Rapid Resilience Assessment Protocol Reveals Good Coral Reef Conditions in the Parque Nacional Arrecife Alacranes, off the Northern Yucatan Peninsula, Mexico

Protocolo de Evaluación de Resiliencia Rápida Revela Buenas Condiciones del Arrecife Coralino en el Parque Nacional Arrecife Alacranes, Norte de la Península de Yucatán, México

Un Protocole Rapide d'Évaluation de la Résilience Révèle de Bonnes Conditions de Récifs Coralliens dans le Parque Nacional Arrecife Alacranes, au Large de la Péninsule Nord du Yucatan, au Mexique

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ABSTRACT

A rapid coral reef resilience assessment protocol was implemented in 2016 for the Parque Nacional Arrecife Alacranes (PNAA), off the northern Yucatan Peninsula, Mexico, southern Gulf of Mexico. Trained diver teams surveyed 18 reef sites in the PNAA, completing 72 surveys from September to October 2016. Coral reef conditions in surveyed sites were considered in good condition, with high live coral cover and low macroalgal levels. Coral bleaching was low in the PNAA at a time when regional forecasts indicated high likelihood of bleaching in the southern Gulf of Mexico. Grouper (Epinephelidae) abundance was low, but that of snappers (Lutjanidae) was higher, although with variable fish size classes across the marine protected area. We recommend implementing management strategies in the PNAA to increase coastal resilience via enforcement planning with partners, targeted outreach/ education to build compliance, coral bleaching response, monitoring of visitation, water quality monitoring, and further bio-physical monitoring. The coral reef resilience protocol was successfully used for the first time in PNAA and proved efficient to rapidly describe coral reef condition and provide an initial assessment of resilience in a remote protected area where frequent and in-depth coral reef monitoring can otherwise be challenging.

KEY WORDS: Yucatan Peninsula, Alacranes Reef, coral reef, reef resilience, Mexico

INTRODUCTION

The combination of human activities (e.g. overfishing and pollution), natural stressors (e.g. hurricanes), and effects of climate change together threaten the resilience of coral reefs and the well-being of hundreds of millions of people that depend on these ecosystems for their livelihoods (Hoegh-Guldberg et al. 2007, Hoegh-Guldberg 2011). The main negative changes observed are the loss of live coral cover and the substantial increase in macroalgae. These changes have been reported for many coral reefs of the western Atlantic (including the Gulf of Mexico and Caribbean). In the context of change in coral-algal levels, managers and scientists are focusing efforts on the development of conservation strategies to ensure that coral reefs persist as coral-dominated habitats and that they continue to provide goods and services (Day 2008, Done 1999, McCook et al. 2010).

The Comisión Nacional de Áreas Naturales Protegidas (CONANP), a Mexican government agency responsible for managing natural protected areas, is among natural protected area managers who face the imperative of managing coral reef resilience. One of this areas managed by CONANP is the Parque Nacional Arrecife Alacranes (PNAA), located in the southern Gulf of Mexico. PNAA is part of the MPA Connect network and collaborates with the MPA management capacity building partnership between the Gulf and Caribbean Fisheries Institute (GCFI), the Coral Reef Conservation Program of the US National Oceanic and Atmospheric Administration (NOAA) and a group of 30 Caribbean coral reef MPAs. PNAA indicated to GCFI and NOAA that bio-physical monitoring was a top priority need for capacity building at PNAA and, as was the case with many other Caribbean MPAs, PNAA reported low capacity for managing coral reef resilience in the face of risks from climate change. In response, support from GCFI and NOAA enabled the development of a rapid resilience assessment protocol for PNAA which was piloted in 2015 and implemented in 2016.

The Phase I reports Rapid Resilience Assessment Protocol Project in PNAA found that since the inception of the national park, *ad hoc* monitoring and assessment of ecological condition have informed management of the MPA. Intensive surveys led by the Universidad Autonoma de Yucatan (UADY for its Spanish abbreviation) during 1998 - 2003 provided baseline information on benthic composition and fish communities. Semi-quantitative surveys by video transects and issue-specific scientific studies (such as conch population assessments) have been the main method for recording conditions on PNAA since 2003. While much effort has been made regionally in the past decade towards monitoring coral health of the Meso-American Reef through the Healthy Reefs Initiative and using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) Protocol, this work has not extended to the PNAA.

Given the opportunity to address coral reef monitoring through the current project, the GCFI and CONANP team sought to build upon sub-regional best practices (from the Meso-American Reef Region) and to ensure consistency with regional coral health monitoring protocols (especially the Global Coral Reef Monitoring Network, GCRMN). In particular, we sought to apply the same indicators, as used in the Healthy Reefs Initiative and AGRRA protocol, and to ensure consistency with the following key recommendations of the GCRMN:

i) Design of local monitoring (20 survey sites if possible, or fewer due to operational limitations);
ii) Key biophysical parameters (core information to be collected - density and size structure of all species of snappers (Lutjanidae), groupers (Serranidae), parrotfish (Labridae –Scarinae), and surgeonfish (Acanthuridae) + sensitive species/ invasive species);
iii) Abundance and biomass of key reef fish taxa - level 2 modified AGGRA protocol, count and size the core species (snappers, groupers, parrotfish and surgeonfish);
iv) Relative cover of reef-building organisms and their dominant competitors;
v) Assessment of coral health (core information recommended by GCRMN plus information on coral disease and bleaching);
vi) Abundance of key macro-invertebrate species (core information recommended by GCRMN).

