Florida Fish and Wildlife
Conservation Commission

National Park Service
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South Florida Natural Resources Center
Everglades and Dry Tortugas National Parks

Implementing the Dry Tortugas National Park Research Natural Area Science Plan

The 5-Year Report

Prepared by the

National Park Service and the

Florida Fish and Wildlife Conservation Commission

2012

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
FLORIDA KEYS NATIONAL MARINE SANCTUARY
North
Middle Ground
HISTORIC ADAPTIVE USE ZONE DETAIL
Inset scale
0 0.25 Kilometer
0 0.25 Statute Mile
0 0.25 Nautical Mile
Iowa Rock
Fort Jefferson on Garden Key
Shoal
Bush Key
Light
24°37'41"N
82°52'19"W
Long Key
(closed to public)
Tortugas anchorage
Nurse Shark Special Marine Protection Zone
(closed to public)
Brick wreck
GOOD SNORKELING
Bird Key anchorage
Bird Key Bank
Coral Special Marine Protection Zone
(closed to public)

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Dry Tortugas National Park

Research Natural Area Science Plan:

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Homestead, Florida

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Tallahassee, Florida

Cover photograph of mutton snapper by Jiangang Luo, UM RSMAS.
Cover background photograph by Brett Seymour, Submerged Resources Center, NPS.

Implementing the Dry Tortugas National Park Research Natural Area Science Plan: The 5-Year Report 2012

EXECUTIVE SUMMARY

In 2007, the National Park Service (NPS) and the Florida Fish and Wildlife Conservation Commission (FWC) developed a science plan, *Assessing the Conservation Efficacy of the Dry Tortugas National Park Research Natural Area*, specifically to assess the effectiveness of a 46-mi^2 Research Natural Area (RNA). The Dry Tortugas National Park (DRTO) RNA is a no-take (all forms of fishing are prohibited), no-anchoring (strategically placed mooring buoys are provided) marine reserve that was implemented 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). This 5-year report summarizes the progress of science plan activities to date. Progress in implementing the science plan has been facilitated by cooperative relationships between federal and state agencies, academic scientists, and continuous coordination between the FWC and NPS. The results of monitoring programs and scientific studies presented here document existing baseline conditions and analyze how resources have responded thus far to the protection provided. The 5-year report is structured around the six focal topic areas described in the science plan. A summary of each project and an evaluation of RNA 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 – Jerald S. Ault et al.

From 1999 to 2011, fishery independent visual surveys were conducted to assess the status of the coral reef fish community, and evaluate spatial and temporal trends in species abundance metrics in the Tortugas region with particular emphasis on the RNA post-implementation. In both the TNER and DRTO, abundance, as measured by occupancy rates and density at survey sites, and sizes of red grouper, mutton snapper, yellowtail snapper, and hogfish at or above the legal size of capture have increased since the implementation of the RNA. In contrast, abundance and size of these species either remained the same or decreased in nearby areas of the Tortugas region that are open to fishing. Abundance of adult spawning-sized fish has increased within the RNA relative to other areas, as well. The protection afforded to these reef fish species by the RNA is likely an important component for the recovery of their populations.

Chapter 2: Nursery function of seagrasses within the Dry Tortugas National Park Research Natural Area – Theodore Switzer et al.

Fishery independent trapping surveys designed to assess fish assemblages associated with seagrass, including juveniles, were conducted within DRTO, inside and outside the RNA. In general, white grunts and red grouper collected in seagrass beds were smaller than those observed at nearby reefs. Juvenile red and black groupers were most frequently collected in the shallow seagrass beds of the RNA. Seagrass beds within the RNA most likely function as an important nursery habitat for juveniles of exploited reef fish species of the Tortugas region.

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

Chapter 3: Regional connectivity of fishes within the Tortugas region of Florida – Michael W. Feeley et al.

A migratory corridor for adult mutton snapper between the RNA and offshore spawning habitat at Riley's Hump (RH) was identified using acoustic telemetry. Mutton snapper were observed to make that migration 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 RH. 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.

The RNA, complemented by the TNER and the TSER, provides critical protection of essential reef fish habitat and important fish spawning habitat for species such as mutton snapper. Photo by ©Christopher Parsons, Photography by Chris Parsons.

Chapter 4: Spillover of select reef fish species in and near the Dry Tortugas National Park Research Natural Area – Michael W. Feeley et al.

Home range estimates of acoustically tagged snappers and groupers were utilized to evaluate spillover across the boundaries of the RNA. Spillover was detected for all the species that were acoustically tagged. Many home ranges of individual fish straddled the RNA boundary. Low rates of return of conventionally tagged fish limited the ability to evaluate spillover from this method. However, long-range movements were detected for one red grouper and two yellowtail snapper. The RNA is likely providing benefits to the surrounding region through spillover.

Chapter 5: Use of Dry Tortugas National Park by threatened and endangered marine turtles – Kristen M. Hart et al.

Satellite and acoustic tracking results for green turtles, hawksbills, and loggerheads have revealed patterns in the proportion of time that tagged turtles spend within various zones of the park, including the RNA. Green turtles primarily utilize the shallow areas in the northern portion of the park. Hawksbills were mostly observed near Garden Key and loggerheads were observed throughout DRTO. Our record of turtle captures, recaptures, and sightings over the last 4 years serves as a baseline database for understanding the size classes of each species present in the park, as well as species-specific habitats in DRTO waters.

The record of turtle captures, recaptures, and sightings over the last 4 years provides baseline data for understanding the size classes of each species present in the park, as well as species-specific habitats in DRTO waters. Photo by Matt Patterson, NPS.

RNA Topic 3: Monitor changes in species composition and catch rates of exploited species throughout the surrounding region

Chapter 6: Status of the development and implementation of a creel survey and vessel permit system at Dry Tortugas National Park – Tracy A. Ziegler et al.

National Park Service staff has been working with University of Miami fisheries scientists to develop an improved creel census for DRTO. The survey design is complete and creel survey data will be used to calculate catch per unit effort for exploited fisheries species, which can help provide an estimate of species abundance during a given time period. The vessel permit system is in place and will be used in concert with the creel surveys to help assess the effects of RNA implementation on recreational fishing areas surrounding the RNA.

RNA Topic 4: Evaluate the effects of RNA implementation on marine benthic biological communities

Chapter 7: Assessing the effects of diving activities on coral communities at designated dive sites within the Dry Tortugas National Park Research Natural Area – Rob Ruzicka et al.

The goal of this project is to determine if diver-related impacts will occur at RNA dive sites designated with mooring buoys. In 2009, permanent monitoring stations were established at four RNA dive sites and three equivalent reference sites that have little or no diving activity and do not have mooring buoys. Surveys conducted in 2009 and 2010 established excellent baseline information prior to installation of the mooring buoys, which was completed in 2011. Post-installation surveys will be conducted to evaluate the extent of diver impacts.

Chapter 8: Baseline surveys to detect trophic changes in shallow hard-bottom communities induced by the Dry Tortugas National Park Research Natural Area – Ilsa B. Kuffner et al.

A study was initiated to examine the potential impacts of reduced abundance of exploited reef fish species on herbivores, macroalgae, and corals. Surveys were performed inside and outside of the RNA to characterize relationships between different trophic level organisms inhabiting the coral reef ecosystem. No significant differences in the abundance of herbivorous fish and urchins or in the abundance of exploited fish species in the shallow, low-relief hard-bottom communities were observed inside vs. outside the RNA. Evaluating and understanding trophic changes that may occur related to the RNA will require a long-term research and monitoring effort. Future surveys will be necessary to determine if changes have occurred in the proportions of major coral reef ecosystem components and to help determine if the implementation of the RNA results in balanced benthic communities at DRTO.

Chapter 9: Eight years of coral reef community monitoring: Results from inside and outside the Dry Tortugas National Park Research Natural Area – Jeff Miller et al.

The National Park Service conducts annual monitoring designed to observe long-term status and trends of benthic communities, with particular attention focused toward monitoring change associated with the RNA. Decreases in coral cover were observed at Bird Key Reef from 2004 to 2011 while coral cover at all other sites remained relatively constant through that time period. A benthic habitat map was developed that now identifies more than 10,000 ha of DRTO habitats previously unclassified, including areas of previously unclassified hard bottom.

Chapter 10: Evaluation of submerged cultural resource conditions within Dry Tortugas National Park – Memory et al.

Many submerged cultural resources exist inside and outside the RNA. A survey in 2009 was conducted at 40 of 50 submerged cultural resource sites and condition assessments were performed at each site. Baseline condition data have been collected and will be used for monitoring change in the condition of cultural resources within the RNA and other areas of DRTO. Because submerged cultural resources serve as substrate for benthic natural resources and associated fish and invertebrate communities, opportunities exist for collaborative studies between NPS natural and cultural resource divisions to determine benefits of RNA implementation.

A survey in 2009 was conducted at 40 of 50 submerged cultural resource sites and condition assessments were performed at each site. Photo by Brett Seymour, Submerged Resources Center, NPS.

RNA Topic 5: Assess reproductive potential of exploited species by evaluating egg production and larval dispersal

Chapter 11: Larval transport modeling to assess the reproductive potential of reef fish spawning in the Tortugas region – Jerald S. Ault et al.

A south Florida marine ecosystems model was developed to simulate the larval drift of marine organisms. This model was used to assess the reproductive potential of exploited reef fish species by evaluating the expected physical transport and fate of fish eggs and larvae spawned in the Tortugas region to the adjacent waters of the south Florida coral reef ecosystem. Simulation results indicate that spawning in the Tortugas region is likely supplying newborn recruits to reef fish populations throughout southern Florida, including the Dry Tortugas and Florida Keys reef tract, coastal bays along the West Florida Shelf, and along the east coast of Florida north of Miami.

RNA Topic 6: Incorporate social sciences into the research and monitoring program

Chapter 12: A survey of visitor demographics, attitudes, perceptions, and experiences at Dry Tortugas National Park – David Loomis.

This project will survey park visitors who participate in recreational boating, fishing, SCUBA diving, snorkeling, and other activities within DRTO, with an emphasis on understanding the use of the RNA. This survey will help managers understand the behaviors and actions of park visitors that have significant impacts on resources and the success of the RNA. The survey results will provide basic demographic information on the respondents, the frequency and extent to which they engage in different types of recreational activities, and their perceptions of the RNA.

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 as their primary goal finding the means to fund and otherwise 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, evaluate juvenile fish within the seagrass beds of the RNA, conduct acoustic tagging studies of fish movements, and model larval-transport. 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. Specifically, extensive surveys of adult fish (Chapter 1, this volume) observed increases in the abundance of exploited species within the RNA. Studies that tracked acoustically tagged fish not only detected spillover, but identified a previously unknown migratory behavior of mutton snapper where they travelled to Riley's Hump from within the RNA as many as 4 times during one spawning season (Chapters 3 and 4, this volume). This research team also observed for the first time aggregations of actively spawning mutton snapper at Riley's Hump. They conclude that protection of mutton snapper offered by the RNA has been important to the recovery of the aggregation. The larval transport models indicate that fish larvae from these spawning aggregations settle throughout south Florida, including the Dry Tortugas (Chapter 11, this volume). Finally, the surveys conducted within the seagrass beds of the RNA indicate that these beds likely serve as juvenile nursery grounds for many exploited fish species of the region (Chapter 2, 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. Baseline studies for assessing the impact of diving on benthic habitats (Chapter 7, this volume) and initial surveys to set the baseline for understanding future trophic changes (Chapter 8, this volume) were completed. A more accurate habitat map was developed that will support future research (Chapter 9, this volume). Finally, the stage has been set for future evaluation of the human dimension components of the science plan (Chapters 6 and 12, this volume). The RNA and associated reserves should serve as an important focal point for future research designed to understand the role that no-take marine reserves can play in marine ecosystem management.

Surveys conducted within the seagrass beds of the RNA indicate that these beds likely serve as juvenile nursery grounds for many exploited fish species of the region. Photo by Naomi Blinick, USGS.

Gray snapper and a red grouper congregate near a large coral head. Photo by Naomi Blinick, USGS.

