Implementing the Dry Tortugas National Park Research Natural Area Science Plan - The 10-Year Report

Florida Fish and Wildlife Conservation Commission

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Tortugas National Park

Research Natural Area Science Plan

The 10-Year Report

Implementing the

Dry Tortugas National Park

Research Natural Area Science Plan:

The 10-Year Report

Prepared by the

Florida Fish and Wildlife Conservation Commission

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Photograph of Fort Jefferson by Jingang Luo

Implementing the Dry Tortugas National Park Research Natural Area Science Plan: The 10-Year Report 2017

EXECUTIVE SUMMARY

In 2007, the Florida Fish and Wildlife Conservation Commission (FWC) in conjunction with the National Park Service (NPS) developed a science plan to assess the successfulness of the 46-mi^2 Research Natural Area (RNA) within the Dry Tortugas National Park (DRTO). Entitled 'Assessing the Conservation Efficacy of the Dry Tortugas National Park Research Area', this science plan outlined how the RNA was to be evaluated after its implementation.

The RNA is a no-take (all fishing is prohibited), no-anchoring (purposefully placed mooring buoys are provided) marine reserve that was designed to protect shallow water habitats and reef fish species in conjunction with two nearby existing marine reserves, the Tortugas North Ecological Reserve (TNER) and the Tortugas South Ecological Reserve (TSER).

In 2012, the Commissioners were updated with a 5-year report. Based on the science presented in the report, it was decided to continue the RNA marine reserve for an additional 5-years. This 10-year report summarizes the progress of the science plan activities to date. The science presented in this report had been facilitated by cooperation between federal and state agencies as well as collaboration with NOG and academic partners. The results of the monitoring programs and scientific studies presented here show how resources have responded thus far to the protection provided. The 10-year report is organized around central topics that were described in the original science plan. As summary of each project and their performance is provided here.

RNA Topic 1: Quantify changes in the abundance and size-structure of exploited species within the RNA relative to adjacent areas

Chapter 1: Status of reef fish resources of the Tortugas region based on fishery-independent visual and trap survey assessments – Jeffrey Renchen et al.

Fishery independent visual surveys were conducted from 1999 to 2016 to monitor the status of reef fish throughout the Dry Tortugas region. This report examined the change in abundance and size structure of four commercially and recreationally important fish species, and specifically if the establishment of the no-take RNA has enhanced the protection of these species.

Scientist conducting reef fish visual census count in the Dry Tortugas. Photo by Jingang Luo

RNA Topic 2: Monitor the immigration and emigration of targeted species in the RNA

Chapter 2: Regional connectivity of mutton snapper within the Tortugas region of Florida – Michael Feeley et al.

Acoustically tagged mutton snapper were observed to make migrations between the RNA and the TSER as many as four times during each summer spawning season. A large mutton snapper aggregation and repeated spawning events were documented for the first time in Florida, 5 days after the full moon, along the south slope of a feature known as Riley's Hump (RH) in the TSER. The RNA, complemented by the TNER and the TSER, provides critical protection of essential reef fish habitat and important fish spawning habitat. The results suggest that the RNA may provide important support to the mutton snapper spawning aggregation at RH.

Mutton snapper acoustically tagged in a spawning aggregation in the TSER have home sites in the RNA outside of the spawning season.

Chapter 3: Riley's Hump as a multispecies aggregation site – Danielle Morley et al.

Since 2011 FWC scientists have been collaborating with peers at the National Oceanic and Atmospheric Administration (NOAA) and the Florida Keys National Marine Sanctuary (FKNMS) to monitor patterns of fish use of Riley's Hump in the TSER. Using diverse tools including remotely operated vehicles, technical divers and stereo cameras they have recorded elevated densities of snapper and grouper species. Couple these observations with larval transport models produced for the 5-year report and the importance of the TSER for maintaining healthy reef fish populations within other parts of the Florida Keys and the Florida peninsula becomes apparent.

FWC scientist preparing to deploy remotely operated vehicle to search for fish aggregations in the TSER.

Chapter 4: Yellowtail snapper movements in and near the Dry Tortugas National Park Research Natural Area – Jennifer Herbig et al.

Home range estimates of acoustically tagged yellowtail snapper were utilized to evaluate movement across management boundaries in DRTO. Movement across management zones was detected for xx of the acoustically tagged yellowtail snapper with xx fish having home ranges that straddled the RNA boundary. The RNA is likely providing benefits to the surrounding region through spillover.

Chapter 5: Use of Dry Tortugas National Park by nurse sharks as a mating ground – H. Wes Pratt et al.

Acoustic tracking of adult nurse sharks revealed patterns in movement not previously known for this species. Male nurse sharks come to DRTO annually and females appear bi- or triennially during the June/July mating season. Once the mating season has ended, males depart immediately while females remain through the next spring. Monitoring these animals' movements through acoustic tracking has shown that these animals can make large migrations to and from these mating grounds with several individuals being detected 335 km away on the west coast of Florida and one individual returning to DRTO six times. These migration patterns and site fidelity suggests that DRTO is a vital mating and nursery ground for nurse sharks.

A courting male nurse shark (left) attempts to grasp the pectoral fin of a female on the Dry Tortugas shark mating grounds. The fin grasp is a necessary prelude to mating. Photo by Harold L. Pratt, Jr., Mote Marine Laboratory

Summary Evaluation of Dry Tortugas National Park Research Natural Area Performance

Upon completion of the DRTO RNA science plan in 2007, NPS and FWC science managers set their primary goal to be finding the means to fund and support research projects focused on the immediate high-priority RNA performance topic areas, especially those related to changes in fish populations. Their efforts to address this goal resulted in the initiation or expansion of projects designed to survey adult fish populations, and conduct acoustic tagging studies of fish movements. Taken together, the results of these studies suggest that the RNA has played a substantive role in enhancing some exploited reef fish species populations in the region and, especially in the case of mutton snapper, has likely contributed to the recovery of the spawning aggregations located at Riley's Hump. Extensive surveys of adult fish (Chapter 1, this volume) observed increases in the abundance of commercially and recreationally exploited species within the RNA. Monitoring fish use of Riley's Hump through several different types of technology have shown researchers that this area is utilized by several different snapper and grouper species and when coupled with previously developed larval transport models generated for the 5-year report indicate that fish larvae from these spawning aggregations settle throughout south Florida, including the Dry Tortugas (Chapter 3, this volume). Studies that tracked acoustically tagged fish not only detected spillover with yellowtail snapper, but identified a previously unknown migratory behavior of nurse sharks that travel hundreds of kilometers to mating grounds within DRTO (Chapters 4 and 5, this volume).

Overall, protection offered by the RNA has added substantial benefits to the protection already provided by the preexisting reserves in the Tortugas region. These benefits have not only occurred within its borders, but extend beyond its borders via larval transport. Because it was expected that any changes in the habitat structure or trophic cascades would be slow to occur and only detectable over a longer time-period than five years, the science managers' main goal was to ensure that appropriate baseline studies were conducted for these performance topics.

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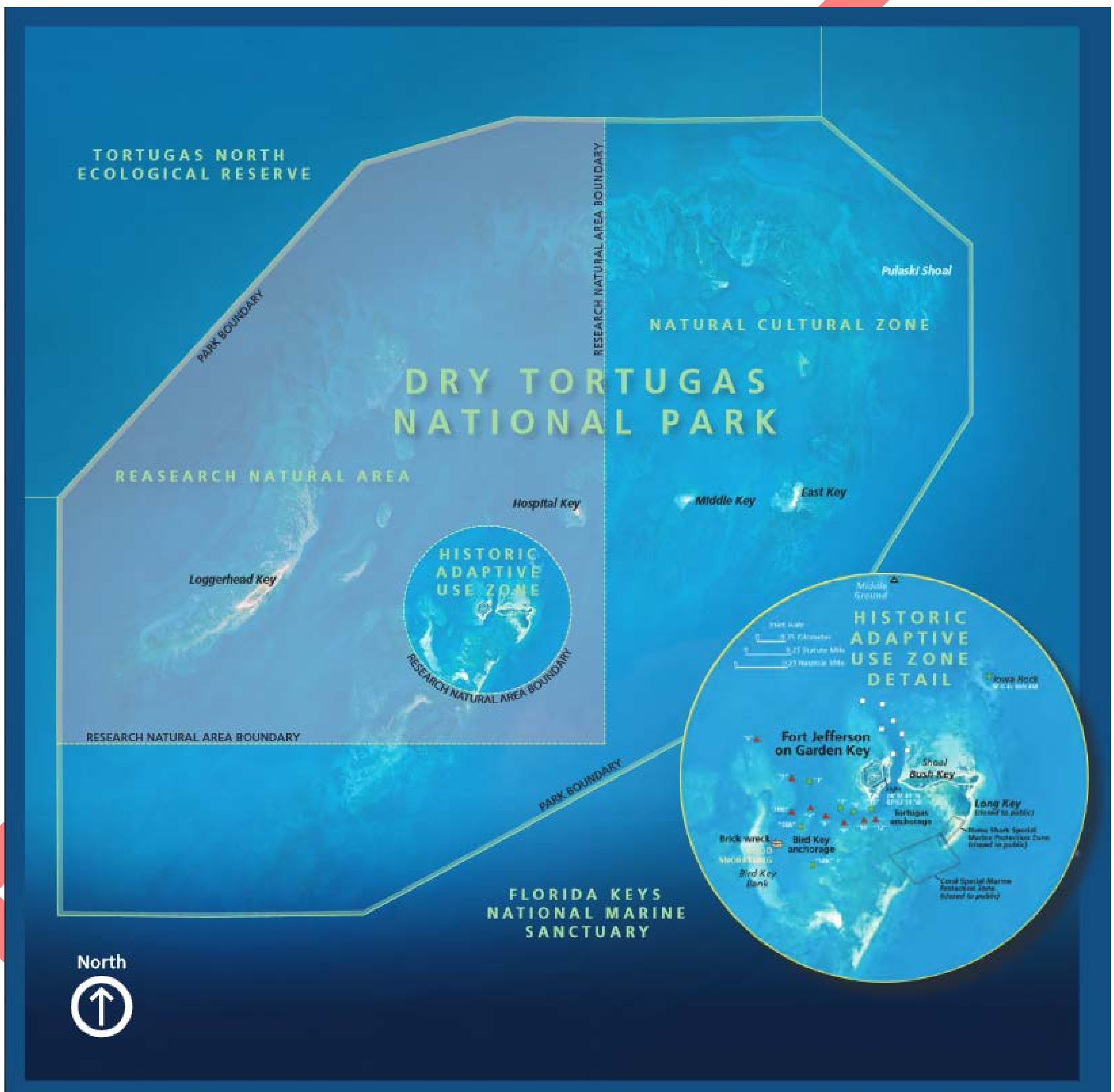
TORTUGAS NORTH
ECOLOGICAL RESERVE
PARK BOUNDARY
RESEARCH NATURAL AREA BOUNDARY
Pulaski Shoal
NATURAL CULTURAL ZONE
DRY TORTUGAS
NATIONAL PARK
REASEARCH NATURAL AREA
Hospital Key
Middle Key
East Key
Loggerhead Key
HISTORIC
ADAPTIVE
USE ZONE
RESEARCH NATURAL AREA BOUNDARY
RESEARCH NATURAL AREA BOUNDARY
PARK BOUNDARY
Middle
Ground
HISTORIC
ADAPTIVE
USE ZONE
DETAIL
Iowa Rock
Fort Jefferson
on Garden Key
Shoal
Bush Key
Long Key
Tortugas
anchorage
Brick wreck
Bird Key
anchorage
Bird Key
Bank
FLORIDA KEYS
NATIONAL MARINE
SANCTUARY
North

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LIST OF ABBREVIATIONS

ASMIS	Archeological Sites Management Information System
ATRIS	Along Track Reef Imaging System
CPUE	Catch per unit effort
CREMP	Coral Reef Model Evaluation and Monitoring Project
DRTO	Dry Tortugas National Park
FKNMS	Florida Keys National Marine Sanctuary
FSA	Fish spawning aggregation
FWC	Florida Fish and Wildlife Conservation Commission
FWRI	Fish and Wildlife Research Institute
HAU	Historic Adaptive Use Zone
KDE	Kernel density estimate
MCP	Minimum convex polygon
MPA	Marine protected area
NCZ	Natural Cultural Zone
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTMR	No-take marine reserve
RNA	Research Natural Area
SPZ	Special Protection Zone (as in Nurse Shark SPZ or Coral SPZ)
TNER	Tortugas North Ecological Reserve
TSER	Tortugas South Ecological Reserve
USGS	U.S. Geological Survey

INTRODUCTION

In 2007, the National Park Service (NPS) and the Florida Fish and Wildlife Conservation Commission (FWC) established the 46-mi^2 Research Natural Area (RNA) of Dry Tortugas National Park (DRTO) and prepared a science plan specifically to assess the effectiveness of the RNA (SFNRC and FWC 2007). The science plan was developed using an open and transparent process that started with a meeting (February 12 and 13, 2007) to obtain recommendations from state and federal agency scientists. Participating agencies included: Florida Fish and Wildlife Conservation Commission (Division of Marine Fisheries Management and Fish and Wildlife Research Institute), National Park Service (DRTO, South Florida Caribbean Network, and Water Resources Division), National Oceanographic and Atmospheric Administration (Fisheries, National Marine Sanctuary Program, and National Ocean Service), and the U.S. Geological Survey. Using the recommendations gathered, the NPS and FWC produced a draft science plan and distributed it to agency scientists, academic scientists, and members of the public for a 30-day review period. A public meeting was then held to gather additional comments and input on the draft science plan (May 3, 2007). The meeting was well attended by agency and academic scientists, representatives of nongovernmental organizations, and concerned citizens. Their comments were addressed in the final science plan.