Facing a reality similar to many Caribbean coral reef MPAs, the PNAA has only limited human, technical, equipment, and financial resources that can be applied to support coral reef monitoring. This reality underpins the design of the current project, which itself brought limited resources to help park managers take a step forward in their capacity for management of resilience to climate change by using a practical tool to take a snapshot of reef health at a previously little-researched area and during a relatively short fieldwork period. Further, in designing this project the GCFI and NOAA team was mindful of ensuring the feasibility of a GCRMN recommendation regarding frequency of sampling, every one to two years under normal conditions, which required prioritization of efficiencies in fieldwork and the potential for implementation in partnership with local universities, dive operators and NGOs.

In 2015, CONANP and PNAA participated in the regional workshop entitled 'MPA Management Challenges Through a Climate Change Lens' coordinated by GCFI and TIDE Belize and sponsored through a NOAA Cooperative Agreement. This workshop had the participation of nine MPAs from Mexico, Belize and Honduras, and with experts from the Caribbean, the USA, Australia, and expert groups such as The Nature Conservancy's Reef Resilience program. The workshop addressed projections for regional climate change, background to coral bleaching, coral reef monitoring approaches, reef resilience and MPA management actions, and examined global best practices for monitoring and management. One of the approaches considered was the monitoring program developed for the Great Barrier Reef known as Eye on the Reef, which is based on key indicators of the health of coral reef communities (EotR, for more details of the method see Beeden et al. 2014, http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/eye-on-the-reef). This approach appealed to managers of the PNAA for its potential to be adapted to include key regional Caribbean indicators of coral reef health, its ability to respond to regional recommendations about monitoring, its process efficiency and its potential for both staff and partner implementation. In the first phase, the EotR approach was adapted to coral reefs of the PNAA. This paper presents preliminary results of the subsequent implementation phase of the rapid assessment protocol by CONANP and UADY and discusses the findings of the assessment. The information aims to help managers to monitor future change in the condition of reefs in the PNAA and respond with appropriate management strategies.

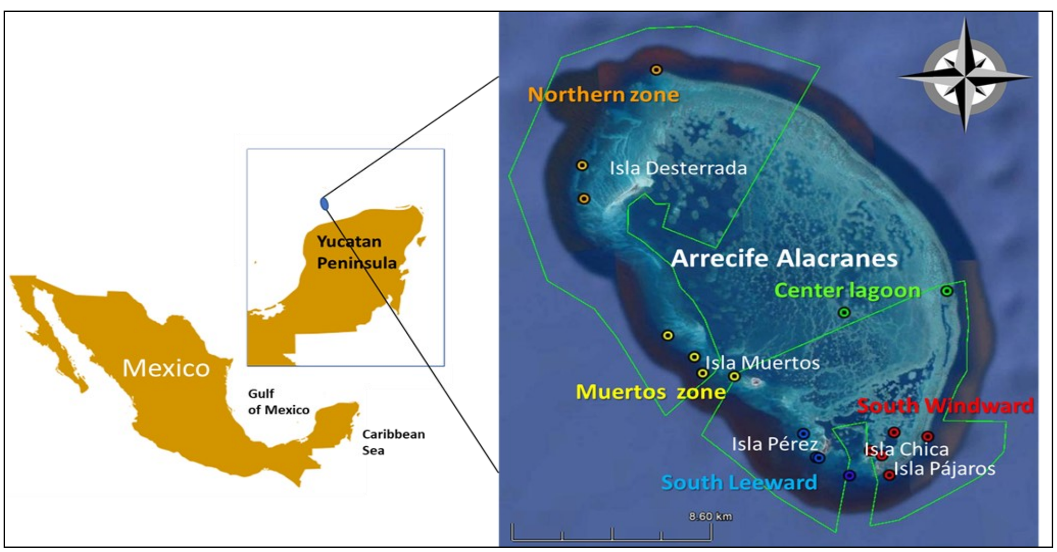

Figure 1. Parque Nacional Arrecife Alacranes, southern Gulf of Mexico (modified from López-Gómez et al. 2014) showing the five areas assessed in this study (Northern, Muertos, Center Lagoon, South Leeward and South Windward) with their corresponding sites sampled. Polygons (green lines) show boundaries of core zones (north and south) of the natural protected area.

MATERIALS AND METHODS

Study Area

Arrecife Alacranes (22°21'44'', 22°35'12''N; 89° 26'30'', 89°48'00''W) is located 135 km off the northern coast of the Yucatan Peninsula and is the largest reef formation in the southern Gulf of Mexico (Figure1). It is a semi-elliptic feature (420 km^2) with massive coral reefs and five small keys: Pérez, Muertos, Pájaros, Chica and Desterrada (Chávez et al. 2007). Established in 1994 as the Parque Nacional Arrecife Alacranes (PNAA), it is a protected area managed by CONANP. The site is part of UNESCO's Man and the Biosphere Programme (MAB – UNESCO), it is a Ramsar Site and is recognized as an Important Bird Area (IBA) (Gombos et al. 2011). Coral reefs in PNAA support 34 species of corals, 136 fish species, 24 shark species, sea turtles, and mollusks (Gombos et al. 2011).

