Understanding movement of Caribbean coral reef fishery species: Improving the design of marine reserves in the Caribbean

FINAL REPORT

Craig Dahlgren

Perry Institute for Marine Science
100 N. US Hwy 1, suite 202
Jupiter, FL 33477

Project Overview

Designing effective marine reserves for fisheries management requires an understanding of the movement rates and ranges of key fishery species and how these species use habitats within and outside reserve areas. In this project, the Perry Institute for Marine Science mapped marine habitats, and examined the habitat use and movement of key Caribbean fishery species, particularly Nassau grouper in existing and proposed marine protected areas (MPAs) in the Bahamas. While the initial focus of the proposed research included two national parks with extensive marine areas and several sites within a network of Fishery Reserves being developed by the Bahamas Department of Marine Resources, partnering stakeholders requested that we also conduct some of our work in several newly created and proposed National Park areas. To accommodate this request, we expanded the scope of our habitat mapping and assessments of species distributions. Due to resource limitations, however, expanding the scope of this aspect of the project meant that we had to limit tracking studies, with detailed studies of movement being focused on Nassau grouper (*Epinephelus striatus*). Nevertheless, in addition to Nassau grouper, movement of other important species, such as Caribbean spiny lobster (*Panulirus argus*), queen conch (*Strombus gigas*), and snappers (e.g., *Lutjanus apodus, L. griseus, L. synagris*) were also examined.

For Nassau grouper, we examined movements on multiple spatial (meters to hundreds of kilometers) and temporal (daily to seasonal) scales as they relate to key ecological processes (daily foraging movements to spawning migrations) and seascape features such as habitat characteristics and bathymetry. To do this, we mapped habitats within several existing and proposed MPAs using satellite imagery and *in situ* ground-truthing, we examined species distributions using in situ survey techniques, and we tracked movement of key fishery species using visual and acoustic tagging techniques. This research, conducted with the input from Bahamian marine resource management authorities and with the assistance of various stakeholders, has contributed to the MPA and fishery management planning processes in the Bahamas. In this final report, we present the results and key outcomes and outputs of our progress to date with respect to the five key objectives of the study:

1. Mapping habitats and distributions of key species in existing and proposed marine reserves in the Bahamas

2. Determining movement rates and patterns of key species on multiple spatial and temporal scales using GIS analyses to examine movements against seascape features and MPA boundaries.

These data were collected in partnership with Bahamian marine resource management agencies, local conservation organizations, and other stakeholders. Based on the data collected, we have made both general and specific recommendations on MPA planning and Fisheries management to marine resource management authorities in the Bahamas. Several of these studies are ongoing with funding from additional sources.

Project Accomplishments

Objective 1: Mapping habitats and distributions of key species in existing and proposed marine reserves in the Bahamas

Detailed habitat maps were created from high resolution Ikonos satellite imagery and lower resolution Landsat satellite imagery for several existing and proposed MPAs in the Bahamas. Mapping efforts are being conducted in partnership with researchers involved with the Bahamas Biocomplexity Project (Dr. Craig Dahlgren, the PI of this project is part of the Bahamas Biocomplexity Project). Due to requests from various partnering organizations and the availability of matching funds for habitat mapping, we mapped more areas than initially planned in the original grant proposal. Sites where our mapping efforts are focused in the Bahamas include:

Exuma Cays Land and Sea Park (existing National Park)
Fowl Cay preserve, Abaco (proposed National Park)
Southern Exuma Cays area (proposed as Fishery Reserve)
Central Andros (existing National Parks since 2002)
Bimini (proposed as Fishery Reserve)
San Salvador (proposed National Park)

Within all areas mapped, in situ surveys provided ground-truthing to validate habitats mapped from satellite imagery. Primary habitats and a brief description are included in Table 1 (from Mumby et al. in prep)

Table 1. Classification of coral reef and lagoonal habitats of The Bahamas although each class has a Caribbean-wide distribution

Habitat type	Characteristics
Marine / terrestrial interface	
Fringing mangroves	Found on shorelines, tidal creeks and offshore islands and surveys. Refers to sites along the outer edge of stands of red mangrove (*Rhizophora mangle*)
Lagoon	
Sparse seagrass	Dominated by the genera *Syringodium* and *Halodule*.
Medium-density seagrass	Dominated by *Thalassia* but may contain *Syringodium* and *Halodule*.
Dense seagrass	Dominated by *Thalassia* but may contain *Syringodium*.

Sand and sparse algae.	Sand with a sparse algal community
Algal-dominated hard-bottom.	Found in both lagoonal and reef environments. Very low relief hard-bottom with mixed marcoalgal community and few gorgonians
Patch reef	This is a geomorphological term but is typically dominated by a community of massive corals and dense gorgonians
Outer coral reef	
Acropora palmata	Found in reef crest environments between approximately 1 and 5 m. *Acropora palmata* visually dominates.
Dense gorgonians	Often located just seaward of the *Acropora palmata* zone but also found in shallow, wave-swept areas. Characterised by extremely high densities of gorgonians (> 10 m^{-2}) and little hard coral cover
Sparse gorgonians and algae.	Also known as a 'gorgonian plain'. Characterised by sparse gorgonians on hard-bottom with some macroalgae
Montastraea reef	*Montastraea* is the dominant reef-building coral in this habitat. Typically in relatively sheltered areas and has extremly high structural relief.