Fort Jefferson National Monument was established in 1935 and reauthorized in 1992 as Dry Tortugas National Park. Congress established DRTO to "preserve and protect for the education, inspiration, and enjoyment of present and future generations nationally significant natural, historic, scenic, marine, and scientific values in south Florida." The enabling legislation stipulated that the park be managed to protect, among other values, "a pristine subtropical marine ecosystem, including an intact coral reef community." The RNA directly supports the mission of the park as the RNA was established to protect shallow water marine habitat, ensure species diversity, and enhance the productivity and sustainability of fish populations throughout the region. The marine regulations instituted within the boundaries of the RNA prohibit all forms of fishing and do not allow anchoring (a limited number of strategically located mooring buoys are provided). Together, the RNA and the adjacent Tortugas North Ecological Reserve and nearby Tortugas South Ecological Reserve of the Florida Keys National Marine Sanctuary will help to ensure the success of the marine ecosystems, and thereby contribute to a region-wide effort to strengthen resource protection.

The intent of the RNA science plan was to develop long- term studies and monitoring to document existing baseline conditions and analyze how natural resources will respond to the protection provided. Consequently, the science plan identified six areas of RNA performance to be evaluated:

1. Quantify changes in the abundance and size-structure of exploited species within the RNA relative to adjacent areas,
2. Monitor the immigration and emigration of targeted species in the RNA,
3. Monitor changes in species composition and catch rates of exploited species throughout the surrounding region,
4. Evaluate the effects of RNA implementation on marine benthic biological

communities,

5. Assess reproductive potential of exploited species by evaluating egg production and larval dispersal, and
6. Incorporate social sciences into the research and monitoring program.

Because ecosystems take time to respond to management actions, the science plan included a variety of indicators designed to evaluate RNA performance both in short and long time frames. Natural variability in sea temperature, weather events such as hurricanes, and other factors can affect many of the indicators described in the science plan and thereby have the potential to complicate RNA assessment. The full benefit of the RNA to the Tortugas region will only be measurable in the long-term. In 2010, NPS and FWC scientists submitted a 3-year report (Hallac and Hunt 2010) that described progress in the implementation of science projects and some preliminary results. This 5-year report provides the first evaluation of the performance of the RNA. Although the results presented in this report provide considerable useful information regarding RNA performance, many of the research projects presented in this report are ongoing, and monitoring continues. Future evaluations will have the capacity to provide a more expansive discussion of the performance of the RNA.

The NPS and FWC remain committed to working together to conduct research, education, and adaptive management of the Dry Tortugas ecosystem. They jointly developed a 5-year report in 2012 (Ziegler and Hunt 2012). Then, they signed and additional MOU in 2013 which resulted in the creation of this 10-year report.

Literature Cited

Hallac, D.E. and Hunt, J., editors. 2010. Implementing the Dry Tortugas National Park Research Natural Area Science Plan: The 3-year report. South Florida Natural Resources Center, Everglades and Dry Tortugas National Parks, Homestead, FL, and the Florida Fish and Wildlife Conser- vation Commission, Tallahassee, FL. 37 pp.

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Ziegler and Hunt. 2012. Implementing the Dry Tortugas National Park Research Natural Area Science Plan: The 5-year report. South Florida Natural Resources Center, Everglades and Dry Tortugas National Parks, Homestead, FL, and the Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. 63 pp.

TORTUGAS REGION MANAGED AREA OVERVIEW

The scientific activities reported in this document were conducted within the different management areas of the Tortugas region. Each chapter examines a specific performance measure and presents the results relative to these management areas. In order to facilitate the understanding of the chapters, we present an overview and definition of each of these management zones and their associated levels of resource protection.

The DRTO, located approximately 70 miles to the west of Key West, includes 100 mi^2 of marine waters and seven small islands, one of which contains Fort Jefferson, a national historic site. Marine-related activities allowed park-wide include boating, snorkeling, SCUBA diving, and wildlife viewing. Commercial fishing and spearfishing are prohibited throughout the park. DRTO is comprised of three management zones: the Research Natural Area, the Natural Cultural Zone, and the Historic Adaptive Use Area.

The RNA encompasses 46% of the park. It is located in the western portion of the park. Recreational fishing is prohibited within the RNA. Snorkeling and SCUBA diving are allowed; however, boaters are required to use mooring buoys, as anchoring is prohibited.

The NCZ encompasses approximately 51% of the park. It is located in the eastern and southern portions of DRTO. Recreational fishing is allowed in this area as well as in the Historic Adaptive Use Zone. Anchoring is allowed within the NCZ, except on known cultural resources and on corals.

The HAU encompasses approximately 3% of the park. Like the NCZ, recreational fishing and anchoring are allowed within the HAU. The HAU is the only zone where overnight anchoring is allowed. Garden Key Harbor Light is the center of the HAU. The HAU extends outward for a distance of 1 nautical mile to encompass sur- rounding waters, including those around Bush and Long Keys. Within the HAU are two areas of increased protection: the Nurse Shark Special Protection Zone (SPZ) and the Coral Special Protection Zone (SPZ). Located to the west and south of Bush and Long Keys, these areas are closed to the public. The Nurse Shark SPZ is a shark-mating site and contains a high number of pregnant females during mating season. The Coral SPZ is an area that contains a large portion of the park's rare and threatened corals, including elkhorn coral (*Acropora palmata*), staghorn coral (*Acropora cervicornis*), and the elkhorn-staghorn hybrid (*Acropora prolifera*).

The Florida Keys National Marine Sanctuary (FKNMS) surrounds the boundary of DRTO. Two ecological reserves, the Tortugas North Ecological Reserve (TNER) and the Tortugas South Ecological Reserve (TSER), together encompass nearly 160 mi^2. The TNER is contiguous to the park along the northwestern boundary of the RNA. The TSER is located approximately 7 miles to the southwest of DRTO and contains Riley's Hump, a historically known fish spawning aggregation site. Fishing and anchoring are prohibited in the TNER and the TSER. SCUBA diving and snorkeling are allowed in the TNER at mooring buoy locations and with appropriate permits. SCUBA diving and snorkeling are prohibited within the TSER.

The remaining area within the FKNMS and adjacent waters are open to fishing. Fishing regulations for these areas are governed by the Florida Fish and Wildlife Conservation Commission in state waters, and by the South Atlantic Fishery Management Council and the Gulf of Mexico Fishery Management Council outside state boundaries.

Snorkeling and SCUBA diving are allowed in the RNA; however, boaters are required to use mooring buoys, as anchoring is prohibited. Photo by Naomi Blinick, USGS volunteer/NPS.

RNA Performance Topic 1

Chapter 1: Status of reef fish populations of the Dry Tortugas region based on fishery-independent visual surveys

Investigators

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Project Description

The Florida coral reef ecosystem extends from Dry Tortugas to Miami, and supports multibillion-dollar tourism and fishing industries (Ault et al. 2005). The Tortugas region is of particular importance to reef fish populations in South Florida due to evidence of several spawning aggregations, which were located using passive acoustics (Locascio and Burton 2016), fishery data (Lindeman et al. 2000), and diver surveys (Burton et al. 2005). Larval connectivity studies using ocean models and drifters have suggested that the Dry Tortugas region is a source of recruits that supply reef fish populations along the Florida reef tract (Lindeman et al. 2001; Domeier 2004; Bryan et al. 2015). Due to this larval connectivity, it is critical to monitor the reef fish community within the Dry Tortugas region to understand the effects that protected areas have on the abundance and size structure of exploited fish species.

Baseline fishery-independent monitoring to assess the status of coral reef fish communities within the Dry Tortugas region was first conducted in 1999-2000 using the Reef Visual Census (RVC) methodology described in Smith et al. (2011). This habitat based survey design has been identified as a cost-effective method of providing accurate and precise abundance metrics for reef fishes in the Tortugas region (Ault et al. 2006; Smith et al. 2011). The RVC monitoring program is a collaborative effort that uses divers from the National Oceanic and Atmospheric Administration, the University of Miami, the National Park Service, and the Florida Fish and Wildlife Conservation Commission. Following the initial assessment, surveys were conducted biennially from 2004-2016 to evaluate spatial and temporal trends in reef fish abundance metrics. Each sampling year, the RVC monitoring program allocated site locations by habitat type and management zone throughout Dry Tortugas. This type of sampling allocation relies on benthic habitat maps to accurately partition a sampling grid (Figure 1) into defined strata based on reef habitat characteristics (rugosity, patchiness, and depth). Within a selected sampling grid, highly trained divers collected biological data over hardbottom habitat adhering to a standard monitoring protocol (Brandt et al. 2009). Each diver conducts a stationary point-count recording the size and number of every reef fish species within a circular 15 m diameter plot. A quick benthic assessment is then conducted to classify the survey into a specific habitat strata. The RVC data was used to assess changes in size structure, density, and occupancy rate of exploited fishe species throughout the Dry Tortugas management zones from 1999 to 2016.