Human activity in PNAA is low and mostly concentrated at Isla Pérez in the south. Users are primarily commercial lobster fishers (around 100 persons), recreational fishers, and recreational divers. Commercial fishing is mostly focused around Isla Desterrada, while recreational visitors (including divers) arrive at Isla Pérez and visit to Pajaros and Chica. Fishing is mostly based on spiny lobster (*Panulirus argus*) and, despite being a natural protected area, lobster fishing is allowed by permit to three fishery groups known as "cooperativas" from July 1st to February 28th every year. Fishers travel to PNAA on vessels and stay for 15 days or until reaching their quota of lobster. Every vessel has at least five smaller 6.6 feet boats for two fishers, one drives the boat and the other dives to catch lobsters. Onboard each fishing vessel is in total 14 persons including the cook. At least eight vessels travel to PNAA during the lobster season. Lobsters are taken directly from the coral reef using hooks; however, in middle of the lobster season fishers also use traps in deeper areas of PNAA. At the beginning of the season (July), all vessels stay in PNAA and anchor at the north (close to Isla Desterrada). They remain there until October or November when the number of vessels in PNAA is variable (not all eight vessels remain simultaneously) and then they move and anchor in the middle of PNAA (close to Isla Muertos). Depending on the abundance of lobster and the prevailing weather conditions, some will remain in the north. Snappers (Lutjanidae) and groupers (Epinephelidae) are commonly taken in the PNAA by both commercial and recreational fishers under a legal framework. There are currently no fishery regulations applying to snappers in the southern Gulf of Mexico. The grouper fishery is regulated by only a one-month ban (February - March), which coincides with the beginning of the lobster-fishing ban. While parrotfish (Labridae: Scarinae) has no commercial importance, some fishers take them for subsistence consumption.

Visitors in the PNAA

Visitors are mostly recreational divers arriving during June to October when weather conditions permit safe navigation to PNAA. Outside this period, cold fronts in the Gulf of Mexico restrict recreational activity at PNAA. PNAA grants special permits for tour guides and for site visitation. Tourism is based on the use of speedboats that can visit the site. Recreational visitors mostly anchor on the western side of Isla Pérez, where anchoring is permitted by CONANP, and visitors camp on Isla Pérez. There is a park entrance fee. Recreational visitation tends to focus on the summer months of calmer seas and less stormy weather.

Local Human Impacts

Although largely spared the immediate impacts of surrounding urban and agricultural development that so many Caribbean MPAs typically face, the users of PNAA bring with them local pressures on coral reefs such as:

i) Over-fishing and illegal fishing in no-take areas. Although PNAA has two core no-take areas, awareness of these areas is low and compliance with no-take regulations is low;
ii) Physical damage to coral from anchoring, groundings and physical contact by divers/ snorkelers;
iii) Pollution from vessel discharges, some land-based sources of pollution and marine debris;

PNAA is also affected by invasive species, most notably lionfish (López-Gómez et al. 2014), and is also affected by some coral disease.

The Protocol

The rapid resilience assessment protocol (based on EorR) was implemented at PNAA in September-October 2016 by CONANP staff and volunteers (university students) after adequate training in data collection. A data sheet, previously designed in consultation with CONANP, was used to record key information from the coral reefs of PNAA. Key attributes evaluated in PNAA were:

i) Benthic community (corals, gorgonids, sponges, etc);
ii) Key fish groups (parrotfish, groupers, snappers, etc.);
iii) Other (lionfish, sea cucumber, lobster, conch, etc.);
iv) Coral health (bleaching, diseases, damage);
v) Rubbish (presence, type);
vi) Human activities (number of boats, divers, etc.).

Some thresholds were established to measure coral reef condition based on these key attributes. These thresholds were established based on known conditions reported from other coral reefs in the Caribbean region (e.g. the report card by Healthy Reefs Initiative -http://www.healthyreefs.org/cms/report-cards/-) and worldwide (e.g. Long Term Monitoring Program -LTMP-, http://www.aims.gov.au/docs/research/monitoring/reef/reef-monitoring.html). Survey sites were based in part on coral reef topography, presence of hard bottom to permit a focus on the condition of key coral species, such as corals of ecological importance (e.g Acroporids), gorgonids and other outstanding groups. The survey sites can be expected to have more profuse growth of corals than might have been found using random survey site selection, and data should be interpreted based on this proviso. Survey site selection was also based on the level of threat due to pressure from lobster fishing (medium-high) and the level of visitation by recreational divers (medium-high). Additional survey sites were selected on the periphery of PNAA, in areas where there was concern about a potential impact on reefs by recreational divers, and around Isla Muertos where there is little human activity. A total of 18 sites were surveyed in the PNAA, at each of which four circle plots were assessed for a total sample size of 72 circle plots. The survey sites were grouped for analysis into five zones that are most meaningful for analysis based on the MPA zoning and on human activity levels (Figure 1): Northern zone, Muertos zone, South Leeward, South Windward, and Center lagoon.