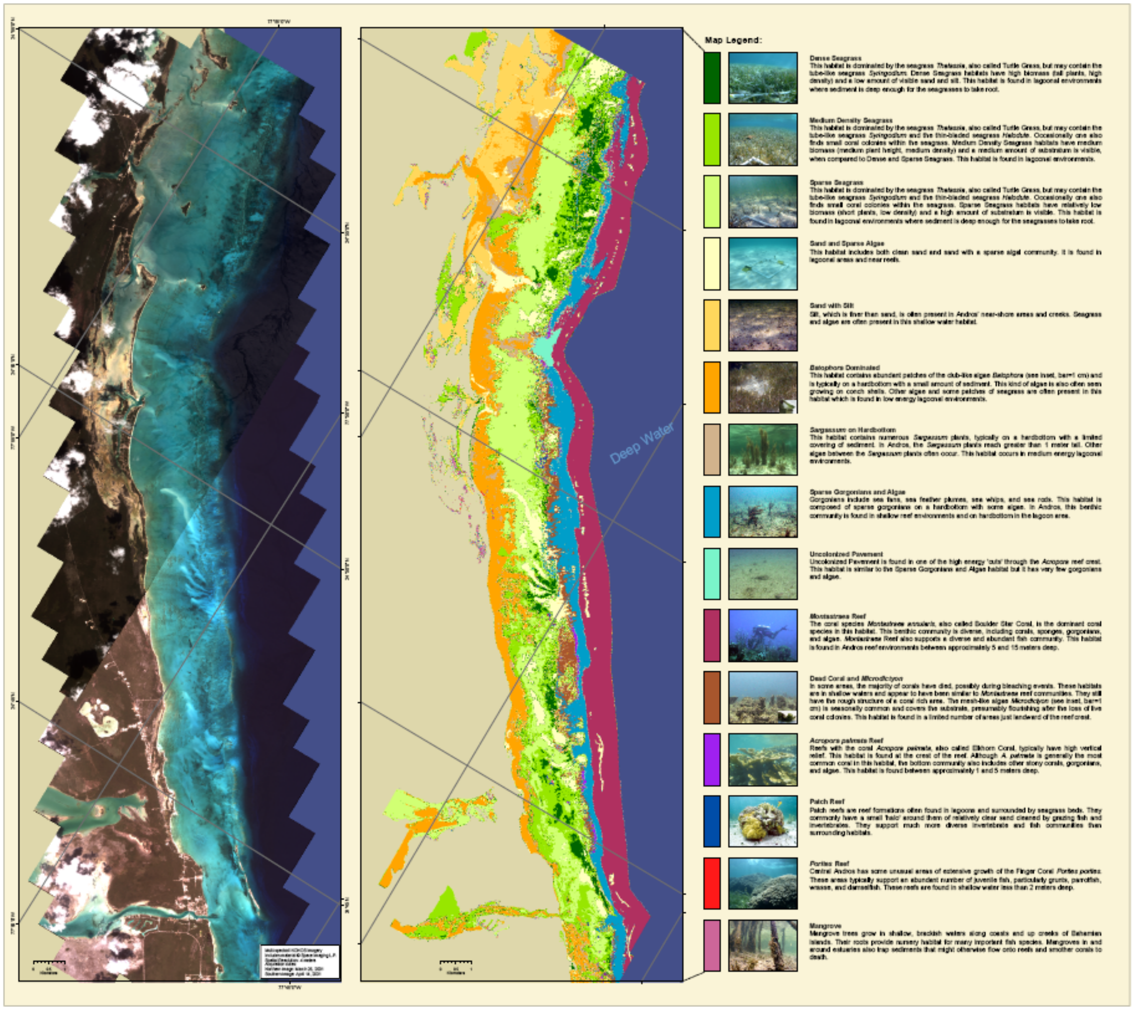
Other habitat types unique to specific locations were also categorized. Figure 1 provides an example of habitat maps derived from satellite imagery. Figures 2 and 3 show additional satellite imagery being used to create habitat maps as part of this project.

In several proposed MPA areas, key habitat features included nursery areas for important fishery species such as Nassau grouper (*Epinephelus striatus*) and Caribbean spiny lobster (*Panulirus argus*). These nursery areas, dominated by the macroalgae Laurencia sp., are difficult to discern from satellite imagery using spectral characteristics and were under-represented in our initial in-situ sampling. Thus, we conducted additional in situ sampling using towed video surveys to distinguish habitat composition in greater detail, followed by the development of algorithms that predicted habitat likelihood based on both spectral characteristics and contextual features that could be determined from satellite imagery (e.g., depth, substrate type). We are currently still refining model algorithms and developing habitat maps for several areas including:

Southside of Great Exuma (proposed Fishery Reserve)
Bight of Old Robinson, Abaco (proposed Fishery Reserve)
Central Andros (potential expansion of National Park)
Pelican Cays Land and Sea Park (potential expansion of existing National Park)

At each of these sites, we have also collected data on the distribution and abundance of fish in several different habitat types. In addition to the sites listed, earlier surveys of fish and benthic communities that were conducted in 2002 in the Moriah Harbour Cay National Park area were added to analyses and reports to MPA management authorities at the request of Mr. Basil Minns, the Chairman of Great Exuma's Tourism and Environment Committee (TEAC). Data from the Moriah Harbour Cay area is currently being used to strengthen park protection in the area and expand the existing park to include all areas that were initially proposed for park protection in 2002.

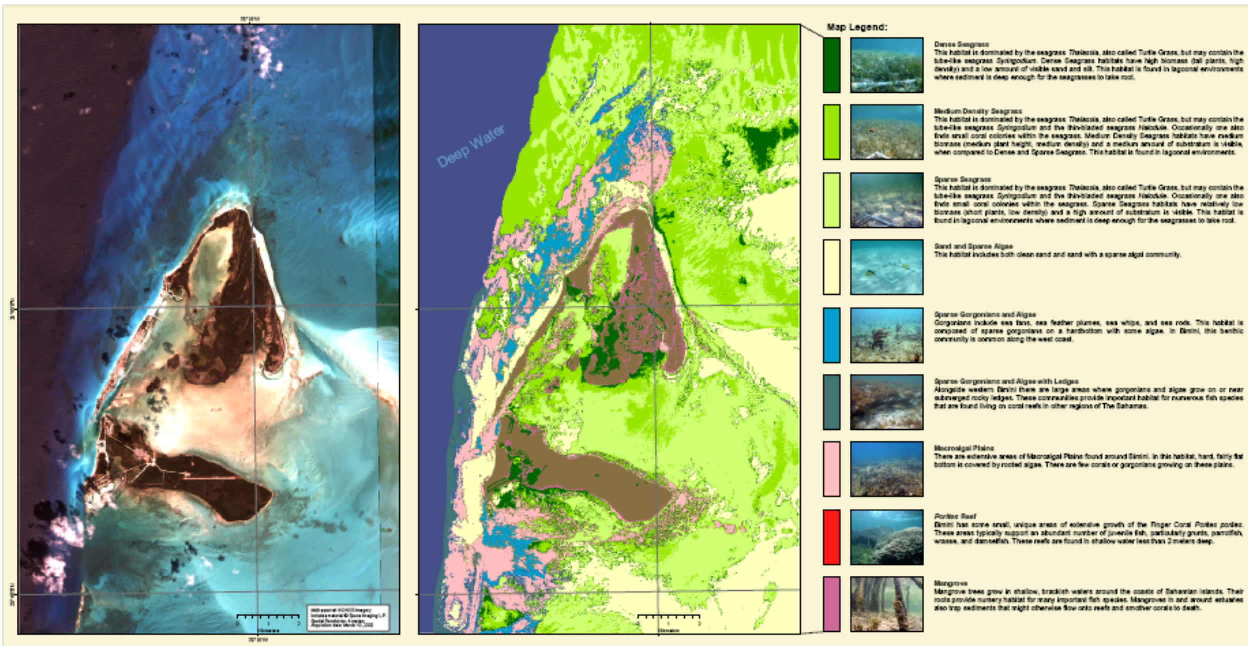
Figure 1A. Habitat map of Central Andros



Images of the east coast of Central Andros, The Bahamas. The depicted area ranges from 3 kilometers north of Stafford Creek to just south of Fresh Creek.

The photo-like image on the left was created from spectral data collected by the IKONOS satellite sensor in March and April 2001. The habitat map on the right, including the 15 common, shallow bottom habitat types represented, was constructed from this spectral data as well. The habitat classification process used habitat-type data from more than 600 ground-truthing spot surveys to assist with and verify classifications.