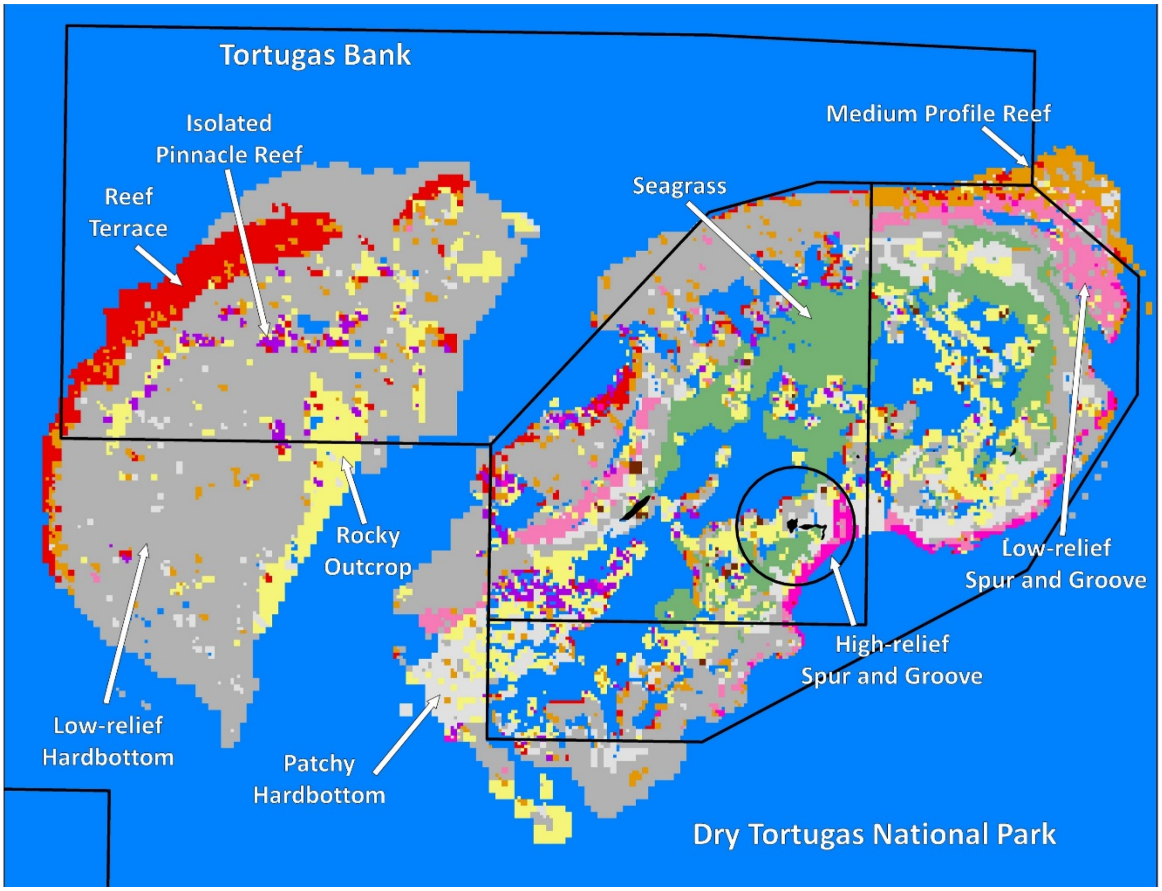


Figure 1. Map of benthic habitats and management zones in the Tortugas region

The Dry Tortugas region RVC samples were divided into four areas using the management boundaries: TNER, RNA, NCZ/HAU, and open areas of the Tortugas. The occupancy rate for each species was calculated within each management zone by calculating a frequency of occurrence (the percentage of sites that had a legal-sized fish present) and then weighting this value based on the proportion of habitat within each zone. The first RVC surveys (1999-2000) were collected before the implementation of the no-take marine zones, and were used as baseline values for each management zone within the Dry Tortugas region. All analyses of species abundance only included individuals that were greater than or equal to each species' respective minimum size limit. The analysis within the Dry Tortugas National Park focused on the 2006-2016 time period to examine changes in fish size structure between pre- and post- implementation of the no-take RNA. For each species, the proportion of observed fish that were legal-sized and the change in mean length of legal-sized fish were calculated to indicate changes in size structure. The RVC data for this report was collected before the 2017 increase in minimum legal-size limit for mutton snapper (16'' to 18'') and hogfish (12'' to 16''), thus the 2016 legal-size limits were used for all analyses.

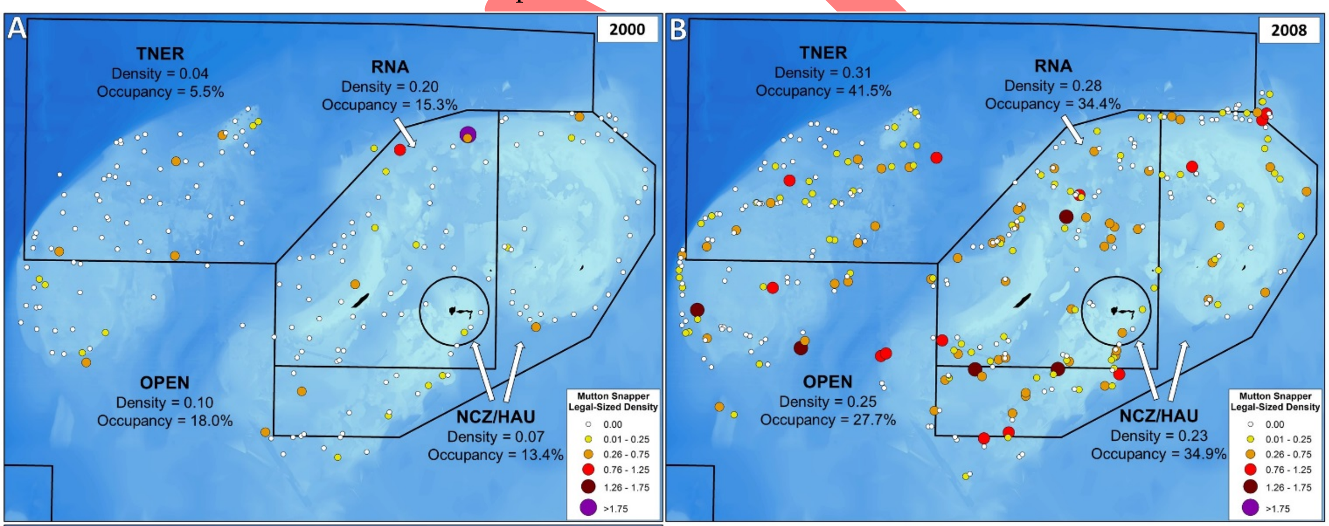
Results

The spatial abundance of reef fish species was depicted using the density of individuals at each sampling location for three time periods: 1) before the implementation of the TNER (2000), 2) after the implementation of the DRTO RNA (2008), and 3) using the most recent RVC dataset (2016). Spatial abundance maps were generated for four recreationally and commercially important reef fish species: *Lutjanus analis* (mutton snapper), *Ocyurus chrysurus* (yellowtail snapper), *Epinephelus morio* (red grouper), and *Lachnolaimus maximus* (hogfish). Each point in Figures 2-5 represents the mean density of legal-sized fish per unit sample area (177 m^2, the area of each diver's circular plot). The abundance metrics (density and occupancy rate) in Figures 2-5 were calculated for the three protected areas and the open areas of the Dry Tortugas using the RVC samples within each management zone.

The effect of the RNA's establishment on the size structure of the selected species was also examined using only the RVC samples conducted within DRTO. The RVC samples from 2006 to 2016 were separated into three time periods: 1) baseline values before RNA implementation (2004-2006), 2) after RNA implementation (2008-2010), and 3) using the most recent RVC surveys (2014-2016). Similar to the evaluation of density and occupancy, the change in each species size structure over the time periods and between DRTO management zones was examined.

Mutton Snapper

Results from the spatial abundance maps indicate that mutton snapper density has increased over time within the TNER, RNA, and NCZ/HAU (Figure 2). Although occupancy rate within DRTO plateaued from 2008 to 2016, density has continued to increase. These trends



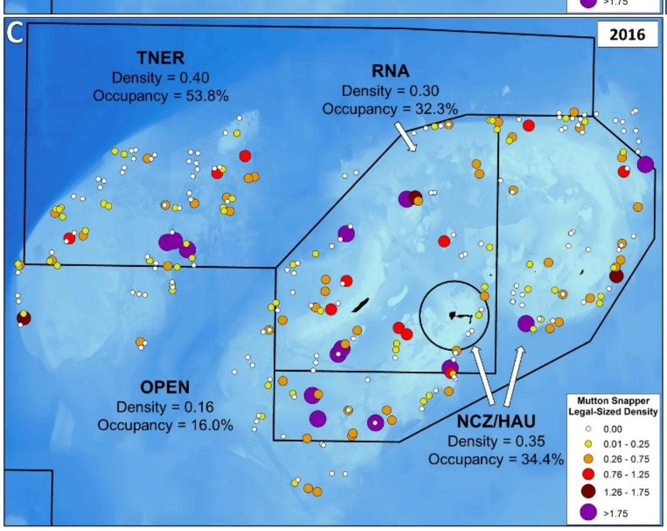
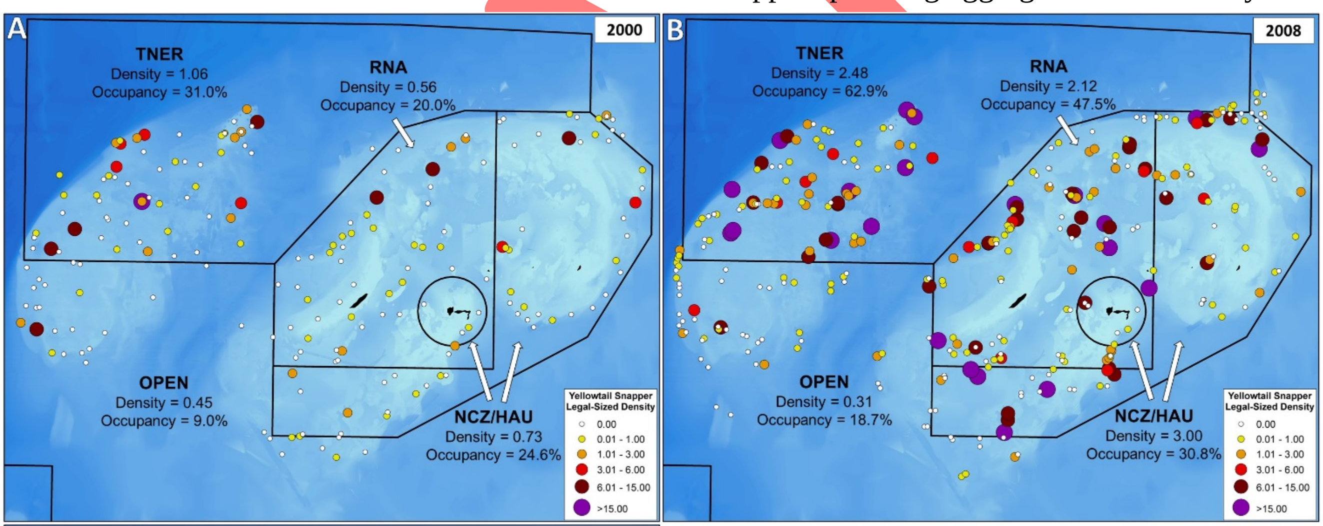


Figure 2. Spatial distribution of legal-sized mutton snapper density (mean number of fish per sample unit, 177 m^2) depicted for Tortugas region RVCs conducted in (A) 2000, (B) 2008, and (C) 2016. The average density and occupancy rates for four areas (TNER, RNA, NCZ/HAU, and Open areas) were also calculated. Each point represents the average of four diver visual point counts, where white points represent no mutton snappers observed.

for occupancy rate and density inside the protected areas indicate that while mutton snapper were present at a similar proportion of sampling locations in 2008 and 2016, they were generally observed in greater densities in 2016. Outside the protected areas, mutton snapper recovery has not been as apparent. The most recent surveys (2016) within the open areas indicated that mutton snapper density and occupancy rate were similar to the baseline values observed in 2000. The increase in mutton snapper spawning stock throughout the protected areas of Dry Tortugas has coincided with an increase of mutton snapper observed at a spawning aggregation site located on Riley's Hump (RH) within the TSER. Mutton snapper were documented undertaking seasonal spawning migrations between the RNA and RH, which demonstrated the ecological connectivity of biological processes for this species (Feeley et al. *in press*). This suggests that the recovery of the mutton snapper population in the TNER and DRTO contributed to the re-formation of the RH spawning aggregation site.

The majority of observed mutton snapper inside DRTO, regardless of time period, was primarily greater than or equal to the minimum size limit (16 inches). The proportion of observed mutton snapper that were legal-sized was fairly consistent over time, but the mean length of legal-sized mutton snapper increased within both DRTO zones following the RNA's establishment. The protection of a mutton snapper spawning aggregation site at Riley's



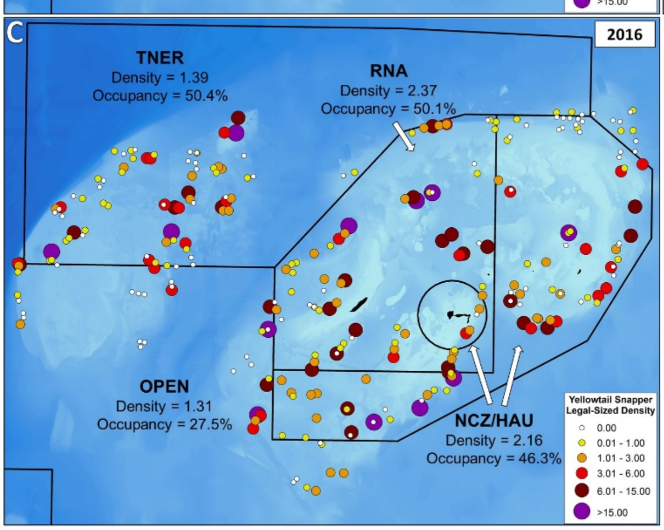


Figure 3. Spatial distribution of legal-sized yellowtail snapper density (mean number of fish per sample unit, 177 m^2) depicted for Tortugas region RVCs conducted in (A) 2000, (B) 2008, and (C) 2016. The average density and occupancy rates for four areas (TNER, RNA, NCZ/HAU, and Open areas) were also calculated. Each point represents the average of four diver visual point counts, where white points represent no yellowtail snappers observed.