The rapid resilience assessment protocol developed in Phase I of the project was only slightly modified for implementation to use a weighted and marked rope, which helped the field team to accurately estimate the area of circle plots during surveys. This rope was marked everyone meter with green tape and every 5 m with red tape with the extremes of the rope weighted with lead sinkers. Once the area to be assessed was selected, two divers (observers) each laid down a 20 m-long, marked rope on the reef bottom. The distance between each diver (and consequently between each circle plot) was at least 20 m. Each diver surveyed two circle plots on each dive, consequently each diver had two sheets in each slate to record the key indicators properly. The rope was very helpful for the observers to be able to more accurately assess the distance of the circle plot. The observer first recorded the fish species selected in the outer circle taking as reference mark the rope and 5 m markers. Once the fish census was completed, then the observer proceeded to estimate the benthic components from the circle plot. Divers swam together an approximate distance of 20 m, split to either right or left a further 20 m from each other, and then they laid down the rope and proceeded to do the next survey. Once the second circle plot was completed, the divers regrouped and surfaced together. Details of the complete method can be seen at Beeden et al. 2014 and http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/eye-on-the-reef.

RESULTS

Coral Reef Condition

Coral cover was high and macroalgal levels were low, as compared with reference values from the Healthy Reefs Initiative (http://www.healthyreefs.org/cms/). In contrast, unhealthy reefs have less live coral cover and more macroalgae. Live coral cover was highest in the Northern and Muertos reefs at around 35%, which is considered good. Lowest coral cover was at the Center Lagoon reefs at around 15%, which is considered fair according to Healthy Reefs Initiative reference values. Macroalgae was generally good at 5% or less, except for the Northern zone where it reached its highest level at 30%, which is considered critically high according to Healthy Reefs Initiative reference values.

Coral disease and bleaching are also indicators of the health of coral reefs - bleaching is an indicator that coral is under stress, principally linked to temperature, light, and mixing of the water (Marshall and Schuttenberg 2006). Further good news for PNAA was that the incidence of coral bleaching was found to be low with only 5% of corals (mainly *Acropora*) showing signs of bleaching, which was sparsely observed in some areas, and did not show a particular spatial pattern of occurrence. This situation is notable at a time when the NOAA Coral Reef Watch forecasts for the likelihood of bleaching were high. Incidence of coral disease was also low, with only 1% of corals affected across various coral species. Disease can threaten coral abundance and diversity, sending the ecosystem into decline (Woodley et al. 2008). Further, no broken coral due to anchoring was detected at any of the survey sites nor was any anthropogenic damage detected despite tourist visitation. One broken coral that was encountered was attributed to storm damage. Coral types were characterized by mound shape and to a certain degree by boulder type-shape in the surveyed sites, varying according to the location of site in relation to the reef platform.

Fish Community

A total of 3,737 individuals were counted in 18 sites of which 1,367 were larger than 20 cm TL (37%) and the remaining 2, 370 were less than 20 cm TL (63%). Parrotfish showed relatively high abundance at PNAA, which bodes well for the health of coral reefs. Parrotfish, surgeonfish, and other herbivores eat algae. Parrotfish can protect coral reefs from algal overgrowth and foster an ecosystem where corals are dominant. Playing a similar role in controlling algae, *Diadema* were not detected in significant numbers. Parrotfish were most abundant in the South-Windward zone, followed by the Northern zone. The greatest number of large parrotfish was in the Muertos zone, which is significant in terms of their role in protecting coral reefs. The lowest abundance of parrotfish was in the South-Leeward zone, which had a notably low abundance of large-sized parrotfish. Numbers of small parrotfish were highest at South-Windward (Figure 2), suggesting potential for recovery.

Status of Commercially Important Fish Species

Groupers (Epinephelidae) and snappers (Lutjanidae) serve as an example and indicator of the abundance of commercially important species. Snappers and groupers are of commercial importance at PNAA and are fished under a legal framework, but overall, they showed a relatively low abundance. Groupers were found in very low abundance in all areas of PNAA. The greatest numbers of large groupers were seen in the Northern and Center Lagoon zones, but still at low levels (< 5 or < 10 fish). The greatest abundance of small groupers was found in the South Leeward zone (around 12 fish). Snappers were most abundant overall in the Muertos zone. The greatest numbers of large snappers were found in the Muertos and Center Lagoon zones. Snappers were found in lowest numbers overall in the Northern zone, with fewest large snapper found in the South-Leeward zone. Despite the overall positive picture from this snapshot of current reef condition, there was spatial variability in the key coral types, benthic types and fish abundance and size, as shown in Figure 2, which has implications for risk in the face of climate change and is relevant for management actions.

Human Activity

At least 30 recreational boats were detected undertaking activities related to recreational fishing. Relatively few boats (at least two) were conducting recreational diving during surveys. At least three lobster vessels were anchored in the northern area. No marine debris was sighted at surveyed area, nor was any detected in coral reef areas.

