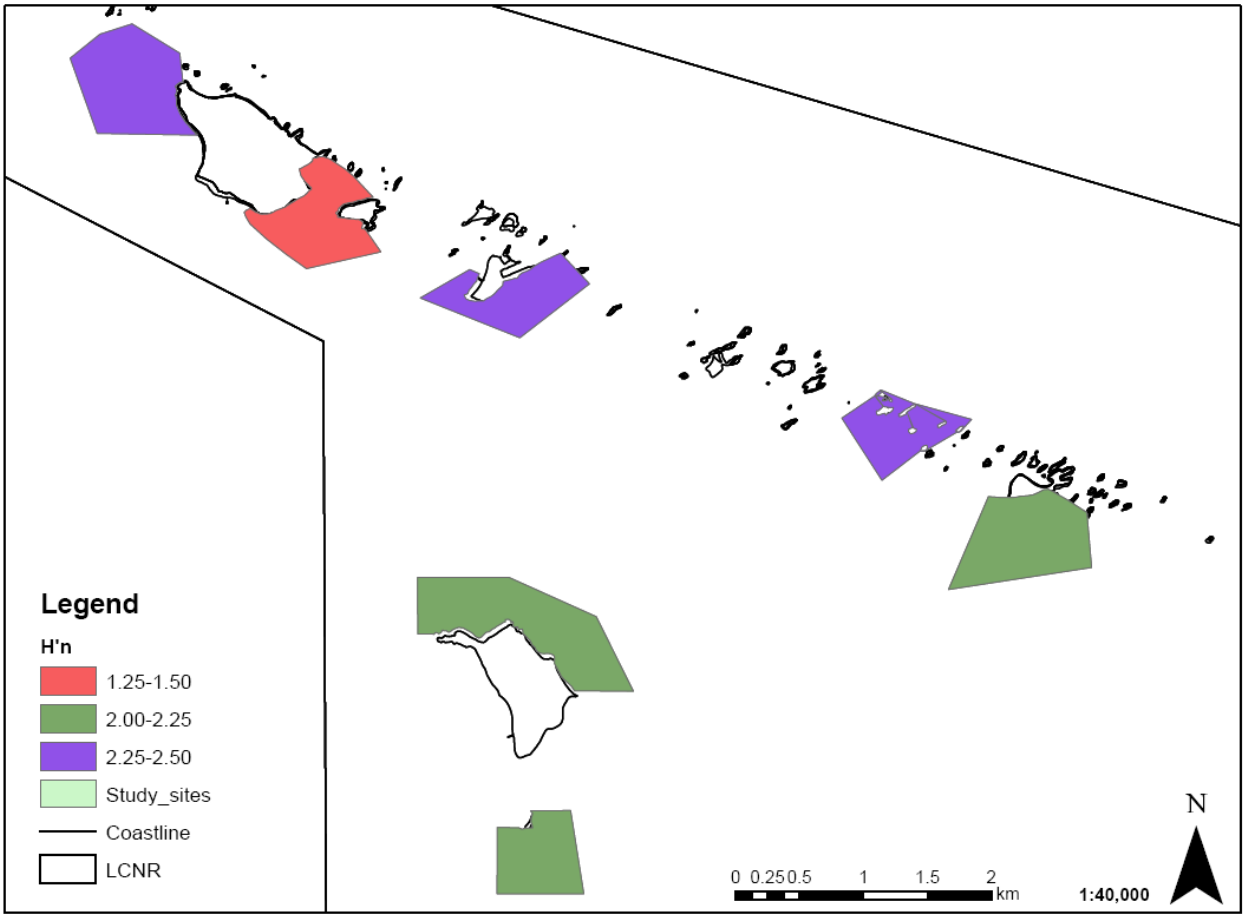

FIGURE 4.2. Spatial rankings of H'n per sample.

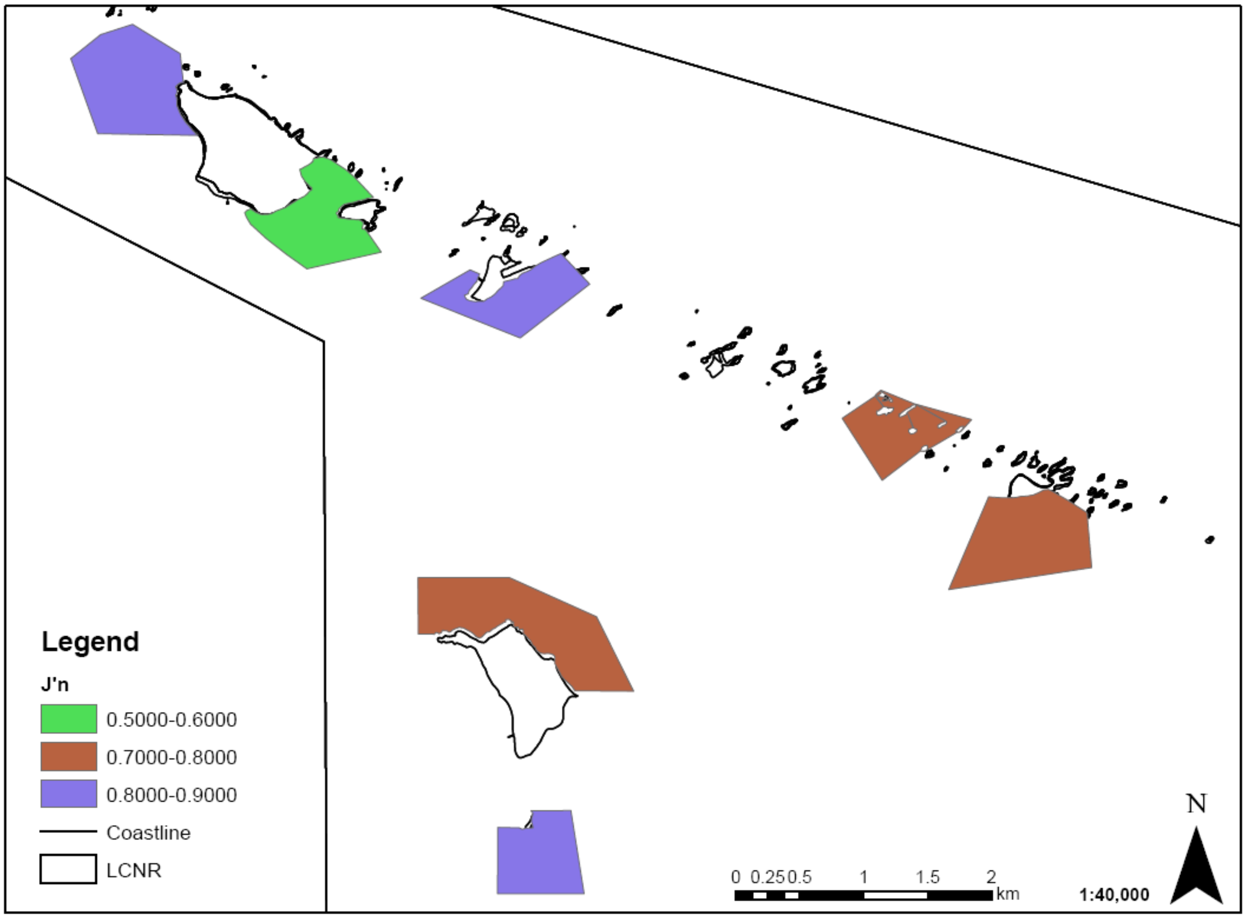

FIGURE 4.3. Spatial rankings of J’n per sample.

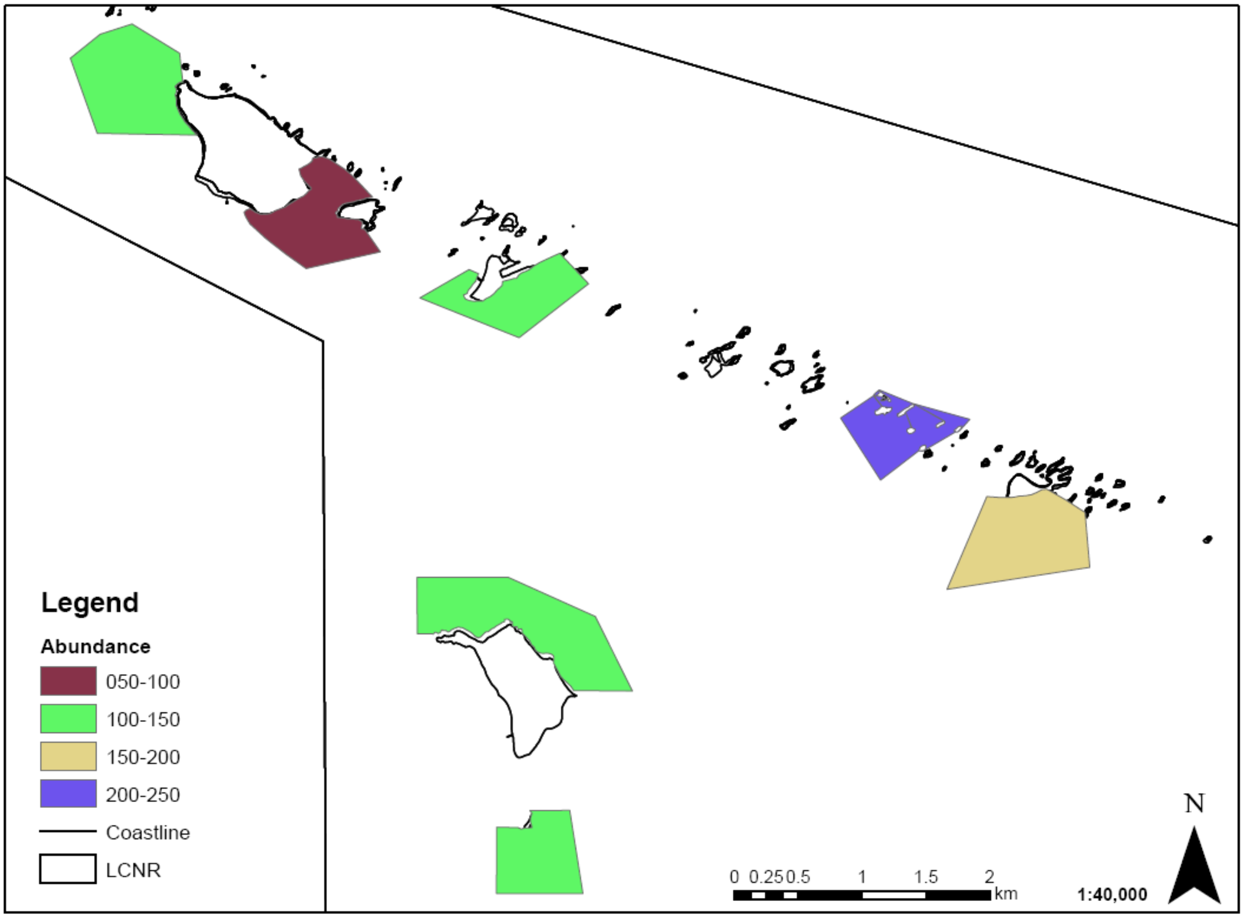

FIGURE 4.4. Spatial rankings of total abundance per sample.

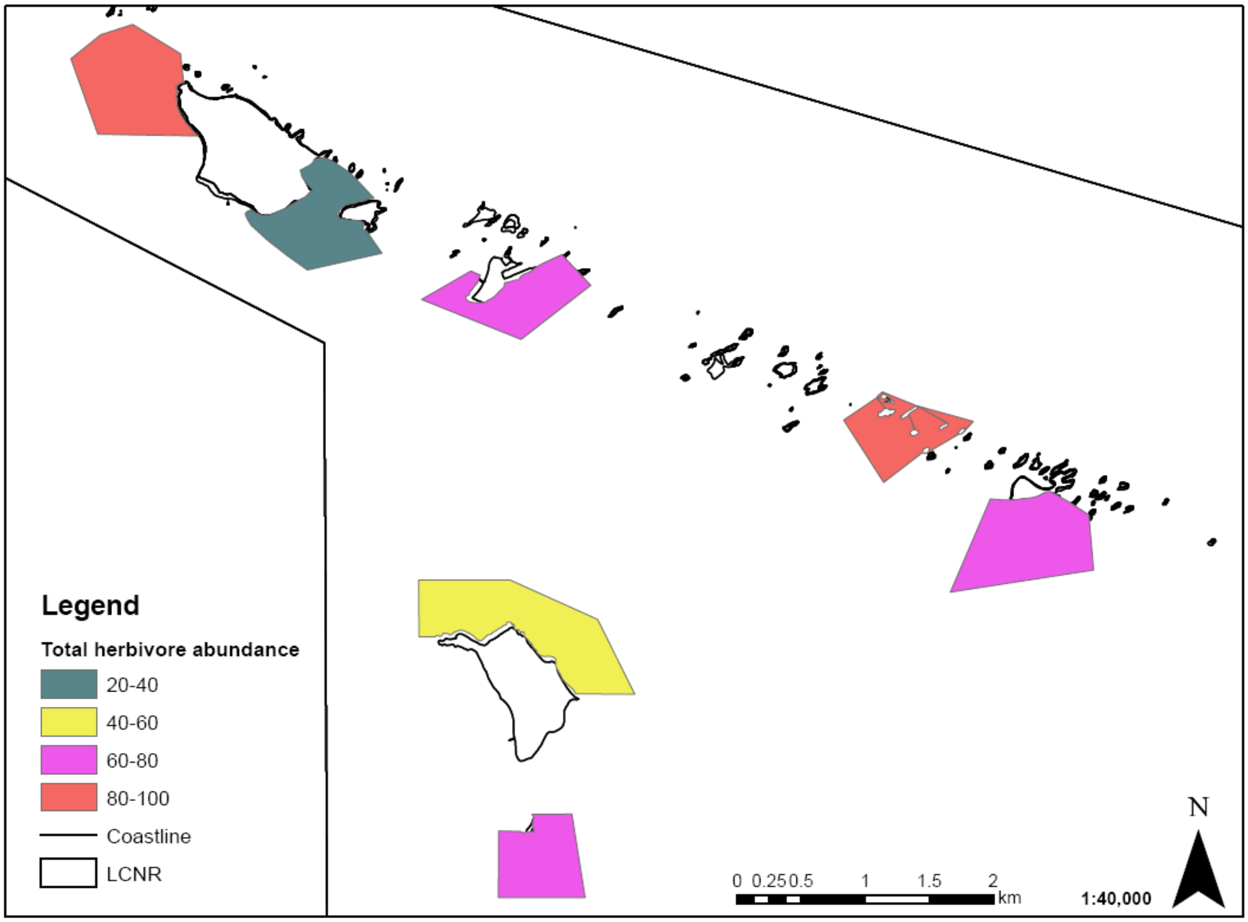

FIGURE 4.5. Spatial rankings of total herbivore abundance per sample.