Hump combined with the network of protected areas throughout the Dry Tortugas may have led to the overall increase in mutton snapper size.

Yellowtail Snapper

The yellowtail snapper spatial abundance maps indicated an initial increase in density and occupancy rate throughout the Dry Tortugas protected areas, followed by similar abundance metrics between 2008 and 2016 (Figure 3). The yellowtail snapper population within in the open areas of the Tortugas exhibited an increase in density subsequent to the increase in yellowtail snapper density within the adjacent protected areas. The largest densities of yellowtail snapper within the open area were observed near the boundaries of the protected areas (Figure 3C).

The increase in yellowtail snapper densities near the management boundaries in 2016 following the increase in yellowtail snapper densities inside the protected areas is evidence of spillover into the open areas. This movement of legal-sized yellowtail snapper was further demonstrated with acoustic telemetry (Chapter 4, this volume), where yellowtail snapper were documented moving from the RNA to outside the southern boundary of the NCZ on several occasions.

The increase in yellowtail snapper abundance within DRTO did not coincided with an overall increase in size structure. The proportion and size of legal-sized yellowtail snapper is similar between management areas throughout the different time periods.

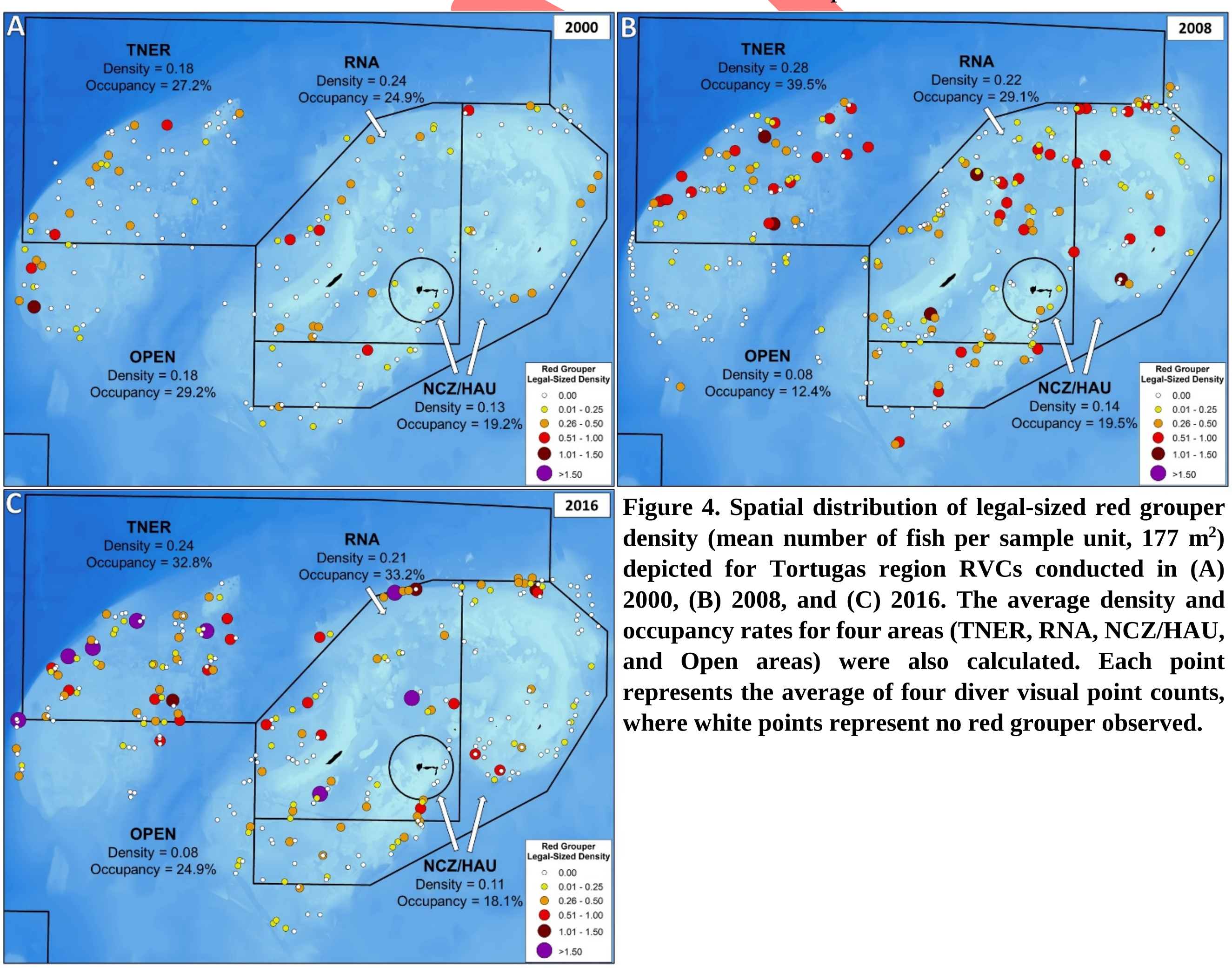
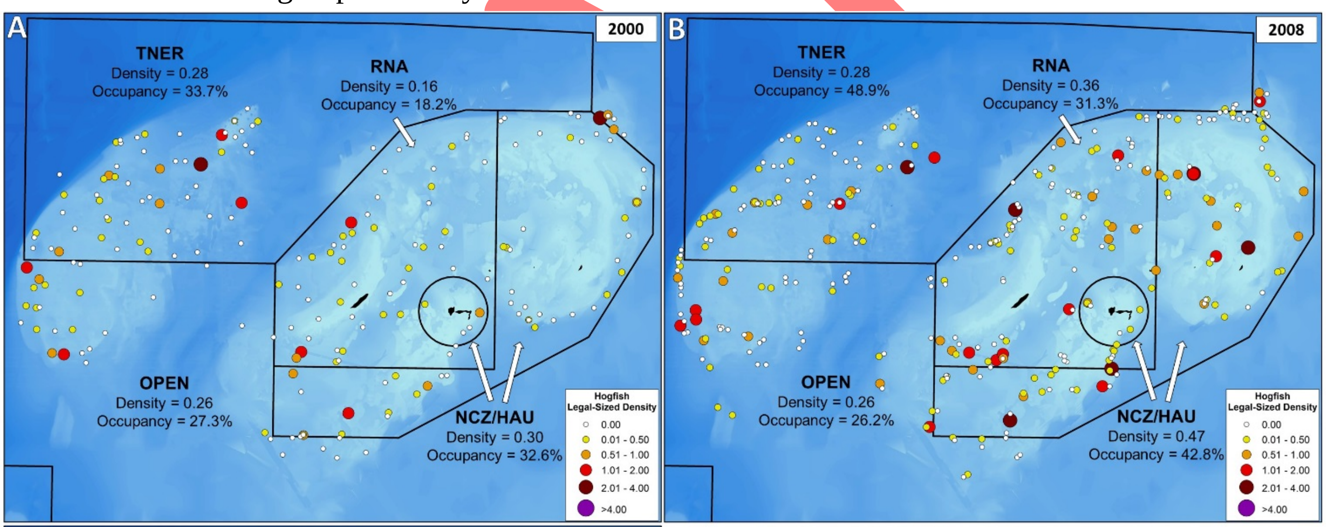


Figure 4. Spatial distribution of legal-sized red grouper density (mean number of fish per sample unit, 177 m^2) depicted for Tortugas region RVCs conducted in (A) 2000, (B) 2008, and (C) 2016. The average density and occupancy rates for four areas (TNER, RNA, NCZ/HAU, and Open areas) were also calculated. Each point represents the average of four diver visual point counts, where white points represent no red grouper observed.

Red Grouper

The red grouper spatial abundance maps indicated that both density and occupancy rate were similar over time throughout DRTO, and slightly increased within the TNER (Figure 4). The two no-take areas consistently exhibited greater red grouper densities and occupancy rates in comparison to the open areas and the NCZ/HAU. Follows its implementation as a no-take area, the red grouper density within the RNA has been approximately double the NCZ/HAU red grouper density. The management areas inside DRTO contain a similar mosaic of reef habitat, which suggests that differences in red grouper populations are associated with the varying levels of protection. The difference in red grouper density between the adjacent management zones also suggests there is little spillover between areas. Red grouper exhibit high site fidelity and small home ranges (Farmer et al. 2011), which would result in less movement across management boundaries.

The proportion of legal-sized red grouper observed has increased over time within the RNA, but not inside the NCZ/HAU. This matches the spatial abundance map for red grouper, where the occupancy rate increased over time inside the RNA and decreased inside the NCZ/HAU.



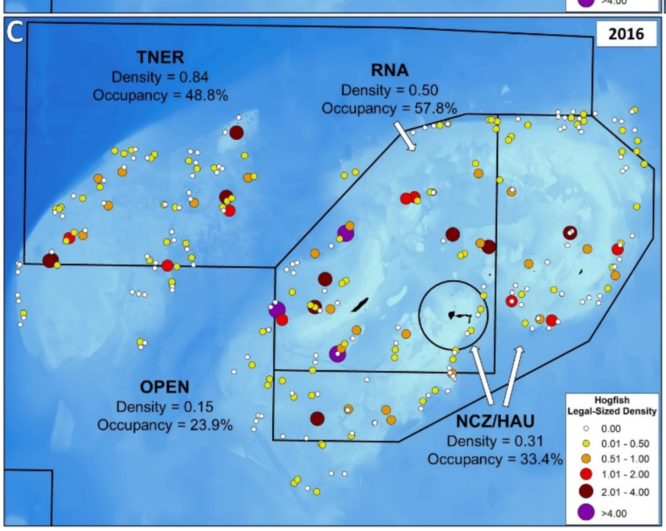


Figure 5. Spatial distribution of legal-sized hogfish density (mean number of fish per sample unit, 177 m^2) depicted for Tortugas region RVCs conducted in (A) 2000, (B) 2008, and (C) 2016. The average density and occupancy rates for four areas (TNER, RNA, NCZ/HAU, and Open areas) were also calculated. Each point represents the average of four diver visual point counts, where white points represent no hogfish observed.

Hogfish

The hogfish spatial abundance maps indicate that there was an increase in hogfish density and occupancy rate for the management zones inside DRTO and the TNER (Figure 5). Hogfish population density within DRTO started to recover after the establishment of the RNA, while the increase in the TNER hogfish density was more recent. The 2016 RVC data indicated that hogfish density and 200% from the baseline values, which the largest increase within any of the management zones. Similar to red grouper, the density of hogfish throughout the open areas has continued to decline over time. A recent increase in the hogfish minimum size limit from 12 inches to 16 inches in 2017 may help to reverse this trend in the open areas.