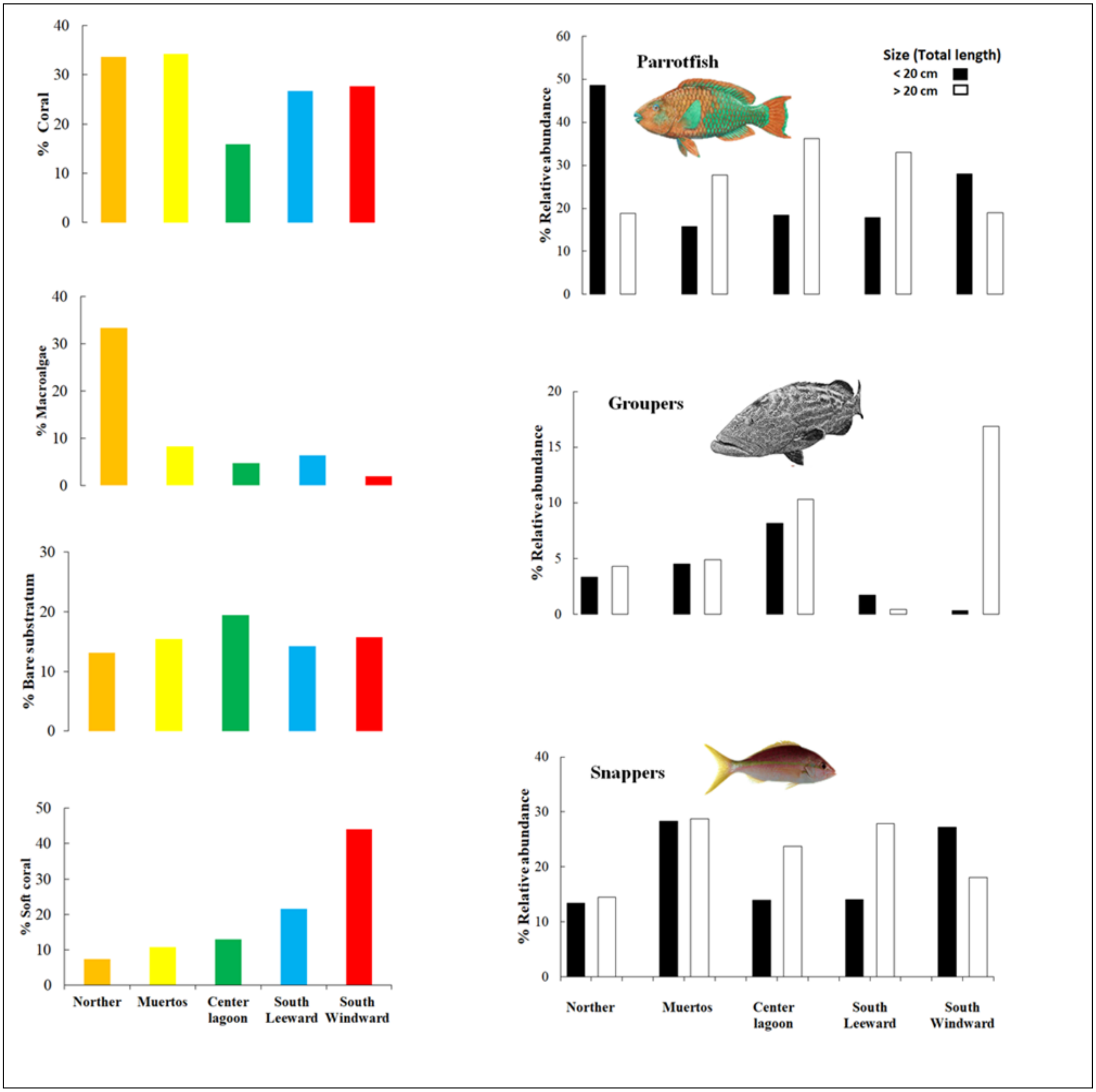

Figure 2. Key rapid resilience assessment indicators: coral cover, macroalgae, soft coral, and bare substratum, and relative abundance of herbivorous fish (parrotfish) and commercially important fish (groupers and snappers) at each zone. For fish, black bars represent size < 20 cm (total length) while white bars fish > 20 cm.

DISCUSSION

Lessons on the Rapid Resilience Assessment Protocol

In terms of lessons learned about the rapid resilience assessment protocol, this study proved instructive in adapting the methodology to coral reefs in PNAA. This protocol was used for the first time in PNAA by the dive team that had specialized knowledge to undertake surveys. However, before doing surveys this team familiarized with the selected key indicators to be assessed at the PNAA and learnt how to measure the dimensions for the suggested circle plots. First, it was necessary to adjust some key indicators and consider special items from the Eye on the Reef protocol used in coral reefs from Australia (Beeden et al. 2014). Also, a concern emerged on how to accurately measure the distance of the circle plot or how to use reference marks at the reef to assess cover percentage. As explained in previous sections, a marked rope was used for the observer to be able to identify reference marks. Using the rope proved effective in the way that facilitated measurements and it was not a problem rolling it out and rolling it back in. The dive team learned how to follow the process of using the rope and recording data. A concern emerged about the effectiveness of special underwater paper, and acrylic dive slates were instead used to record data, which was then input to a laptop computer at the end of each day.

When applying the protocol in future surveys, key indicators for coral reefs need to be clearly defined and understood by observers. In order to avoid confusions or overestimations, adequate attention must be paid to training observers for consistency. An especially important aspect of applying the protocol is to train observers in how to estimate percentage cover of benthic groups. In contrast, recording data about fish species, abundance, and size distribution was found to be straightforward, and the groups selected were clear and estimation was relatively easy. Therefore, the rapid resilience assessment protocol proved to be a useful and practical tool for taking a snapshot of reef health at a previously little-researched area and during a relatively short fieldwork period.