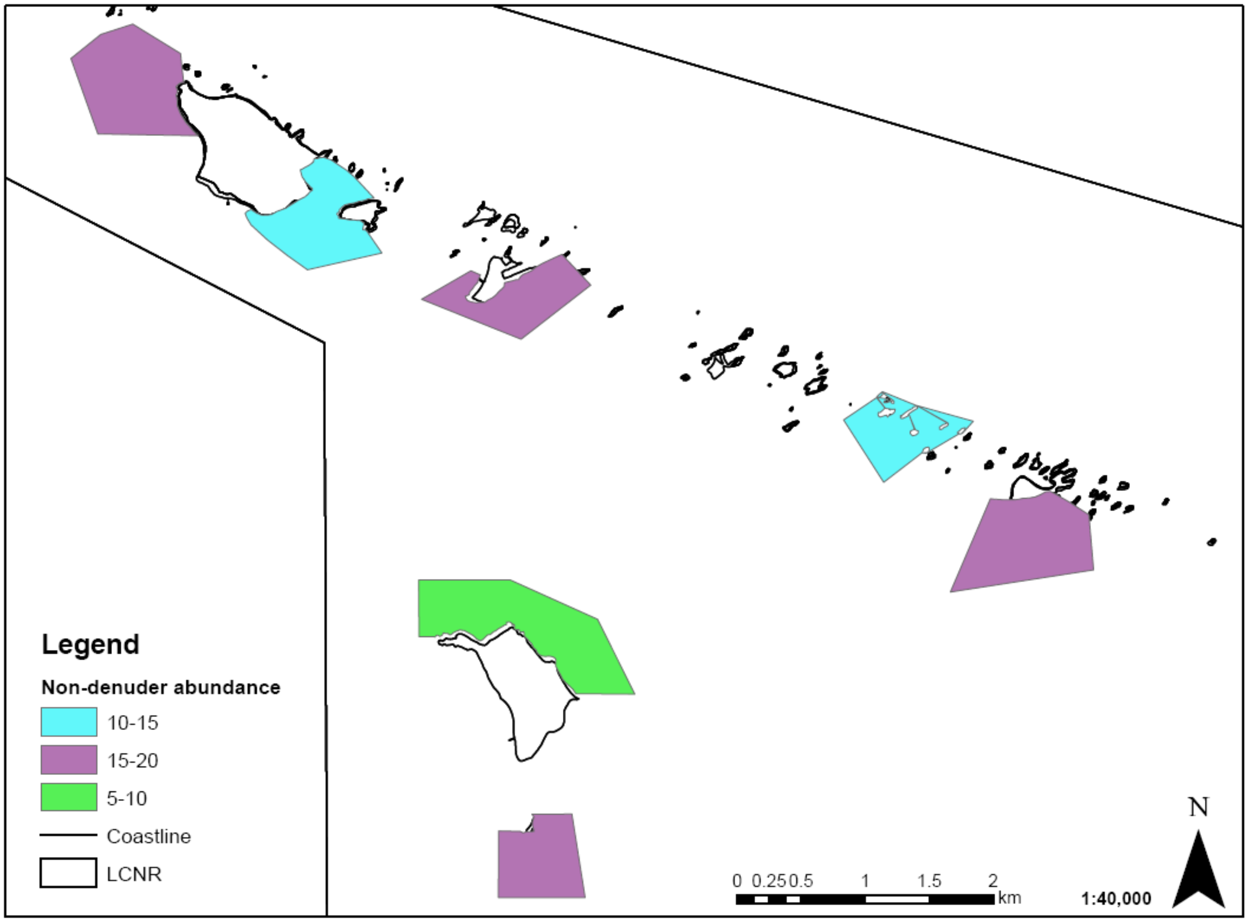

FIGURE 4.6. Spatial rankings of non-denuder abundance per sample.

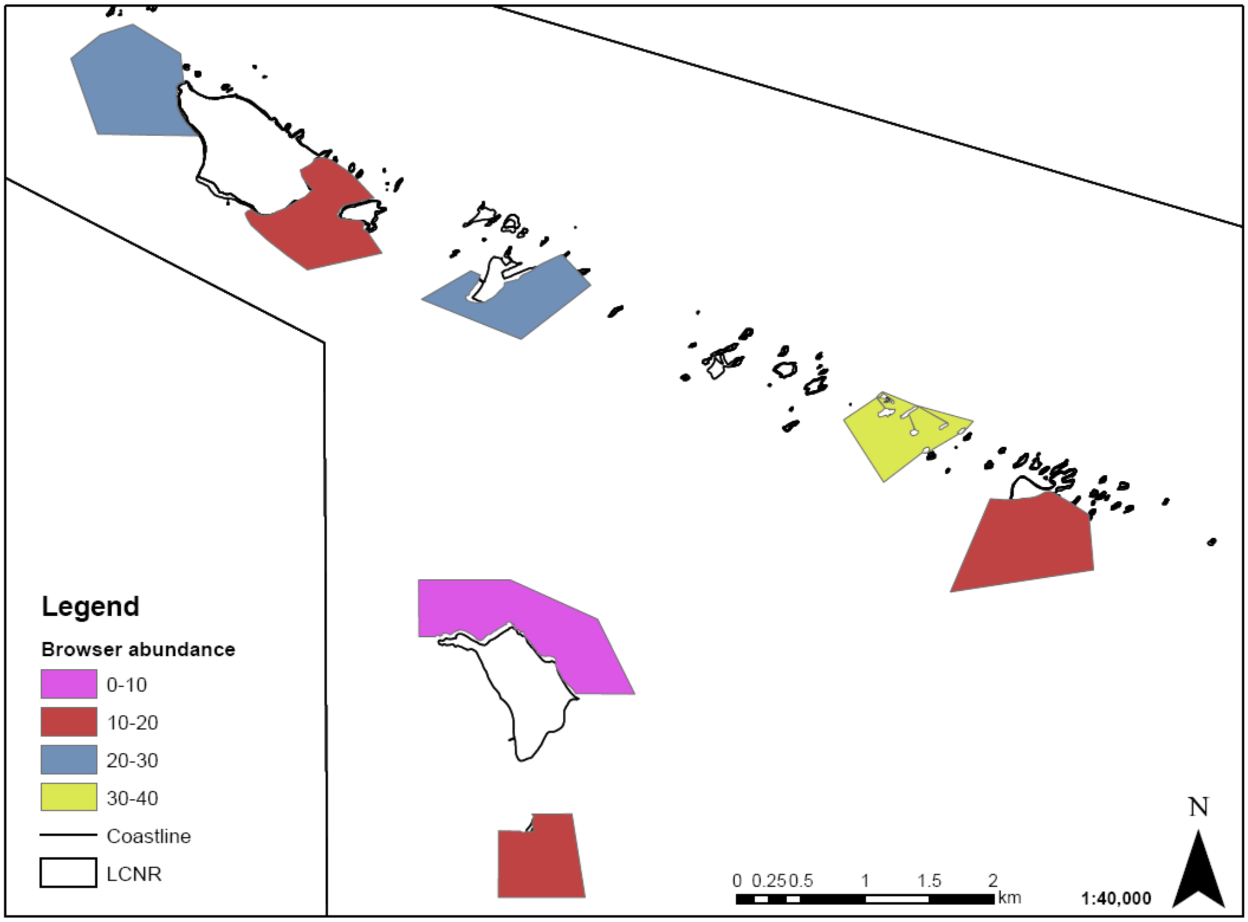

FIGURE 4.7. Spatial rankings of browser abundance per sample.

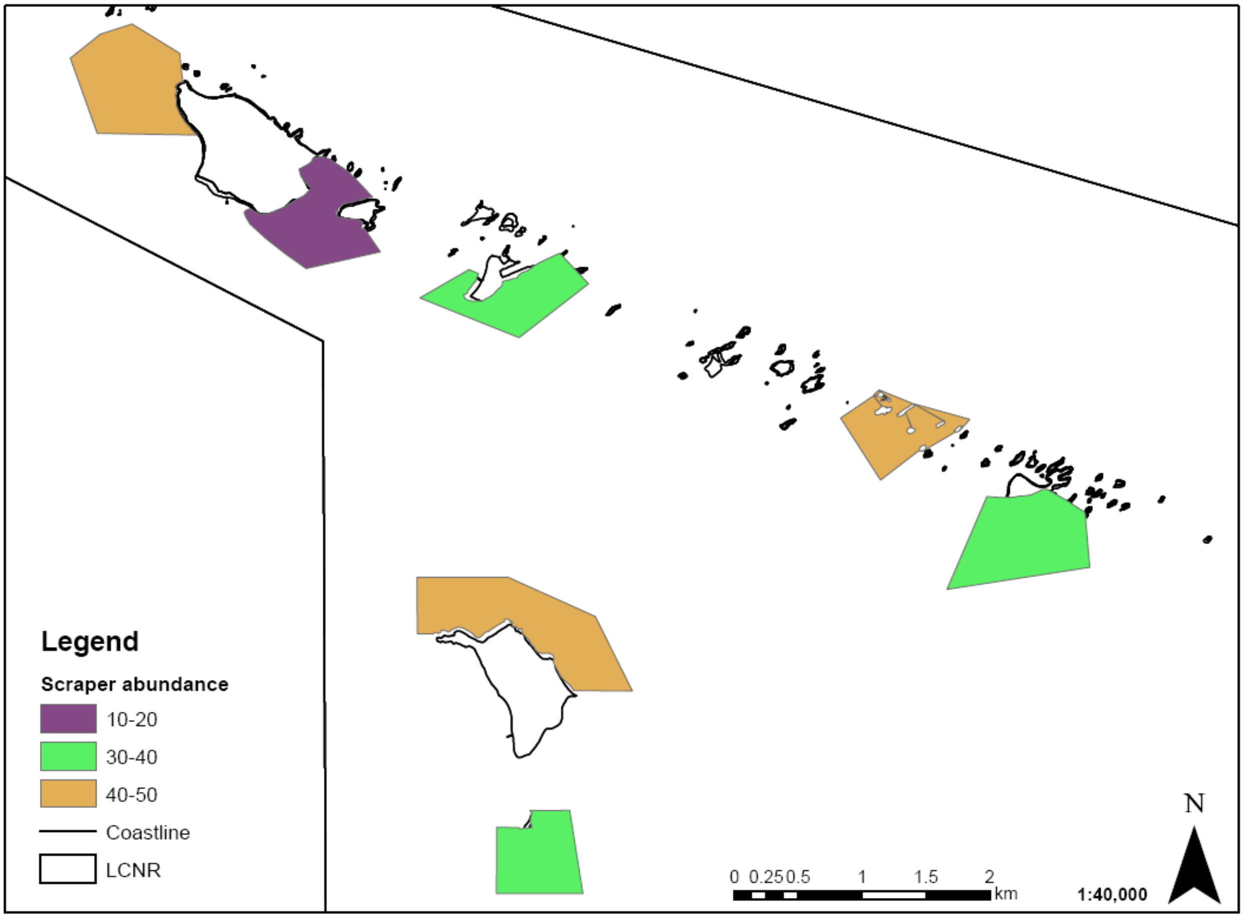

FIGURE 4.8. Spatial rankings of scraper abundance per sample.

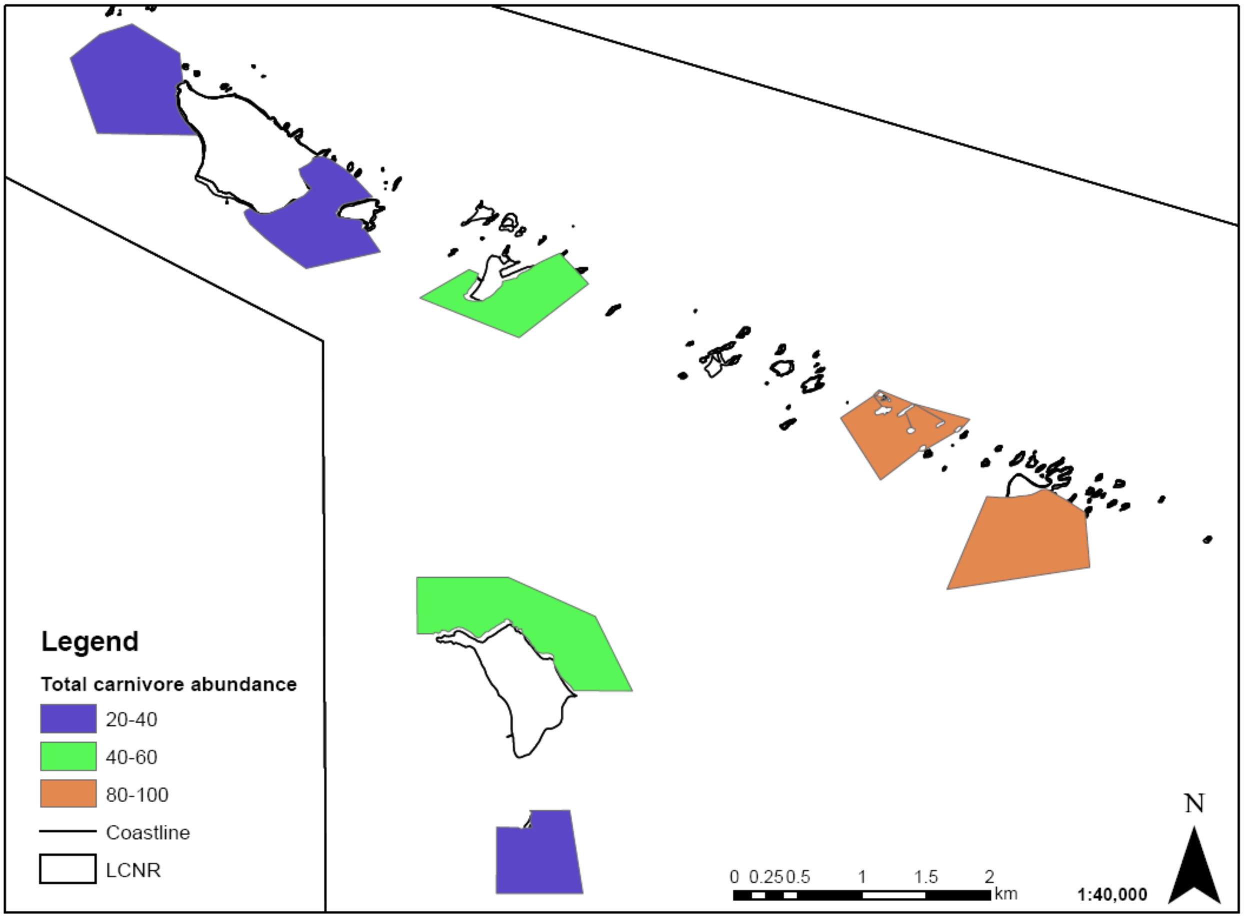

FIGURE 4.9. Spatial rankings of total carnivore abundance per sample.

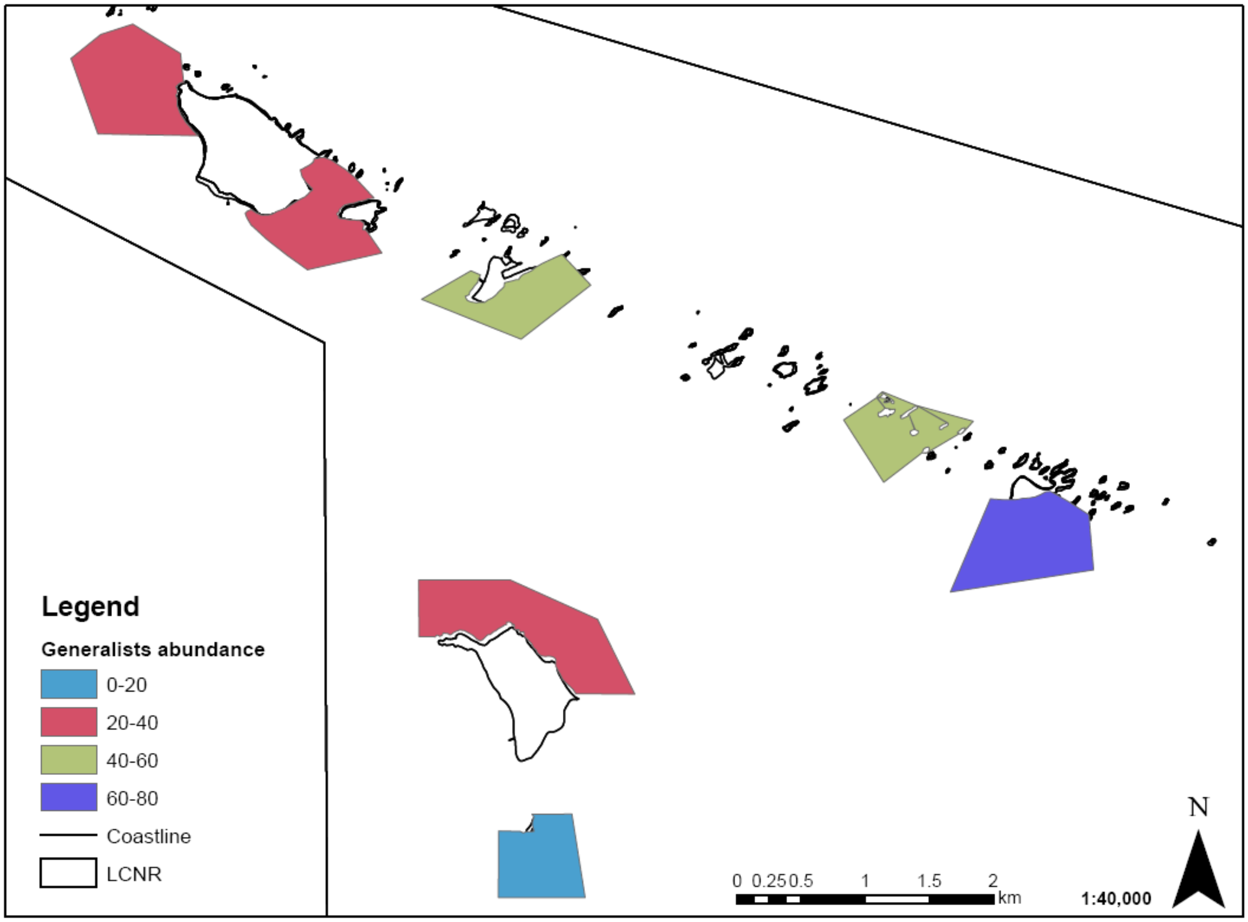

FIGURE 4.10. Spatial rankings of generalists abundance per sample.