The size structure of hogfish within DRTO has exhibited a change over time. The proportion of legal-sized hogfish within both the RNA and

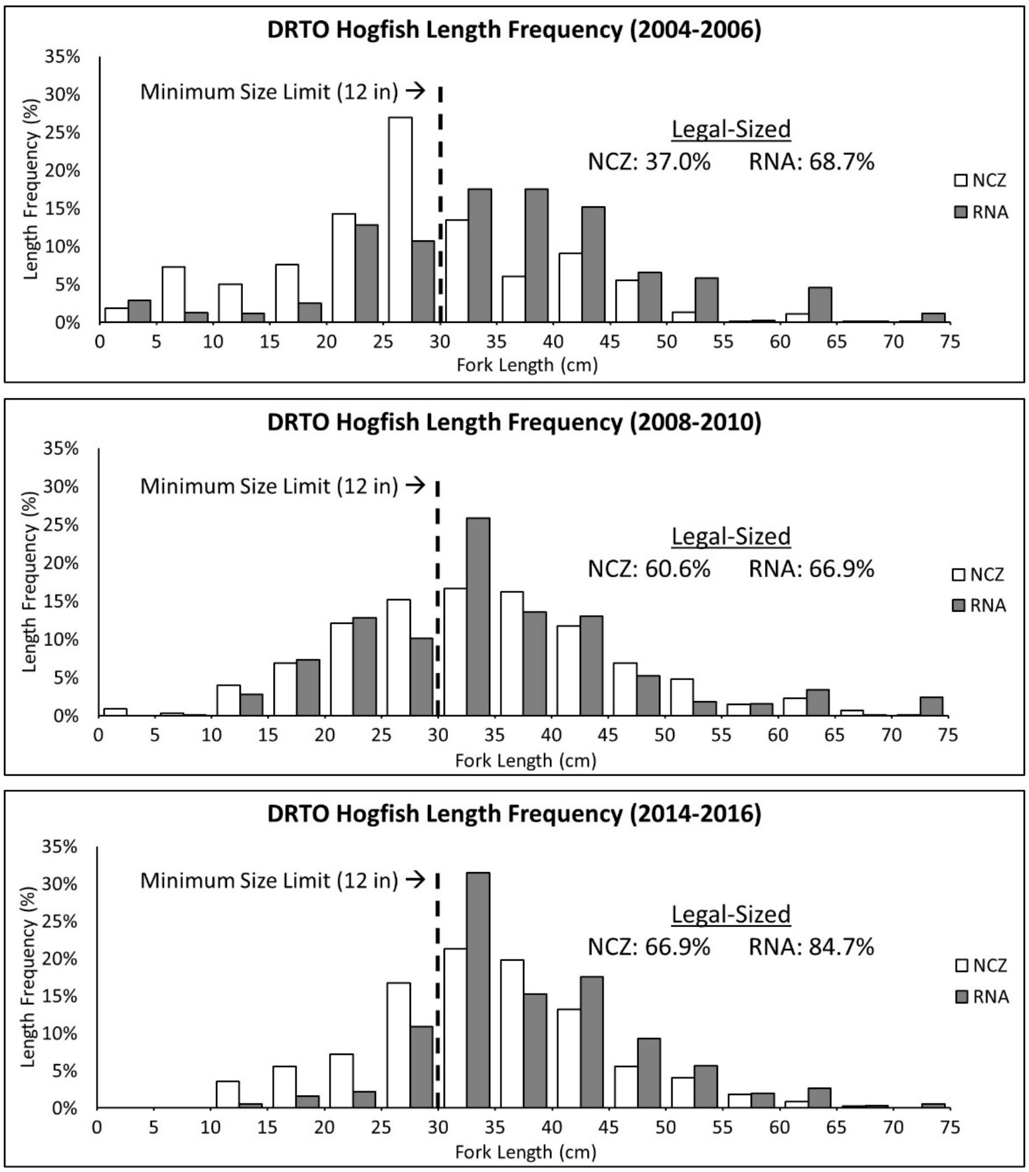


Figure 6. Hogfish length frequency inside the DRTO for the no-take RNA and limited take NCZ/HAU. The percent of individuals greater than or equal to the minimum size limit (dashed line) for each area and time period is displayed

NCZ/HAU has consistently increased, which corresponds to the increase in density inside DRTO over time (Figure 6). The mean length of legal-sized hogfish was similar between areas and time periods, which may be a result of their social behavior. There is evidence for hogfish ontogenetic migration offshore to deeper water as they grow larger (Collins and McBride 2011), so the larger hogfish inside DRTO may be migrating to deeper water outside the park boundaries. This is further supported by the most recent RVC surveys, which indicated hogfish were ~6 cm larger in the deeper water TNER compared to the shallow water RNA.

Performance Measure Evaluation

The spatial framework of the RVC produces consistent habitat-weighted reef fish abundance and size structure information that can be used to monitor changes in fish populations. This report used the RVC data from 2000-2016 to evaluate the differences of four principal fishery species (mutton snapper, yellowtail snapper, red grouper, and hogfish) over time and between the Dry Tortugas management zones.

The most recent RVC data indicated that the trends for the fish species cited in the 2008 report have persisted through 2016. The increasing density and occupancy rates have continued inside the protected areas, while the open areas have consistently recorded the lowest density and occupancy rate for these species. Specific to the RNA, the 2016 abundance metrics were 50% greater than the baseline values for three of the four fish species. Red grouper densities within the RNA did not increase over time, but there was a difference in density between zones. The 2016 red grouper densities throughout the open areas of the Dry Tortugas have declined to less than half the density inside the RNA.

There is evidence that the RNA is not just benefiting exploited fish species within its boundaries, but also those in adjacent unprotected areas. Following the establishment of the RNA, yellowtail snapper density has increased within the NCZ and the open areas of the Dry Tortugas. This is could be due to density-dependent spillover, as the RVC samples in the open areas with the largest yellowtail snapper densities located near the boundaries of the RNA. In addition, hogfish densities first increased within the RNA and DRTO before increasing inside the TNER. Hogfish move offshore to deeper water as they grow (Collins and McBride 2011), which may explain why hogfish first recovered within the shallow habitat within the RNA before the deeper habitat within the TNER. This highlights the importance of protecting a variety of habitats to ensure that species are protected at all life stages.

The network of no-take zones throughout the Dry Tortugas is adequately protecting exploited fish species, and in some instances enhancing the surrounding fish populations. On a regional scale, the Dry Tortugas is potentially a major source point of recruits to populations of important reef fish species in the Florida Keys (Ziegler and Hunt 2012). Continued protection of the RNA, TNER, and TSER sets aside a variety of habitats which allow for the juveniles and adults of exploited reef fish species to grow and reproduce with minimal human impacts. This is especially important for the future sustainability of these fishery resources that are influenced by both natural and anthropogenic stressors.

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RNA Performance Topic 2

Chapter 2: Regional connectivity of mutton snapper within the Tortugas region of Florida

Investigators

Danielle Morley[1], Alejandro Acosta[1], Michael W. Feeley[1,2], and Michael Burton.[3]

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Project Description

An understanding of migration patterns, home and habitat requirements of fish species is critical to establishing an effective marine protected area (MPA) design (Sale et al. 2010), particularly no-take marine reserves (NTMR). NTMRs can be effective in sustaining fish populations when spawning occurs within their boundaries or when strong connectivity exists between populations within NTMR boundaries and spawning aggregations located elsewhere.

The establishment of the Dry Tortugas National Park no-take Research Natural Area (RNA) in 2008 prompted performance measures to assess the efficacy of the RNA in protecting marine habitat, conserving biodiversity, and enhancing productivity and sustainability of exploited fish populations. Subsequently, field studies examined immigration and emigration of targeted fish species in the RNA (Performance Topic 2) and assessed connectivity of fishes in the greater Tortugas region.

One targeted species was mutton snapper (*Lutjanus analis*) which has been described as a transient snapper species that migrates to form spawning aggregations (Claro et al. 2009). Riley's Hump is currently located within the Tortugas South Ecological Reserve (TSER) and is considered the most valuable snapper aggregation site in south Florida (Lindeman et al. 2000). Little else was known regarding mutton snapper movements in the Tortugas region or how the NTMRs within the area would affect these movements.

To examine movement patterns of this species, 55 mutton snapper were surgically implanted with acoustic transmitters from May 2008 to August 2012. An array of 84 underwater VEMCO acoustic receivers deployed by July 2008 in 6 to 50 meters of water to provided coverage of approximately 800 km^2 in the Dry Tortugas regions was used to track these tagged mutton snapper (Figure 1).

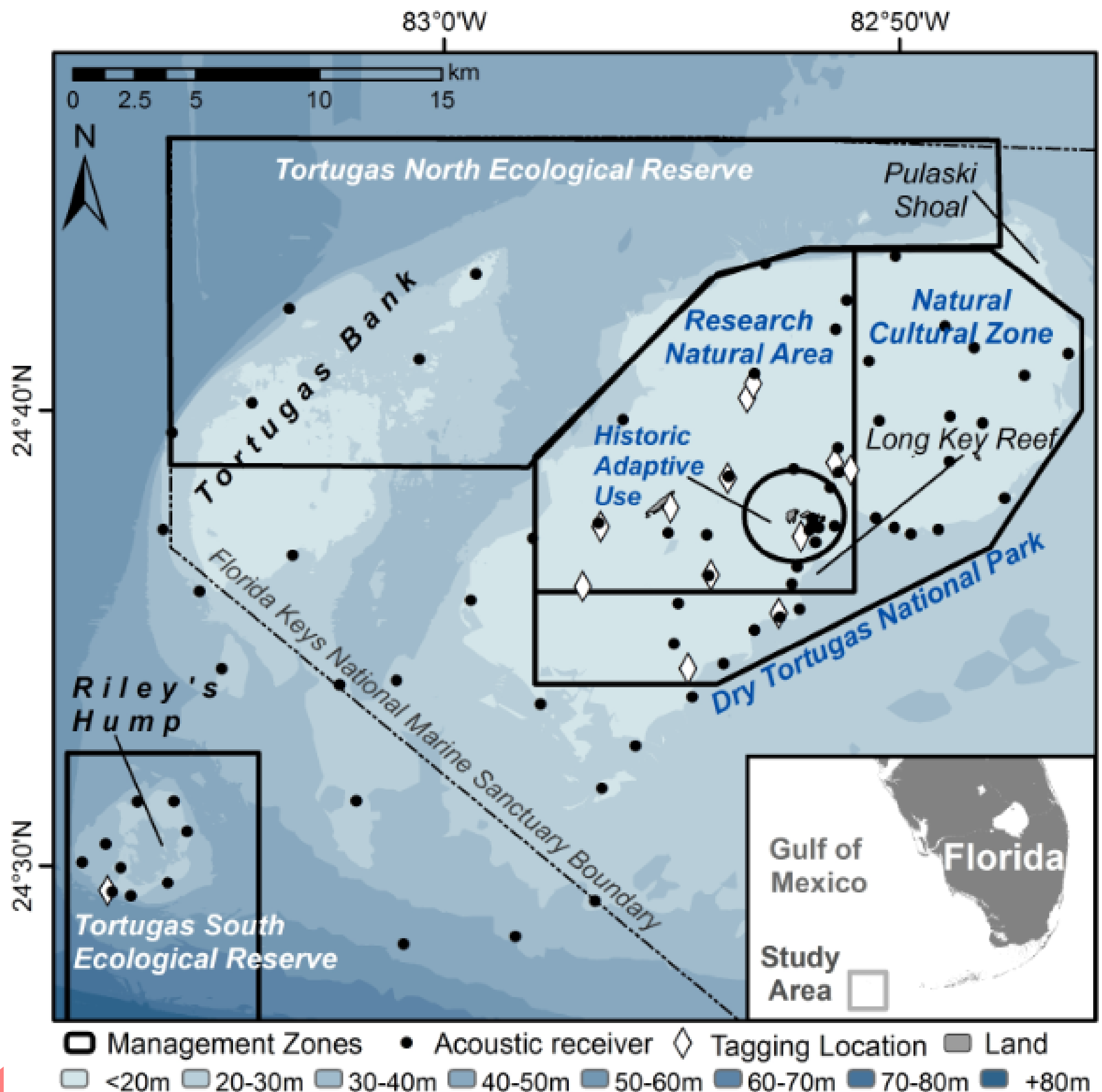

Figure 1. Map of the Dry Tortugas acoustic array and mutton snapper tagging locations

Results

Of the 55 mutton snapper (45.7–89.7 cm total length) acoustically tagged during this study, 28 were tagged at the spawning aggregation in the TSER and 27 were tagged within the RNA and Natural Cultural Zone (NCZ). Four of the 55 tagged mutton snapper were never detected on the array and were removed from further analysis.