Risks to Coral Reefs from Climate Change

The most resilient reefs in PNAA are those with:

i) Good coral cover, coral diversity, mixed size classes of coral, abundance of herbivorous fish;,
ii) Dominance of more tolerant boulder/brain corals reef builders,
iii) Proximity to deep water and upwelling,
iv) Reefs known to have recovered from past bleaching, and
v) Reefs in naturally more turbid water.

The proportion of live coral cover to macroalgae, the low levels of bleaching and the finding of little coral disease indicate that coral reefs surveyed at PNAA are in generally good condition. However, the finding of a critically high level of macroalgal cover in the Northern zone stands out as an exception among otherwise good and fair macroalgal scores at other sites surveyed. Nutrient pollution makes it easier for fleshy macroalgae to grow on reefs, which in turn makes it harder for corals to attach and grow. To determine whether macroalgal levels found in this study are attributable to nutrients, for example from sewage discharge from vessels anchoring in the area, or whether it is an area of naturally higher macroalgal cover, requires further investigation.

Knowing that numbers of *Diadema* sp. were low in PNAA, it is important to track the abundance of parrotfish, especially in the Northern zone. While parrotfish conservation is not the only way to ensure the protection of coral reefs, parrotfish serve as an indicator of overall reef health (http://www.healthyreefs.org/cms/). Parrotfish, surgeonfish, and other herbivores eat algae, and parrotfish can protect coral reefs from an overgrowth of algae and foster an ecosystem with healthy coral cover, which in turn helps to ensure sustainable fisheries. In this snapshot, the Northern zone had the second highest abundance of parrotfish in the PNAA survey sites. Building, or at least ensuring that their numbers do not drop, will likely help to enhance the health of the reefs in the Northern zone. Large parrotfish have a greater impact on coral reef health, so a target could be to increase the abundance of parrotfish in the Norther zone equal to or beyond that found in the lesser disturbed Muertos zone which had the greatest number of large parrotfish of all PNAA. Based on this very first assessment, the most resilient coral reefs in PNAA are judged to be those in the Muertos and South Windward zones which have the healthiest corals, most fish abundance and least human impact. The most vulnerable reefs are judged to be those in the South Leeward and Northern zones where there is more human activity, lower fish abundance, lower coral cover and some sites have critically high macroalgal levels. Additional surveys are needed to support these findings, and these might suggest some adjustments to the core zones of the PNAA (Figure 3).

Risks to Fisheries From Climate Change

Abundance of groupers (Epinephelidae) was particularly low across PNAA. In general, grouper serve as an indicator of the abundance of commercially important species of fish and are essential to the coral reef ecosystem as they serve as reef predators, facilitating population control including of invasive lionfish species. In other areas of the Western Atlantic, groupers face threats from over-fishing and unsustainable fishing practices, and are especially vulnerable to over-fishing of spawning aggregations. Effective protection in MPAs can have a spillover effect with benefits for local fishers, so it is especially important to protect any remaining local grouper spawning aggregations and to protect the few remaining large groupers in PNAA. The abundance and size of snappers (Lutjanidae) was highest in the relatively undisturbed Muertos zone and lowest in the Northern zone with highest visitation from fishing vessels. This might suggest excessive removals by commercial fishers, especially in the areas where they anchor during lobster season. This could be further investigated and potentially controlled by a strategic enforcement in the Northern zone, especially between July and October. Second lowest abundance of snapper was in the South Leeward zone where recreational visitation is high, similarly indicating high removal by

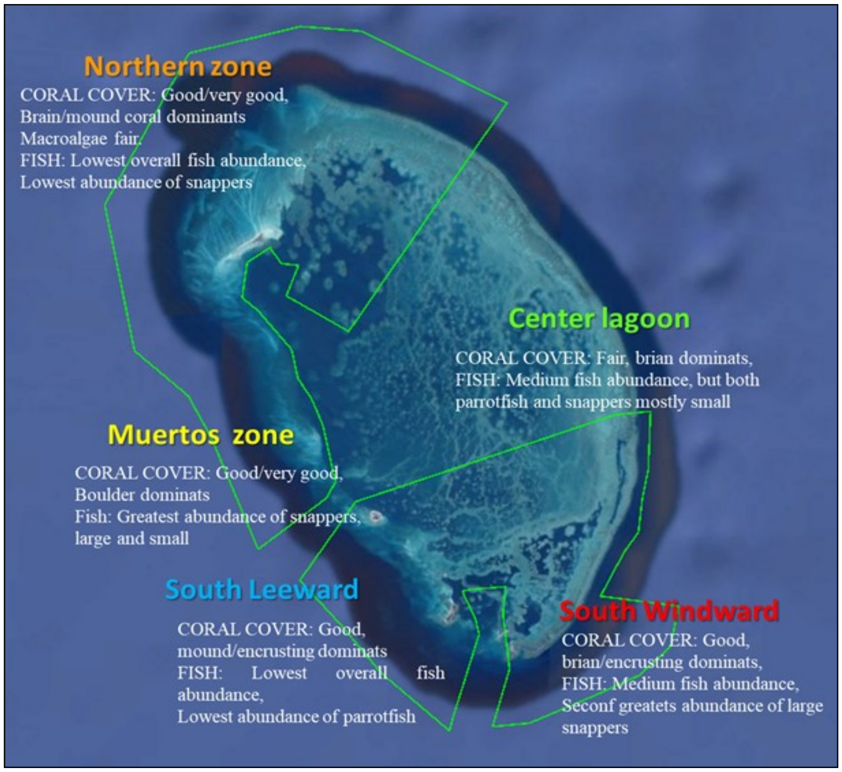

Figure 3. Key rapid resilience assessment indicators per area in the Parque Nacional Arrecife Alacranes, southern Gulf of Mexico.

recreational visitors and suggesting that strategic enforcement would be an appropriate response.