Figure 1B. Habitat map of area around North and South Bimini, including proposed MPA within the lagoon of North Bimini and surrounding waters.



Comparisons of fish distributions and abundances revealed several key findings. Not surprisingly, fish communities showed distinct differences among habitat types in terms of species richness and composition. Furthermore, different habitats were used by key target species (e.g., Nassau grouper) at different stages in their life history. For example, examination of the size distribution of Nassau grouper on patch reefs in lagoon environments was dominated by smaller size classes than outer reef habitats (Fig. 4).

Fish communities within a particular habitat type often differed among sites. In some cases, this may be due to natural occurrences such as differences in microhabitat, environmental conditions or larval transport across the widespread Bahamian archipelago. In other cases, observed differences could be attributed to protection afforded by an existing MPA. This was true of the Exuma Cays land and Sea Park, but not other MPAs in the Bahamas, probably because the Exuma Park is the largest and oldest MPA in the Bahamas, and it is the only one in which a prohibition on all fishing and other consumptive activities is enforced by a full time park Warden.

Figure 2. Pelican Cays Land and Sea Park (National Park, top part of image) and Bight of Old Robinson (proposed Fishery Reserve, large embayment in bottom half of image and surrounding areas), Abaco. Habitat maps of key nursery areas are still in development.

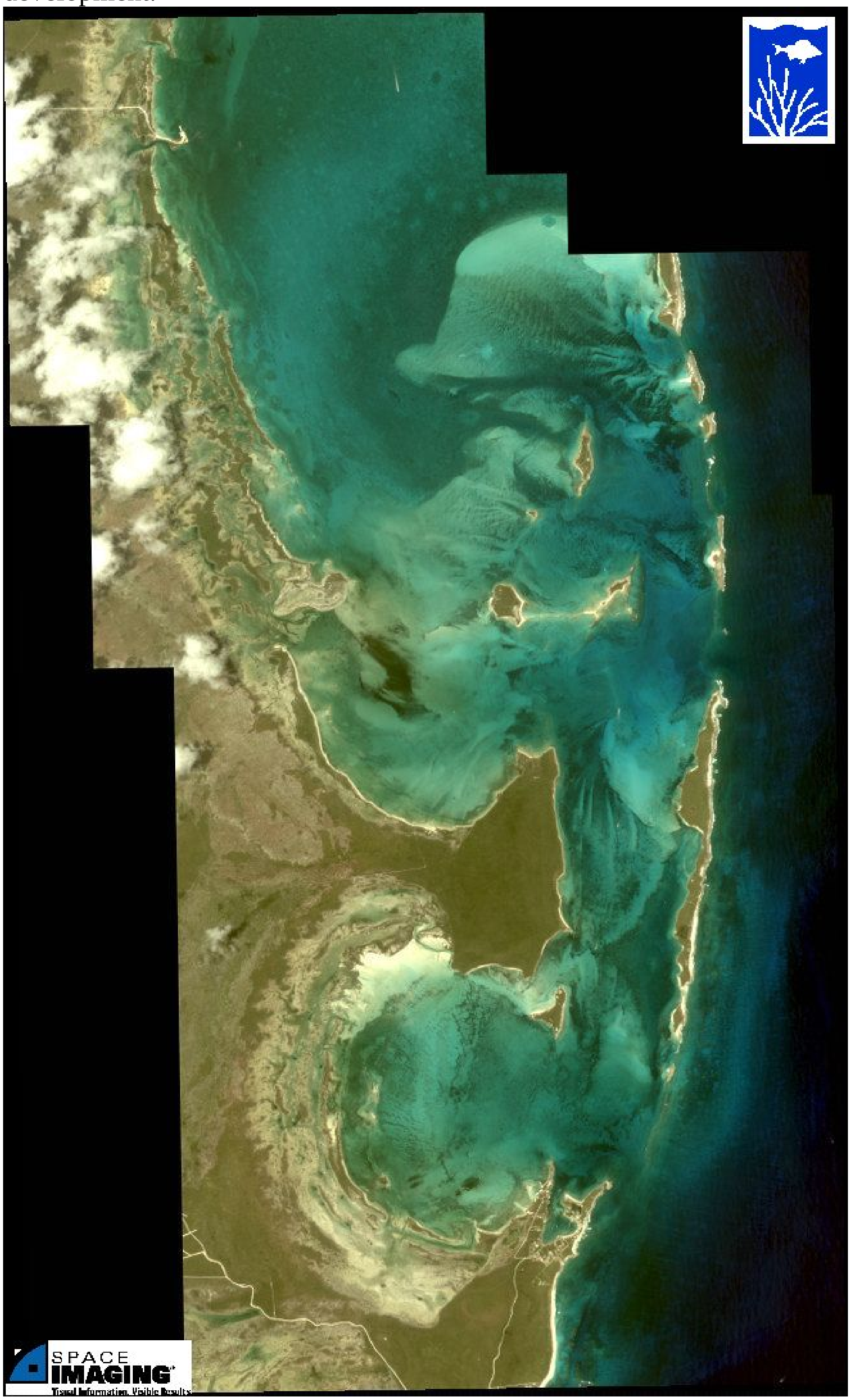
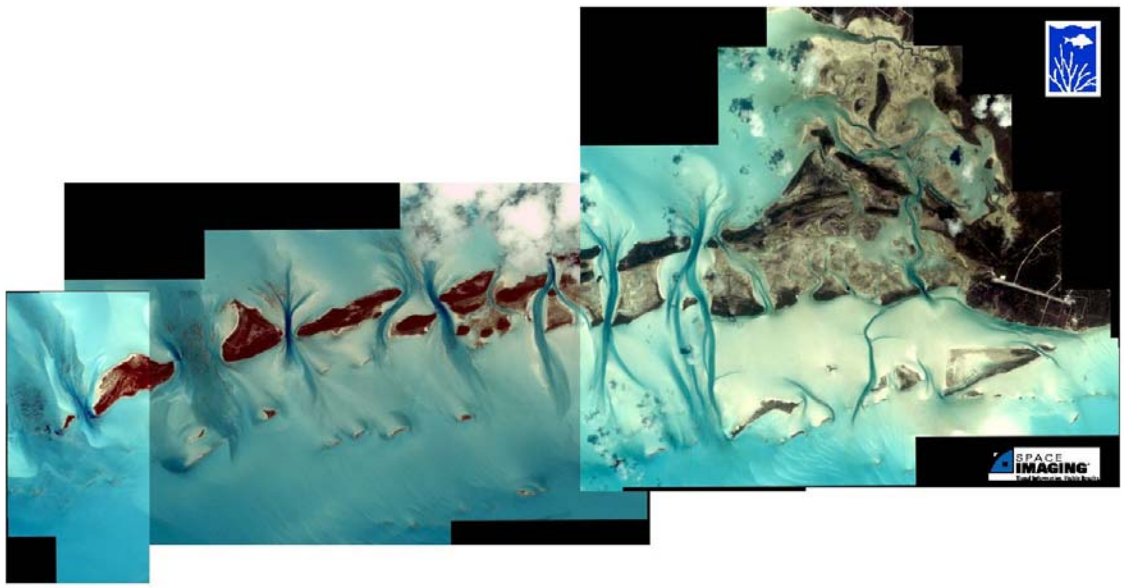


Figure 3. Southside of Great Exuma (proposed Fishery Reserve). Habitat maps of key nursery areas are still in development.