Approximately 1.63 million mutton snapper detections were recorded from May 2008 through September 2012. Time-at-liberty (number of days between initial tagging and last detection) was 404 ± 430 d (mean ± sd) with a range of 2–1296 d. Twenty-one mutton snapper swam repeated migratory tracts to Riley's Hump (≤5 trips fish^{-1} season^{-1}), with 88% of these fish migrating at least twice per year. The minimum linear distance traveled ranged between 23.4 – 35.2 km while one fish was recaptured 50 km away (Ada Afaro, pers comm). Twelve tagged mutton snappers that had home sites within the RNA made short (<1 week) seasonal trips to the spawning aggregation at RH before returning to the RNA (Figure 2). The mean area of habitat use for resident fish at their home site was 2.50 ± 1.31 km^2.

Functional migration areas were calculated for 17 tagged fish that had detection periods of two years or more (667 ± 299 d) and detected 39 ± 31 % of days possible. The average functional migration area was 115.34 ± 41.25 km^2. These functional migration areas were used to understand the distances covered by mutton snapper to reach the spawning aggregation site in the TSER from their home sites. These functional migration areas were then used to calculate a minimum catchment area, meaning the minimum total area from the surrounding waters where mutton snapper might travel to the spawning aggregation site within the TSER. The functional migration area calculated using the subset of 17 tagged mutton snapper was 334.0 km^2. If the single confirmed tag recapture from 50 km away is included, the catchment area estimate increases to 732.0 km^2.

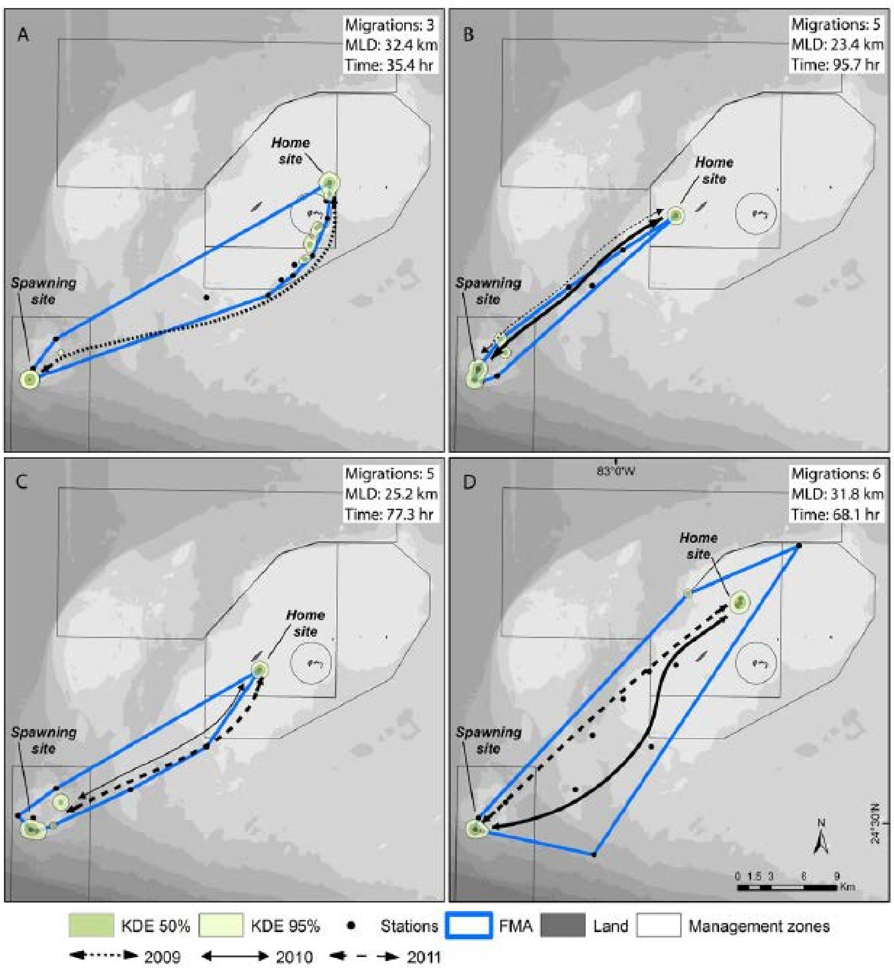

Figure 2. Migration patterns of four mutton snapper with home sites within the RNA. Blue lines outline the functional migration area for each individual. Light green color indicates the probability of finding the fish 95% of the time, the darker green indicates the probability of finding the fish 50% of the time. Migrations are the number of times we recorded that individual swimming to the spawning grounds, MLD is the minimum linear distance traveled by that fish to reach the spawning site. Time indicates the number of hours it took for the fish to swim that distance.

Performance Measure Evaluation

In the 2015 5-Year Report, preliminary results for this study were presented (Feeley et al. 2012). Here we have fully examined the data and present our final conclusions. This study demonstrated a critical ecological link between different management zones in the Dry Tortugas region. Mutton snapper with home sites located in the RNA were documented traveling from the RNA to the spawning site in TSER multiple times a year during the spawning season. These movements ensure trophic connections between these two habitats, shallow foraging habitat and deeper spawning habitat, while demonstrating how a network of marine reserves can protect various life history stages of a species.

This study also documented the reach of the spawning site within the TSER by calculating a conservative catchment area of 334.0 km^2 with another estimate expanding the catchment area to 732.0 km^2. These estimates underline the importance of these management zone not only to the immediate waters of the Dry Tortugas, but to surrounding waters as well. This was further emphasized by a lack of home site documentation for eight of the 21 fish making repeated migratory trips to the spawning aggregation area.

Acknowledgements

Paul Barbera FWC/FWRI; Harold L. Pratt, Mote Marine Lab; Kristen Hart, USGS

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RNA Performance Topic 2

Chapter 3: Riley's Hump as a multi-species aggregation site

Investigators

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Project Description

Riley's Hump is a submerged seamount located approximately 20 km^2 southwest of Garden Key in the Tortugas South Ecological Reserve (TSER) and ranges from 30 - 55 m in depth (Figure 1). There is considerable historic commercial fishery evidence of snapper aggregations around this geographic feature (Lindeman 2000, Burton 2005). When Feeley et al. 2012 documented mutton snapper spawning events at Riley's Hump in 2009, it made researchers question whether other species also use this site for spawning purposes.

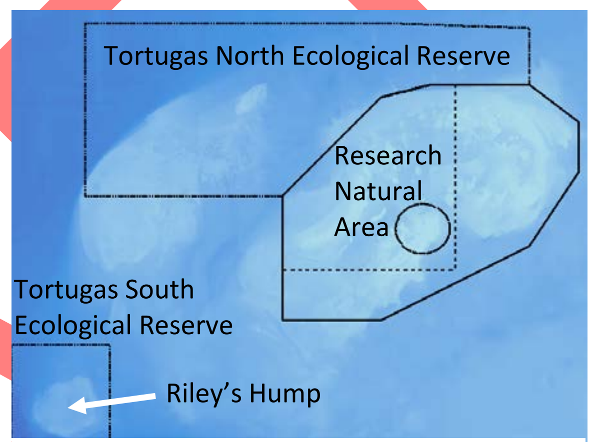

Figure 1. Location of Riley's Hump in relation to other no-take marine reserves in the Dry Tortugas region. Black lines indicate management zone boundaries.

Since 2011, FWC scientists have been collaborating with researchers at the National Oceanic and Atmospheric Administration (NOAA) and the Florida Keys National Marine Sanctuary (FKNMS) to monitor patterns of fish habitat use within the TSER. Because much of the habitat is deeper than recreational dive limits, scientists augment conventional scuba surveys with specialized tools including remotely operated vehicles, technical divers, wave gliders, multibeam sonars, and stereo cameras to determine how different species utilize Riley's Hump. Using a diverse range of tools ensures that observations can be made in a wide variety of conditions both above and below the water.

Figure 2. Remotely Operated Vehicle being deployed to explore Riley's Hump.

Results

Over seven years of observations, researchers have documented evidence of potential spawning aggregations for several species such as ocean triggerfish, black grouper, and cubera snapper, in addition to the previously documented mutton snapper. Of these species, substantial information has been collected for cubera snapper (*Lutjanus cyanopterus*). These aggregations have been consistently observed on the west side of Riley's Hump in waters of approximately 200 ft. in depth from 2011 to 2016 (Table 1). While spawning by this species has not been confirmed at this site, fish in the aggregation displayed distended bellies, twitching behavior associated with courtship, and exhibited color changes typically associated with reproduction (Heyman et al. 2005).

The use of equipment such as splitbeam or multibeam sonars has allowed scientists to document large aggregations of fish in the water column off Riley's Hump. Data on aggregation size, shape, and position are obtained from the echogram generated by these instruments. For example, the echogram in Figure 3 depicts an aggregation (confirmed by divers be cubera snapper) that measured over 90 m long. Also, this equipment can allow scientists to estimate the number of individuals within the school. In June of 2015, 621 cubera snapper, with and average total length of 67 cm, were estimated to be contained within a school that measured 67 m long by 40 m wide and 25 m high (Table 1).

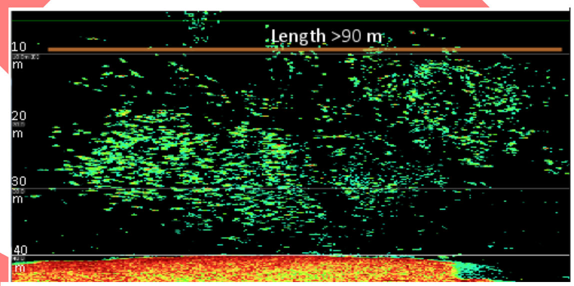

Figure 3. Echogram showing the sonar backscatter signal of a cubera aggregation. The length of the aggregation was estimated at greater than 90 m.

Table 1. Observations of cubera snapper at Riley's Hump.

Date	Number Observed	Equipment Used
March 21, 2011	~300	Rebreather Divers
July 13, 2012	>200	Rebreather Divers
August 3, 2012	~150 fish pass in front of camera	FWC Drop Camera off Nancy Foster
August 6, 2012	40 in field of view of camera	FWC Drift Diver video off Nancy Foster
July 23-27, 2013	100s	Drift diver surveys
June 17, 2015	621	multibeam and splitbeam sonars
July 2-6, 2015	~300	Drift diver surveys
August 19, 2016	~70 in field of view of camera	FWC Stereo Camera

Cubera snapper are not the only fish that have been observed in high densities at Riley's Hump (Figure 4). Diver surveys and ROV footage have documented elevated densities of triggerfishes, jacks and grouper species including horse-eye jacks (*Caranx latus*), blue runners (*Caranx crysos*), goliath grouper (*Epinephelus itajara*), scamp (*Mycteroperca phenax*), black grouper (*Mycteroperca bonaci*), yellowmouth grouper (*Mycteroperca interstitialis*), red grouper (*Epinephelus morio*), and red hind (*Epinephelus guttatus*).

In addition to direct observations, indirect evidence supports the hypothesis that Riley's Hump is used by multiple species for reproduction. Passive acoustic dataloggers have recorded patterns of fish sound production associated with courtship and spawning at different locations around Riley's Hump (Locascio and Burton 2016). Increased levels of sound production by black grouper (*Mycteroperca bonaci*), red grouper (*Epinephelus morio*), and red hind (*Epinephelus guttatus*) were recorded during the general spawning season of these species (Figure 5). The results suggest that these important grouper species also use Riley's Hump as spawning grounds.

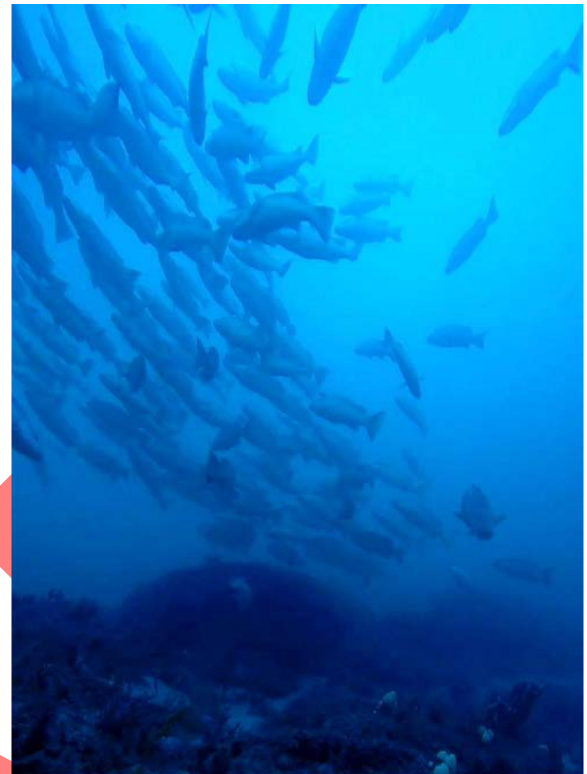

Figure 4. Stereo cameras captured large aggregations of cubera snapper in 200 ft of water off Riley's Hump.