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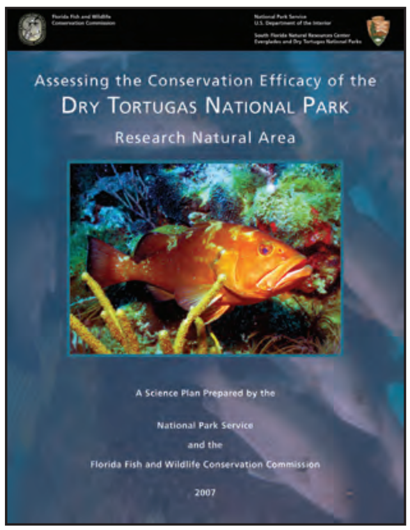
Editors:

Tracy A. Ziegler, National Park Service, Everglades and Dry Tortugas National Parks
John Hunt, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute



Science activities in the Dry Tortugas National Park Research Natural Area are guided by the science plan prepared in 2007 by the National Park Service and the Florida Fish and Wildlife Conservation Commission. All reports are available online at: http://www.nps.gov/ever/naturescience/technicalreports.htm

Comments and Questions on the RNA Science Plan, 3-Year Report, and 5-Year Report:

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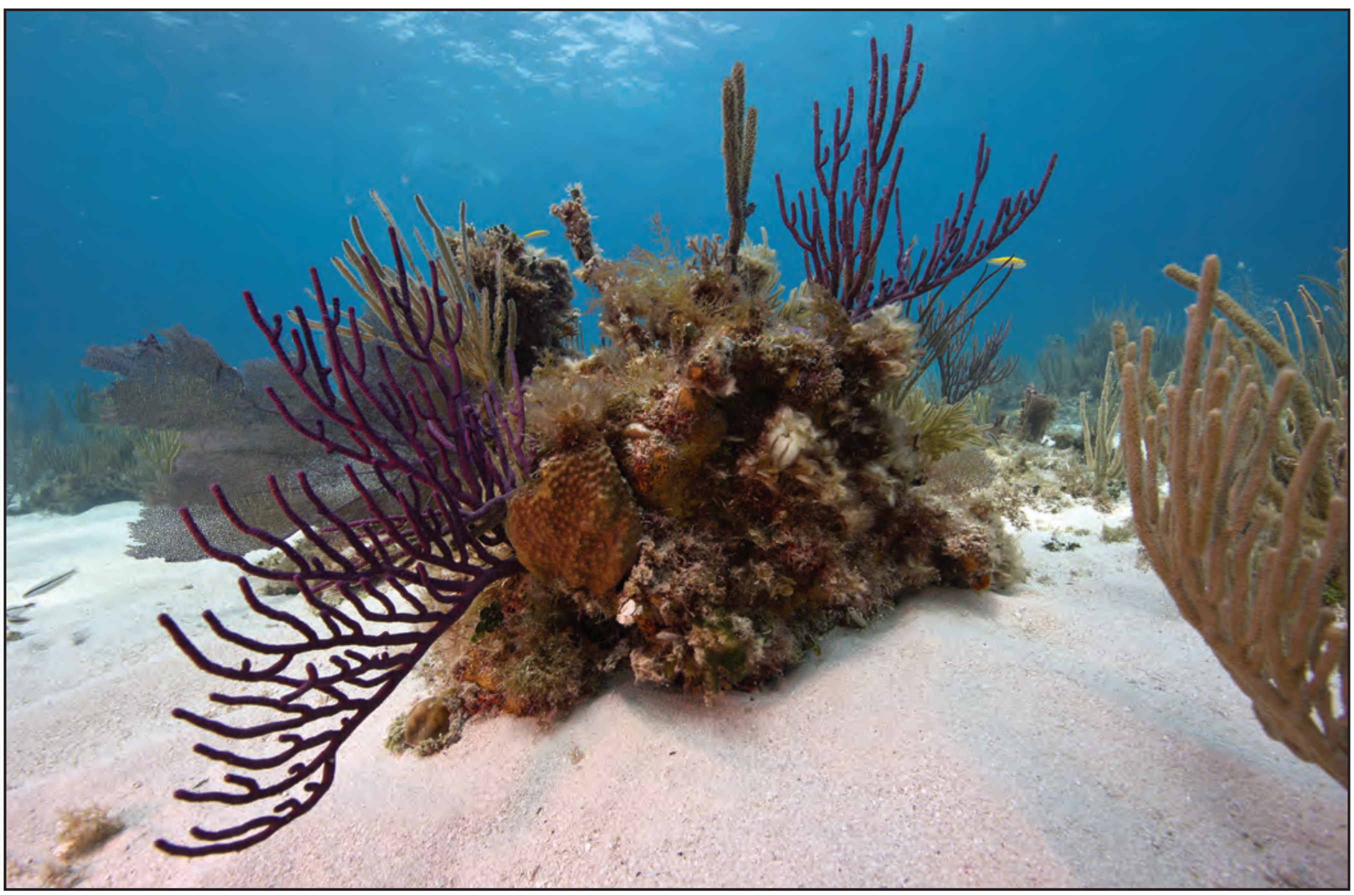
LIST OF ABBREVIATIONS

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
GIS	Geographic information system
GPS	Global Positioning System
HAU	Historic Adaptive Use Zone
HYCOM	Hybrid Miami Isopycnal Coordinate Ocean Model
KDE	Kernel density estimate
LiDAR	Light Detection and Ranging
MCP	Minimum convex polygon
MML	Mote Marine Laboratory
MPA	Marine protected area
NCZ	Natural Cultural Zone
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTMR	No-take marine reserve
OMB	Office of Management and Budget
PIT	Passive integrated transponder
RH	Riley's Hump
RNA	Research Natural Area
RSMAS	Rosenstiel School of Marine and Atmospheric Sciences
SCL	Straight carapace length
SFCN	South Florida/Caribbean Network
SPZ	Special Protection Zone (as in Nurse Shark SPZ or Coral SPZ)
SRC	Submerged Resources Center
TBO	The portion of Tortugas Bank south of the TNER and west of DRTO that is open to fishing
TNER	Tortugas North Ecological Reserve
TSER	Tortugas South Ecological Reserve
UM	University of Miami
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.



Dry Tortugas National Park is managed for the protection of a pristine subtropical marine ecosystem—including an intact coral reef community—for the enjoyment of present and future generations. Photo by Brett Seymour, Submerged Resources Center, NPS.

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. This jointly developed 5-year report provides a summary of the research results on the six areas of RNA performance and meets the requirements (Article III, Sections B(3) and C(4)) of the Memorandum of Understanding established between the FWC and DRTO and finalized in February of 2007. The report is structured by performance topics as established in the science plan. Each chapter contains a summary of progress and results obtained thus far, plus an evaluation of those results relative to the stated goals of the RNA.

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 Conservation Commission, Tallahassee, FL. 37 pp.

SFNRC and FWC. 2007. Assessing the conservation efficacy of the Dry Tortugas National Park Research Natural Area. South Florida Natural Resources Center, Everglades and Dry Tortugas National Parks, Homestead, FL, and the Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. 47 pp.

The RNA protects shallow water marine habitat, ensures species diversity, and enhances the productivity and sustainability of fish populations throughout the region. Photo by Jiangang Luo, UM RSMAS.

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. All management zones and locations discussed in this section are referenced on the maps located on the front and back inside covers of this report.

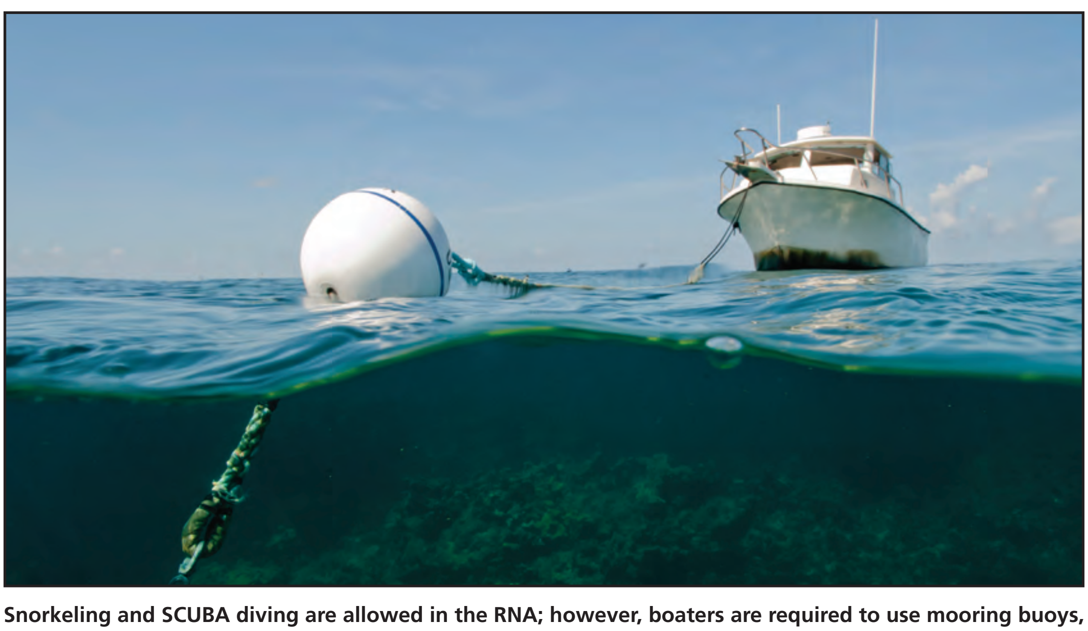
Dry Tortugas National Park (DRTO), located approximately 70 miles to the west of Key West, includes 100 mi^2 of marine waters and seven small islands, one of which contains Fort Jefferson, a national historic site. Marine-related activities allowed park-wide include boating, snorkeling, SCUBA diving, 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 Research Natural Area (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 Natural Cultural Zone (NCZ) encompasses approximately 50% 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 Historic Adaptive Use Zone (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 surrounding 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 resources of the Tortugas region based on fishery-independent visual and trap survey assessments

Investigators

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Project Description

The National Park Service established the Research Natural Area (RNA), a no-take marine reserve (NTMR), in the western half of Dry Tortugas National Park (DRTO) in 2007. The RNA was designed as a shallow-water complement to two relatively large marine reserves, the Tortugas North Ecological Reserve (TNER) and the Tortugas South Ecological Reserve (TSER), established in 2001 in the Florida Keys National Marine Sanctuary. The remainder of the park, the Natural Cultural Zone (NCZ), has been closed to commercial fishing, recreational spearfishing, and lobstering since the 1960s. This section of the park is, however, open to recreational hook-and-line fishing.

To better understand the effects of RNA implementation on the abundance and size structure of exploited species within the RNA relative to adjacent areas (Performance Topic 1), it is important to view DRTO and the Tortugas region relative to the larger Florida coral reef ecosystem and in relationship to the regional spatial management actions implemented during the past decade. The Florida coral reef ecosystem, stretching 400 km southwest from Miami to the Dry Tortugas, supports multibillion-dollar tourism and fishing industries (Ault et al. 2005a). Regional spawning in the Tortugas region provides the Florida Keys with recruits because of its relative isola-

Fishery-independent visual surveys were conducted during 1999–2011 throughout the Tortugas region to assess the resource status of the coral reef fish community, including hogfish and other exploited species. Photo by the South Florida/Caribbean Inventory and Monitoring Network, NPS.

tion and upstream location where the Loop Current merges into the Florida Current (Schmidt et al. 1999; Ault et al. 2006; Chapter 11, this volume). However, the sustainability of these fisheries resources is in question. The ecosystem's lucrative multispecies snapper-grouper complex has been intensively fished since at least the late 1970s (Ault et al. 1998; 2005b; 2009). The number of recreational vessels in Florida, an index of sportfishing fleet size, has risen in step with increases in the human population. From 1960 to 2010, Florida's human population increased from 4,951,560 to 18,801,310. During this same period registered recreational vessels increased by 697%, reaching 896,093 at present. The commercial fleet, in contrast, has remained stable during this period.

Fishery-independent visual surveys were conducted during 1999–2011 throughout the Tortugas region to assess the resource status of the coral reef fish community, and specifically to evaluate spatial and temporal trends in species-specific abundance metrics (occurrence, density, abundance, and size composition, for example) before and after implementation of the TNER and RNA (Performance Topic 1). Sampling effort was concentrated inside DRTO and the adjacent Tortugas Bank to the west of the park (Fig. 1). Highly trained and experienced divers collected biological data following a standard, non-destructive, in-situ monitoring protocol in which a stationary diver records reef-fish data (number and sizes of each species) while centered in a randomly selected circular plot 15 m in diameter. The field research team was comprised of scientific personnel from the National Oceanic and Atmospheric Administration, the University of Miami, the National Park Service, and the State of Florida. The statistical field design partitioned Tortugas Bank and DRTO into strata based on reef habitat characteristics (complexity and patchiness of reef structures, and depth) and spatial management zones (Fig. 1 and map shown on inside cover). This habitat-based survey design was developed in 1999 and 2000, and has been shown to provide accurate and precise abundance metrics for reef fishes in the Tortugas region in a cost-effective manner (Ault et al. 2006; Smith et al. 2011). Tortugas region-wide surveys were conducted during 1999, 2000, 2004, 2006, 2008, and 2010, with sample sizes ranging from 327 to 704 stations. In addition, DRTO-specific surveys were conducted in 2002, 2009, and 2011, with sample sizes ranging from 191 to 445 stations.