Although not a key finding of the rapid resilience assessment protocol, as a commercially important fishery in PNAA, lobster (*Panulirus argus*) deserves special attention in terms of the risks posed by climate change. Recent research in Parque Nacional Arrecifes de Xcalak (Glazer 2016) suggests that sea level rise could have a positive impact on lobster as new shallow habitat becomes available, at least in the short term. However, increases in sea surface temperature could have a profoundly negative effect on lobster biology. The thermal threshold for lobster is 31°C (Kearney et al. 2014, in Glazer 2016) and that exposure to prolonged temperatures above this will affect critical functions including reproduction and respiration. Higher sea surface temperatures will likely result in high mortality for post-larval lobsters recruiting to currently used shallow-water habitats. Decreases in rainfall will likely be accompanied by increases in salinity, which could exceed lobster thresholds and affect reproduction. This could have the net effect of reducing the coastal areas that are suitable for lobster. An increase in storm intensity could lead to rapid decreases in salinity and lead to mass mortality, or force lobsters into deeper waters. Overall, it is likely that adult lobster populations will relocate from shallow-water reef habitats to deeper water and that the shallower-water populations will decline.

Another effect of climate change is ocean acidification. The ocean absorbs about 30% of the carbon dioxide we emit, and lower ocean pH levels -ocean acidification- due to carbon absorption can affect the calcium in lobster shells and negatively affect growth in the larval phase. Like grouper, the number and quality of eggs released by female lobsters increases nearly exponentially with age so there is substantial value from large lobsters for reproduction. The protection of lobsters in undisturbed areas such as the national park helps to realize the greater reproductive potential of large lobster.

Links with Coral Restoration Efforts

Findings on coral types at PNAA are of value in considering risks in the face of climate change. Boulder and brain corals predominated at the Northern, Muertos, South Windward, and Center Lagoon survey zones, and these slow growing corals are considered more resilient to coral bleaching than the faster growing, branching coral species such as *Acropora*. This composition of PNAA's coral reef possibly underpins the relatively low level of bleaching that was observed during fieldwork in September - October 2016 at PNAA, which was otherwise considered a period of high alert for coral bleaching given high sea surface temperatures. Coral reefs at PNAA might naturally be relatively resilient to climate change, a possibility deserving further monitoring especially during and following bleaching alerts. CONANP has established *Acropora* coral nurseries (*A. cervicornis*, *A. palmata*) as a management tool to face anthropic factors and climate change. At least 120 fragments of *A. cervicornis* and 120 fragments of *A. palmata* have been mounted on PVC frames, which serve as nurseries at shallow reef sites (2 m deep) off Isla Pérez. However, the predominance of boulder and brain corals found at PNAA suggests that the species grown in the coral nursery should not focus solely on *Acropora*. Given PNAA's connectivity with other southern Gulf of Mexico and Caribbean coral reefs, ensuring the health of naturally predominant corals in the face of climate change is regionally significant. Thus, a case could be made for incorporating the slower growing but more resilient boulder, mound and brain coral species in coral nursery cultivation and outplanting efforts at PNAA.

RECOMMENDATIONS

MPA Enforcement

i) Ensure clear demarcation of the no-take zones in PNAA via in-water buoys. Although damage to coral reefs from anchoring and groundings was not significant in this assessment, PNAA could continually review reef condition according to changes in user pressure and practices, and consider fixed mooring buoys as needed.

ii) Demarcation and/or fixed mooring buoys could also be considered as a measure to protect the healthiest and largest brain and boulder corals in PNAA.

iii) In consultation with the PNAA Advisory Committee, develop and implement a strategic enforcement plan for CONANP and enforcement partners to most effectively allocate resources to build compliance with fisheries and management regulations and support coral reef resilience. This could consider and focus on the following strategic enforcement needs highlighted in this assessment:

- Considering the complex climate change scenarios associated with lobster biology, ecology and distribution, and its sustainability for future generations, focus on ensuring compliance by commercial fishers with lobster fishery regulations.
- In the Northern zone, especially target enforcement presence between July and October. Especially target the need for compliance with protective measures for parrotfish in this zone to support coral reef resilience. As a target, work towards achieving abundance and size distribution for parrotfish in the Northern zone at least as high as in Muertos zone.
- In the South Leeward zone especially target enforcement presence between June and October. Especially target the need for compliance with protective measures for snappers to enable small snappers to grow into reproductive adults. As a target, work towards achieving abundance and size distribution of snappers in the South Leeward zone at least as high as in Muertos zone.
- Develop a network of enforcement contacts and supporting materials/ exercises to provide practical training for enforcement partners in fisheries and MPA regulations.
- Prevent or strictly control dredging within or near PNAA.