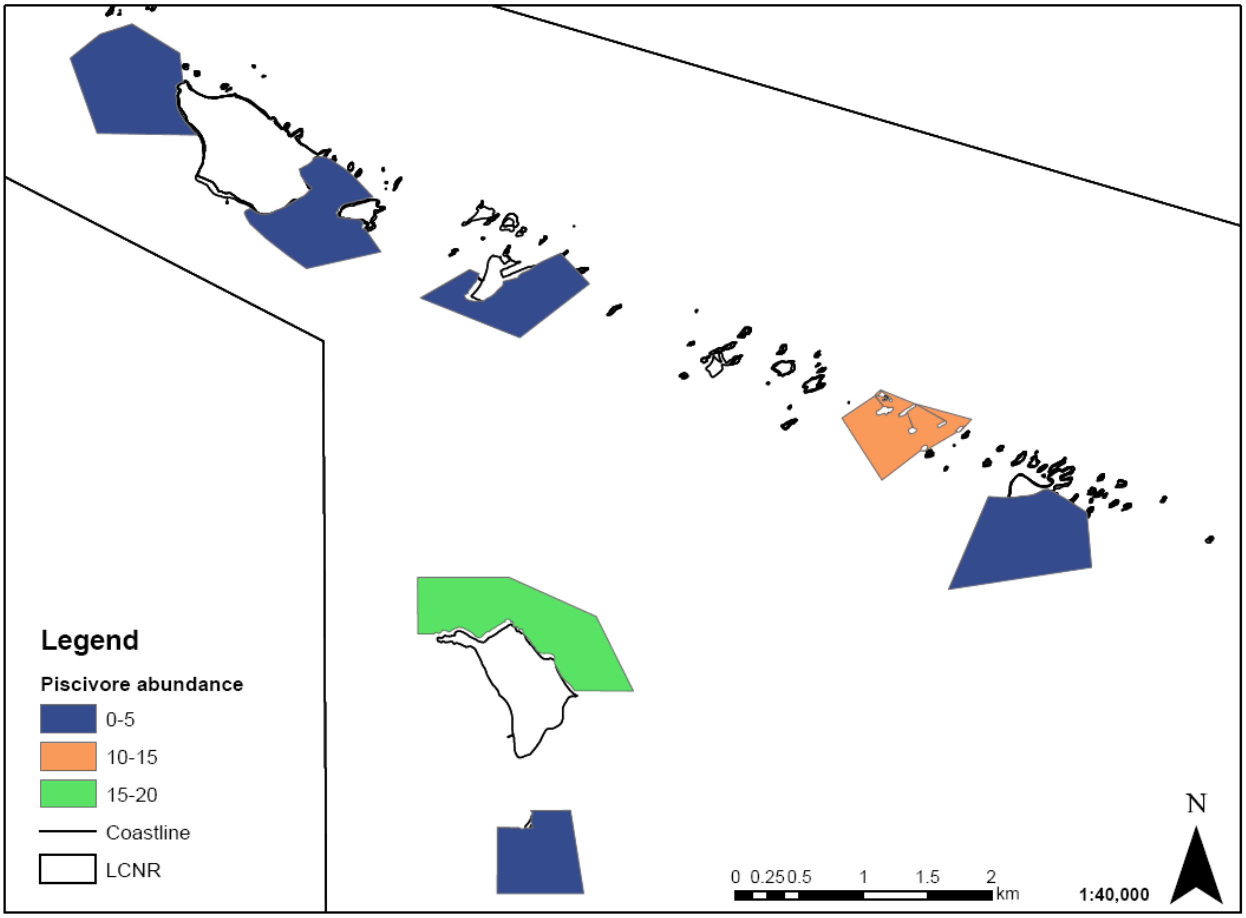

FIGURE 4.11. Spatial rankings of piscivore abundance per sample.

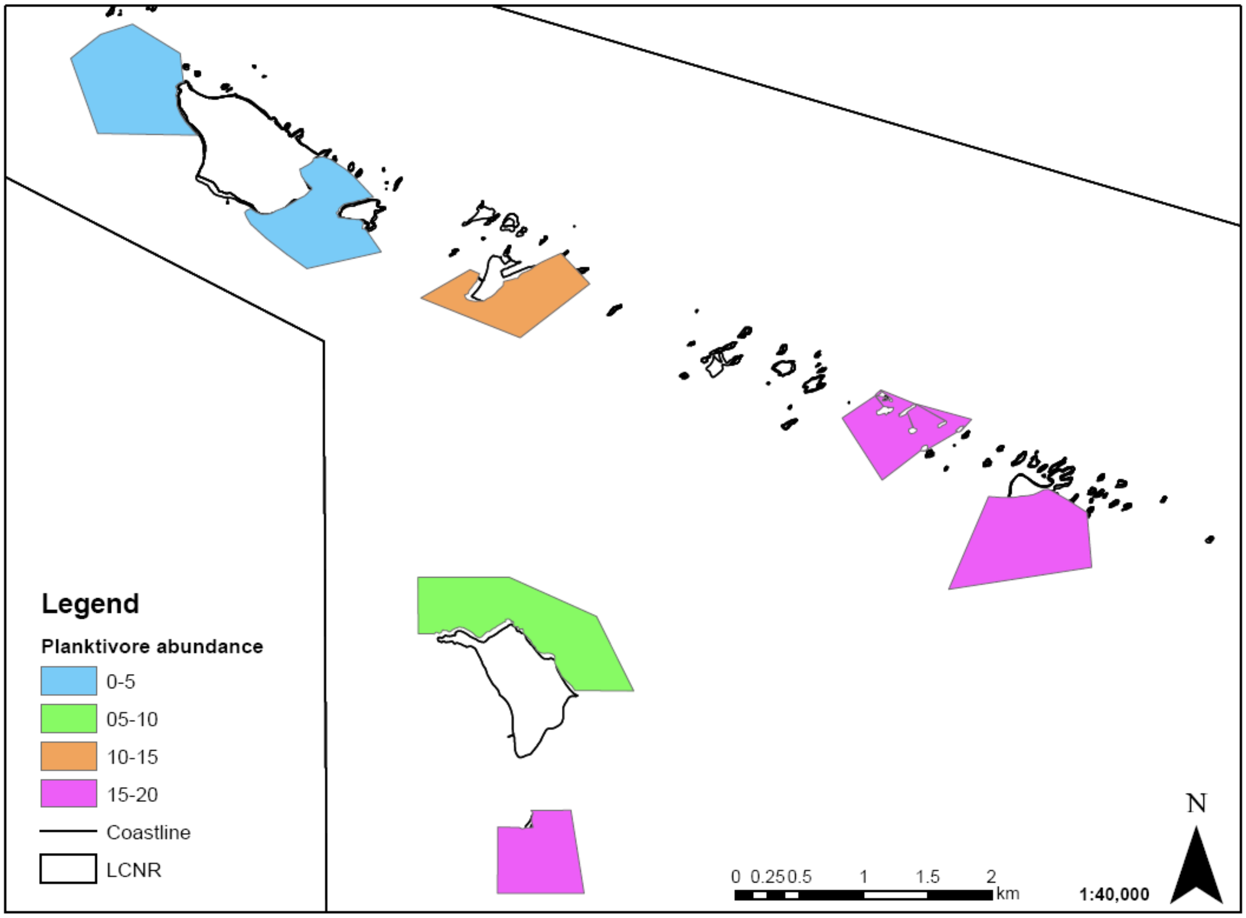

FIGURE 4.12. Spatial rankings of planktivore abundance per sample.

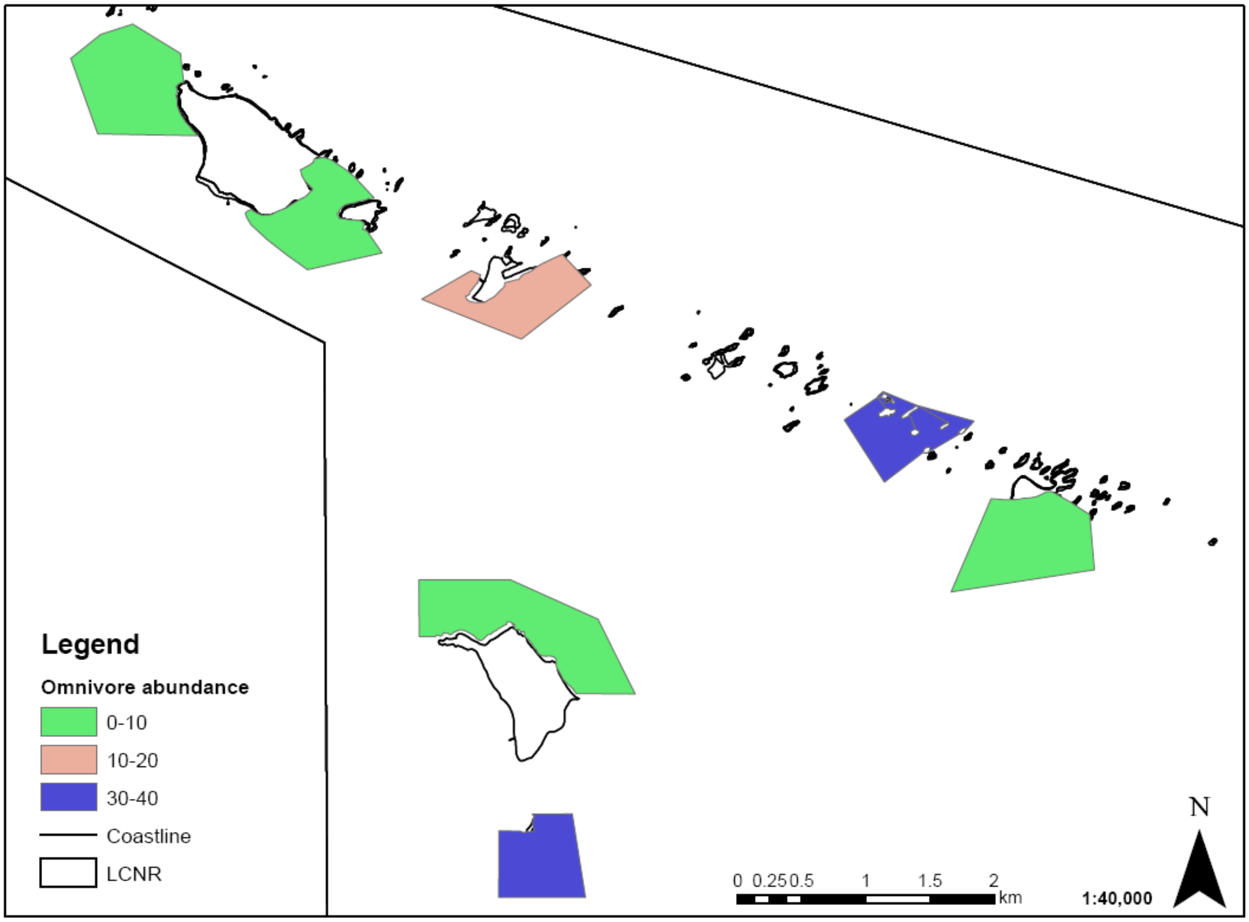

FIGURE 4.13. Spatial rankings of omnivore abundance per sample.

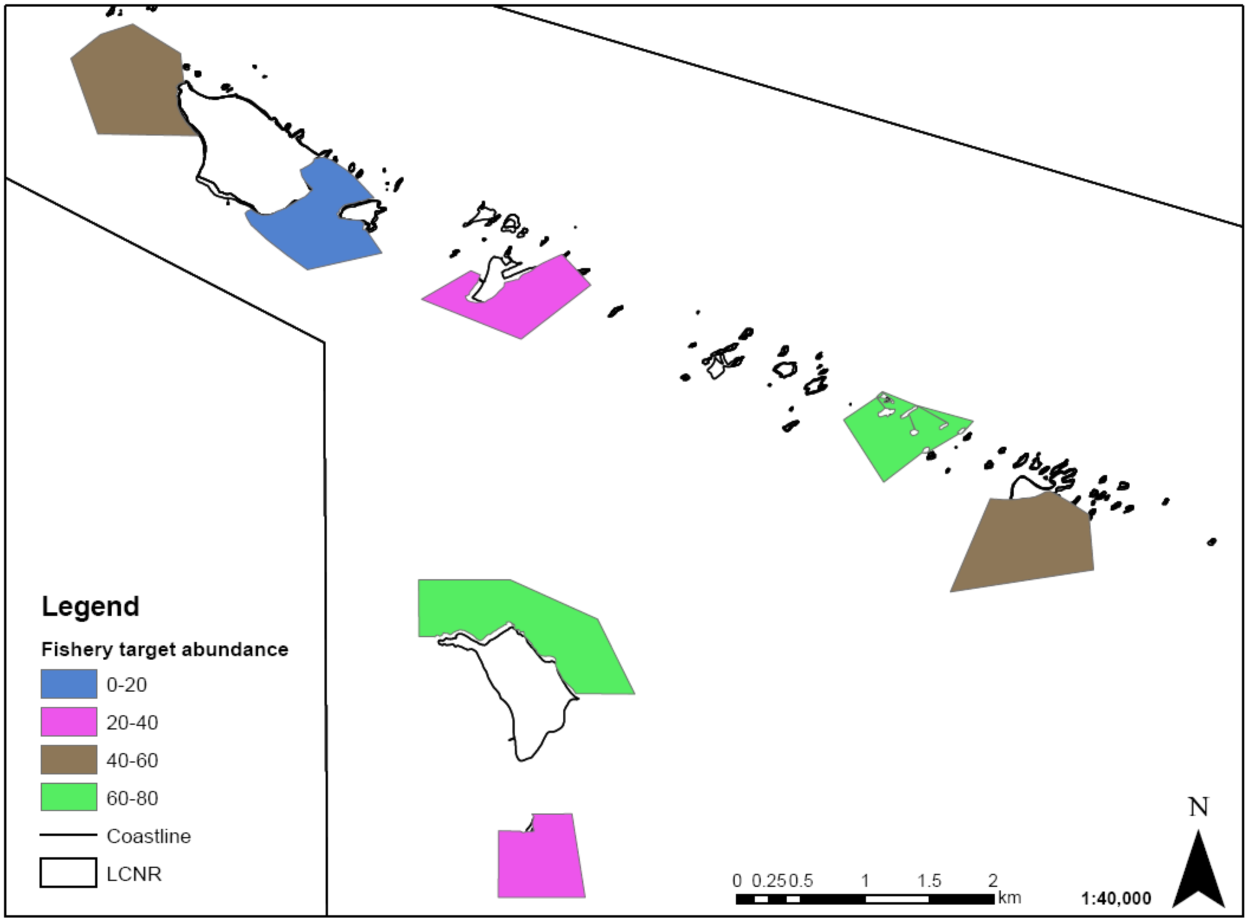

FIGURE 4.14. Spatial rankings of fishery target species abundance per sample.