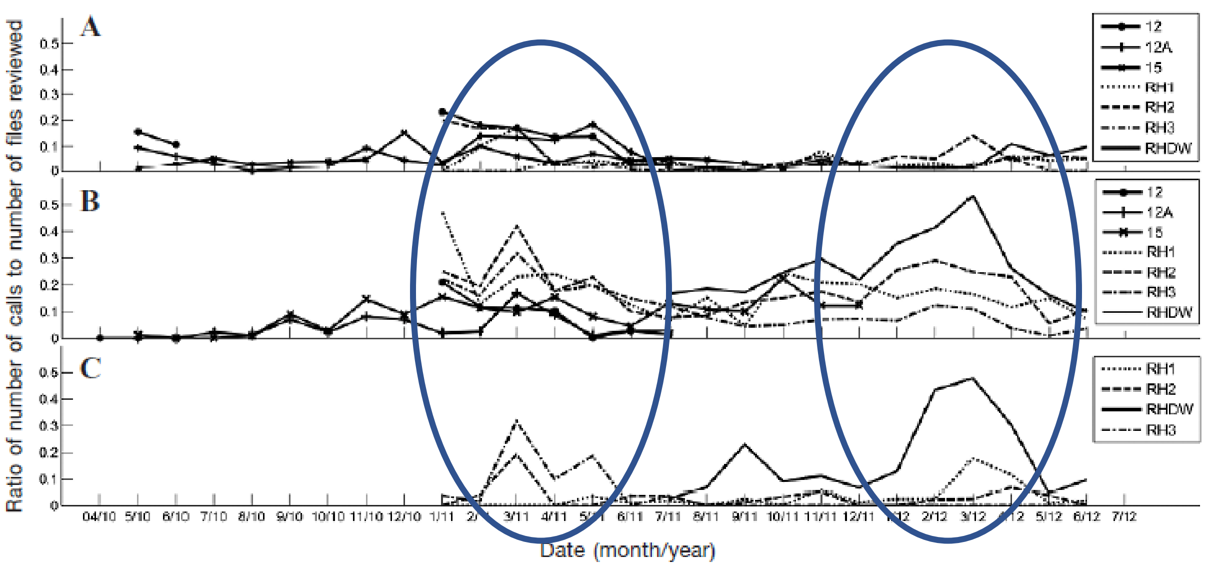

Figure 5. Adapted from Locascio et al. 2016. Time series of ratio of number of calls for three grouper species, (A) black grouper, (B) red grouper, (C) red hind, at different stations around Riley's Hump. Elevated call levels are highlighted in the ovals and coincide with the winter-spring reproductive season.

Performance Measure Evaluation

Evidence of spawning aggregations located on Riley's Hump has been collected for a variety of species using visual, remote and acoustical survey techniques. Although direct spawning has only been observed for mutton snapper, the elevated densities, behavior and physical appearance of other snappers and groupers suggest that they are also using this location for reproductive purposes.

While actual tracking of these fish has not happened, it has been suggested that cubera snapper may behave similarly to mutton snapper in that they may migrate to spawning areas and then disperse throughout a region after the spawning season. If this is true, we can hypothesize that the benefits mutton snapper are receiving from the network of no-take marine reserves in the Dry Tortugas may also apply to cubera snapper aggregations in the area.

This information, coupled with larval distribution models (Domeier 2004), further emphasizes the importance of Riley's Hump for recruitment of commercially and economically important fish species to the rest of the Florida peninsula.

Acknowledgements

FWC biologists Paul Barbera, Dave Eaken. Dr. Michael Feeley of the National Park Service, Erik Ebert from NOAA and the crews of the M/V Spree, the Peter Gladding and NOAA ship Nancy Foster.

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Chapter 4: Yellowtail snapper movements in and near the Dry Tortugas National Park Research Natural Area

Investigators

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Project Description

Yellowtail snapper, *Ocyurus chrysurus* (Bloch, 1970), is a species that occurs year-round in south Florida and has been a component of Florida reef fish landings for more than a century (Lindholm et al. 2005; O'Hop et al. 2012). It is one of the most profitable commercial reef fish fisheries in the Florida Keys (Waters et al. 2001). In the state of Florida, about 92.6% of the commercial landings of yellowtail snapper since 2006 have come from Monroe County, accounting for approximately 18 million pounds and generating 51 million dollars in ten years (Commercial Fisheries Landings Summaries 2017). Due to the value of this fishery, the sustainable management of this species is of

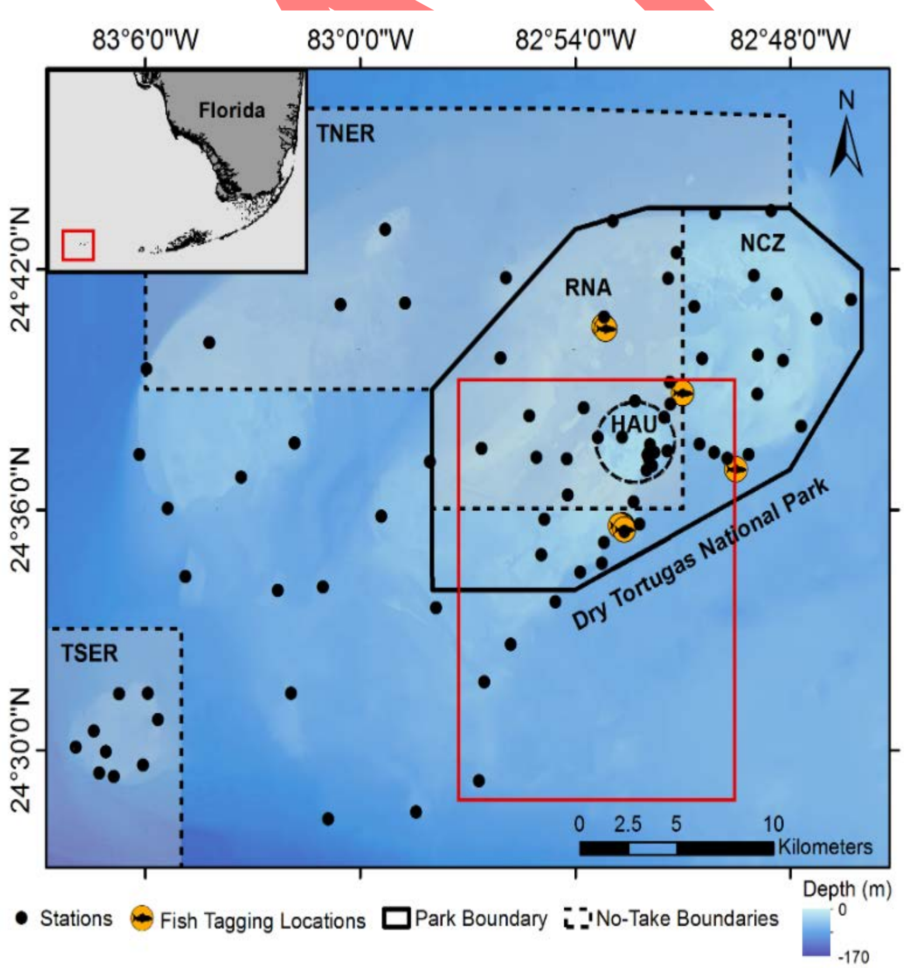


Figure 1. Map of station and fish tagging locations in the Dry Tortugas. The solid black line represents the Dry Tortugas National Park boundary, while the dotted lines indicate management zones within the Dry Tortugas. Shaded areas indicate no-take reserves. The red box outlines the area depicted in Figure 3.

critical importance. This management will need to include understanding the life history, ecology, and movement of yellowtail snapper.

To better understand the ecology and movement of this species, during 2008 and 2009, 18 yellowtail snapper were tagged with acoustic transmitters and tracked using an array of 86 stationary receivers in the Dry Tortugas region (Fig. 1). The detection data from acoustically tagged yellowtail snapper was used to asses site fidelity, home range and patterns of habitat use to evaluate RNA Performance Topic 2: Monitor the immigration and emigration of targeted species in the RNA.

Results

Eighteen yellowtail snapper were tagged, measuring 37.5 cm to 51.4 cm total length. Throughout the study, 37,623 yellowtail snapper detections were recorded on the deployed array. The recorded number of detections per fish varied by individual fish with an average of 2,513 detections (± 933.4) per fish. Three fish were never detected after release, while 15 fish were tracked from 1 to 427 days. Of the 18 tagged yellowtail snapper, six had enough data to analyze. These six fish had an average of 5,882 detections (± 2,711) per fish and each was tracked for approximately a year (± 23 days).