A complementary fishery-independent survey using baited chevron traps was conducted from May 2008 to June 2011 to evaluate potential changes in the relative abundance and size structure of exploited reef fishes within the RNA and NCZ. Sampling followed a seasonal (spring and fall) stratified-random survey design within the southern portion of DRTO (south of 24° 40' N). The survey design was based on the reef fish visual census, although reef habitats were aggregated into three reef strata: contiguous reef; spur-and-groove reef; and isolated reef. At each sampling station, four chevron traps were baited with Atlantic mackerel and deployed over sand bottom adjacent to targeted reef habitat. Traps were allowed to soak for a minimum of 90 minutes prior to retrieval. All trapping was conducted during daylight hours. Seasonal sampling effort ranged from 29 to 46 stations. In total, trapping

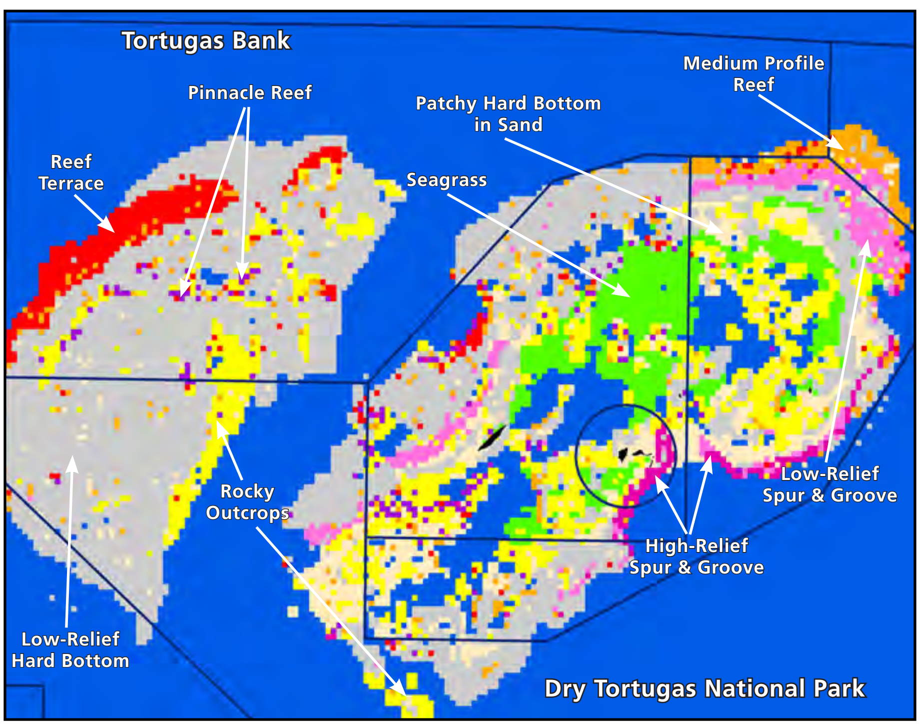

Figure 1. Map of benthic habitats and management zones in the Tortugas region (redrawn from Ault et al. 2006). See map on inside front cover for management zone identification.

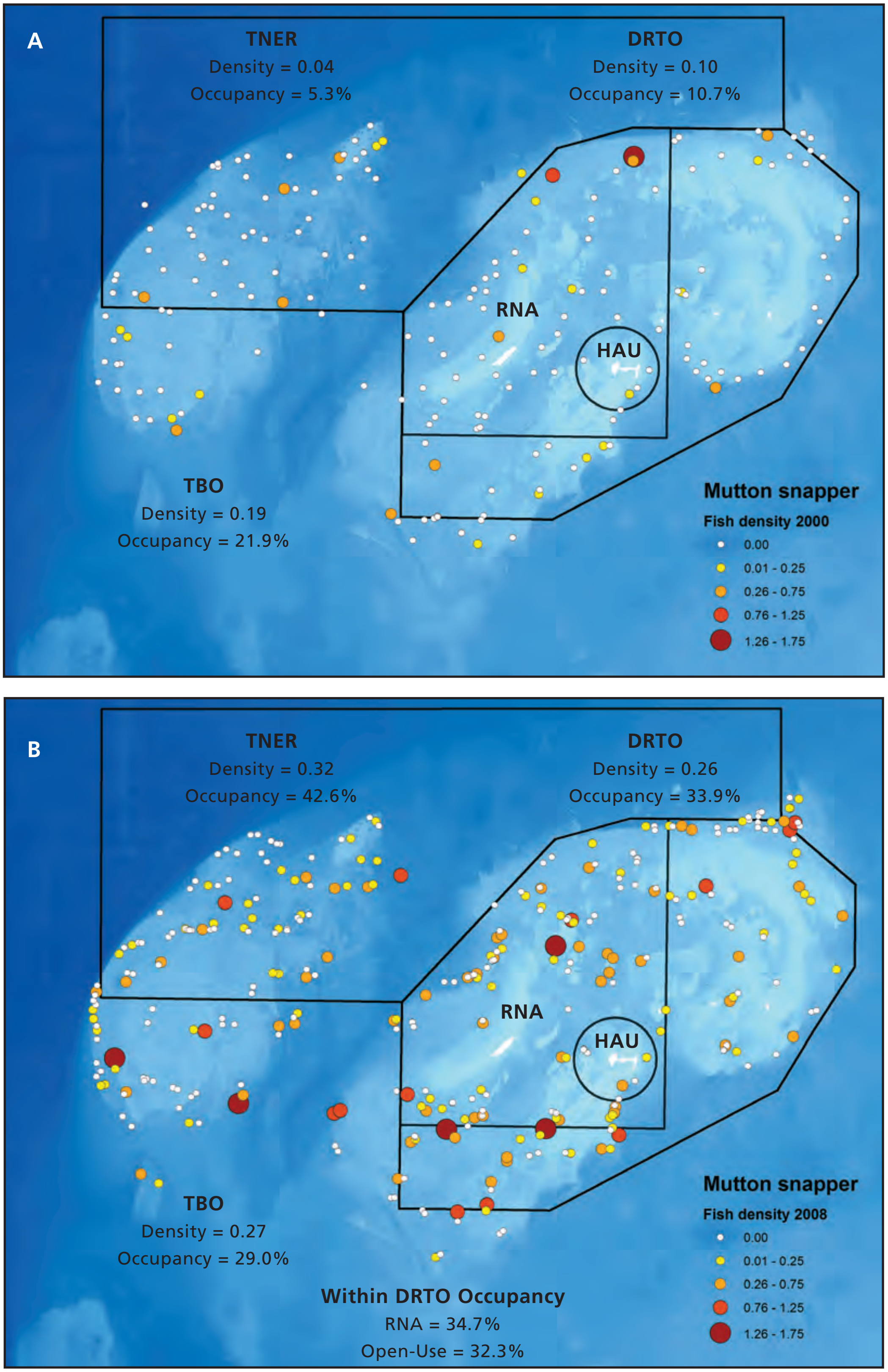

Figure 2. Spatial distribution of exploited mutton snapper density (mean number of fish per sample unit, 177 m^2) for Tortugas region visual surveys conducted in (A) 2000 and (B) 2008, and corresponding average densities and occupancy rates for three areas (TNER, DRTO, and TBO). Each sample point represents the average of four diver visual point counts. White circles represent sample points where no mutton snapper were observed. Colored circles represent sample points where mutton snapper were present. Occupancy rates within DRTO (RNA and open-use zones) are provided for 2008. Note that though the RNA was not established in 2000, boundary lines are shown for reference in Panel A.

surveys were conducted at 117 stations (468 chevron trap sets) within the RNA and 122 stations (488 chevron trap sets) within the NCZ. In the RNA, 3,968 fish representing 35 taxa were collected, whereas 4,130 fish representing 32 taxa were collected in the NCZ. In both areas, the three most abundant and frequently occurring taxa were yellowtail snapper, white grunt, and red grouper. Accordingly, we focused our trap data analyses on these three species.

Results

Reef-fish population metrics from fishery-independent surveys were assessed from three perspectives: (1) changes at the regional scale from 1999 to 2011, pre- and post-implementation of both the TNER and RNA; (2) changes within DRTO focusing on the 2006–2011 time period, pre- and post-implementation of the RNA; and, (3) analysis of the ecological role of DRTO in the ecosystem for providing habitat for both juveniles and adults.

Visual survey abundance metrics were evaluated for the region through time, beginning with the baseline pre-NTMR implementation surveys during 1999–2000, through implementation of the TNER (2001) and DRTO RNA (2007) management zones, and concluding in 2011. A principal abundance metric evaluated was animal density, the number of individuals per unit sample area (177 m^2, the area of a diver circular plot). Maps of spatial density are illustrated in Figure 2 for mutton snapper in the exploited life stage (fish at and above the minimum legal size of capture). A second abundance metric evaluated was frequency of occurrence (the percentage of diver visual samples in which at least one individual of a given species was observed). This statistic provides a measure of the occupancy rate (the percentage of the coral reef habitat area that is occupied by a species). As shown for mutton snapper in Figure 2 , both density and occupancy rates increased in the open-use area of Tortugas Bank (TBO), the TNER, and DRTO between the pre-implementation baseline survey of 2000 and the 2008 survey, post-implementation of both the TNER and DRTO RNA.

Evaluation of changes in density during 1999–2011 is illustrated for exploited-phase hogfish in Figure 3A. Because hogfish density in 1999, prior to implementation of management zones, varied across the region, density that year was set as a baseline of zero. Standard statistical procedures were used (described in Ault et al. 2006) to test for differences in density within each zone for each post-baseline survey year and the baseline level. For hogfish, statistically significant densities ($p<0.05$) above the baseline were detected in DRTO in three of seven years (2002, 2008, and 2011), whereas densities below baseline levels were detected in the TBO in two of the seven years (2006 and 2010) and were never above baseline. No differences from baseline levels were detected at the TNER. Table 1 summarizes the change in density from the 1999 baseline for a suite of exploited and non-target reef fish species, as well as two formerly exploited species that have been protected by a fishery moratorium since 1994. In DRTO, the densities of the exploited stage of the 5 exploited species were never below the baseline, and 4 were above the baseline in 16 of 35 sampling occasions. In contrast, densities of these species below the 1999 baseline were detected only in the TBO. As expected, the pattern of density change for non-target species fluctuated in a pattern unrelated to the management zones. The pattern of change was mixed for the two species under fishing moratoria. Densities above baseline were detected for goliath grouper in both the TNER and DRTO, whereas the density of Nassau grouper below the baseline was detected in DRTO during one survey.

Comparisons of length composition among management areas and time periods from the visual survey are illustrated for black grouper in Figure 4. A general increase between 2000 and 2008 in the proportion of fish at sizes at and above the legal minimum was observed in the TNER and particularly

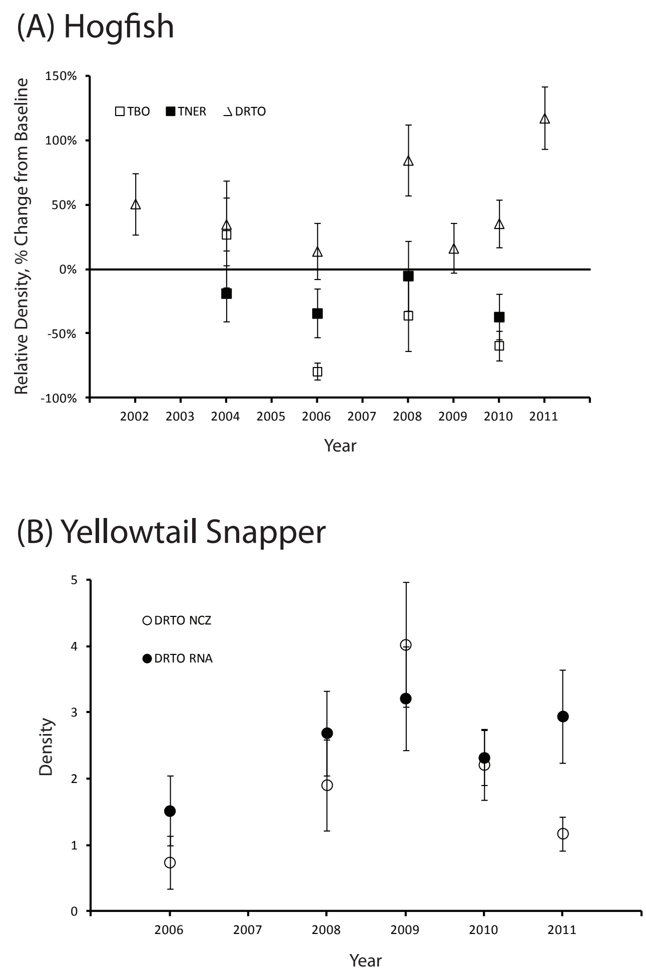

Figure 3. (A) Visual survey estimates of relative mean density (± Standard Error (SE)) for the exploited life stage of hogfish, 2002–2011, for three management areas. Density (number of fish per diver visual point count of area 177 m^2) is expressed as percent change from 1999–2000 baseline levels (solid line). (B) Visual survey mean densities (± SE) for the exploited life stage of yellowtail snapper in Dry Tortugas National Park, 2006–2011.