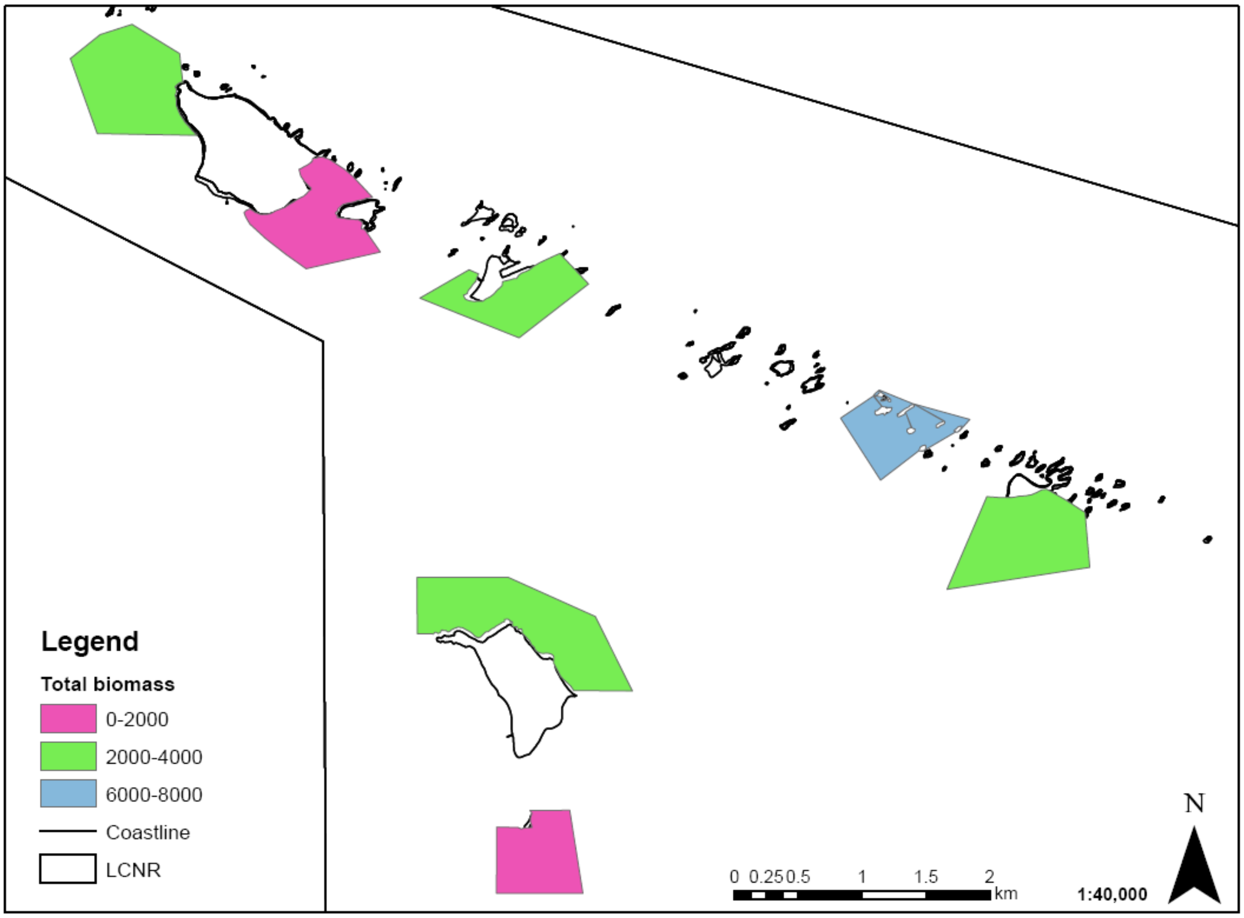

FIGURE 4.15. Spatial rankings of total biomass (g/count).

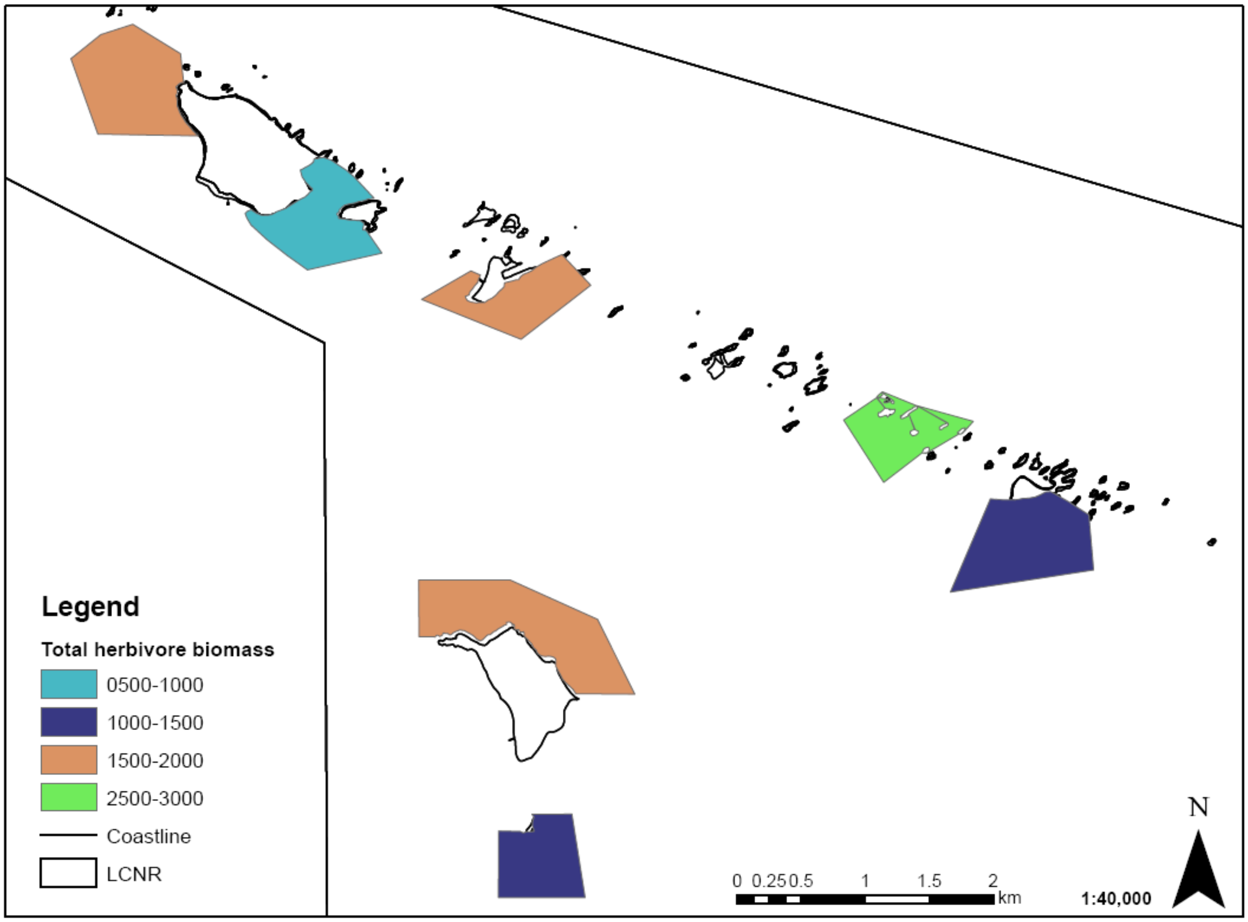

FIGURE 4.16. Spatial rankings of total herbivore biomass (g/count).

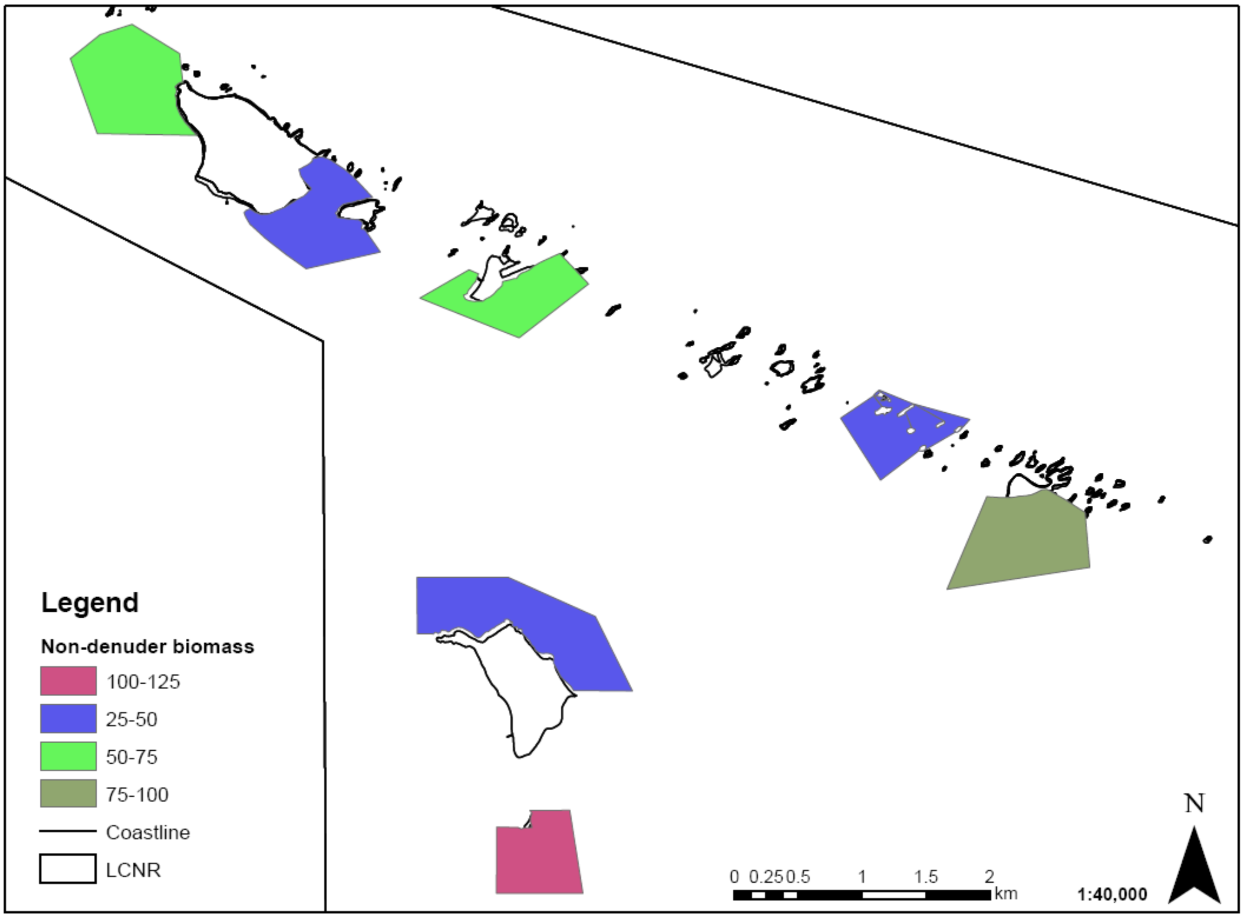

FIGURE 4.17. Spatial rankings of non-denuder biomass (g/count).

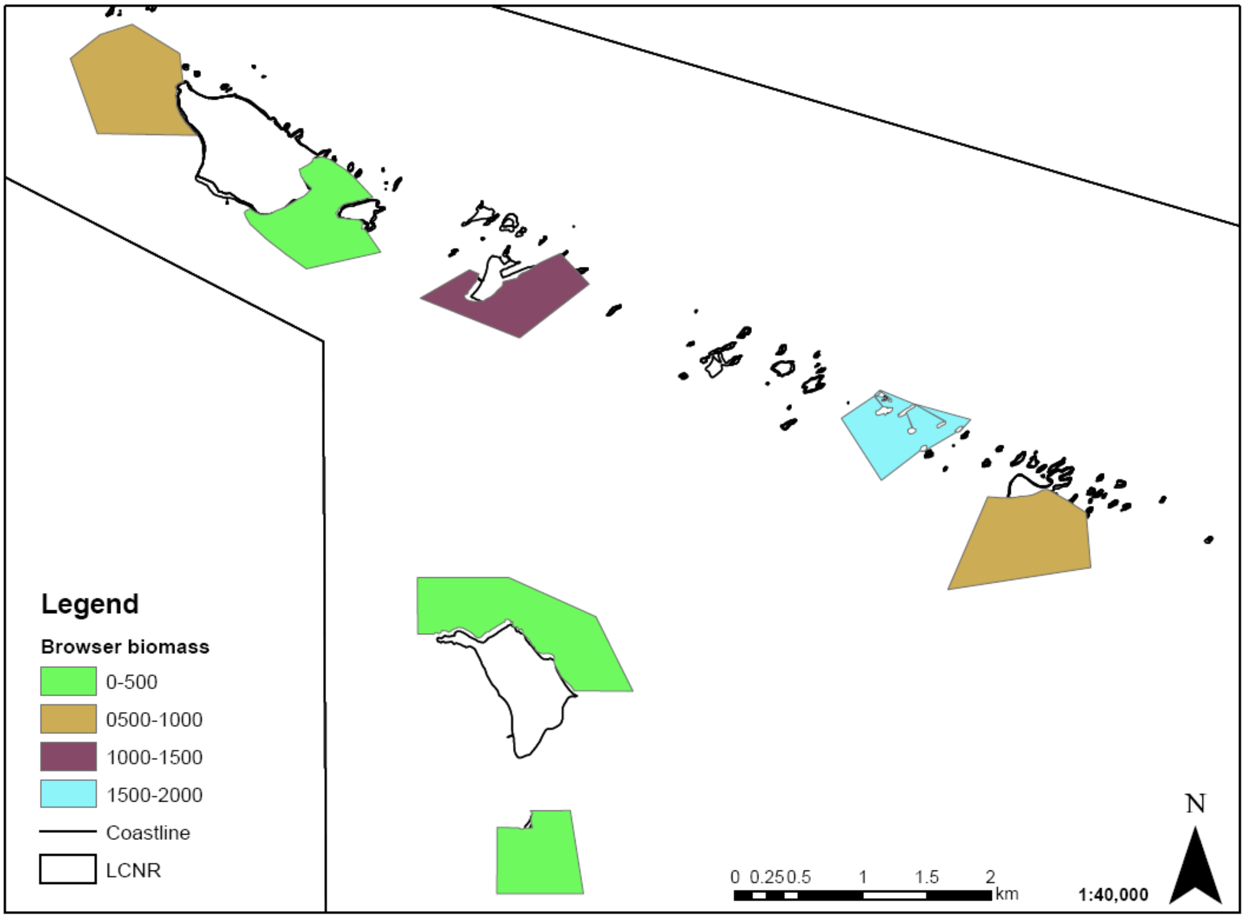

FIGURE 4.18. Spatial rankings of browser biomass (g/count).