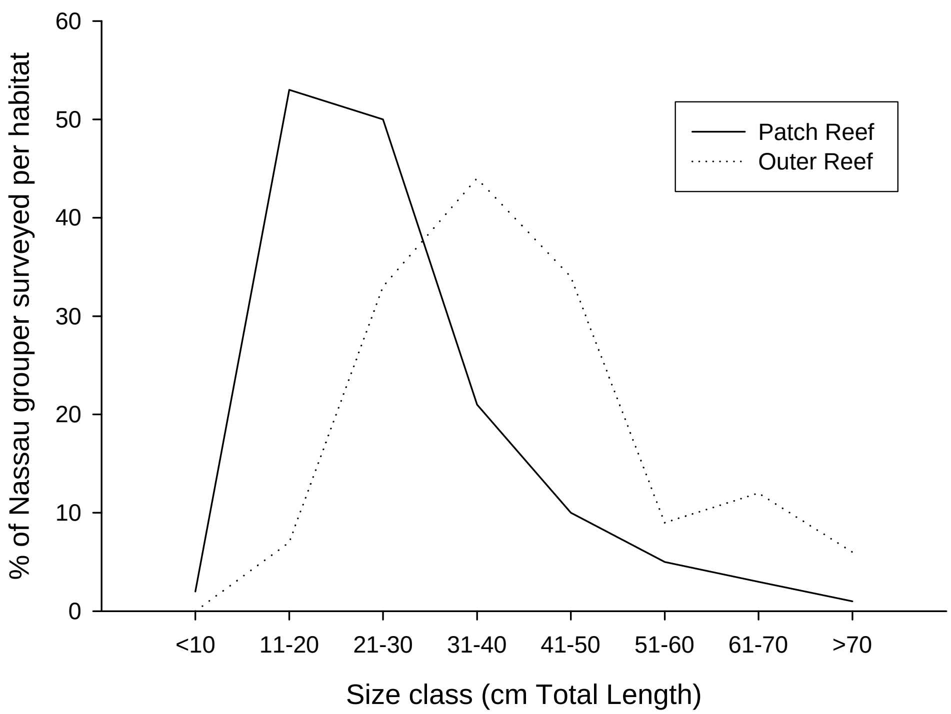


Figure 4. Size frequency distribution of Nassau grouper surveyed throughout the Bahamas in Patch reef (n=145) and Outer coral reef habitats (n=145). See Table 1 for description of habitat types.

A recent paper by Mumby et al. (2006) that was conducted as part of this project and supported in part by funding from this grant illustrates some of the differences in fish communities between the Exuma Cays Land and Sea Park and other sites in the Bahamas. Within the Exuma Park, targeted species like the Nassau grouper had several times greater biomass than at other sites surveyed. There were also complex interactions between protection from fishing and the increase in Nassau grouper (an important predator) biomass. For example, the biomass of smaller parrotfish species was lower in the park due to the increase in large Nassau grouper. Large parrotfish species abundance was greater in the park, however, due to protection from their take as bycatch in trap fisheries and their apparent size refuge from Nassau grouper and other predators. These differences in fish communities also had significant trophic affects whereby there was less algae and more corals within the Exuma Park than other sites.

These results have significant implications for the design of specific MPAs in the Bahamas, as well as general MPA design considerations. For specific MPAs, habitat maps are a powerful tool for ensuring the conservation of biodiversity. Because different habitats have different fish assemblages associated with them, MPAs that contain a wide range of habitats are more likely to harbor greater species richness than MPAs with fewer habitats. Thus, for the examples of Bimini and Andros shown in Figures 1 A and 1 B, creating (or expanding) MPAs to go from shore to the shelf edge will ensure the greatest diversity of habitats represented (as opposed to only including the interior lagoon in the case of Bimini, or only the outer reef in the case of central Andros). Because species assemblages differed among areas for the same habitat, however, only protecting one example of each habitat type is insufficient. Multiple MPAs in different area that protect similar habitats will also enhance biodiversity conservation. Furthermore, including a range of lagoon and outer reef areas will ensure that species using multiple habitats (either on a daily basis for refuging and foraging, or those like Nassau grouper that make ontogenetic habitat shifts), will receive maximum protection.

Objective 2: Determining movement rates and patterns of key species on multiple spatial and temporal scales using GIS analyses to examine movements against seascape features and MPA boundaries

As mentioned previously, our expansion of the habitat mapping and species distribution portion of this project resulted in a somewhat reduced ability to track movement. Thus, we focused our main efforts on examining Nassau grouper movement across a range of spatial and temporal scales and at different stages in their life cycle. In addition to this, however, we were also able to conduct preliminary examinations of spiny lobster, queen conch and snapper movements.

Nassau grouper – Nassau grouper were chosen as our primary species to examine movement based on its ecological and economic importance, our history of working with this species and the availability of complementary funds (through NURP and the Disney

Wildlife Conservation Fund). Furthermore, Nassau grouper are an excellent model species since they were expected to exhibit movements on a scale that is most relevant to the design of marine reserves. Nassau grouper are also currently listed on IUCN's red list of endangered species, so designing marine reserves to conserve Nassau grouper populations is of high importance in the Caribbean.

Our studies focused on examining daily movement of sub-adults and adults, ontogenetic habitat shifts from lagoon systems to offshore reefs, and annual spawning migrations. We accomplished this by implanting acoustic transmitters in 26 fish and tracking their movement using receivers deployed in an array to detect their presence within their home range (i.e., daily movements), cross-shelf movement (i.e., ontogenetic habitat shifts) and along shelf movement (i.e., spawning migrations). We also conducted these studies in areas in which we had detailed habitat maps to determine how seascape features affected movement and we arranged acoustic receivers to detect movement into or out of the Exuma park to determine whether there was a "spillover effect" and whether park protection affected movement (e.g., was movement correlated with a density gradient).

In October and November, 2004 a total of 11 Nassau grouper were captured in the Southern 1/3 of the Exuma Cays Land and Sea Park (ECLSP) and acoustic transmitters (Vemco V-8 and V-13 transmitters) were implanted into their body cavity. At the same time, a total of 19 acoustic receivers were deployed across the shelf edge at different distances from the southern boundary of the ECLSP (10, 5 and 1 km inside the park and 0, 2.5 and 5 km outside the park; Fig. 5). In June 2005, the acoustic receivers were retrieved, their archived data downloaded and then redeployed. Data from June 2005 indicated that of the 11 fish tagged, the majority of the fish remained within the area in which they were initially captured and released, but 3 of the larger fish (>50 cm) migrated out of the park along the shelf edge on the same day in December, 2004 and returned to the park along the shelf edge within 24 hours of each other 2 weeks later. This movement corresponded with the December full moon, thus it was assumed to be movement associated with annual spawning migrations.