Table 1. Summary of 1999–2011 visual survey results for density for a suite of exploited and non-target reef fish species, and two other species under fishing moratoria. Baseline surveys were conducted during 1999–2000; four surveys were conducted post-baseline in the TBO and TNER zones, and seven surveys were conducted post-baseline in DRTO.

		TBO			TNER			DRTO		
Family	**Species**	**Increase**	**Decrease**	**No Change**	**Increase**	**Decrease**	**No Change**	**Increase**	**Decrease**	**No Change**
					Exploited					
Groupers	Red grouper	0	3	1	0	0	4	0	0	7
Groupers	Black grouper	0	0	4	1	0	3	2	0	5
Snappers	Mutton snapper	1	0	3	2	0	2	7	0	0
Snappers	Yellowtail Snapper	0	0	4	0	0	4	4	0	3
Wrasses	Hogfish	0	2	2	0	0	4	3	0	4
	Overall Exploited	**1**	**5**	**14**	**3**	**0**	**17**	**16**	**0**	**19**
					Non-Target					
Damselfishes	Bicolor damselfish	2	1	1	2	1	1	3	1	3
Damselfishes	Threespot damselfish	1	0	3	0	4	0	1	3	3
Parrotfishes	Princess parrotfish	2	0	2	0	2	2	2	1	4
Seabasses	Harlequin bass	1	1	2	2	0	2	0	2	5
Surgeonfishes	Ocean surgeon	0	0	4	1	0	3	0	1	6
Wrasses	Puddingwife	0	0	4	0	0	4	1	2	4
	Overall Non-target	**6**	**2**	**16**	**5**	**7**	**12**	**7**	**10**	**25**
					Moratorium					
Groupers	Goliath grouper	0	0	4	1	0	3	3	0	4
Groupers	Nassau grouper	0	0	4	0	0	4	0	1	6
	Overall Moratorium	**0**	**0**	**8**	**1**	**0**	**7**	**3**	**1**	**10**

in DRTO. These changes are characteristic of a relaxation of fishing pressure (fishing mortality rate) during the time frame, during which more fish survived and grew to larger mature sizes. In contrast, very few exploited phase fish were observed in the TBO in both time periods. Similar time-space patterns of change in length composition were observed for red grouper, mutton snapper, and hogfish. We also used our survey data to estimate abundance for the exploited phase of black grouper within each management zone pre- and post-implementation. Abundance markedly increased within DRTO, decreased in the TBO, and remained constant in the TNER. Six hurricanes impacted the Tortugas region between the surveys of 2004 and 2006, and many species, fishery and non-target alike, experienced declines in density and abundance during this period. Even though Figure 4 shows similar levels of exploited phase abundance for black grouper, in 2004 prior to the intense hurricane period, abundance of exploited phase black grouper in the TNER more than doubled over 1999–2000 baseline levels (Ault et al. 2006).

Direct comparisons of densities between the RNA and the NCZ are presented for yellowtail snapper in Figure 3B. Increases in density relative to the 2006 pre-RNA baseline

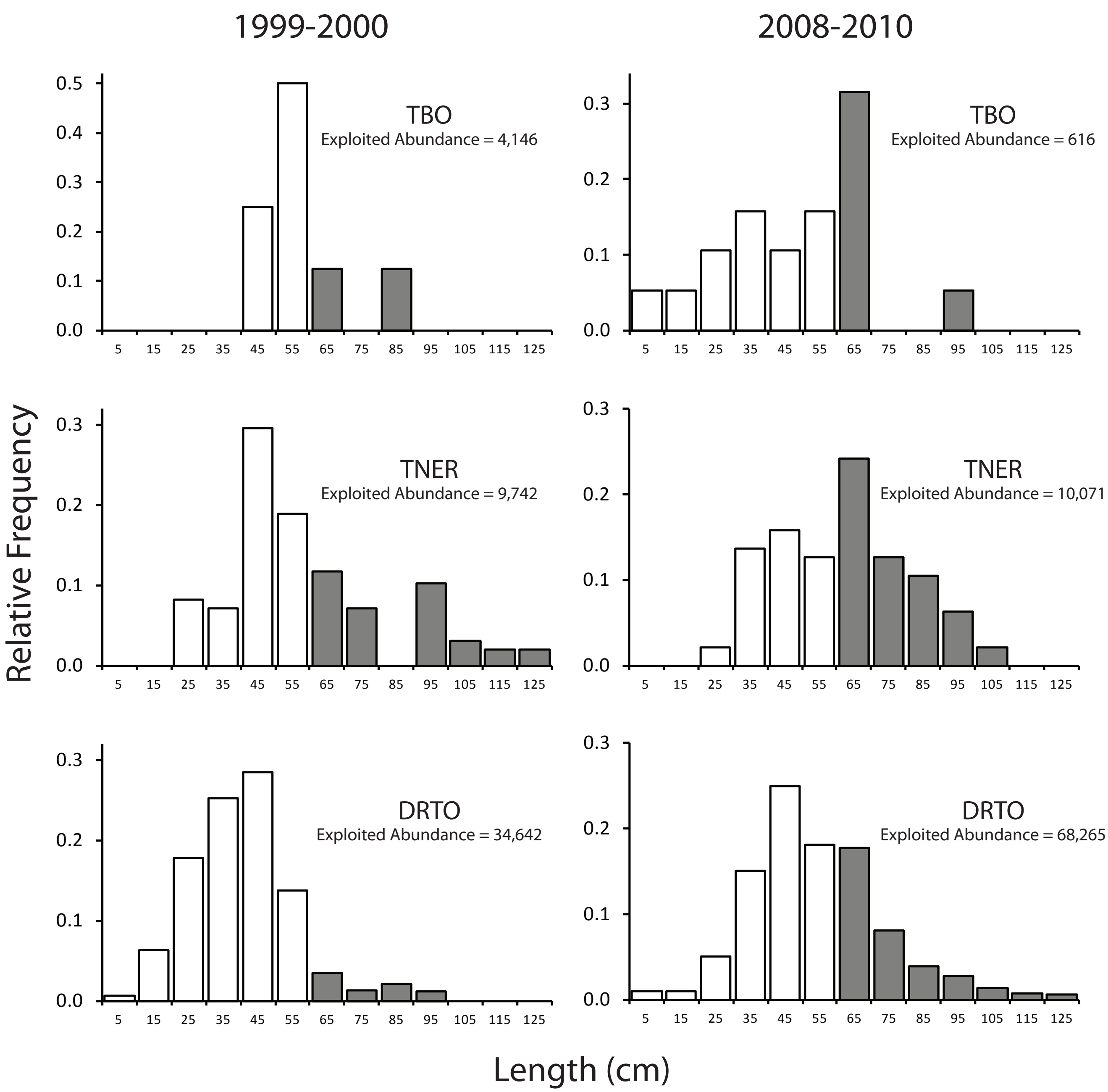

Figure 4. Visual survey length compositions for black grouper among three management zones for two time periods: the pre-implementation baseline, 1999–2000, and post-implementation of the TNER and RNA, 2008–2010. Open bars are the pre-exploited life stage, shaded bars are exploited (fished) life stage animals; exploited abundance is noted on each panel.

were detected for yellowtail snapper during the post-RNA period 2008–2011, but the pattern was inconsistent: significant increases occurred in both the NCZ and RNA zones in 2009, only in the open-use area in 2010, and only in the RNA in 2011. Similar inconsistent patterns of post-RNA density changes also were observed for hogfish, red grouper, and mutton snapper, with no changes detected in either zone for black grouper. Additionally, occupancy rates also were similar between the RNA and the NCZ for most species (for example mutton snapper, Fig. 2B). Similarly, no consistent differences in the relative abundance of red grouper, yellowtail snapper, or white grunt were evident between the NCZ and RNA zones in the trap survey. A comparison of size structure of red grouper, yellowtail snapper, and white grunt from the trap survey showed that the size of individuals was similar between the RNA and NCZ (Fig. 5). For both red grouper and yellowtail snapper, a substantial proportion of individuals collected were at and above the recreational legal-minimum size limit.

The Tortugas region-wide visual surveys also were analyzed to evaluate the ecological role of DRTO in providing habitat for juvenile and adult life stages of principal fishery species. While DRTO contains about 60% of the Tortugas survey area (live coral reef habitats, 0–33 m depth), the percentage of juvenile abundance in DRTO was similar to or greater than this percentage, ranging from 62 to 93% for the five species analyzed (Table 2A). The proportion of adult spawner abundance, which includes the exploited life stage, increased by 10% or more in DRTO during 1999–2000 and 2008–2010 for four of five fishery species (Table 2B). Over this period, the total number of adult spawners in the region decreased by about 10% for red grouper and hogfish, increased by 60% for black grouper, and more than tripled for mutton snapper and yellowtail snapper. By 2008–2010, DRTO contained 62–87% of adult spawners in the Tortugas region for four of the five species. The analysis of adult spawners was expanded to include the combined Dry Tortugas and Florida Keys survey areas (mapped live coral habitats, 0–33 m depth), which

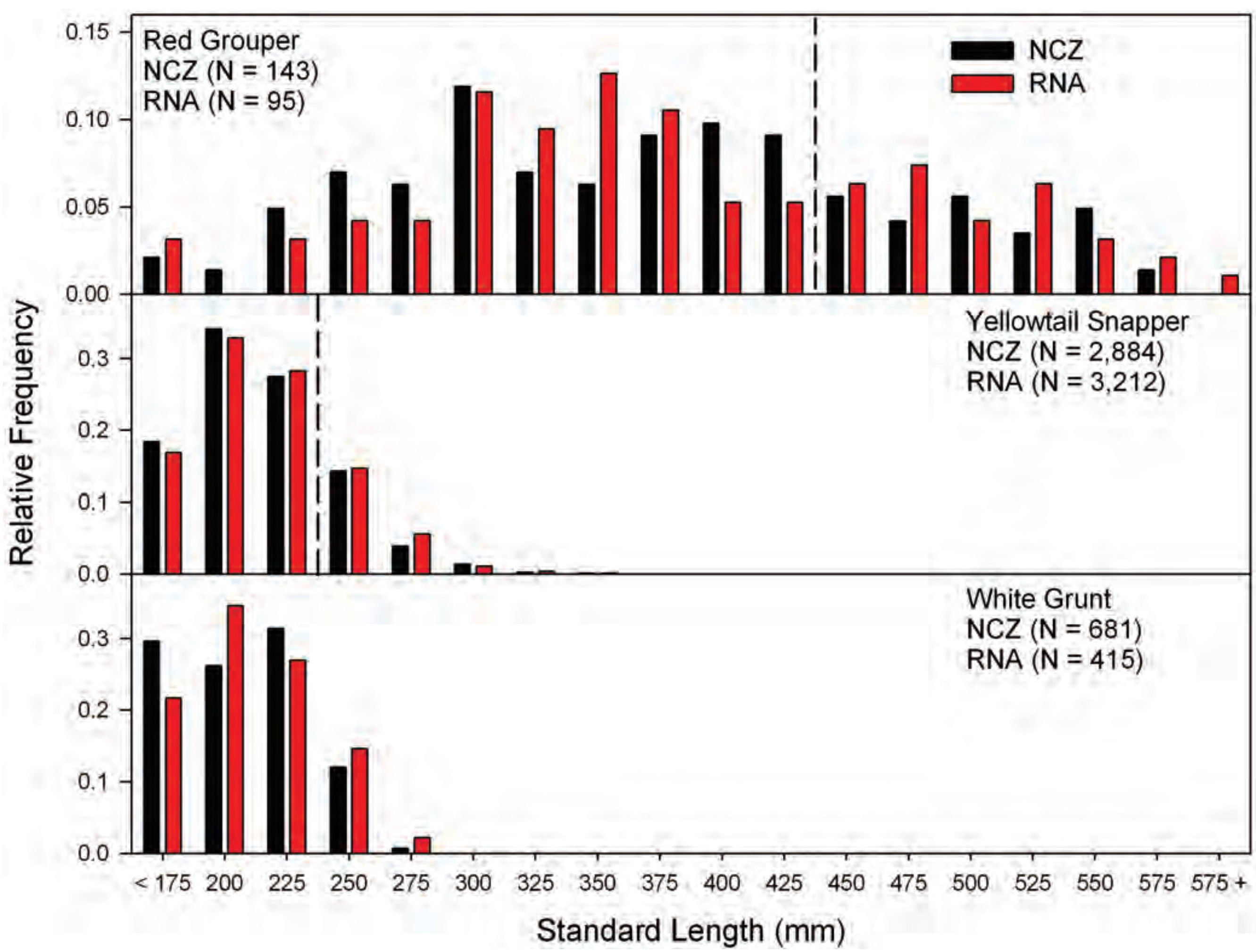

Figure 5. Length frequencies of red grouper, yellowtail snapper, and white grunt collected during the trap survey in the RNA and NCZ areas, 2008–2010. Dashed lines represent the recreational size limit for red grouper and yellowtail snapper; no size limit exists for white grunt.