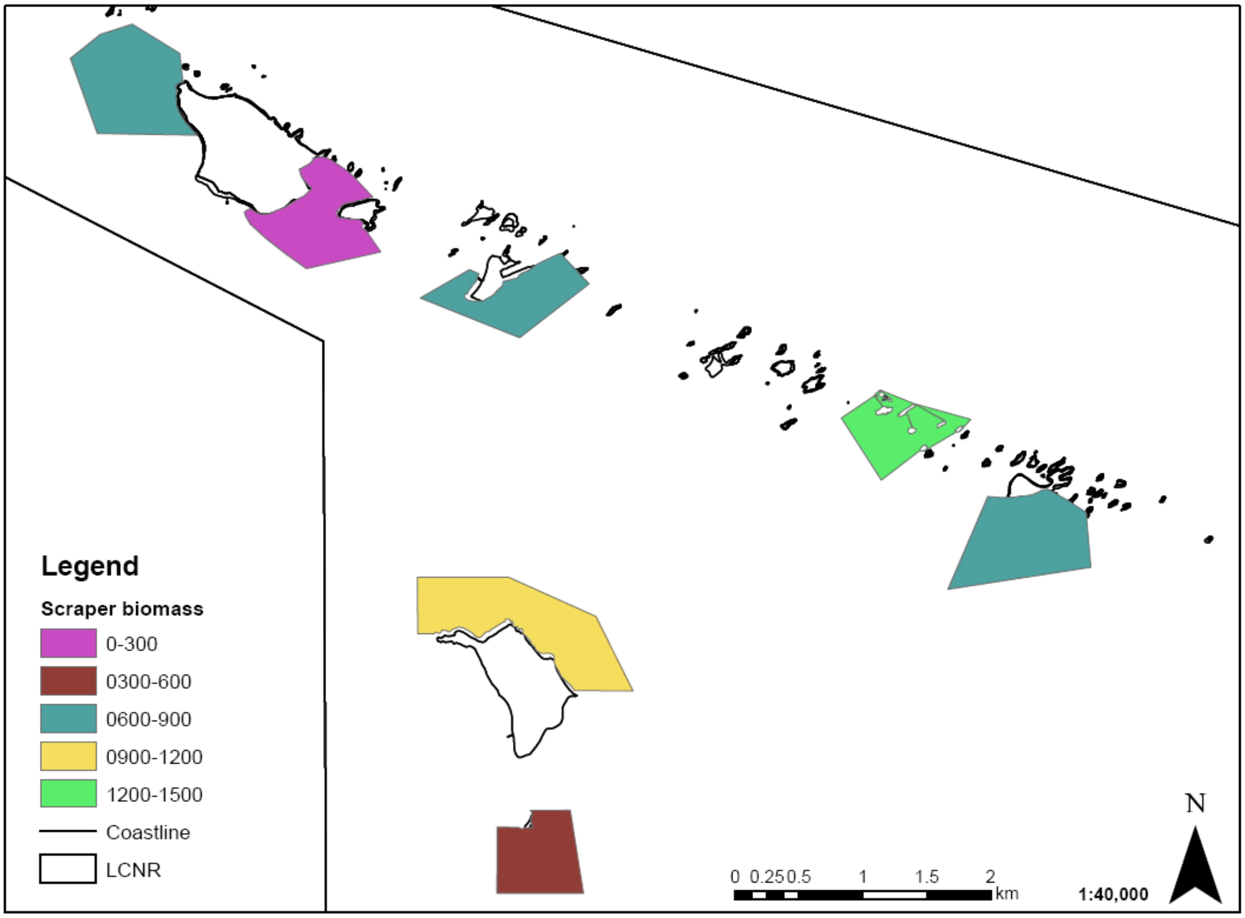

FIGURE 4.19. Spatial rankings of scraper biomass (g/count).

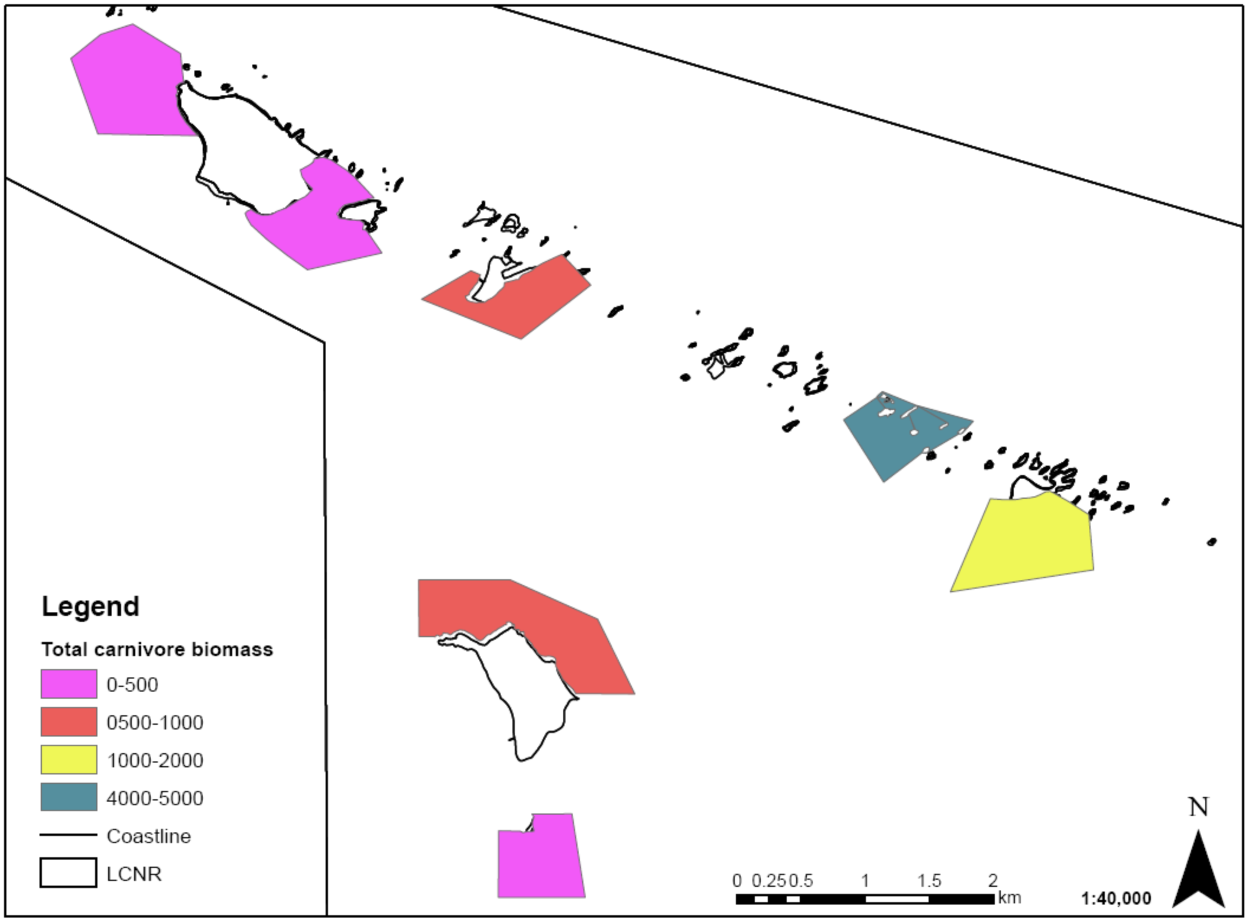

FIGURE 4.20. Spatial rankings of total carnivore biomass (g/count).

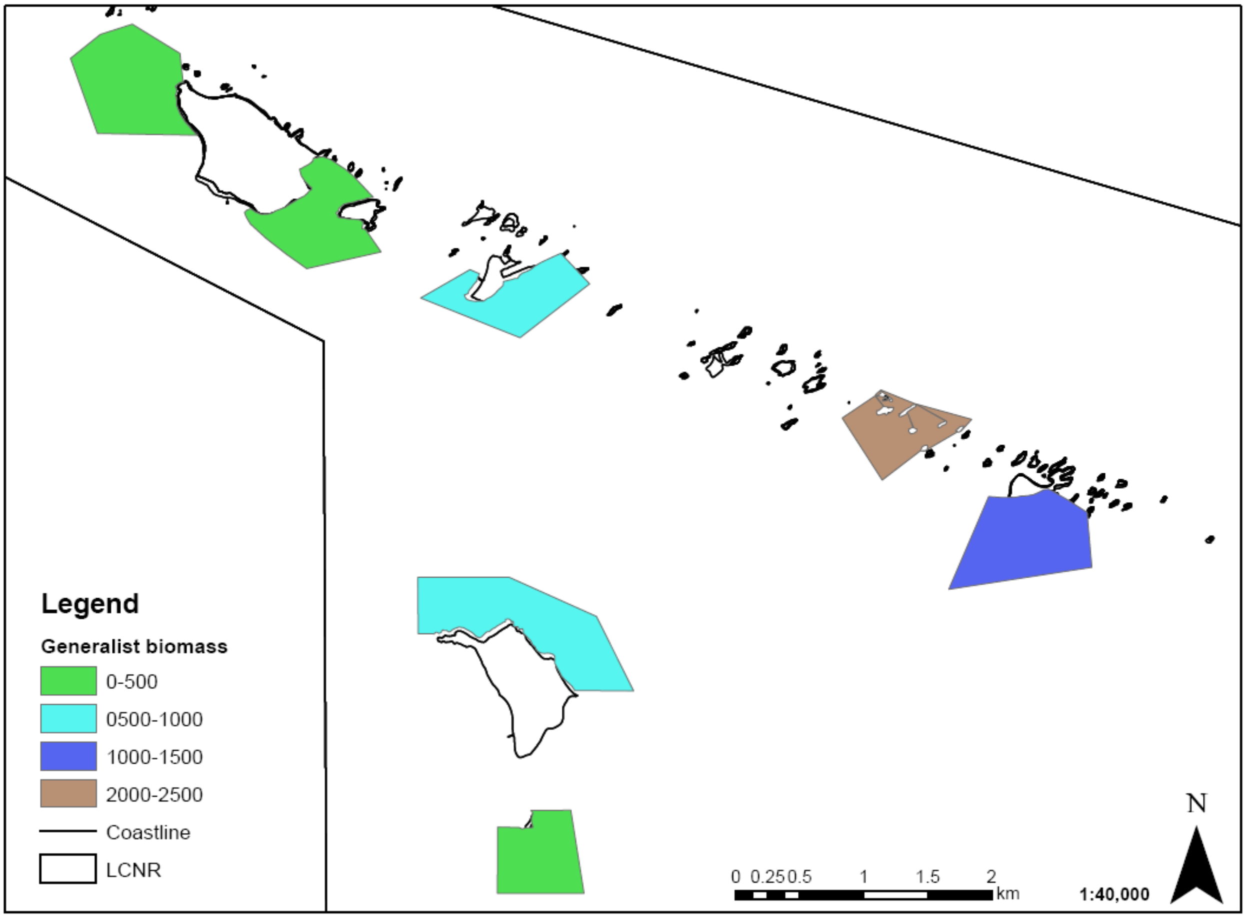

FIGURE 4.21. Spatial rankings of generalist biomass (g/count).

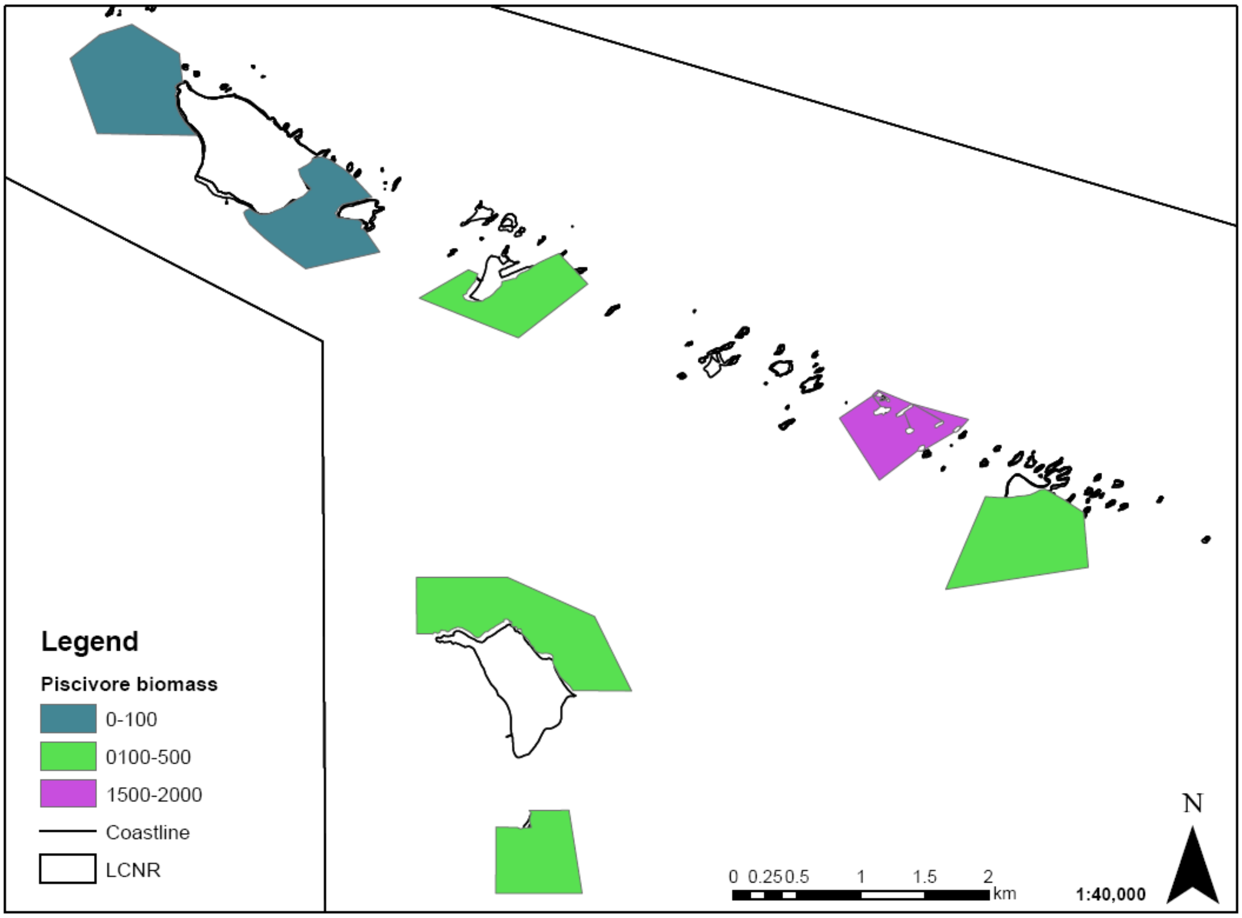

FIGURE 4.22. Spatial rankings of piscivore biomass (g/count).

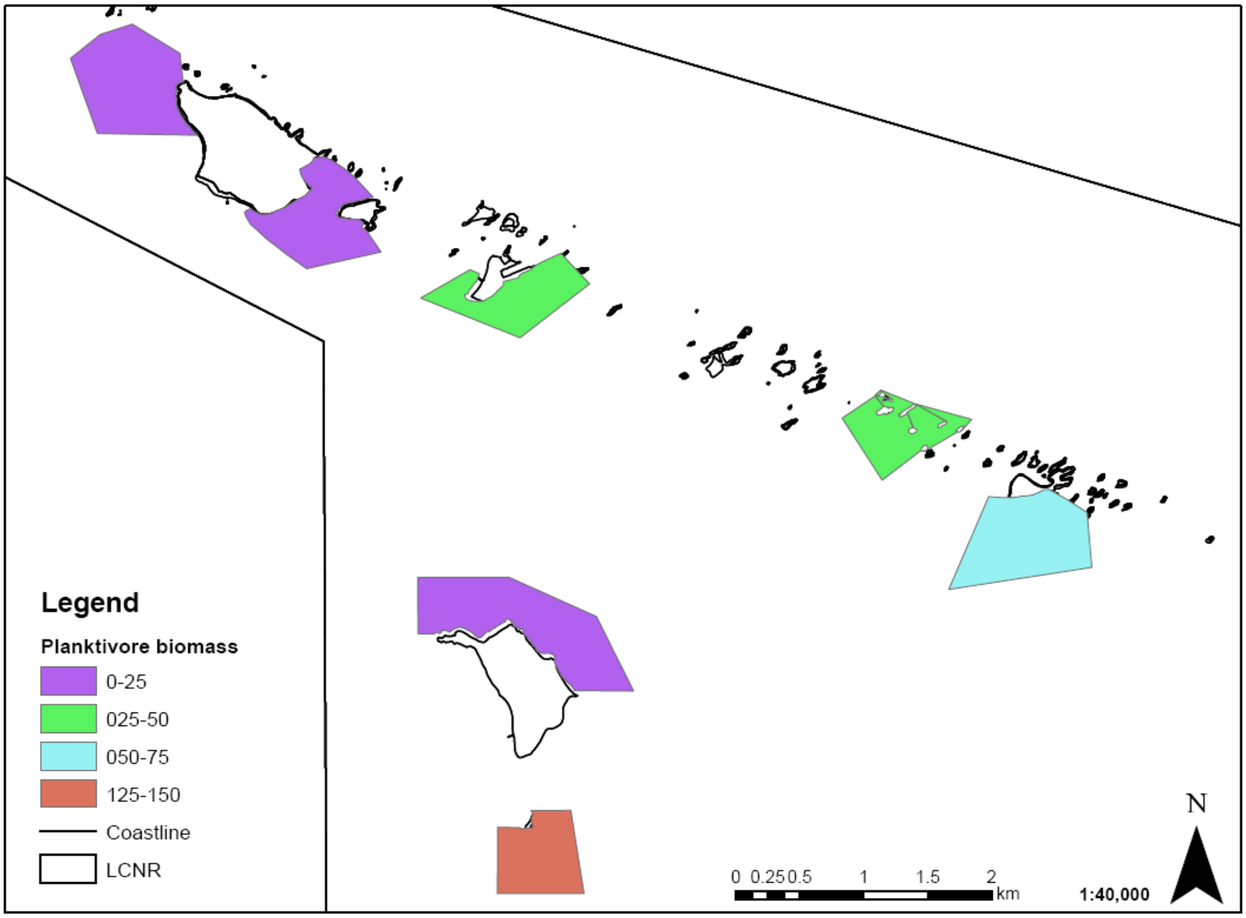

FIGURE 4.23. Spatial rankings of planktivore biomass (g/count).