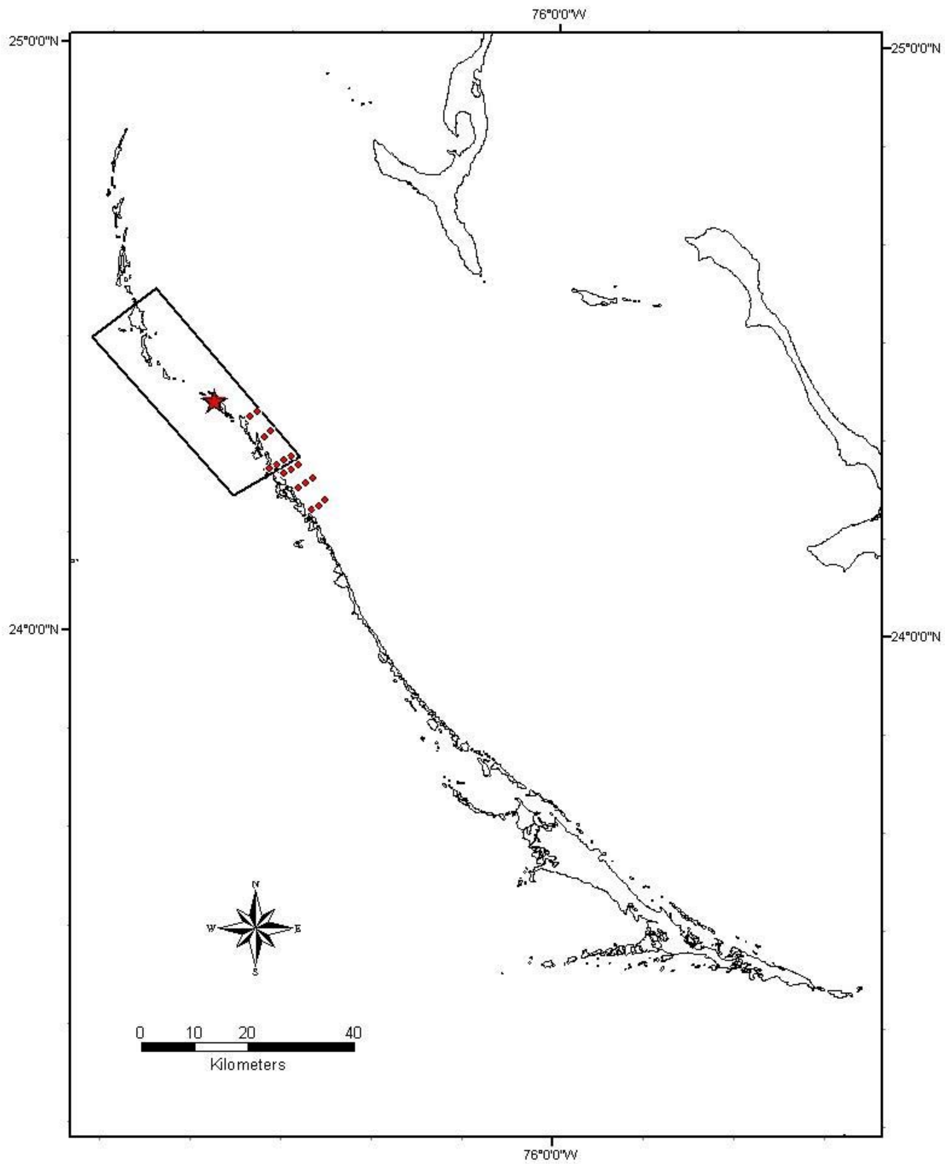


Figure 5. Map of Exuma Cays showing Exuma Cays Land and Sea Park (box), and park Headquarters on Warderick Wells cay (star) as well as the location of acoustic receivers deployed in 2004 to detect movement of Nassau grouper across the southern boundary of the Exuma Park. The area covered by each circle represents each acoustic receiver and its approximate detection range.

In October, 2005 acoustic telemetry receivers (28 total) were deployed within 300 m of the shelf edge (marked by a sharp drop off to depths >150 m) of the western margin of Exuma Sound, from the area near Sail Rocks in the north of Exuma Sound to the area between Long Island and Little Exuma in the south of Exuma Sound. Receivers were deployed at approximately 10 km intervals. An additional 2 receivers were placed across the shelf at the southern boundary of the ECLSP to improve our ability to detect movement of fish from the ECLSP. This sampling design will allow us to better track the movement of fish migrating to and from spawning aggregations and determine the extent to which fish move in the Exuma Sound system and whether there is spillover from the ECLSP. Figure 6 shows the approximate location of receivers deployed to track fish movement from October 2005, through the 2006/07 spawning season.