Table 2. (A) Percentage of abundance (total numbers) of juveniles in three management zones in the Tortugas region for five principal reef fishery species; the percentage of reef habitat area is denoted for each zone. (B) Adult spawner abundance and percentages among management zones in the Tortugas region for two time periods, 1999–2000 and 2008–2010. (C) Adult abundance and percentages among management zones in the combined Florida Keys/Dry Tortugas reef ecosystem for two time periods.

(A) Tortugas region, Juveniles, 2008–2010

Species		Percentage of Juveniles		
		TBO	TNER	DRTO
	Area =	16.5%	23.7%	59.8%
Red Grouper		11.8	20.1	68.1
Black Grouper		2.3	4.7	93.0
Mutton Snapper		26.1	1.5	72.4
Yellowtail Snapper		10.3	28.1	61.6
Hogfish		3.8	12.7	83.6

(B) Tortugas region, Adults

Species	Time Period	Spawner Abundance (1000s)		Percentage of Adults		
				TBO	TNER	DRTO
			Area =	16.5%	23.7%	59.8%
Red Grouper	1999–2000	468.1		20.5	28.4	51.1
	2008–2010	423.6		6.6	31.5	61.9
Black Grouper	1999–2000	48.5		8.5	20.1	71.4
	2008–2010	79.0		0.8	12.8	86.5
Mutton Snapper	1999–2000	177.5		26.8	12.5	60.7
	2008–2010	616.9		21.4	22.7	55.9
Yellowtail Snapper	1999–2000	3,379.5		17.2	33.5	49.2
	2008–2010	10,021.1		4.9	25.9	69.2
Hogfish	1999–2000	1,067.7		21.9	21.6	56.5
	2008–2010	937.5		13.9	19.9	66.2

(C) Florida Keys and Dry Tortugas, Adults

Species	Time Period	Spawner Abundance (1000s)		Percentage of Adults				
				TBO	TNER	DRTO	Keys Open-Use	Keys NTMR
			Area =	6.2%	8.9%	22.4%	58.9%	3.6%
Red Grouper	1999–2000	522.8		18.3	25.4	45.7	9.9	0.6
	2008–2010	540.1		5.1	24.7	48.6	19.9	1.6
Black Grouper	1999–2000	68.5		6.1	14.2	50.6	16.0	13.2
	2008–2010	130.5		0.5	7.7	52.3	34.9	4.6
Mutton Snapper	1999–2000	409.7		11.6	5.4	26.3	53.1	3.6
	2008–2010	1,078.4		12.3	13.0	32.0	39.5	3.3
Yellowtail Snapper	1999–2000	7,707.5		7.6	14.7	21.6	38.9	17.3
	2008–2010	14,982.7		3.2	17.3	46.3	28.5	4.6
Hogfish	1999–2000	2,758.3		8.5	8.3	21.9	59.0	2.3
	2008–2010	4,314.1		3.0	4.3	14.4	74.8	3.4

were conducted concurrently over the 1999–2010 time period (Smith et al. 2011). Between 1999–2000 and 2008–2010, total spawner abundance increased for all five species, more than doubling in most cases (Table 2C). For the combined Florida Keys/Dry Tortugas regions, DRTO contained 22% of the total survey area yet harbored a disproportionately larger percentage of the adult spawners in 2008–2010 for four of the five fishery species, ranging from 32 to 52%.

Performance Measure Evaluation

The visual survey enabled evaluation of changes in reef fish populations in the Tortugas region during the 1999–2011 time period. Key management and environmental events occurring during these years were implementation of the TNER in 2001, intense hurricanes in 2004–2005, and implementation of the RNA in 2007. A complementary trap survey provided additional information for evaluating changes in reef-fish population metrics between the NCZ and RNA zones during 2008–2011.

For five principal fishery species (red and black grouper, mutton and yellowtail snapper, and hogfish), visual surveys showed an increase in the density and abundance of fish at and above the legal size of capture in both the TNER and DRTO between the baseline years 1999–2000 and 2010, post-implementation of the TNER and RNA. These increases in density were generally accompanied by increases in both the occupancy rate and the size of fishes in the exploited life stage. In contrast, density, occupancy rate, and sizes of these fishery species either remained the same or decreased in the TBO during the same time period. This same spatial pattern of change also was observed for goliath grouper, a species under a fishing moratorium in U.S. (Florida) waters since 1994. Density and occupancy rates for a suite of non-target reef fishes showed a different spatial pattern of change during the 1999–2010 period, with fluctuations above and below baseline levels occurring in each management zone depending on the species.

Within DRTO, the visual survey detected some increases in density and occurrence for principal fishery species before (2006) and after (2008–2011) implementation of the RNA; however, these increases occurred in the NCZ and RNA zones with equal frequency. The focused trap study conducted during 2008–2011 also detected no consistent pattern of differences in relative abundance or size structure between the NCZ and RNA zones for three fishery species: red grouper, yellowtail snapper, and white grunt. Acoustic tagging studies of fish movement (Farmer and Ault 2011; Chapters 3 and 4, this volume) show that the principal fishery species move freely between the NCZ and RNA zones, both of which comprise a similar mix of reef habitat types (Fig. 1) and depths. Taken together, results from the visual and trap surveys and tagging studies indicate that there has been no dramatic displacement of fishing effort from the RNA to the NCZ post-implementation of the RNA. From a broader fishing perspective, more and larger reef fish are available for capture by recreational anglers in the NCZ at present (2011) compared to 1999 before implementation of the TNER and RNA.

Visual surveys showed an increase in the density and abundance of mutton snapper in both the TNER and DRTO between the baseline years 1999–2000 and 2010, post-implementation of the TNER and RNA. Photo by Douglas Morrison, NPS.

Visual surveys conducted concurrently in the Dry Tortugas and Florida Keys regions (Ault et al. 2006; Smith et al. 2011) provide a unique perspective on the ecological role of DRTO in both the Tortugas region and in the larger Florida Keys/Dry Tortugas reef ecosystem. DRTO comprises 60% of the coral reef habitat in the Tortugas region, yet it harbors a disproportionately greater number (62–93%) of juveniles of principal fishery species in the region. This is likely attributed to the wider range of depths and reef habitats present in DRTO as compared to Tortugas Bank, as well as the presence of shallow seagrass habitats in DRTO, which are known nursery areas for juvenile reef fishes (Chapter 2, this volume). DRTO also contains a disproportionately greater number of adult spawners (>60% in most cases) of fishery species in the region, likely owing to the combination of favorable adult reef habitats in DRTO as well as the restrictions on fishing to recreational angling only.

Viewed from the perspective of the southern Florida coral reef ecosystem, the role of DRTO with respect to reef fish spawning stock is even more striking. Although DRTO accounts for 22% of the total reef habitat area, it contains one-third to one-half of the adult spawners for four of the five principal species analyzed, and this proportion has generally increased from 1999 to 2010. These results, combined with studies of regional connectivity, oceanography, and larval transport (Chapters 3 and 11, this volume) strongly indicate that DRTO is perhaps the major source point providing production of newborn recruits to populations of principal reef fishery species in the Tortugas region, but also the Florida Keys and southeast Florida reef tract, and the West Florida shelf. Setting aside the RNA within DRTO as a place of refuge for juveniles and adults of principal reef fishery species to live, grow, and reproduce with minimal human impacts is thus beneficial for the future sustainability of these economically and ecologically important fishery resources in Florida, particularly in light of the ever-increasing human population, environmental changes, and accompanying increases in recreational boaters and anglers using the Florida coastal marine ecosystem.

Literature Cited

Ault, J.S., Bohnsack, J.A., and Meester, G.A. 1998. A retrospective (1979–1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fishery Bulletin* 96:395–414.

Ault, J.S., Bohnsack, J.A., Smith, S.G., and Luo, J. 2005a. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. *Bulletin of Marine Science* 76:595–622.

Ault, J.S., Smith, S.G., and Bohnsack, J.A. 2005b. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. *ICES Journal of Marine Science* 62:417–423.

Ault, J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Harper, D.E., and McClellan, D.B. 2006. Building sustainable fisheries in Florida's coral reef ecosystem: Positive signs in the Dry Tortugas. *Bulletin of Marine Science* 78:633–654.

Ault, J.S., Smith, S.G., and Tilmant, J.T. 2009. Are the coral reef finfish fisheries of south Florida sustainable? *Proceedings 11th International Coral Reef Symposium* 11:989–993.

Farmer, N.A. and Ault, J.S. 2011. Grouper and snapper movements and habitat use in Dry Tortugas, Florida. *Marine Ecology Progress Series* 433:169–184.

Schmidt, T.W., Ault, J.S., and Bohnsack, J.A. 1999. Site characterization for the Dry Tortugas region: Fisheries and essential habitats. Florida Keys National Marine Sanctuary and National Park Service. NOAA Technical Memorandum NMFS–SEFSC–425.

Smith, S.G., Ault, J.S., Bohnsack, J.A., Harper, D.E., Luo, J., and McClellan, D.B. 2011. Multispecies survey design for assessing reef-fish stocks, spatially explicit management performance, and ecosystem condition. *Fisheries Research* 109:25–41.

RNA Performance Topic 1

Chapter 2: Nursery function of seagrasses within the Dry Tortugas National Park Research Natural Area

Investigators

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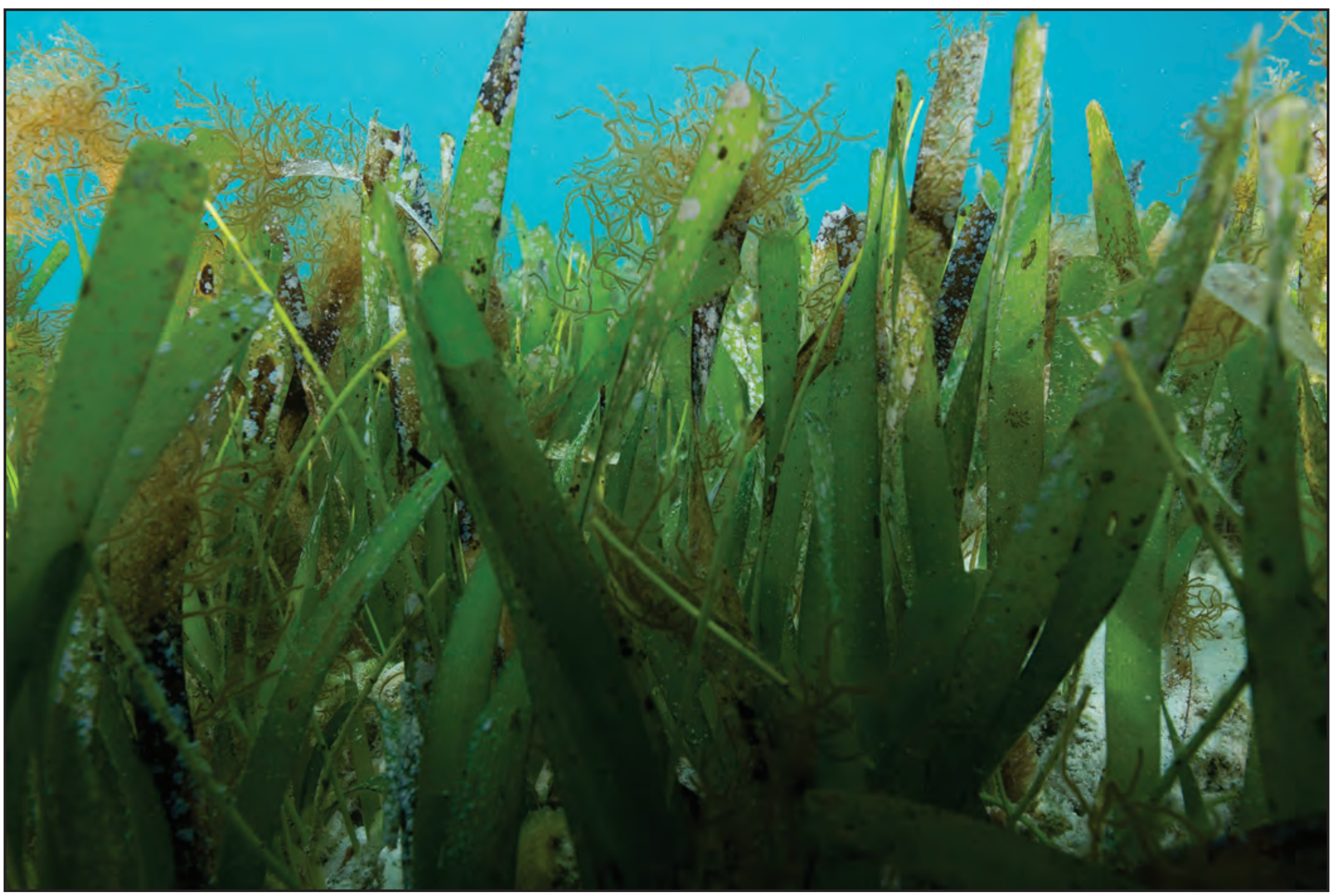
Project Description

The ecosystems of Dry Tortugas National Park (DRTO) are unique in terms of the variety and complexity of available habitat, including extensive seagrass beds in addition to a diverse range of coral reef habitats (Franklin et al. 2003). In an attempt to mitigate the effects of fishing and habitat loss in the park, a large (11,914 ha) Research Natural Area (RNA) was established in 2007, within which fishing and other potentially destructive activities were restricted or eliminated. Combined with the Tortugas North Ecological Reserve (TNER) and the Tortugas South Ecological Reserve (TSER), established outside the park in 2001 by the National Oceanic and Atmospheric Administration, the RNA brings the total protected area within the Tortugas region to 67,235 ha. Although all three areas protect a large quantity of coral reef habitat, the RNA is the first to offer direct protection to shallow seagrass beds. The nearest shallow seagrass beds to the Tortugas region are close to the Marquesas Keys, approximately 70 km away.