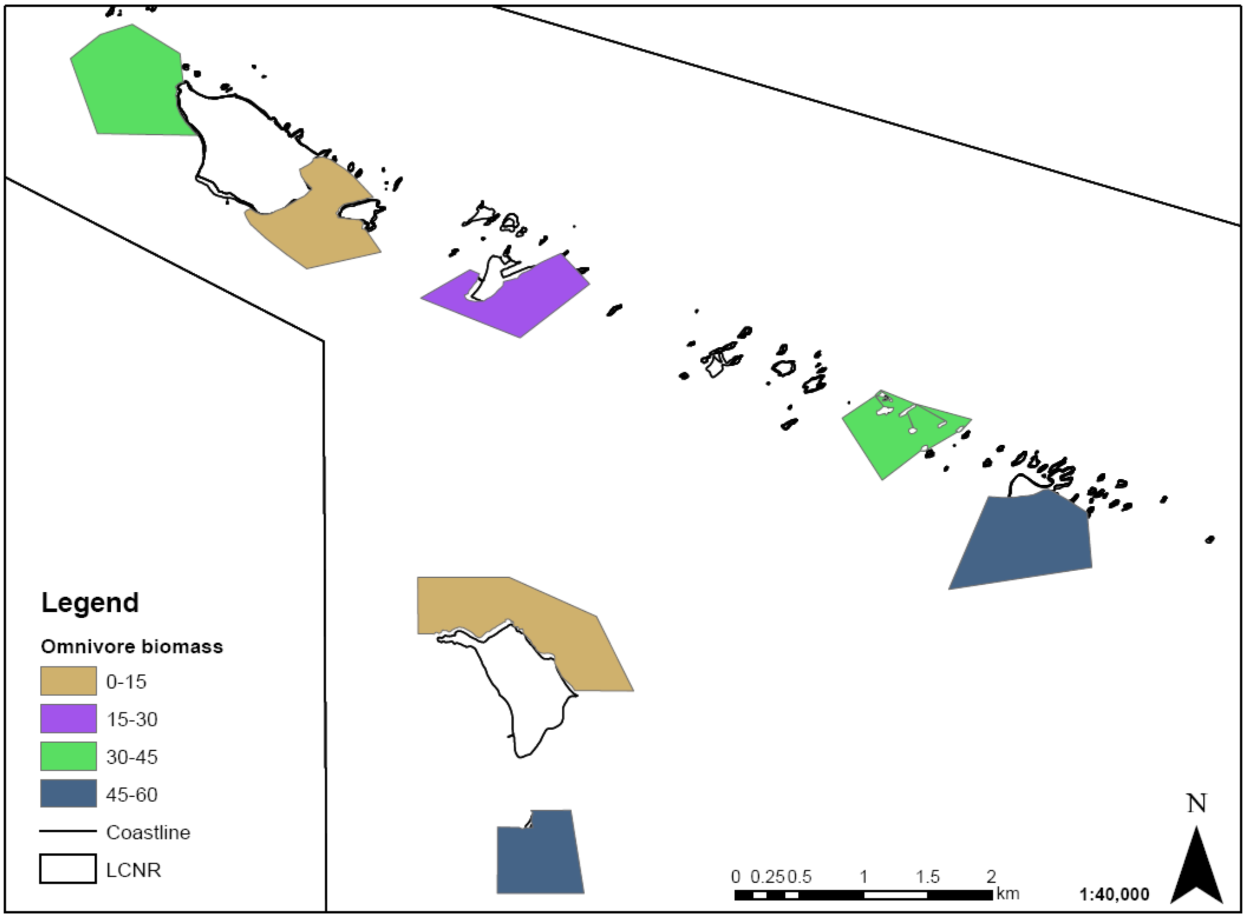

FIGURE 4.24. Spatial rankings of omnivore biomass (g/count).

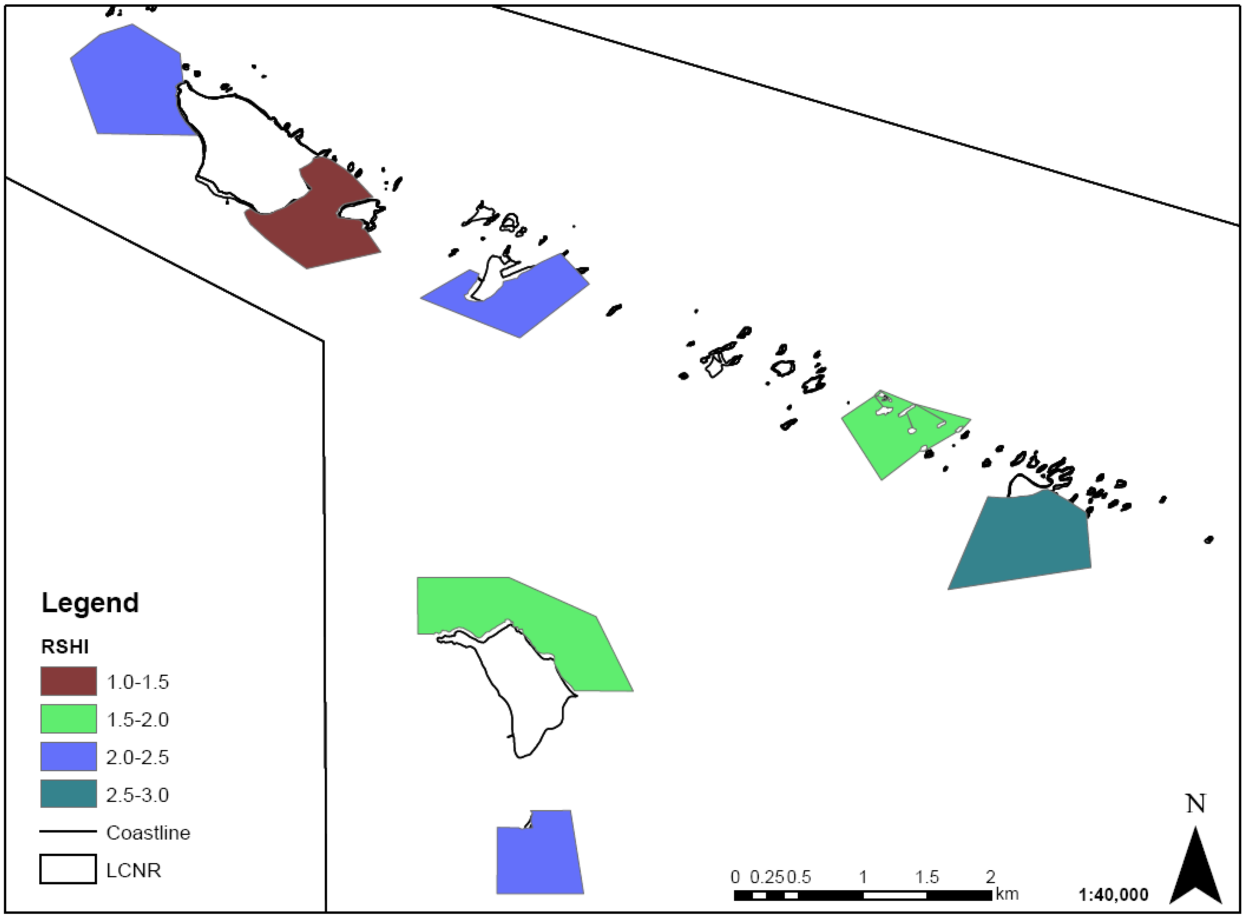

FIGURE 4.25. Spatial rankings of reef spatial heterogeneity index (RSHI).

TABLE 4.2. Ecological criteria ranking analysis of candidate no-take MPA sites*.

Criteria	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
Biodiversity	2	2	2	2	2	1	2
Naturalness	1	1	1	2	1	0	1
Dependency	2	2	2	2	2	2	2
Representativeness	2	2	2	2	2	1	2
Uniqueness	2	1	2	1	2	1	1
Integrity	2	2	2	2	2	1	1
Productivity	1	2	1	2	0	0	0
Ecological status benthic communities	1	0	1	1	0	0	0
Connectivity to other reefs	2	2	2	2	2	2	2
Cumulative points	**15**	**14**	**15**	**16**	**13**	**8**	**11**
Final score	**83.3**	**77.8**	**83.3**	**88.9**	**72.2**	**44.4**	**61.1**

*Rank scores: 0= Low ranking; 1= Moderate ranking; 2= High ranking. Total maximum score was 18 cumulative points.

Geo-spatial rankings of candidate no-take sites based on ecological criteria.

Table 4.2 summarizes geo-spatial rankings of study sites based on ecological criteria. Overall, SDP ranked highest with a score of 88.9%, followed by DIA and PLT (83.3% each one). These results suggest that, based on ecological rankings, the SDP-DIA complex also ranked highest as a no-take MPA candidate, followed by PLM and LOB.

TABLE 4.3. Regional criteria ranking analysis of candidate no-take MPA sites*.

Criteria	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
Regional significance	2	2	2	2	2	1	2
Subregional significance	2	2	2	2	2	1	2
Subregional connectivity	2	2	2	2	2	1	1
Cumulative points	**6**	**6**	**6**	**6**	**6**	**3**	**5**
Final score	**100**	**100**	**100**	**100**	**100**	**50**	**83.3**

*Rank scores: 0= Low ranking; 1= Moderate ranking; 2= High ranking. Total maximum score was 6 cumulative points.

Geo-spatial rankings of candidate no-take sites based on regional criteria.

Table 4.3 summarizes geo-spatial rankings of study sites based on regional criteria. Overall, DIA, PLM, PLT, SDP, and LOB ranked highest with a score of 100%, followed by ICW (83.3%) and ICW (50%). These results suggest that, based on regional rankings, the SDP-DIA complex also ranked highest as a no-take MPA candidate, followed by PLM and LOB.

TABLE 4.4. Impacts criteria ranking analysis of candidate no-take MPA sites*.

Criteria	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
Vulnerability	2	2	2	2	2	2	2
Degree of threat	2	2	2	1	2	2	2
Evident overfishing effects	2	2	2	2	2	2	2
Cumulative points	**6**	**6**	**6**	**5**	**6**	**3**	**5**
Final score	**100**	**100**	**100**	**83.3**	**100**	**100**	**100**

*Rank scores: 0= Low ranking; 1= Moderate ranking; 2= High ranking. Total maximum score was 6 cumulative points.

Geo-spatial rankings of candidate no-take sites based on impacts criteria.

Table 4.4 summarizes geo-spatial rankings of study sites based on impacts criteria. Overall, all sites, with the exception of SDP, ranked highest with a score of 100%, although we consider the entire ALCNR at a high risk of impacts.

TABLE 4.5. Pragmatic criteria ranking analysis of candidate no-take MPA sites*.

Criteria	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
Urgency	2	2	2	2	2	2	2
Size	2	1	1	1	2	1	2
Effectiveness	2	2	2	2	2	2	2
Opportunism	2	2	2	2	2	2	2
Availability	2	2	2	2	2	2	2
Restorability	2	2	2	2	2	1	1
Cumulative points	**12**	**11**	**11**	**11**	**12**	**10**	**11**
Final score	**100**	**91.7**	**91.7**	**91.7**	**100**	**83.3**	**91.7**

*Rank scores: 0= Low ranking; 1= Moderate ranking; 2= High ranking. Total maximum score was 12 cumulative points.

Geo-spatial rankings of candidate no-take sites based on pragmatic criteria.

Table 4.5 summarizes geo-spatial rankings of study sites based on pragmatic criteria. Overall, DIA and LOB ranked highest with a score of 100%, followed by PLM, PLT, SDP, and ICW (91.7%). These results suggest that, based on pragmatic score rankings, basically all study sites should be designated as no-take MPAs.

TABLE 4.6. Economic criteria ranking analysis of candidate no-take MPA sites*.

Criteria	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
Importance to species	2	2	2	2	1	1	1
Importance to fisheries	1	1	1	2	1	1	1
Nature of threats	2	2	2	2	2	2	2
Economic benefits	2	2	2	2	2	2	2
Tourism	2	2	2	2	2	2	2
Cumulative points	**9**	**9**	**9**	**10**	**8**	**8**	**8**
Final score	**90**	**90**	**90**	**100**	**80**	**80**	**80**

*Rank scores: 0= Low ranking; 1= Moderate ranking; 2= High ranking. Total maximum score was 10 cumulative points.

Geo-spatial rankings of candidate no-take sites based on economic criteria.

Table 4.6 summarizes geo-spatial rankings of study sites based on economic criteria. Overall, SDP ranked highest with a score of 100%, followed by DIA, PLM, and PLT (90%). These results, in combination with the socio-economic significance of ALCNR according to the main stakeholders that use the reserve (see Shivlani, Ch. 3), suggest that, based on economic score rankings, basically all study sites should be designated as no-take MPAs.

TABLE 4.7. Social criteria ranking analysis of candidate no-take MPA sites*.

Criteria	**DIA**	**PLM**	**PLT**	**SDP**	**LOB**	**ICE**	**ICW**
Social acceptance	1	2	2	1	2	2	2
Recreation	2	2	2	0	2	2	2
Culture	1	2	1	2	2	2	2
Aesthetics	2	2	2	1	2	2	2
Conflicts of interest	1	2	2	0	2	2	2
Safety	1	1	1	0	2	2	2
Accessibility	2	2	2	2	2	2	2
Research and education	2	2	2	2	2	2	2
Public awareness	2	2	2	1	2	2	2
Conflict and compatibility	2	2	2	2	2	2	2
Benchmark	2	1	1	2	1	1	1
Cumulative points	**18**	**20**	**19**	**13**	**21**	**21**	**21**
Final score	**81.8**	**90.9**	**86.4**	**59.1**	**95.5**	**95.5**	**95.5**

*Rank scores: 0= Low ranking; 1= Moderate ranking; 2= High ranking. Total maximum score was 22 cumulative points.

Geo-spatial rankings of candidate no-take sites based on social criteria.