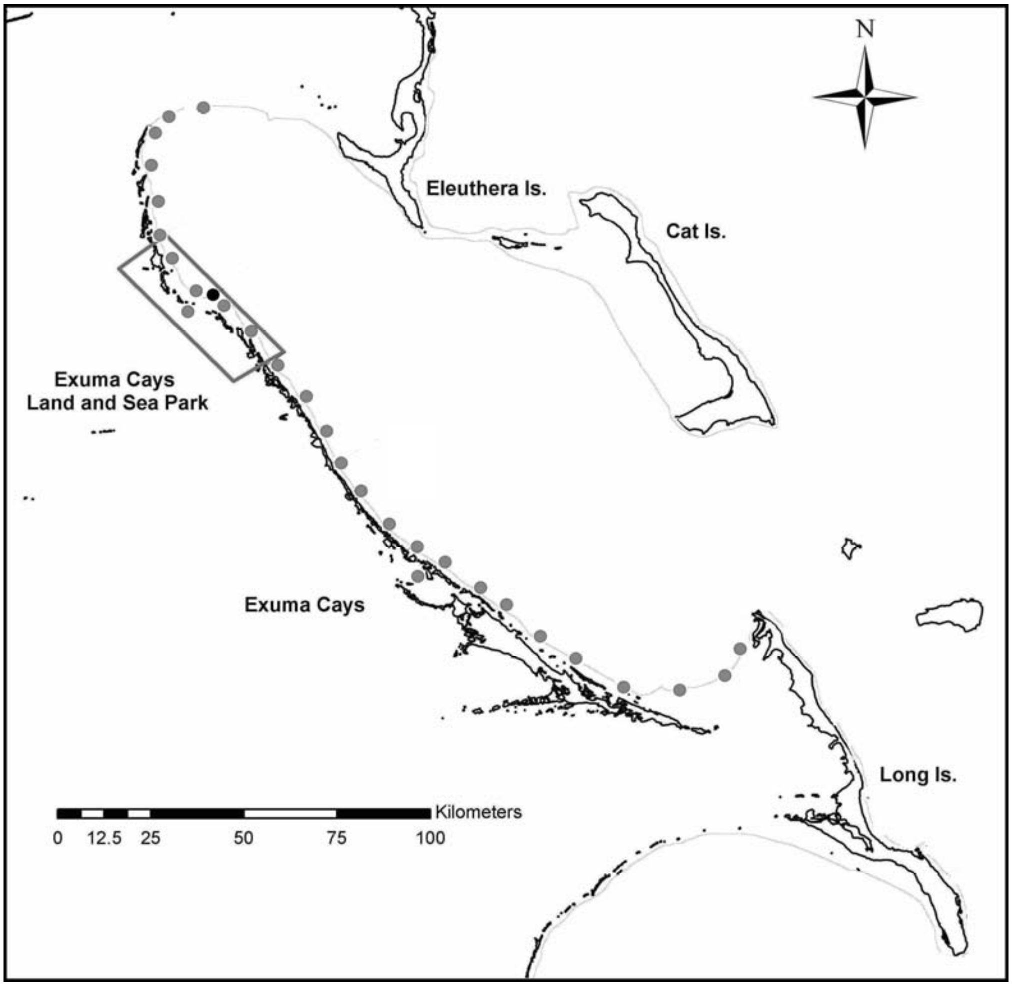


Figure 6. Telemetry receivers deployed along shelf edge and inshore areas in October 2005.

In October 2005, we also implanted acoustic transmitters in a total of 15 Nassau grouper and 1 mutton snapper and tagged them with externally visible tags. One Nassau grouper tagged was captured and tagged immediately South of the southern boundary of the Exuma Cays Land and Sea Park (ECLSP). Six Nassau grouper and the mutton snapper were captured within the ECLSP, and the remaining Nassau grouper were caught in the Lee Stocking Island and Great Exuma area (the largest of the Exuma Cays). Most fish were captured near receiver deployment sites so that their presence/absence could be noted throughout the year. For fish caught at inshore sites such as the Malobar Cays and Conch Cut in the Exuma Park, an additional receiver was deployed at each site to detect their presence/absence.

Following the winter spawning season of 2005-2006, all receivers were recovered, the data downloaded, and the receivers were redeployed with new batteries to continue to detect fish movements through the 2006-2007 spawning season. Data downloaded revealed the detection of 14 tagged fish, including all three fish tagged in 2004 that left the ECLSP to spawn. Of the 14 fish detected by receivers, 6 fish migrated from their home range to spawn during the winter of 2005-2006. Five of these fish migrated in December 2005 and one in January 2006. No fish migrated during both months. Migrations in both December and January bracketed the full moon period by up to 10 days. All fish observed to migrate from their home range were 59 cm total length or more (only 1 fish >59 cm TL was not observed to have moved from its home range; see Table 2 for sizes).

All fish were also observed to make spawning migrations to the south regardless of where they were tagged and all fish tagged in the ECLSP that made a spawning migration left the park. This southern migration took them to receiver locations between near Long Island, then most fish disappeared for several days, presumably continuing their spawning migrations to reported spawning aggregation sites at Long Island. Only one fish was tracked continuously through its migration, a fish tagged off Great Exuma, which left its home range on December 8 and reached the southernmost edge of Exuma Sound December 11, then headed back north on the same day to reach its home range on December 15. Although there is a reported spawning aggregation in this area, it is unclear whether this fish actually spawned, since it left the reported spawning area to return home prior to the full moon.

All fish observed to migrate from their home range returned to their home range within 10 days after the full moon, except for one fish. The fish that failed to return to its home range was one that left the ECLSP and returned to its home range in the 2004-05 spawning season. During the 2005-06 spawning season, however, it left the ECLSP and was tracked to between long Island and Little Exuma, and then it disappeared for a few days before being detected on its return migration. It was tracked on its return from the Little Exuma area, all the way to Black Point on Great Guana Cay (the long, skinny island south of the ECLSP), where it was last detected on December 20, 2005. Presumably this fish was captured by fishers (during the closed season) between receiver stations off Black Point and Staniel Cay.

On a daily scale, our ability to detect Nassau grouper throughout the day at telemetry receivers suggested that their movement did not exceed 300m regardless of their size or location across the shelf from nearshore patch reefs to offshore fore reef habitats. The use of high resolution acoustic receivers that triangulate on the location of fish indicated that although Nassau grouper in the 30 cm TL size were more active in the evening than during the day, their maximum movement off small patch reefs was <30m. Examining fish movement against benthic habitat maps indicates that while movement on this scale often occurred within reef habitats or from the reef to adjacent seagrass habitats, movement across non-reef habitats to another reef rarely occurred.

Ontogenetic migrations from nearshore patch reefs to offshore fore reef environments were observed for a few of the larger fish (>40 cm) tagged on patch reefs. The detection of four (out of five fish tagged in this size range) moving from their home patch reef to offshore reefs at this size, corroborates suggested ontogenetic habitat shift sizes based on the size distribution of fish from nearshore patch reef and offshore reef habitats. The timing of this habitat shift in the winter for all four fish suggests that there may be a seasonal component to this movement as there is with spawning patterns.

Seasonal migrations detected in fish >59 cm indicate that (1) movement to and from spawning aggregations occurs primarily during the first full moon of the spawning season for Exuma Sound; (2) fish from throughout Exuma Sound aggregate to spawn near Long Island > 100 km away from their home range; and (3) fish will only cross Exuma Park boundaries during these spawning migrations. These results have significant implications for MPA design and fishery management strategies. These implications are discussed in the recommendations section of this report.

Other species- During preliminary studies in 2004 in the area around Lee Stocking Island Bahamas, pilot studies to examine the movement of queen conch (*Strombus gigas*), Caribbean spiny lobster (*Panulirus argus*), and lane snapper (*Lutjanus synagris*)were conducted.

Queen conch - During these studies over 300 queen conch were tagged with externally visible tags in seagrass beds that serve as juvenile and adult habitat near Lee Stocking Island. Visual tags had an alphanumeric code to identify individuals during relocations and a distinct color code was used to denote the location where each conch was tagged (Fig. 7). Based on previous work by Stoner and colleagues (reviewed in Stoner 2003) to map habitats based on the quality of their nursery function, we tagged conch found in areas of low, medium and high nursery value. In addition, 6 conch were tagged with acoustic transmitters in areas of high quality. Over a 6 month period, conch with acoustic transmitters were tracked on a weekly basis using boat-based manual telemetry and conch throughout the seagrass beds were resurveyed on a monthly basis to relocate tagged conch.