This chapter addresses the performance measure to quantify changes in the abundance and size-structure of exploited species within the RNA relative to adjacent areas (Performance Topic 1). Exploited fishes are generally thought to respond to the establishment of no-take marine reserves (NTMR) through increased abundances and expanded size structure through time, although the effects of NTMR on non-exploited species and juveniles of exploited species are



Seagrass meadows are known to provide important nursery habitat and forage for a variety of reef species in the Dry Tortugas. Photo by Brett Seymour, Submerged Resources Center, NPS.

much less predictable. Species that exhibit an association with seagrasses during their life history should respond positively as the quality and quantity of seagrass habitat improves within the RNA (Lindholm et al. 2001; Rodwell et al. 2003). Nevertheless, these benefits may be offset to some degree through increased predation from exploited species that generally receive the greatest protection from the establishment of NTMR and are known to leave their coral reef habitat to forage in adjacent seagrass meadows (Robblee and Zieman 1984; Babcock et al. 1999). These potential ecosystem-level changes highlight the importance of considering both exploited and non-exploited species as well as critical habitat when assessing the effectiveness of NTMR, especially in terms of overall ecosystem function.

Fishery-independent surveys were conducted in fall 2009, spring 2010, and fall 2010 (spring surveys were conducted during May/June, whereas fall surveys were conducted during August/September) using wire-mesh Antillean Z-traps. These surveys were designed to complement fishery-independent visual and trap surveys (Chapter 1, this volume) by (1) providing data on seagrass-associated fish assemblages, and (2) providing data on small-bodied fishes, including juveniles of several exploited taxa. Sampling followed a stratified-random survey design within the southern portion of DRTO (south of 24° 40' N). For each seasonal sampling event, sampling sites were randomly selected from identified seagrass and reef habitat strata, with effort equally partitioned between the RNA and adjacent Natural Cultural Zone (NCZ) including the Historic Adaptive Use Zone (HAU). At each sampling station, paired Z-traps, baited with cut Atlantic mackerel (*Scomber scombrus*), were deployed during daytime hours (beginning 1 hr after sunrise and ending 1 hr before sunset) and allowed to soak for 90 min. All fishes collected were identified and enumerated, and as many as 40 individuals per trap were measured to the nearest mm standard length (SL) prior to release.

Results

A total of 72 seagrass and 100 reef stations were sampled during the three seasonal sampling events with two traps deployed per station (Table 1). Reef sampling stations were distributed throughout the sampling area and were divided between 46 stations within the RNA and 54 within the NCZ (Table 1; Fig. 1). Seagrass sampling stations were located in shallower, spatially distinct areas and were divided between 37 stations within the RNA and 35 stations within the NCZ (Table 1; Fig. 1).

A total of 1,388 individuals representing 26 fish taxa were collected from 72 seagrass stations. Yellowtail snapper (*Ocyurus chrysurus*) (n=644), slippery dick (*Halichoeres bivittatus*) (n=472), and white grunt (*Haemulon plumierii*) (n=141) were the most abundant fishes collected over seagrass habitat. A total of 2,381 individuals representing 36 fish taxa were collected from 100 reef stations. Yellowtail snapper (n=1,064), tomtate (*Haemulon aurolineatum*) (n=497), slippery dick (n=272), and white grunt (n=235) were the most abundant fishes collected over reef habitat. Individuals of several managed reef fishes, including red grouper (*Epinephelus morio*), black grouper (*Mycteroperca bonaci*), graysby (*Cephalopholis cruentata*), and lane snapper (*Lutjanus synagris*) were collected at both seagrass and reef stations.

Examination of catch-per-unit-effort data (CPUE; individuals per soak-hour) indicated that differences between spatial zone (RNA vs. NCZ) and habitat (seagrass vs. reef) were minimal, although seasonal differences were evident (Fig. 2). CPUE was higher in fall 2009 than either spring 2010 or fall 2010 for all zones and habitats; observed differences were primarily driven by the CPUE of yellowtail snapper, white grunt, and slippery dick.

Examination of habitat-specific length frequency plots indicated that, although differences in CPUE between habitats

Table 1. Summary of total number of stations sampled with Antillean Z-traps during seasonal fishery-independent surveys of fishes associated with seagrass and reef habitats within the RNA and NCZ. Number in parentheses represents total number of trap sets.

Habitat Strata Spatial Strata	Fall 2009	Spring 2010	Fall 2010	Total
Seagrass				
RNA	14 (28)	12 (24)	11 (22)	37 (74)
NCZ	12 (24)	10 (20)	13 (26)	35 (70)
Reef				
RNA	4 (8)	19 (38)	23 (46)	46 (92)
NCZ	7 (14)	24 (48)	23 (46)	54 (108)

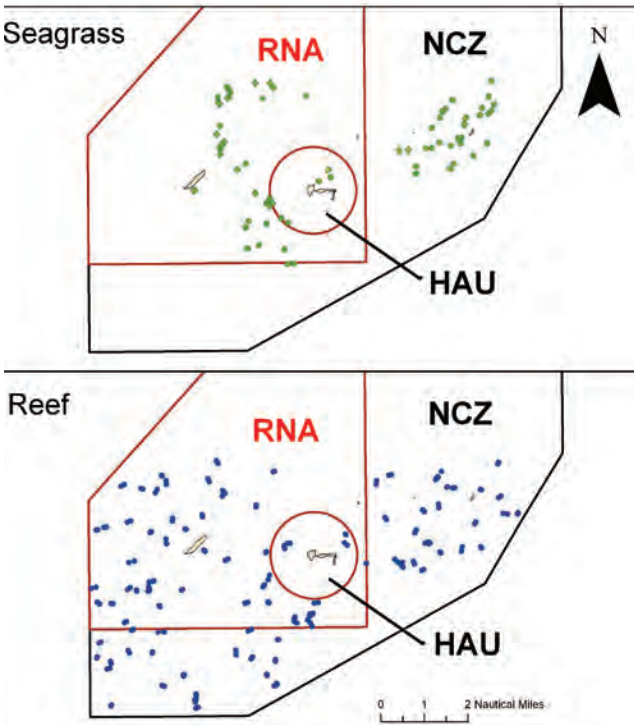


Figure 1. Spatial distribution of overall sampling effort during seasonal fishery-independent surveys of fishes associated with seagrass and reef habitats within the DRTO RNA and NCZ. Each point represents an individual Antillean Z-trap.

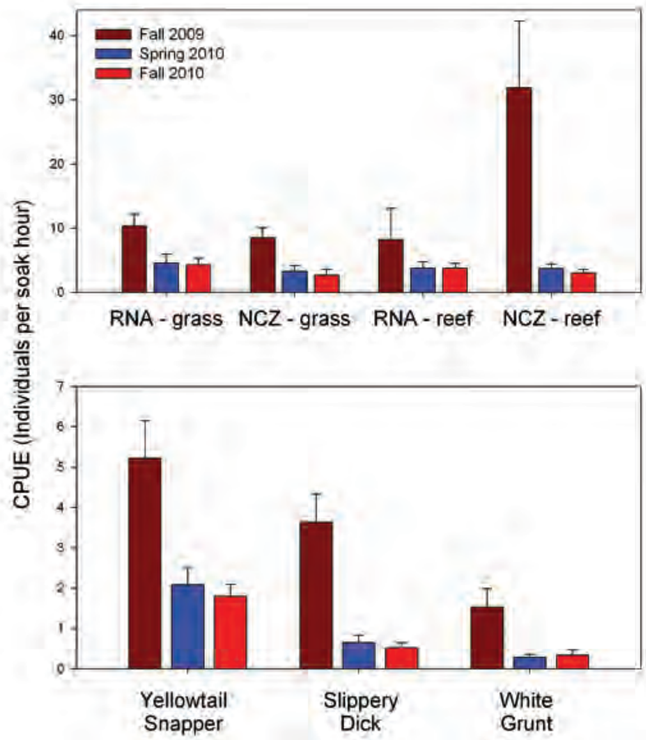


Figure 2. Mean overall catch per unit effort of Antillean Z-traps during seasonal fishery-independent surveys of fishes associated with seagrass and reef habitats within the RNA and NCZ. The top panel represents comparisons between habitats (seagrass vs. reef) and zones (RNA vs. NCZ). The bottom panel represents comparisons for the three most abundant species.

were minimal, some size differences were evident (Fig. 3). For both white grunt and red grouper, smaller individuals were primarily found in seagrass habitat, with a potential ontogenetic shift toward reef habitat for older and larger individuals; individuals in the smallest size classes were mostly observed in seagrass habitats. No such shifts were evident for yellowtail snapper. Locations where all juvenile (≤200 mm SL) red grouper and black grouper were collected, including individuals collected during exploratory surveys, were plotted to explore spatial distributions (Fig. 4). Juveniles of both species were most frequently collected in the shallow seagrass beds of the RNA as well as in the seagrass beds of the HAU. In particular, approximately 50% of the juvenile red and black groupers were observed in the seagrass bed north of Loggerhead Key.

Performance Measure Evaluation

Surveys of non-exploited species and juveniles of exploited species have potential in assessing the ecosystem-level effects of the RNA because (1) increases in the abundance of juveniles of exploited species may be an early indicator of RNA success, and (2) declines in the abundance of non-exploited species may result from trophic cascades as populations of exploited reef fishes recover. On the basis of our results, we are unable to quantify changes in abundance associated through the establishment of the RNA. No marked differences were evident between the RNA and NCZ with respect to overall CPUE or the CPUE of abundant taxa. Although temporal differences were evident, observed declines from fall 2009 to spring 2010 were most likely attributable to an extreme cold snap in January 2010 rather than any effects of RNA establishment.

Results from this study do, however, lend credence to the notion that seagrasses within the RNA may function as nursery habitat for juveniles of exploited reef fishes. For both white grunt and red grouper, smaller individuals were more often collected in association with seagrass habitat whereas larger individuals were most often collected near reef habitat. Similarly, juvenile (≤200 mm SL) red grouper and black grouper were most frequently collected in the shallow seagrass beds of the RNA as well as in the seagrass beds of the HAU. Although observed patterns indicate the potential that seagrass habitat is essential for post-settlement reef fishes, these results do not conclusively establish the nursery function of seagrass beds within DRTO. Accordingly, additional research is recommended to further explore this hypothesis.