Outreach/Education

i) Develop a complementary education/outreach campaign to help build compliance with fisheries and regulations in PNAA, targeting commercial fishers, tour guides and recreational visitors in tandem with more targeted enforcement presence by CONANP and partners.

ii) Train park rangers and enforcement partners as ambassadors for coral reefs and PNAA so they have confidence and credible content to speak about the importance of conservation of ecosystems and species to visitors. Such presentations may also include basic information on the research projects done by scientists and staff at PNAA.

iii) Hold seasonal briefings with PNAA's enforcement partners to target compliance with fisheries and PNAA regulations. Hold seasonal briefings via fisher cooperatives with licensed lobster fishers. Hold seasonal briefings with licensed tour operators.

iv) Effective outreach to commercial fishers can help to build understanding and trust, enabling agreements between rangers and fishers. Fishers are typically not familiar with the details of the PNAA management plan and sometimes reluctant to respect regulations. Communication between rangers and fishers is necessary to build a sense of stewardship of PNAA amongst fishers. The fisher cooperatives provide a potential avenue for targeting communications about reef stewardship and sustainable fisheries.

v) For outreach to recreational visitors about the need for conservation, consider making a grouper -possibly the Black grouper (*Mycteroperca bonaci*)- the official mascot fish for the PNAA. Use this mascot to focus on building understanding of grouper among recreational fishers and visitors to build protection, starting with a focus on the few remaining large groupers in PNAA. Recovery will be slow so set realistic expectations among stakeholders. Focus outreach effort on tour guides and develop educational materials they can share with recreational visitors, especially about the southern no-take zone.

vi) As judged appropriate based on further water quality monitoring and reef research, address possible issue of sewage discharge from vessels in the Northern zone via targeted outreach.

Coral Bleaching Response

i) Subscribe to temperature/bleaching advisories for the Yucatan Peninsula regional virtual station by request to coralreefwatch@noaa.gov or regularly review coralreefwatch.noaa.gov.

ii) When a bleaching warning is issued for the Yucatan Peninsula virtual regional station (= bleaching possible):
- Hold partner agency/board briefings to discuss bleaching response plan and allocate contingency funding for MPA monitoring and communications activities.
- Communicate with frequent reef users (e.g. dive operators), and invite them to report any observations of bleaching to PNAA manager.
- Monitor every other week at the long-term monitoring site(s) using Bleach Watch form.
- Scale back actions when Coral Reef Watch drops to 'no stress'.

iii) When bleaching alert 1 (= bleaching likely) is issued:
- Run communications campaign amongst PNAA stakeholders about the prediction of bleaching and the importance of protect herbivores, regulations against anchoring, coastal development regulations and best practices to minimize impacts of recreational use of reefs.
- Monitor weekly for bleaching at long-term monitoring site using Bleach Watch form.
- Scale back actions when Coral Reef Watch drops to 'no stress'.

iv) When bleaching alert 2 (= mortality likely) issued or 25% or more bleaching is observed:
- Run strategic enforcement blitz within PNAA to ensure strict compliance with fisheries and regulations and best practices, especially at most resilient sites.
- Take restrictive action: request stop to dredging and coastal construction near PNAA; request vessels to use holding tanks in and near PNAA.
- Monitor weekly for bleaching at long-term monitoring site using Bleach Watch form.
- Scale back actions when Coral Reef Watch drops to 'no stress'.

v) Three weeks after onset of bleaching, monitor affected reefs using Bleach Watch form.

vi) Three-six months after onset of bleaching:
- Work with expert partners to restore coral cover by out planting to affected areas from *Acropora* coral nurseries.
- Reintroduce herbivorous fish and/or *Diadema* sea urchins to affected reefs.
- Increase enforcement effort at restoration sites.

Monitoring of Visitation

Record how many visitors travel to the PNAA and what kind of activities they participate in. Integrating this with monitoring data would help identify those sites most at risk from human impacts and therefore requiring regular monitoring.

Further Biophysical Monitoring

i) Continue to track the key indicators assessed under this protocol, both through rapid assessments and long-term monitoring.

ii) Consider potential for on-going implementation of the rapid resilience assessment protocol to generate frequent reef health checks. Fieldwork could be done by CONANP staff, visiting scientists and students, and/or by volunteer recreational divers like the Australian "Eye on the Reef" program. Students and volunteers would require the development and delivery of training courses for recreational dive operators/divers. They would also require management response to collect, collate and communicate findings to PNAA stakeholders. Additional scientific input might be required to identify trends in the condition of coral reefs, to detect diseases and to oversee monitoring of coral bleaching.

iii) If establishing long-term monitoring sites at PNAA, consider establishing these at sites that represent the most resilient coral reefs at PNAA (e.g. survey site number 6 located in the Muertos zone) and the most vulnerable coral reefs at PNAA (e.g. survey site number 16). Monitor these sites using AGRRA protocol every 2-5 years.

Water Quality Monitoring

Given critically high macroalgal levels in the Northern zone, monitoring of levels of tourist visitation and sewage discharge is necessary to compare with further research into coral cover versus macroalgal cover. Check bacterial water quality during period of highest visitation. In tandem, ensure protection of parrotfish and permit growth to large size.

Coral Restoration

Diversify the coral nursery. Develop efforts to include brain and boulder corals in addition to acroporid species.

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