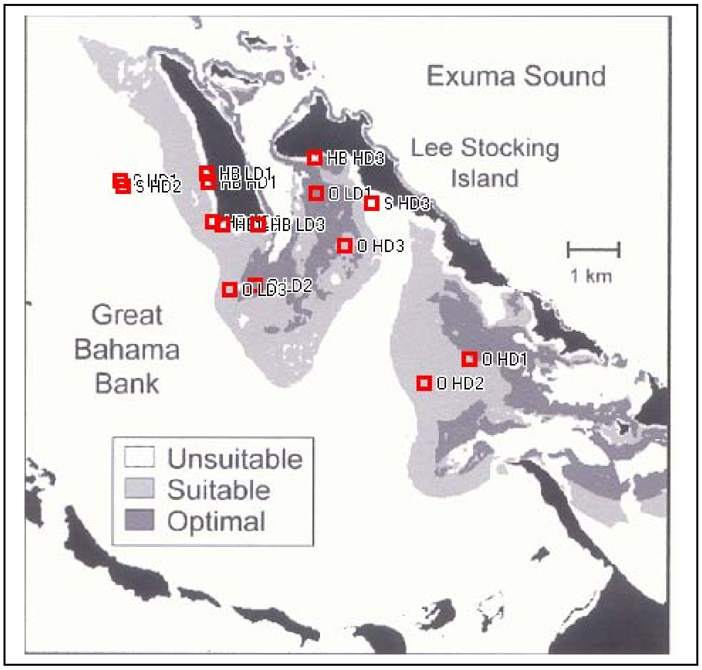
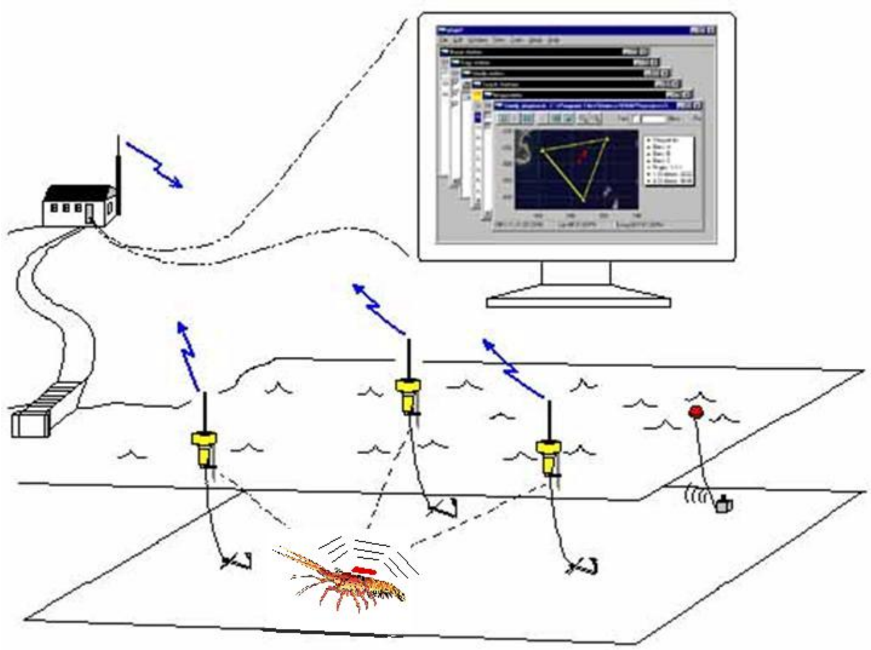


Figure 7. Map of conch tagging locations (red squares) in habitats classified according to their nursery value (Stoner 2003)

During the six month pilot study, all tagged conch were resighted for at least 3 months (after which batteries died on several transmitters) and nearly 50% of tagged conch were resighted. Maximum movement of conch during the study period was <1 km from the tagging location. While we realize that the duration, sample size and sampling frequency of this pilot study could be improved to provide more robust results, we decided not to pursue further conch tagging. This decision was based on the finding that movement rates did not differ among habitat categories and movement between habitat categories was observed in many instances and the scale of observed movement was far less than the scale of proposed MPAs in the Bahamas. Thus, further research along these lines would contribute little new information of relevance to the design of MPAs.

Caribbean spiny lobsters - pilot studies to examine movement of Caribbean spiny lobster were conducted in 2004. These studies involved attaching acoustic transmitters to the carapace of 20 spiny lobster and tracking their movement in the area near Lee Stocking Island using a Vemco ™ VRAP telemetry system that consisted of 3 buoys that are capable of triangulating on each transmitter to determine the exact location of the lobster with up to 10 cm accuracy (Fig. 8). The buoys relay this information to a base station which allows the simultaneous tracking of several lobsters (more than our sample size) in real time against a habitat map to determine habitat use patterns, home range size, and the scale of their movements. Studies in the Lee Stocking Island area were conducted within an array of transplanted and artificial patch reefs spaced at distances of approximately 5, 25 or 250 m apart and separated by a mix of bare sand and seagrass of varying densities. Since acoustic signals from transmitters were blocked by reef structure, we were able to determine when lobsters were within refuges provided y the reef structure (no signal), when lobsters were on the surface of the reef (signal from reef site) and when they were using other habitats during foraging forays or migrations between reefs.

A.

B.
Figure 8. Telemetry equipment used to track lobster movement, including (A) acoustic transmitter attached to lobster carapace, and (B) diagram of VRAP system used to track lobster movement.

In addition to the 20 lobsters tagged with acoustic transmitters, an additional 50 lobsters were tagged with PIT tags, similar to "microchips" used to tag pets and livestock. These small tags, approximately the size of a grain of rice (Figure 9A), were inserted under the carapace on lobsters while they were sheltering on reefs. The tags are coded with an alphanumeric code that can be read when the tag is within the magnetic field of a reading instrument. We used a prototype underwater PIT tag reader provided by Biomark ™ (Figure 9B), which allowed us to get readings in situ of lobsters residing in reefs, rather than having to capture them and take them to the surface to read the tags. Lobsters with PIT tags were recensused weekly for a period of 4 weeks.

A.   B.
Figure 9. Photographs of PIT tags (A) and underwater PIT tag reader used in lobster study.

Results of these pilot studies indicated that lobsters resided within reef structure throughout daylight hours and only emerged within 1 hour of sunset to make foraging migrations. These migrations usually occurred within 250 m of the “home reef”, and often involved visits to other reefs in the study system (Figure 10). Only about 20% of lobsters with either type of tag were observed to move between reefs during the study period, and about 10% of the lobsters left the study system during the course of the study. Of the lobsters that moved between reefs, the majority (>50%) moved between reefs 25 m apart or less, even these reefs only contained 15% of the lobsters tagged. Unfortunately, tag loss during molting limited the duration of our telemetry studies. Nevertheless, these data suggest that lobster movement usually occurs on spatial scales of 100’s of meters at most and site fidelity is strong, particularly for reefs spaced >100 m apart.