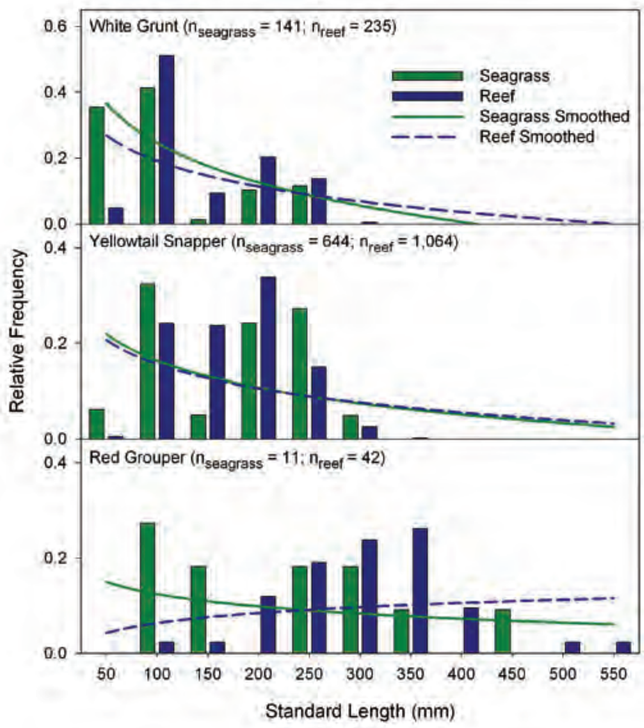


Figure 3. Size/frequency distribution of select fishes captured with Antillean Z-traps in seagrass and reef habitats. Values in parentheses represent total number of individuals collected in association with each habitat type. Smoothed curves were constructed using a two-parameter logarithmic function.

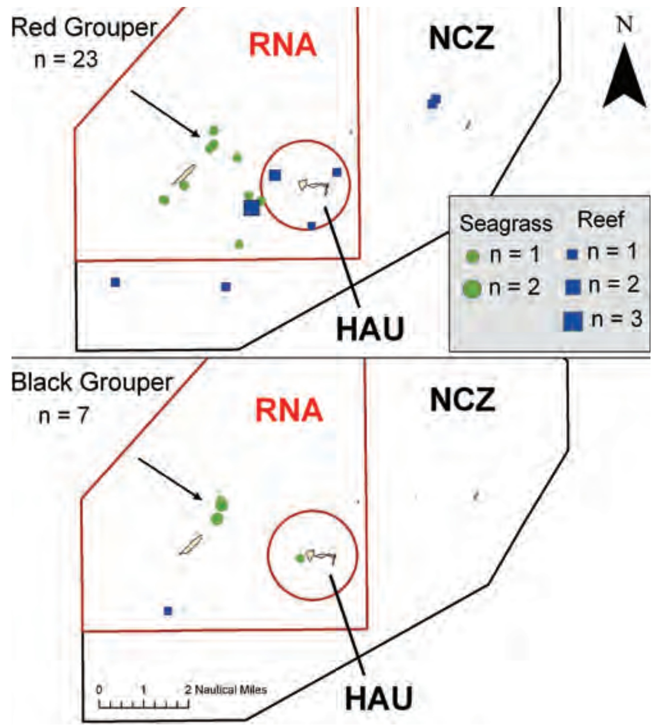


Figure 4. Locations where juvenile (≤200 mm SL) red grouper (*Epinephelus morio*) and black grouper (*Mycteroperca bonaci*) were collected with Antillean Z-traps. Graduated symbols represent the number of individuals per trap set, ranging from one (smallest symbol) to three (largest symbol). The black arrow points to the location of potential seagrass nursery habitat to the northeast of Loggerhead Key.

Acknowledgements

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Literature Cited

Babcock, R.C., Kelly, S., Shears, N.T., Walker, J.W., and Willis, T.J.. 1999. Changes in community structure in temperate marine reserves. *Marine Ecology Progress Series* 189:125–134.

Franklin, E.C., Ault, J.S., Smith, S.G., Luo, J., Meester, G.A., Diaz, G.A., Chiappone, M., Swanson, D.W., Miller, S.L., and Bohnsack, J.A. 2003. Benthic habitat mapping in the Tortugas region, Florida. *Marine Geodesy* 26:19–34.

Lindholm, J.B., Auster, P.J., Ruth, M., and Kaufman, L. 2001. Modeling the effects of fishing and implications for the design of marine protected areas: Juvenile fish responses to variations in seafloor habitat. *Conservation Biology* 15:424–437.

Robblee, M.B. and Zieman, J.C. 1984. Diel variation in the fish fauna of a tropical seagrass feeding ground. *Bulletin of Marine Science* 34:335–345.

Rodwell, L.D., Barbier, E.B., Roberts, C.M., and McClanahan, T.R. 2003. The importance of habitat quality for marine reserve – fishery linkages. *Canadian Journal of Fisheries and Aquatic Sciences* 60:171–181.

RNA Performance Topic 2

Chapter 3: Regional connectivity of fishes within the Tortugas region of Florida

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Project Description

With the establishment of the Dry Tortugas National Park (DRTO) no-take Research Natural Area (RNA), a series of performance measures were defined to assess the efficacy of the RNA in protecting marine habitat, conserving biodiversity, enhancing productivity and sustainability of exploited fish populations, and determining the effects of fishing on surrounding exploited areas. Consequently, field studies were undertaken to monitor the immigration and emigration of targeted fish species in the RNA (Performance Topic 2) and assess connectivity of fishes in the greater Tortugas region. An understanding of migration patterns and habitat requirements of fish species is critical to establishing an effective marine protected area (MPA) design (Sale et al. 2010), especially 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 fish spawning aggregations (FSAs) located elsewhere.

The Tortugas region refers to 1,243 km^2 of ocean located approximately 112 km west of Key West and 225 km from mainland Florida, comprised of three carbonate banks and seven small islands. The carbonate banks are individually known as the Dry Tortugas, Tortugas Bank, and Riley's Hump (RH) and collectively are considered highly productive coral reef habitat critical to the south Florida marine ecosystem (Ault et al. 2006). RH rises to 30 m depths at the intersection of the Gulf of Mexico and the Straits of Florida approximately 20 km southwest of Garden Key, the location of historic Fort Jefferson. The established NTMRs and associated open-use areas of the Tortugas provide an excellent system in which to document habitat use, broad-scale movements of fishes, and connectivity across reserve boundaries. Acoustic telemetry methods were used to determine the temporal dynamics of fishes and to study spawning aggregations and demographic connectivity with emphasis on testing the hypothesis that adult reef fish emigrate from DRTO to spawn at an offshore FSA.

An array of 64 underwater VEMCO (VR2) acoustic receivers provided partial coverage across approximately 755 km^2 and was deployed by July 2008 in water 6–50 m deep (Fig. 1). These receivers recorded the presence of fish tagged with coded transmitters as they swam within a detection range of up to 800 meters when conditions were ideal. A more typical effective range was 300 meters. From May 2008 through March 2011, selected reef fish species were captured and acoustically tagged in DRTO and at RH, which is located within the Tortugas South Ecological Reserve (TSER). Fish were surgically implanted with VEMCO V16 coded transmitters on board a research platform or in situ to avoid barotrauma-induced mortality associated with capturing fish from relatively deep water (30–40 m).

Within the context of how RNA habitat contributes to regional connectivity, results are presented on the annual spawning migratory movements of adult mutton snapper (*Lutjanus analis*) between the RNA and RH, which, according to Lindeman et al. (2000), protects the most valuable known snapper spawning habitat in south Florida. Preliminary observations suggested that the mutton snapper spawning aggregation had begun to reform on RH after years of intensive fishing pressure (Burton et al. 2005) (Table 1). Additionally, the movements of acoustically tagged nurse sharks (*Ginglymostoma cirratum*), lemon sharks (*Negaprion brevirostris*), and bull sharks (*Carcharhinus leucas*) are presented. Nurse sharks, a common resident of Florida waters and DRTO, have been recorded in the waters that are now within the Nurse Shark Special Protection Zone (SPZ) for reproductive activities for nearly 100 years (Gudger 1912) (see map on inside front cover).

Results

Reef Fish

Fifty-five mutton snapper (45.7–89.7 cm) were acoustically tagged offshore at the RH FSA (n=28) and inshore within the RNA and recreational-fishing-only Natural Cultural Zone (NCZ) (n=27). Four of the 55 tagged mutton snapper were never detected on the receiver array and were removed from further analysis. Approximately 1.4 million mutton snapper tag detections were recorded by the array between May 2008 and August 2011. Of those detections, approximately 1.3 million were in DRTO, 265 were in open fishing areas outside of DRTO, 45 were in the Tortugas North Ecological Reserve

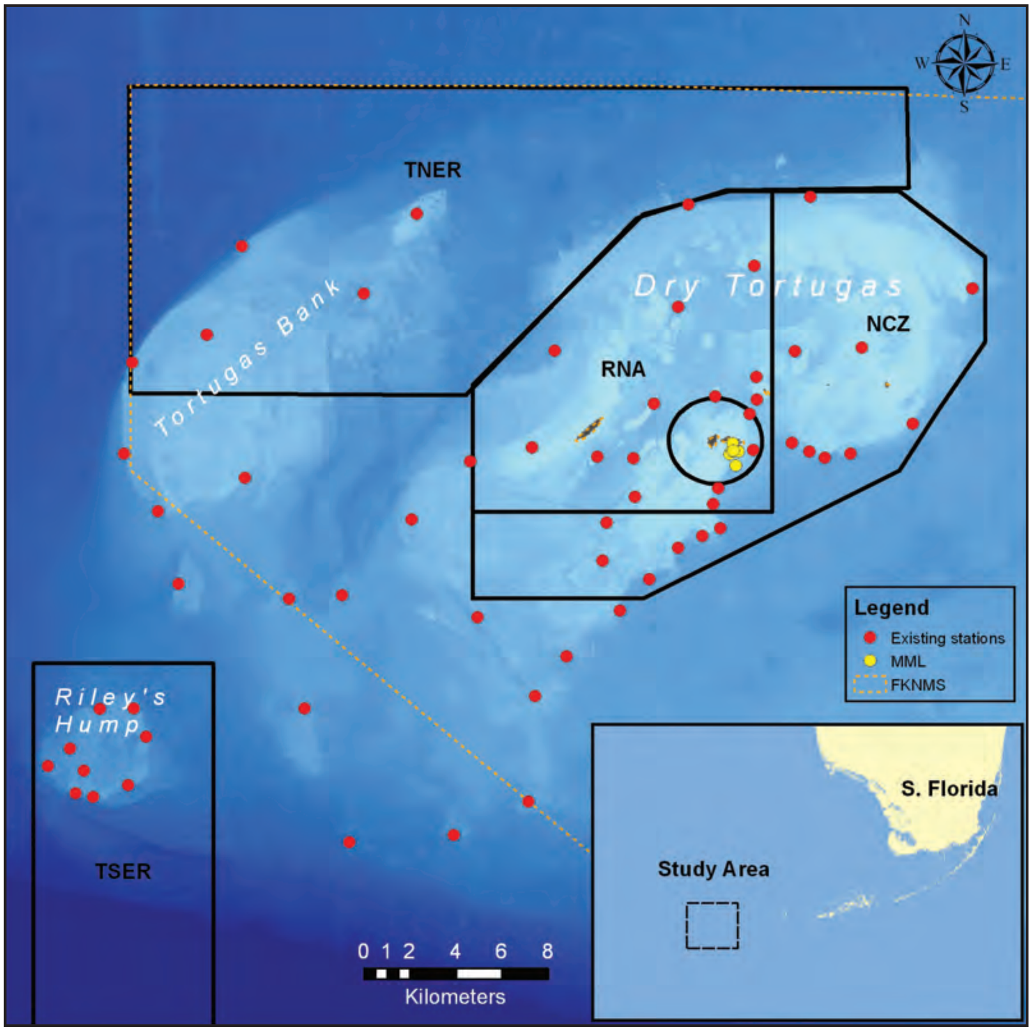

Figure 1. Location of VR2 receiver stations relative to bathymetry and management zones including the recreational fishing only Natural Cultural Zone (NCZ), no-take Research Natural Area (RNA), no-take Tortugas South Ecological Reserve (TSER), no-take Tortugas North Ecological Reserve (TNER), and open-use areas of the Florida Keys National Marine Sanctuary (FKNMS) and surrounding waters in the Tortugas study area, Florida. Mote Marine Laboratory (MML) receivers (yellow) are located in the Nurse Shark Special Protection Zone (SPZ).

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

Date	Number observed	Moon phase
May 28–June 1, 1999	1 fish in 3 of the 11 dives	Full moon May 30[1]
July 31–August 3, 2000	1 fish in 5 of the 6 dives	New moon July 30[1]
July 17, 2001	10	3 days before new moon[1]
May 27, 2002	75–100	1 day after full moon[1]
June 15, 2003	75–100	1 day after full moon[1]
June 15, 2003	200+	1 day after full moon[1]
July 4, 2004	300	2 days after full moon[1]
July 3, 2007	100+	3 days after full moon[2]
June 12, 2009 (1415–1715 hrs)	~4,000	5 days after full moon[3]

[1]Burton et al. 2005.
[2]Michael Burton, NOAA, pers. comm.
[3]This study.