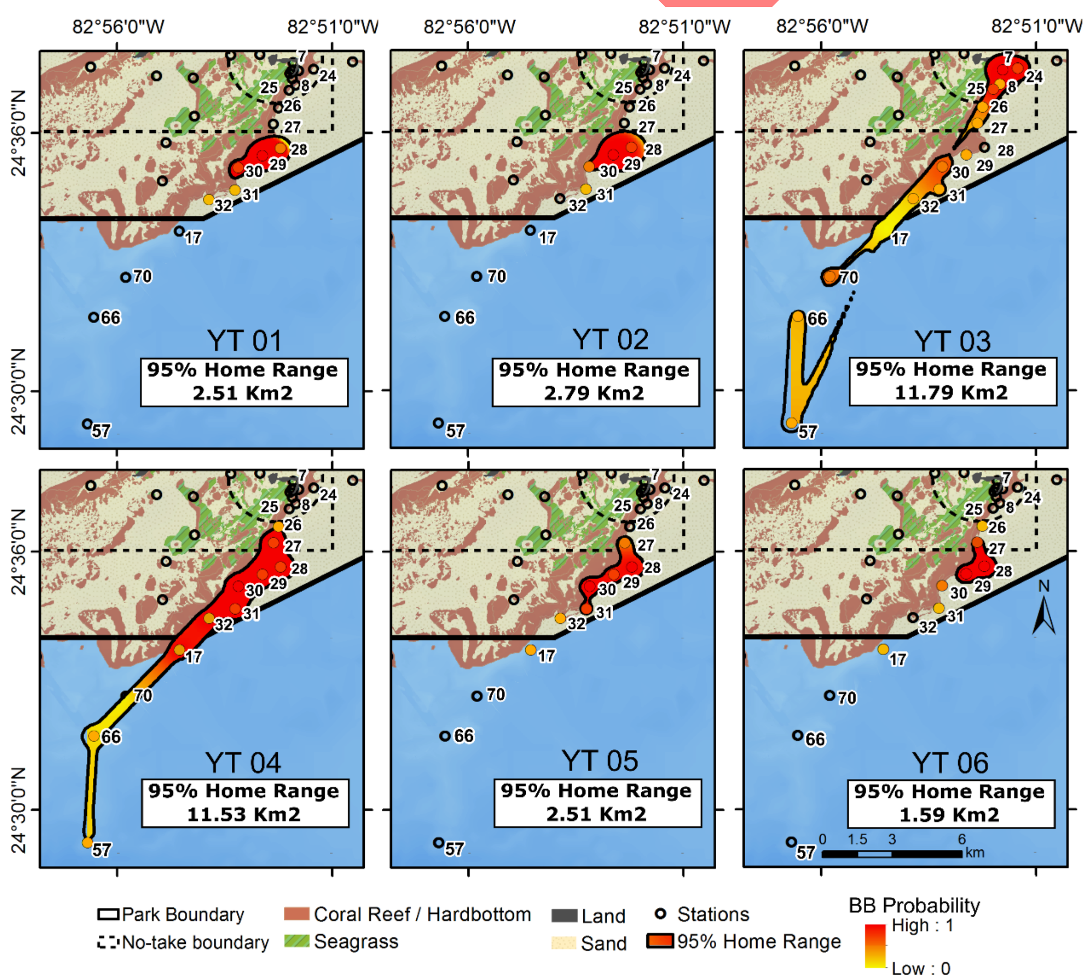


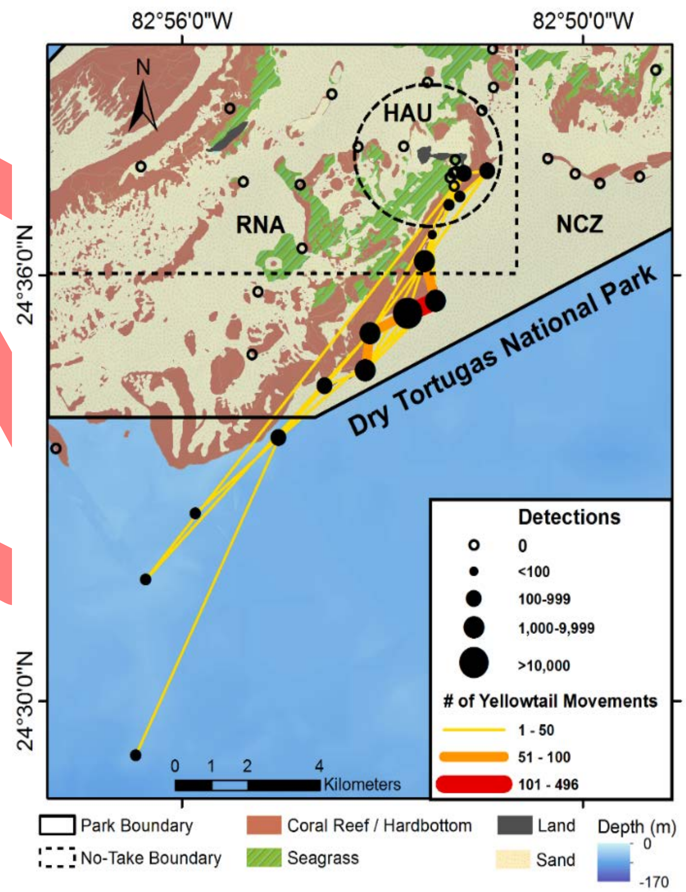
Figure 2. Home range estimates of yellowtail snapper with benthic habitat data. Management zone boundaries are depicted as black lines. The colors within the home range contours indicate the probability of the fish being found in that location with red colors being higher probability than yellow colors.

Site fidelity was calculated as the percent of detections at a single station, and on average fish were detected 58.4% (± 8.4) of the time at the same station. Core areas were defined as the area where a yellowtail snapper can be found 50% of its time. Core areas were small and estimates varied from 0.22 to 1.20 km^2. Home range estimates were defined as the area where a fish can be found 95% of its time. Home range estimates were from 1.59 to 11.79 km^2. Four of the fish (01, 02, 05, and 06) had home ranges with similar size and shape while fish 03 and 04 had larger and more spread out home ranges (Fig. 2).

The analyzed yellowtail snapper spent an average of 96% (± 3.09) of the time they were tracked inside the DRTO with only 5% (± 2.8) of that time within the RNA itself (Fig. 2). The station with the most detections (>10,000) was station 29, located near the RNA and next to a promontory (Fig. 2 and 3). Fish were detected moving frequently between station 29 and the stations closest to it, including the station across the RNA boundary line (Fig. 2 and 3). Fish were detected almost exclusively on hardbottom habitat as they swam up and down the reef edge habitat (Fig. 2).

Performance Measure Evaluation

A successful marine reserve should promote spillover from the reserve into nearby areas (Ault et al. 2006). The success of a marine reserve is often determined by its design, which depends on an understanding of ecological spatial connectivity. Tagged yellowtail snapper were frequently detected moving between stations as they swam in and out of the no-take reserve (Fig. 3), and four fish had home ranges that crossed management boundaries (Fig. 2). Yellowtail snapper demonstrated a preference for continuous reef edge habitat (Fig. 3) and having the RNA boundary line cross the reef edge could have facilitated these movements in and out of the RNA. Although yellowtail snapper frequently moved up and down the reef edge, they exhibited relatively high site fidelity and small home ranges. Despite high site fidelity, fish were more likely to be absent from the array at night and during the summer, which is likely due to foraging and spawning activities. Yellowtail snapper aggregate to spawn; however, the aggregations are smaller and less predictable than those of other snapper species (Lindeman et al. 2000). If yellowtail snapper is traveling to spawning aggregation sites



then these fish could contribute to

Figure 3. Map of the stations and benthic habitat where yellowtail snapper were detected. The size of the black circles indicates the amount of detections at those stations, with most detections (>10,000) at station 29. Open circles are stations with no detections. Lines represent the movements of tracked fish with thicker lines indicative of more commonly traveled pathways.

recruitment outside the management zones, by increasing stock abundance in nearby areas. The observed increase in yellowtail snapper density within the park and near its boundaries (chapter 1, this volume) could be from a potential increase from spawning and from spillover from the RNA. This increase in abundance coupled with spillover from the RNA suggests that this no-take reserve in the Dry Tortugas is helping to enhance the local yellowtail snapper population and is an effective management tool for this species.

Acknowledgments

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Chapter 5: Use of Dry Tortugas National Park by nurse sharks as a mating ground

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Project Description

Nurse sharks are a large (305 cm TL) subtropical/tropical benthic shark species (Castro and Rosa 2005) that occurs in the Western North Atlantic from the Carolinas south through Florida and the Caribbean and along the coast of Brazil (Castro 2011). They are the most abundant large shark population remaining and are likely of significant value to the trophic flow of tropical reef ecosystems. Recently, declines in many shark populations worldwide have been documented (Ward-Paige et al. 2010) and recognizing essential habitat and connectivity is critical to understanding how to change these trends. The reproductive cycle of the nurse shark has been shown to be more accessible to study than other shark species and therefore, it is a good model for gaining such understanding (Pratt and Carrier 2007).

The Dry Tortugas Nurse Shark Investigation (DTNSI) has been studying the Long Key shark population at DRTO for over 25 years. Historic records show that this species has been mating here since the late 1800s and probably as long as these islands have been in existence. Mating takes place in the months of June and July, pregnancy ensues for some females and these sharks use the same shallow waters in the fall for reproductive purposes. To learn more about the movements of this species during this time, acoustic transmitters were applied to nurse sharks while they were in the Dry Tortugas courtship and mating grounds (DTCMG). Fifty-seven adult nurse sharks were tagged from 2005-2014. Forty of the tagged individuals were female and 25 were males. These animals were then tracked using regional acoustic arrays.

Results

This study revealed migratory behavior that was not previously known for this species. During this study, eight nurse sharks were detected up to 335 km away from their tagging location at the DTCMG in an acoustic array off Tampa Bay. Additionally, sex-specific movement patterns to the courtship and mating grounds in the Dry Tortugas were documented. Male sharks returned annually during June and July then would leave the area shortly after mating season. One male was recorded making six annual round trips to return to the same DTCMG lagoon to mate since first tagged in 2010. The males that swam north upon departure of the DTCMG appeared to have very directed movements, covering over 300 km in as little as 18 days.

Female sharks exhibited different timing in their migrations than the males. While males returned annually and left shortly after mating season, females returned bi- or triennially and overwintered in the Dry Tortugas. They would leave the area in the spring before the next making season. Like the males, females that traveled north covered the minimum distance of 324 km between DTCMG and the acoustic array off Tampa Bay in as little as 16 days (Figure 1).

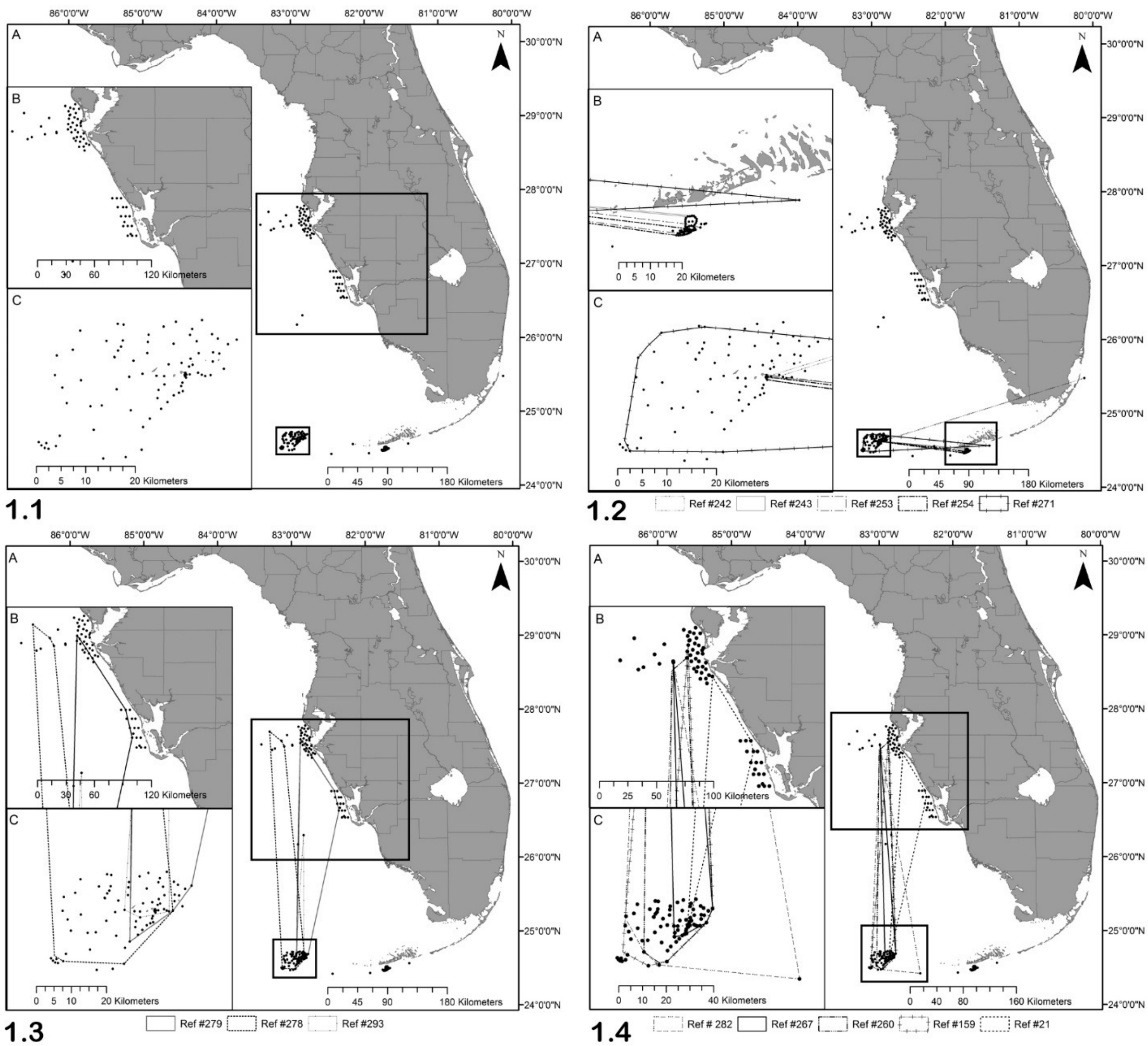

Figure 1. Black circles represent acoustic receivers 1.1 Regional acoustic arrays used to detect tagged nurse sharks throughout Florida 1.2 Nurse sharks that demonstrated an east/west migration to the Dry Tortugas 1.3 Male nurse sharks that migrated to the north 1.4 Female nurse sharks that migrated to the north.

While many of the tagged sharks underwent migrations, not all tagged sharks exhibited this behavior. Two sharks remained within DRTO waters all months for the duration of transmitter coverage. The decision to migrate can be linked to trade-offs between costs and benefits of the energetic requirements of migration versus residency.

Performance Measure Evaluation

Recently, acoustic tracking of adult nurse sharks revealed patterns in movement not previously known for this species. These migration patterns and extreme site fidelity suggests that DRTO is a vital mating and nursery ground for nurse sharks.

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