Table 4.7 summarizes geo-spatial rankings of study sites based on social criteria. Overall, ICE, ICW, and LOB ranked highest with a score of 95.5%, followed by PLM (90.9%), and PLT (86.4%). These results are consistent with results from the stakeholder characterization that suggested

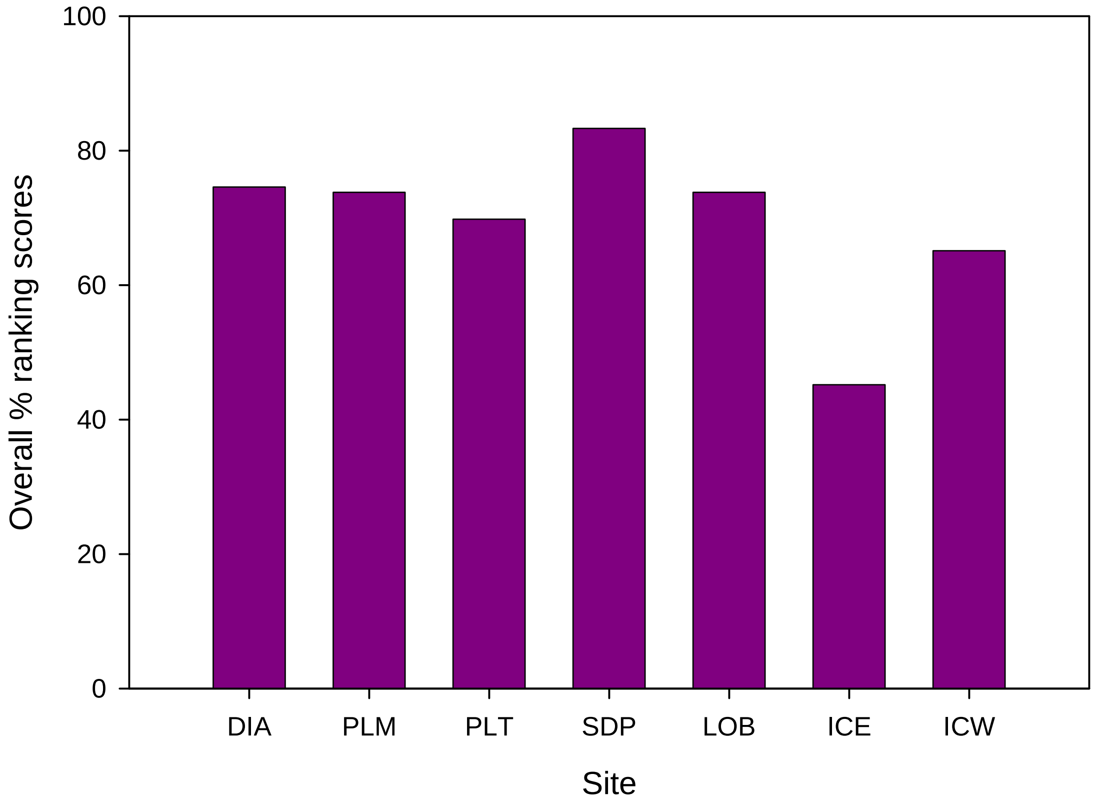

FIGURE 4.26. Percent ranking score of study sites based on all combined criteria.

intensive recreational uses at these sites (see Shivlani, Ch. 3). Based on social criteria score rankings, basically the ICW-ICE-LOB, and PLM-PLT complexes should be designated as no-take MPAs.

Conclusions

Overall, SDP ranked as the most significant site for a no-take MPA designation, with a 83.3% combined score (Figure 4.26). It was followed by DIA with a score of 74.6%, and PLM and LOB, with 73.8%, each one. PLT followed with 69.8%, ICW with 65.1%. ICE scored 45.2%. These results suggest that based on a combination of criteria, three different complexes emerged as potential candidate no-take MPA sites: SDP-DIA complex, PLM-PLT, and LOB-ICE-ICW.

SDP-DIA ranked highest under most criteria, but mostly under biological criteria. These sites are located at approximately 10 km off the Fajardo coast and show the lowest density of visitors (see Shivlani, Ch. 3). Distance and strong oceanographic conditions is a major constraint largely reducing recreational activities east of LOB towards DIA. Therefore, biological criteria strongly supports its designation as a no-take MPA.

PLM-PLT is an area that also showed a moderately high ranking by a combination of criteria. But also, most stakeholders including 80% of the commercial fishermen, 73% of concessionaires and registered vessel operators, and 52% of private vessel operators (Shivlani, Ch. 3) supported its designation as a no-take MPA due to several reasons. These included proximity, easy access, usually protected conditions at frequented areas, and overfished state. Similar justifications were presented for supporting the designation of ICW-ICE-LOB complex.

Therefore, the overall conclusion is that there was a strong agreement between stakeholder perceptions of the status of ALCNR's natural resources (i.e., fish communities, benthic communities, water quality, cleanliness, etc.) and empirical data obtained in this study regarding the status of fish communities within the reserve that strongly support the immediate designation of no-take MPAs within ALCNR. Candidate sites include three different island-key complexes: SDP-DIA, PLM-PLT, and ICW-ICE-LOB. With the exception of SDP-DIA, commercial fishermen strongly supported the designation of all other sites. However, some of the fishermen did support its designation. All other stakeholders strongly supported ICW-ICE-LOB, and PLM-PLT, and in a lower degree SDP-DIA. The suggested three sites is a consensus solution based on empirical data and stakeholder perceptions and recommendations. In chapter 5 we suggest and analyze potential alternatives of no-take MPA designations.

Literature cited

Almy, C.C., Jr., & C. Carrión Torres. 1963. Shallow-water stony corals of Puerto Rico. Caribb. J. Sci. 3:133-162.

Ballantine, D.L., R.S. Appeldoorn, P. Yoshioka, E. Weil, R. Armstrong, J.R. García, E. Otero, F. Pagán, C. Sherman, E.A. Hernández-Delgado, A. Bruckner, & C. Lilyestrom. 2008. Biology and ecology of Puerto Rican coral reefs. 375-406. In, B.M. Riegl & R.E. Dodge (eds.), *Coral Reefs of the World, Vol. I. Coral Reefs of the USA*, Springer-Science + Business Media B.V. 803pp.

CSA Group. 2005. Evaluación, delimitación y análisis de los usos en los habitáculos marinos dentro de la Reserva Natural Arrecifes La Cordillera. Informe Final al Departamento de Recursos Naturales y Ambientales. 125 pp.

Departamento de Recursos Naturales y Ambientales. 2007. Plan de Manejo de la Reserva Natural Arrecifes de La Cordillera, Fajardo. 88 pp (final draft under evaluation of the PR Planning Board).

García, J.R., J. Morelock, R. Castro, C. Goenaga, & E. Hernández. 2003. Puerto Rican reefs: Research synthesis, present threats and management perspectives. 111-130. In, J. Cortés (ed.), *Latin American Coral Reefs*. Elsevier Publ., Amsterdam, Holland. 497 pp.

García-Sais, J.R., R. Appeldoorn, T. Batista, L. Bauer, A. Bruckner, C. Caldow, L.M. Carruba, J. Corredor, E. Díaz, C. Lyliestrom, G. García-Moliner, E. Hernández-Delgado, C. Menza, J. Morell, A. Pait, J. Sabater, E. Weil, E. Williams, & S. Williams. 2008. The state of coral reef ecosystems in Puerto Rico. Pp. 75-116. In, J.E. Waddell & A.M. Clarke (eds.), *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008*. NOAA Tech. Mem. NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 569 pp.

Goenaga, C. & V. Vicente. 1990. Apéndice 4. Informe de observaciones de campo sobre corales y organismos asociados. 13 pp. En: Suplemento técnico para el Plan de Manejo de la Reserva Natural La Cordillera, Fajardo. Departamento de Recursos Naturales, San Juan, P.R.

Goenaga, C., y R.H. Boulon, Jr. 1992. The State of Puerto Rican and U.S. Virgin Islands Corals: An Aid to Managers. Report submitted to the Caribbean Fishery Management Council, Hato Rey, P.R. 66 pp.

Hernández-Delgado, E.A. 1992. Coral reef status of northeastern and eastern Puerto Rican waters: Recommendations for long-term monitoring, restoration and a coral reef management plan. Submitted to the Caribbean Fishery Management Council, Hato Rey, P.R., December 1, 1992. 87 pp.

Hernández-Delgado, E.A. 1994a. Preliminary inventory of the coral reef systems and hard ground communities from La Cordillera Natural Reserve, Puerto Rico. Submitted to Project Reefkeeper, Miami, FL. 10 pp. March 3, 1994.

Hernández Delgado, E.A. 1994b. Rapid degradation of the coral reef system at La Cordillera Natural Reserve, Puerto Rico, deserves priority evaluation in the National Marine Sanctuary Candidate List. Submitted to Project Reefkeeper, Miami, FL. January 3, 1994. 20 pp. + App.

Hernández-Delgado, E.A., A.L. Ortiz Prosper, y L. Alicea Rodríguez. 1996. Caracterización de la comunidad coralina impactada por el encallamiento del transbordador *Caribe Cay* en el Islote Palominitos, Reserva Natural de La Cordillera, Fajardo, Puerto Rico. Informe sometido al Departamento de Recursos Naturales y Ambientales, San Juan, P.R., 14 de mayo de 1996. 24 pp.

Hernández Delgado, E.A., y A.M. Sabat. 1998. Ecological status of essential fish habitats through an anthropogenic environmental stress gradient in Puerto Rican coral reefs. Proc. of the Gulf and Caribbean Fisheries Institute. 51:457-470.

Hernández Delgado, E.A. 2000. Effects of anthropogenic stress gradients in the structure of coral reef fish and epibenthic communities. Unpublished Ph.D. Dissertation, Dept. Biology, University of Puerto Rico, San Juan, P.R. 330 pp.

Hernández-Delgado, E.A. 2005. Historia natural, caracterización, distribución y estado actual de los arrecifes de coral Puerto Rico. 281-356. *In*, R.L. Joglar (Ed.), *Biodiversidad de Puerto Rico: Vertebrados Terrestres y Ecosistemas. Serie Historia Natural*. Editorial Instituto de Cultura Puertorriqueña, San Juan, PR. 563 pp.

Mckenzie, F., y M. Benton. 1972. Biological inventory of the waters and keys of north-east Puerto Rico.Final report submitted to the Division of Natural Resources, Department of Public Works, San Juan, P.R. 90 pp.

United States National Oceanic and Atmospheric Administration. National Ocean Service. National Centers for Coastal Ocean Science Biogeography Program. 2001. Benthic habitats of Puerto Rico and the U.S. Virgin Islands. CD ROM, NOAA, Silver Spring, MD.

CHAPTER 5

Final remarks and management recommendations

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Synthesis

This study identified areas of convergence between different stakeholder groups, ranked candidate no-take MPA sites based in multiple criteria, evaluated the preferred methods of public participation within and between community groups, and determined community expectations of no-take MPA benefits and costs. Furthermore, the information gathered contributed to devise and prioritize strategies by which to maximize coral reef-associated fisheries protection while enabling public participation and maximizing community support for no-take MPAs.

Significance of no-take MPA designations within ALCNR

No-take MPA implementation linked to habitat protection and management can be the most significant tool to recover already depleted fish populations within ALCNR system. The following images present four alternative designation scenarios. Advantages and disadvantages are discussed for each one and recommendations regarding the preferred alternative are given.

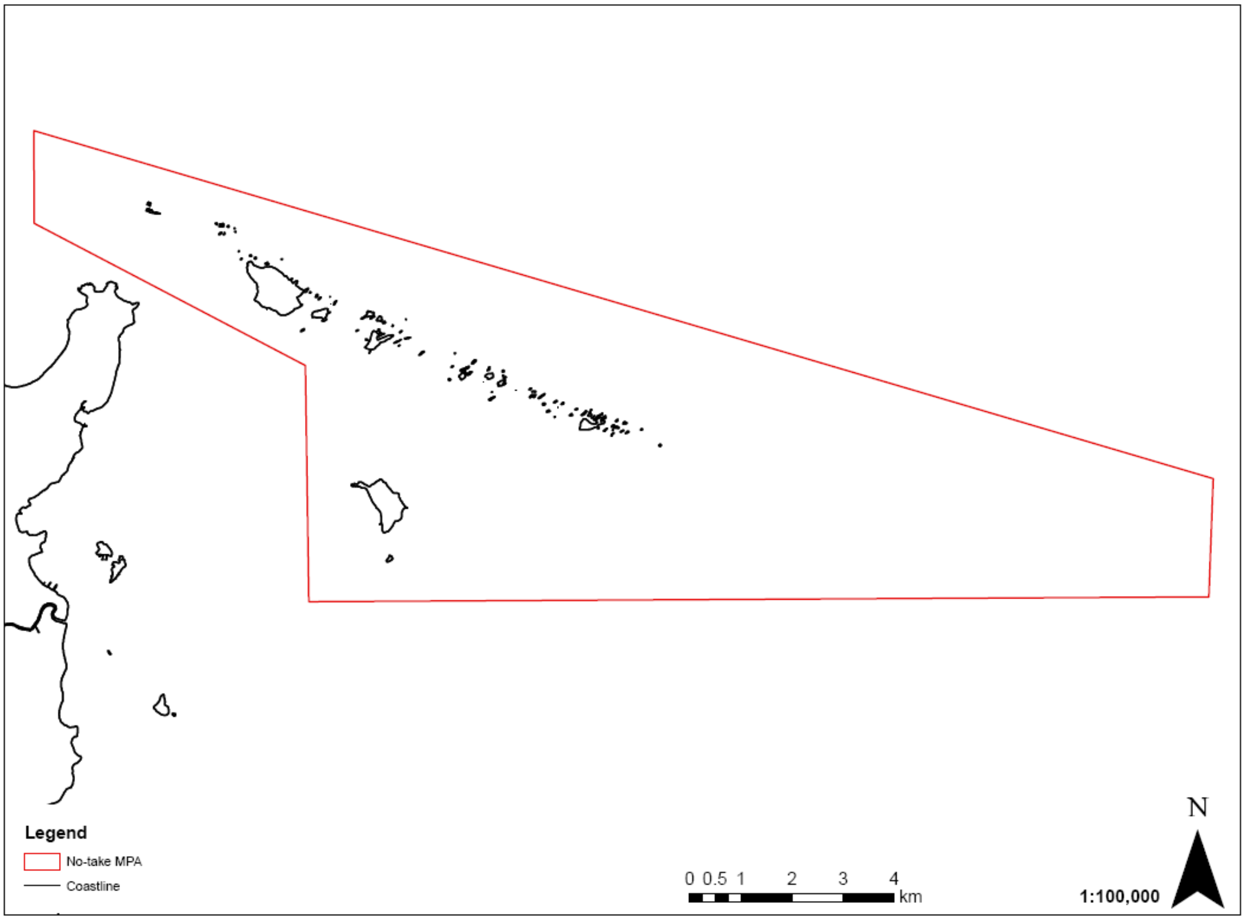

FIGURE 5.1. Alternative 1 for no-take MPA designation at ALCNR: entire reserve.

Alternative 1

Under Alternative 1 (Figure 5.1) the proposed configuration will cover the entire reserve's boundaries. The most significant advantage is that it will provide full-time protection against all consumptive uses within the entire reserve across all habitats. Its disadvantages are that only a minority of the fishermen and other stakeholders supported such a large closure, thus strong opposition to this option could be expected. Also, it would imply stronger enforcement by PRDNER across a large geographic area, as well as additional demarcation with buoys.