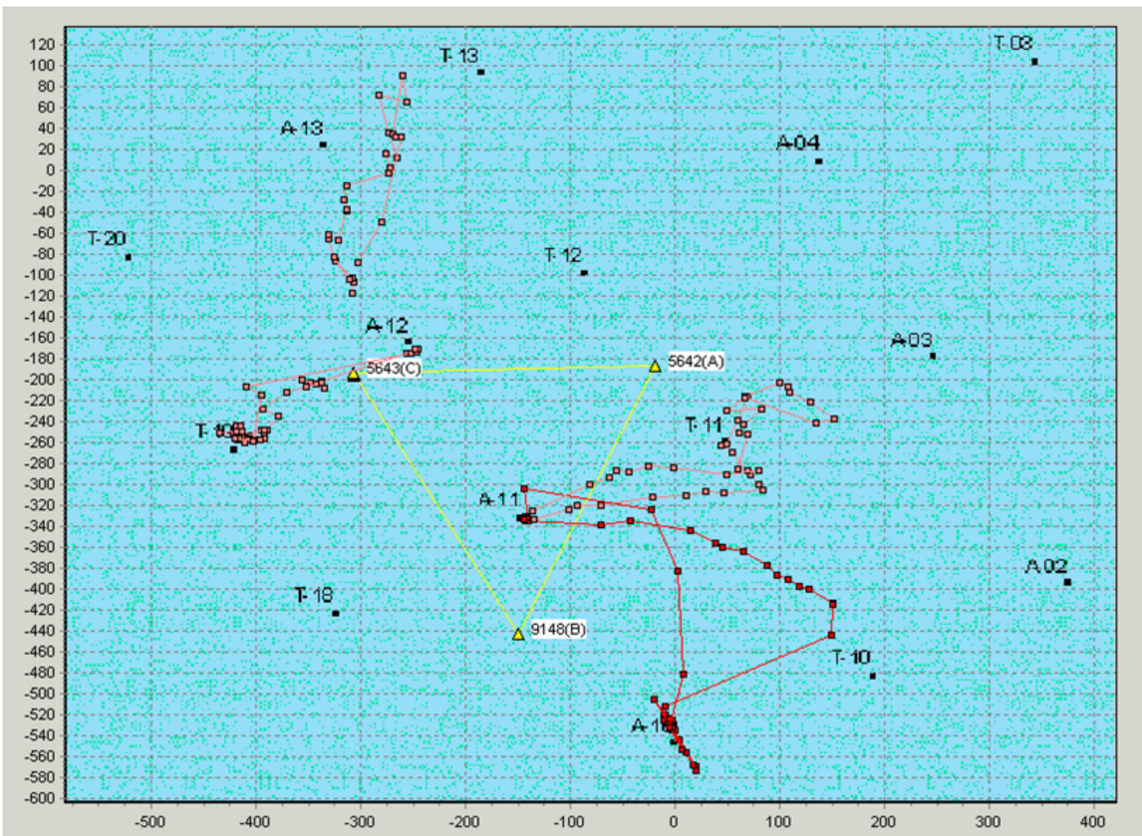


Figure 10. Example of nightly lobster tracks on VRAP software. Tracks shown are nightly foraging migrations of 2 lobsters residing on reef A-12 and two lobsters residing on reef A-11. Reefs are shown as labeled black squares and VRAP telemetry receiver buoys are shown as yellow triangles. Lobster tracks are sown as pink or red points connected by lines. Vertical and horizontal axes show scale of movement in meters.

Snappers - Prior to the start of this project, we conducted a pilot study examining the movement of lane snappers in the area near Lee Stocking Island (the same study system used for lobsters), which indicated that they regularly move on the order of 100’s of meters at night, but reside close to reefs during the day and only make periodic movements between reefs or out of the study system (during the spring spawning season). During the late stages of this project we began to work with local volunteers to examine movement of other species of snapper. This research, conducted in partnership with Dr. Craig Layman of Florida International University and a local environmental organization in Abaco, Bahamas, Friends of the Environment, is called "Adopt a Fish Adopt a School" (www.adoptafish.net). The Adopt a Fish, Adopt a School program is designed to directly integrate students and community members into a scientific research program in an innovative fashion. From a science standpoint, the goal is to track movements of snappers and other fishes in the nearshore marine environment to determine their habitat use and movement rates. Funding from this grant was instrumental in Dr. Craig Dahlgren's initial participation in getting this program started. No results are available to date, but they are expected over the next 6 months as more fish are tagged and tracked.

Conclusions and Recommendations

Based on our habitat mapping, species distribution and abundance data, and movement data for a few species we can make site specific recommendations with respect to specific MPA design considerations in the Bahamas. These recommendations have been presented to the Bahamas National Trust (National Park management authority), Department of Marine Resources (formerly Department of Fisheries, charged with creating and managing Fishery Reserves in addition to general fishery management) and local groups involved with creating new MPAs (see Appendices). In particular, we have been working with the Department of Natural Resources and The Nature Conservancy to develop a formal Fishery Reserve proposal to present to Parliament. This proposal is the final step in the creation of 6 new Fishery Reserves which were initially proposed in 2000. Due to political delays, the proposal has not been completed at the time of this report, but the final draft of this proposal is expected to be submitted and approved in early 2007.

Our surveys of the Exuma Cays Land and Sea Park show that MPAs, particularly large ones, encompassing multiple habitat types and providing full protection against all exploitation, can contribute the conservation of key species like Nassau grouper and queen conch. Furthermore, the effects of protection may be seen throughout the ecosystem through trophic linkages and other forms of species interactions. Thus protection from fishing may have a positive effect on target species and key ecosystem processes that are critical to the resiliency of coral reef ecosystems.

In contrast to this, however, our movement studies show that, while the Exuma Park harbors elevated Nassau grouper biomass, it does not provide protection to Nassau grouper during their most critical time, their spawning season. Since the majority of Nassau grouper in the Bahamas are caught during the spawning season, additional fishery management measures, such as a closed season, may be necessary to protect this economically and ecologically important, but threatened species.

Based on studies of Nassau grouper, queen conch, spiny lobster and lane snapper movement, spillover is likely to benefit only local fisheries immediately outside MPA boundaries (with the exception of grouper and snapper making spawning migrations). Daily movement of key species is quite low (<500m), making spillover from large MPAs unlikely. Analysis of movement against a background of seascape features indicates that, while some habitats appear to be more heavily traveled corridors for movement (e.g., the shelf edge for migrating Nassau grouper), but few habitats were identified as barriers to movement for key species. For example, movement between reefs did not vary extensively based on distance between reefs for lobsters or groupers, indicating that sand and seagrass between reefs does not serve as a barrier. Thus, MPA boundaries may be difficult to site for the purpose of limiting movement from the MPA, but since movement rates are relatively low, spillover is likely to occur on a limited basis.

While habitats may not affect movement of key species on a daily basis, habitat preferences by different species or different life stages of key species makes habitat mapping an important part of designing MPAs. MPAs that include a diversity of habitats are likely to protect a greater diversity of species than areas with fewer habitats. Similarly, areas that include both nearshore and offshore reef habitats are more likely to protect species that make cross-shelf ontogenetic habitat shifts like Nassau grouper. Thus, habitat mapping is a critical step in designing effective MPAs in the Bahamas.

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