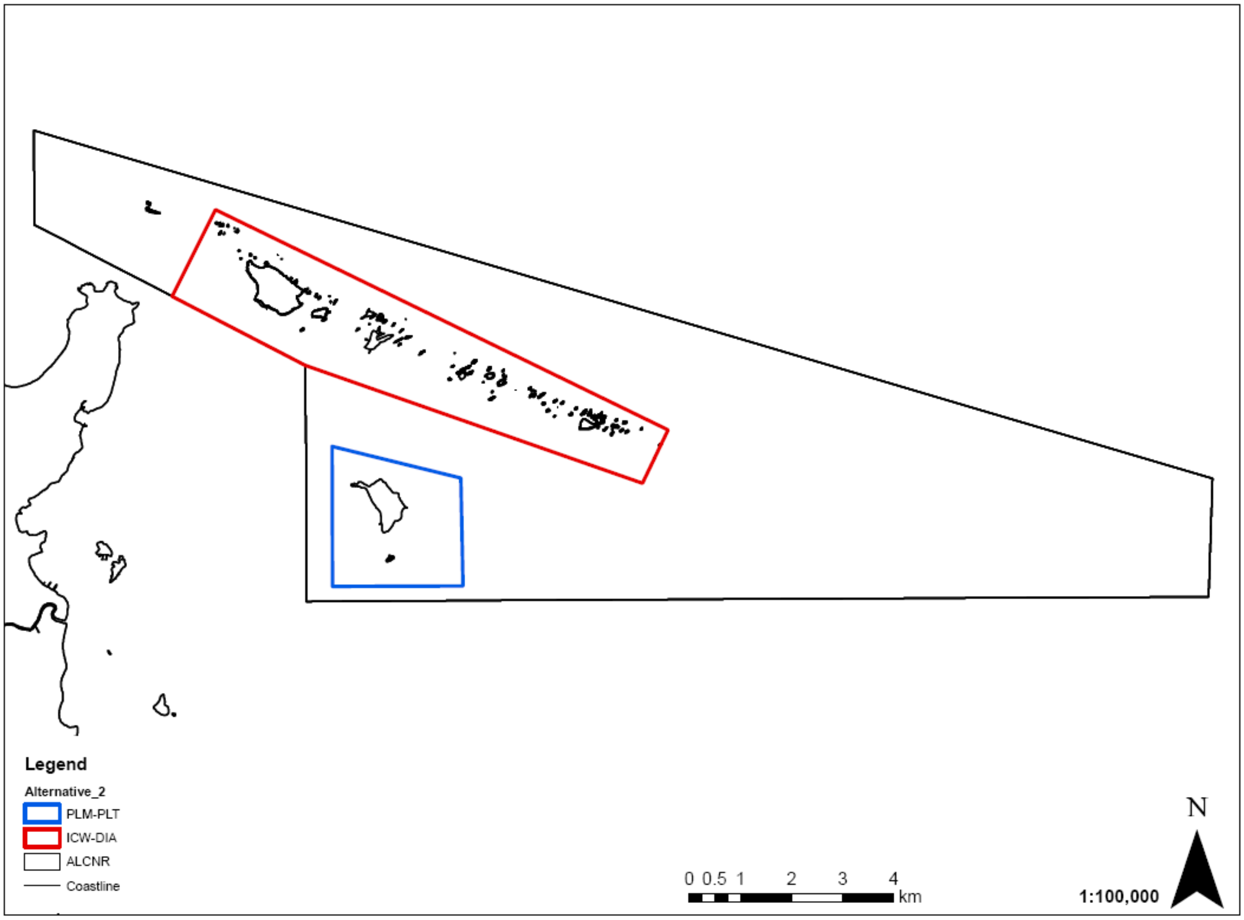

FIGURE 5.2. Alternative 2 for no-take MPA designation at ALCNR: ICW-DIA, PLM-PLT.

Alternative 2

Under Alternative 2 (Figure 5.2) the proposed configuration will cover two segments within reserve's boundaries: a large segment from ICW to DIA, and a second smaller segment including PLM and PLT. The most significant advantage is that it will provide full-time protection against all consumptive uses to significant coral reefs and keys, including a combination of areas impacted by strong recreational uses, as well as areas barely impacted at all, and that have shown to have healthier fish populations. From the standpoint of fish recruitment and spillover effects this approach should be successful in exporting fish to other areas open to fishing within

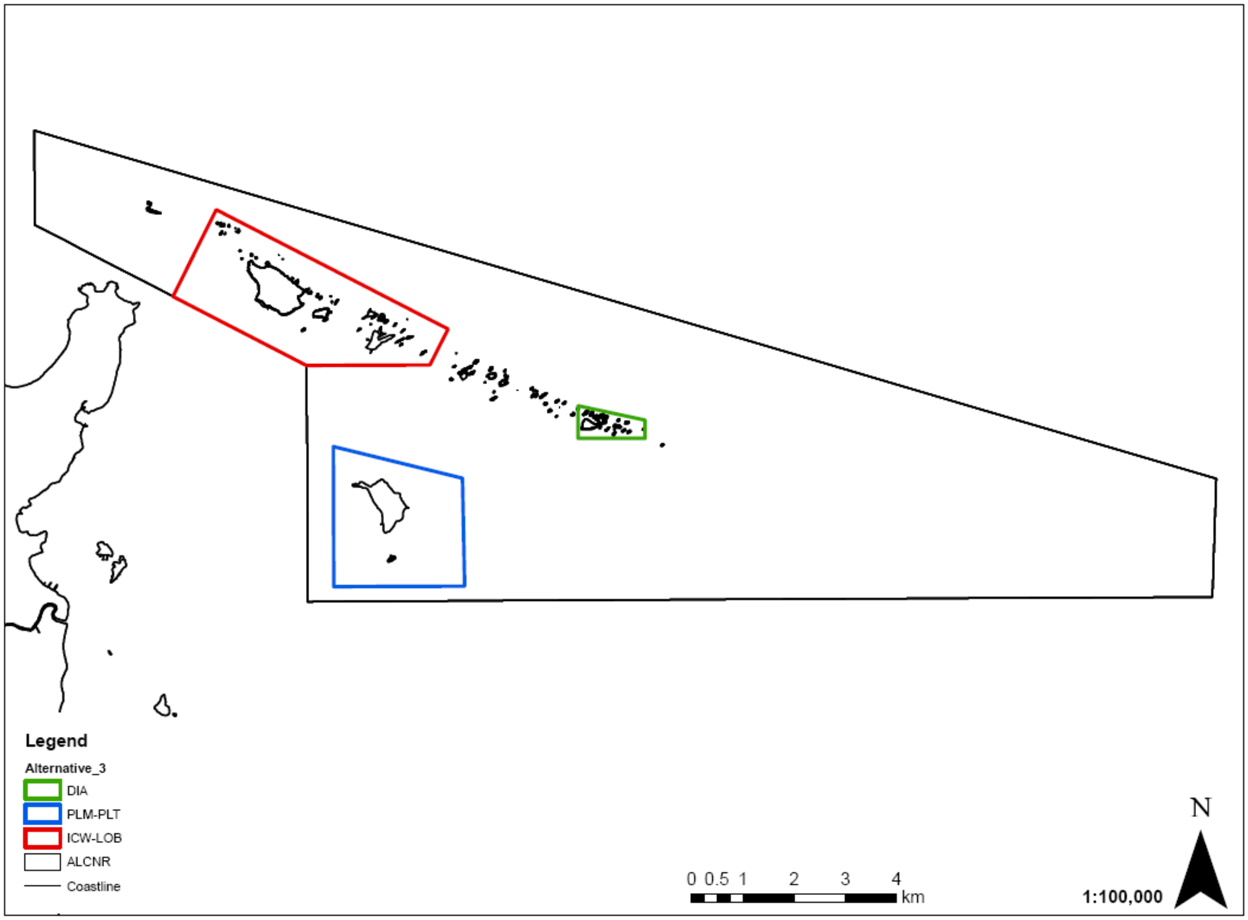

FIGURE 5.3. Alternative 3 for no-take MPA designation at ALCNR: ICW-LOB, PLM-PLT, DIA.

and outside ALCNR. It also had the support of some of the fishermen and other stakeholders. Its only disadvantage might be that some fishermen may still consider this as a large area.

Alternative 3

Under Alternative 3 (Figure 5.3) the proposed configuration will cover three segments within reserve's boundaries: a large segment from ICW to LOB, a second smaller segment including PLM and PLT, and a third segment at DIA. The most significant advantage is that it will provide full-time protection against all consumptive uses to significant coral reefs and keys, including a combination of areas impacted by strong recreational uses. From the standpoint of fish recruitment and spillover effects this approach should be successful in exporting fish to other areas open to fishing within and outside ALCNR. It also had the support of the vast majority of the fishermen and other stakeholders. Its only disadvantage might be the limited size of the DIA segment will leave without full protection significant reef resources around SDP and similar key areas located between LOB and DIA.

Alternative 4

Under Alternative 4 (Figure 5.4) the proposed configuration will cover three segments within reserve's boundaries: a large segment from ICW to LOB, a second smaller segment including PLM and PLT, and a third segment including SDP-DIA. The most significant advantage is that it will provide full-time protection against all consumptive uses to significant coral reefs and keys, including a combination of areas impacted by strong recreational uses, as well as areas barely impacted at all, and that have shown to have healthier fish populations. From the standpoint of fish recruitment and spillover effects this approach should be successful in exporting fish to other areas open to fishing within and outside ALCNR. It also had the support of the vast majority of the fishermen and other stakeholders. Its only disadvantage might be the proposed configuration will leave without full protection significant reef resources located between LOB and SDP. This may create confusion among resource users and potential enforcement problems unless adequate demarcation buoys are established.

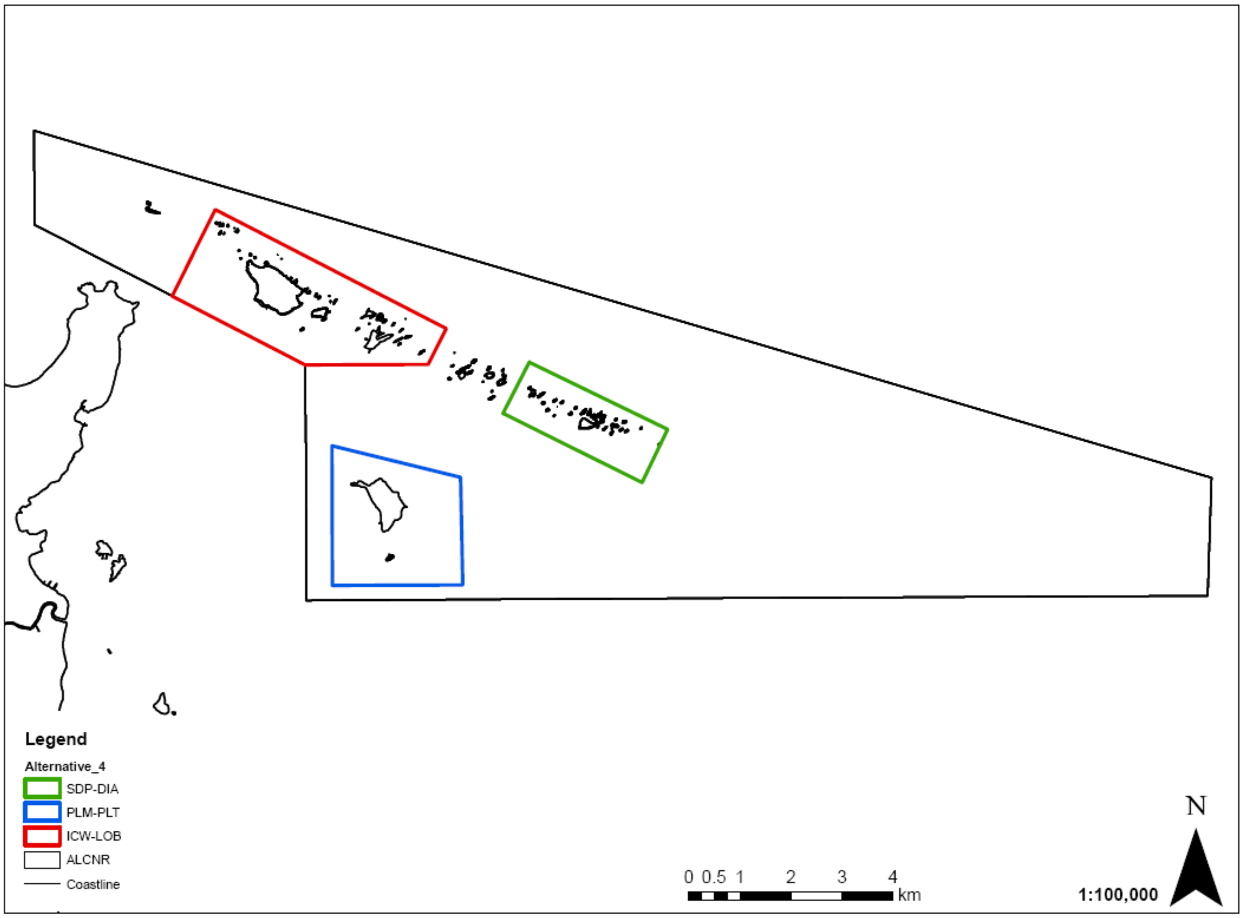

FIGURE 5.4. Alternative 4 for no-take MPA designation at ALCNR: ICW-LOB, PLM-PLT, SDP-DIA.

Discussion

After careful consideration of empiric evidence regarding the depauperate condition of fish communities within ALCNR, and stakeholders perceptions of the status of the reserve, we strongly recommend PRDNER and NOAA to consider alternative 2 as the preferred option, or alternative 4 as a consensus option. Alternative 2 will definitely provide better protection to critical resources as well as facilitate enforcement of no-take areas. However, it will require stronger efforts to seek full support by fishermen and other user groups that may fully support the designation of smaller areas. This solution would be consistent with the ranking analysis performed in Ch. 4. Alternative 4 adjust better to a consensus model more compatible with the options supported by fishermen and other user groups, while simultaneously protecting overexploited resources by overfishing and recreational activities, as well as protecting critical areas that still support healthier fish populations.

Conclusions

This study clearly suggested that coral reef fish communities within ALCNR were showing unequivocal signs of crisis. Populations of the most significant fishery-targeted species were significantly depleted, apex predators were largely absent from most reefs, the most significant predators were small or medium-sized intermediate predators, and herbivore guilds were dominant across most sites (i.e., abundance, biomass). Several fish functional groups were largely depleted through most of the study sites, particularly in areas subjected to very intense recreational activities, including spearfishing. Piscivore guilds were the most affected. Further, benthic communities were also reflecting major recent declines in % coral cover, particularly in the most significant reef-building taxa. This has been largely the result of chronic water quality degradation (i.e., recurrent polluted runoff pulses from the Fajardo coast), variable human recreational impacts (i.e., anchoring), and the massive coral mortality event of 2006 that followed the 2005 unprecedented sea surface warming event and bleaching episode. The actual status of coral reef fish communities within ALCNR is a major cause of concern that requires rapid action to significantly reduce or eliminate consumptive uses through the establishment of a network of small, discrete no-take MPAs.

The proposed management plan for ALCNR (DRNA, 2007), still pending final approval by the PR Planning Board, as well as a recent characterization study of the reserve (CSA, 2005), suggested that no-take MPA segments should be designated to contribute restoring and enhancing depleted fish populations within ALCNR. DNER further suggested that future management efforts should involve inter-agency agreements, and direct participation by base communities and other stakeholders (DRNA, 2007). These may include academia, non-governmental organization, private entities, and individual citizens, among others. Furthermore, we found that local artisanal fishers, as well as other stakeholders, might be willing to support the designation of small no-take MPAs at selected areas at ALCNR.

We strongly recommend PRDNER and NOAA to consider alternatives 2 as the preferred option, or alternative 4 as a consensus option. Alternative 2 will provide better protection to critical resources, will facilitate enforcement of no-take areas, and would be consistent with the ranking analysis performed in Ch. 4. But alternative 4 adjust better to a consensus model more compatible with the options supported by fishermen and other user groups, while simultaneously protecting overexploited resources by overfishing and recreational activities, and protecting critical areas that still support healthier fish populations.

Literature cited

CSA Group. 2005. Evaluación, delimitación y análisis de los usos en los habitáculos marinos dentro de la Reserva Natural Arrecifes La Cordillera. Informe Final al Departamento de Recursos Naturales y Ambientales. 125 pp.

Departamento de Recursos Naturales y Ambientales. 2007. Plan de Manejo de la Reserva Natural Arrecifes de La Cordillera, Fajardo. 88 pp (final draft under evaluation of the PR Planning Board).

Acknowledgments

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