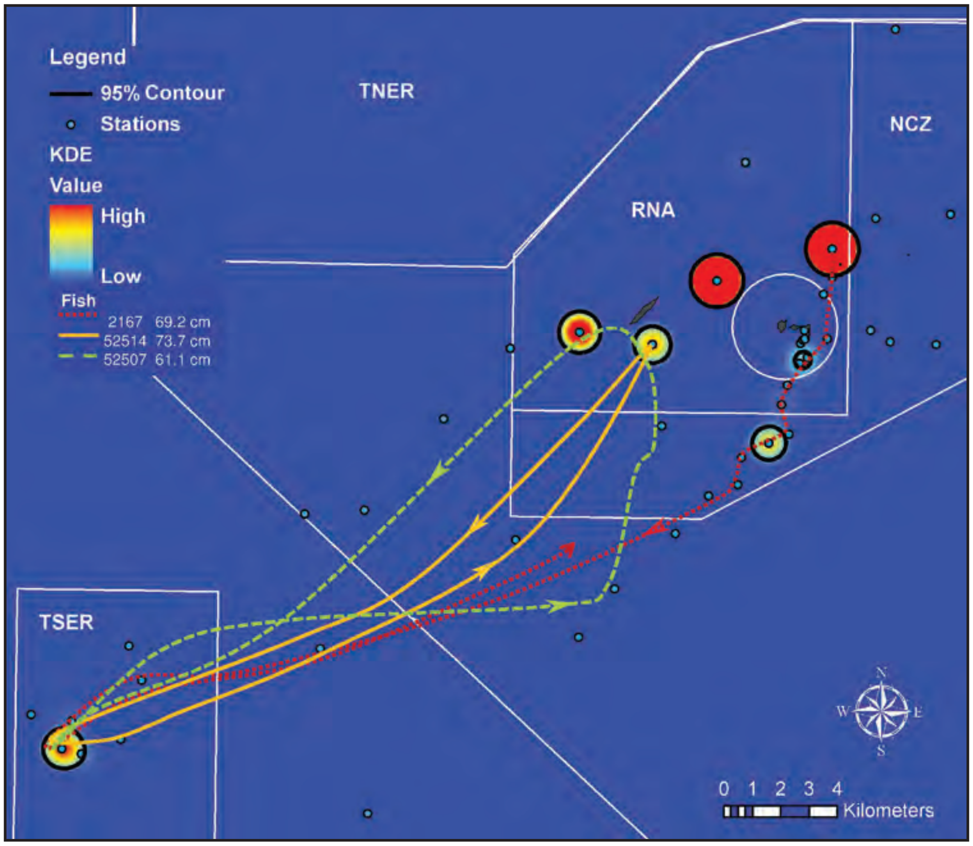

Figure 2. Fixed kernel density estimate (KDE) and home range estimate (95% contour) for pooled DRTO adult mutton snapper (n=12) indicating connectivity between the Research Natural Area (RNA) and Riley's Hump. All VR2 stations detecting tagged mutton snapper, the relative probability of finding a fish in a location (higher color intensity [blue to red] indicates higher probability), and migrations of three individual fish are shown.

(TNER), and the remaining detections were recorded at RH (33,460). Individual mutton snapper (n=51) were tracked an average (±standard deviation) of 315 (±338) days (d) with a range of 3–1,056 d.

Of the 51 tracked mutton snapper, we conclusively documented that 15 made seasonal migratory movements to spawning grounds on RH. These mutton snapper made migratory round trips of as many as four trips per fish per spawning season. Twelve of these mutton snapper were residential fish of the RNA or migrated through the RNA. The home ranges of these mutton snappers and the movement patterns of three selected individual fish are presented in Figure 2 to elucidate the migratory routes. We used the kernel density estimation (KDE) technique to determine "hotspots" of mutton snapper activity in the region.

KDE is a method used to identify one or more areas of disproportionately heavy use (the colored regions on the map) within a home-range boundary. The colored regions within the black contour lines represent 95% of the detections of mutton snapper and within each contour, the probability of finding a fish increases as the coloration moves toward red. The light blue areas outside the contours represent other areas where detections occurred. These mutton snapper resided within the RNA most of the time, as indicated by the yellow to red areas of heavy use; and had hotspots of detections along the migratory route in the southern NCZ and at RH. The migratory routes are hand-drawn but when they pass near one of the stations, it means that a fish was detected at that station. For example, fish 2167 (69.2 cm total length, gender

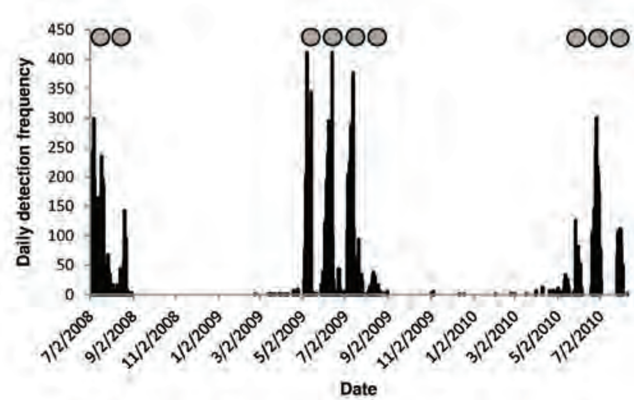

Figure 3. The daily frequency of mutton snapper transmitter detections from the south slope receiver in the Tortugas South Ecological Reserve on Riley's Hump relative to the full moon phase. Circles indicate the time of the full moon.

unknown; see red dashed line, Fig. 2) was initially tagged on May 30, 2008, within the RNA; it first moved offshore near the full moon on June 18, 2008, and returned to the RNA 11 days later. It next arrived at RH on May 6, 2009, and stayed until May 14 (8 days). It arrived back at the RNA on May 15, 1 day later. This fish then remained undetected until June 5 when it again began moving toward RH, arriving 2 days later. It stayed at RH for 6 days and returned to the RNA area 1 day later. This entire pattern was repeated one more time during the July full moon. The tag battery expired shortly thereafter and no more detections of this fish were possible. The other two mutton snapper made similar multiple spawning migrations.

Daily transmitter detection frequency peaked at RH on the full moon during the spawning season (May through August) (Fig. 3). Mean residence time on the spawning grounds was 7 (±3) d. The mean day of arrival relative to the full moon (+1±3 d) varied significantly ($p=0.002$); however, the mean day of departure (+7±1 d; $p=0.06$) did not vary significantly over seven distinct spawning periods.

Twenty-eight of the 55 tagged mutton snappers were initially tagged at RH. Some of these fish were among the residents in the RNA. However, mutton snapper tagged at RH also exhibited a much wider range of movement patterns. One RH-tagged mutton snapper traveled through the TNER and was ultimately detected in the northeastern area of the NCZ near Pulaski Shoal, a movement of 40 km in two days. Another mutton snapper (71.1 cm), initially tagged at RH during the June 2009 full moon, left RH shortly thereafter and was detected on the array in the open fishing area to the south of DRTO and east of RH. It returned to RH during the July 2009 full moon and was again detected in the same area later that month. It was then no longer detected on the array but traveled eastward and was ultimately caught on December 5, 2009, by an angler fishing near Rebecca Shoals approximately 50 km east of RH. Finally, some of the RH-tagged fish left RH but were not detected within our array of acoustic receivers.

A large mutton snapper aggregation (~4,000) and repeated spawning events were documented by divers on June 12, 2009, between 1415 and 1715 hrs, 5 d after the full moon, along the south slope of RH (35–50 m) (Table 1; Fig. 4). Additionally, groups of cubera snapper (*Lutjanus cyanopterus*), dog snapper (*Lutjanus jocu*), and permit (*Trachinotus falcatus*) were observed on the south slope of RH. Spawning coloration displays by blue runners (*Caranx crysos*), horse eye jacks (*Caranx hippos*), crevelle jacks (*Caranx latus*), and actively nesting ocean triggerfish (*Canthidermis sufflamen*) also were noted.

Some mutton snapper demonstrated that they used certain geographic features to travel to and from the spawning aggregation site at RH. For example, six mutton snapper uti-

Figure 4. A subgroup of mutton snapper spirals upward just before a spawning event at Riley's Hump during the fish spawning aggregation of July 2009. Photo by ©Christopher Parsons, Photography by Chris Parsons.

lized the reef edge margin south of Long Key, with the longest continuous reef edge movement recorded as 16.2 km. This movement involved passing through multiple management zones, including the Florida Keys National Marine Sanctuary (FKNMS) waters south of the RNA, through the RNA, and eastward of Long Key on the eastern bank of the NCZ.

Sharks

The receiver array also recorded 190,828 acoustic tag detections from 31 nurse sharks tagged within DRTO. Additionally, 700 detections were recorded within our VR2 array for 3 lemon sharks and 6 bull sharks tagged and released off Jupiter, Florida (Dr. Steven Kessel, pers. comm.). Adult male and female nurse sharks arrive in the Bush Key bight to mate during mid-June. Females typically reside for 3–4 weeks using the shallows within the Nurse Shark SPZ to take refuge from courting males (Pratt and Carrier 2001). Male nurse sharks visit frequently, patrolling Long and Bush Keys. Forty to 60 pregnant females return to the same warm shallows to rest and gestate in September and October prior to giving birth. Three lemon sharks tagged off Jupiter, Florida, reached the Tortugas in late January to early February and all departed the area by the end of April. Six bull sharks tagged off Jupiter, Florida, also made migrations (500 km) to the Tortugas with detections recorded from late November to late May; two of these sharks were later detected by acoustic receivers 320 km miles north in the Gulf of Mexico (Angela Collins, pers. comm.). Most bull sharks were only briefly detected (1 d), with most detections offshore, including four sharks at RH.

Performance Measure Evaluation

Our acoustic telemetry research on mutton snapper has definitively revealed the regional connectivity between the shallow waters of the RNA and the spawning aggregation site at RH. However, the RNA is not the only location from which mutton snapper migratory movements originate. Although some mutton snapper initially tagged at RH moved to the RNA, others moved to a different location within our array, and some have moved off RH and have gone undetected. However, we were able to document DRTO, especially RNA-resident, mutton snapper migrating multiple times over the spawning season to the aggregation site at RH. These results suggest that the RNA may be important to support the mutton snapper spawning aggregation at RH.

Repeated directional use of the high- and low-profile contiguous reef edge near and south of Long Key coinciding with the full moon, suggests that these features play an important role in spawning movements between the RNA and RH. The maximum documented distance along the Long Key route

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.

was 16.2 km, after which the reef edge is less well defined south of the Dry Tortugas. The Long Key pathway includes movement across NTMR boundaries, including movements across RNA boundaries into the recreational fishing areas of the NCZ and the open-use areas of the FKNMS. Farmer and Ault (2011) report similar migration-related movement of a mutton snapper along the contiguous reef edge northwest of Loggerhead Key.

The RNA provides year-round protection to a proportion of the population excluding the estimated time (1–2 d) it takes to migrate across the open-use area between NTMRs. Although this is a relatively short exposure, mutton snapper migration pathways have previously been targeted by commercial fishing leading to permanent collapse of the FSA (Craig 1966), emphasizing the importance of protecting both migration corridors and spawning sites (Graham et al. 2008). As knowledge of migratory pathways of the RNA residents to the spawning areas becomes better defined, consideration of appropriate management action along these corridors could be considered to further enhance the mutton snapper fishery.

The migration of several shark species from as far as Jupiter, Florida, through the Tortugas NTMR network expands the connectivity of this area to both the east and west coasts of Florida (up to 500 km). Pratt and Carrier (2001) determined that DRTO is an important annual mating site for nurse sharks. Preliminary results show juveniles to be year-round residents of the RNA while adults make seasonal movements relative to their gender and reproductive condition. Male sharks wander thru the RNA and the TNER and a few have been detected in the middle and upper Florida Keys. Females may remain in the area until giving birth and then range for hundreds of kilometers, to return every two or three years to the Nurse Shark SPZ mating grounds. Future tag detections will help fill in gaps in our knowledge of their movements. The purpose of the long-range movements of bull sharks and lemon sharks to the Tortugas remains unknown (Dr. Steven Kessel, pers. comm.).

A large mutton snapper spawning aggregation at RH supports the hypothesis that this FSA has rebounded nearly 10 years after the establishment of the TSER and provides direct evidence of the spawning of this species for the first time in Florida. The RNA, complemented by the Tortugas Ecological Reserves, provides critical protection of essential reef fish habitat and multispecies FSA habitat, and temporary refuge for transient fish species. The regional connectivity of fishes and protection of residential habitat within the RNA, combined with the relative increase in the number of mutton snapper at the RH FSA, can be linked to a suite of successful management actions including the establishment of the RNA. This research primarily focused on mutton snapper utilizing one known spawning site; however, other potential ecologically and economically important species also may use RH as an aggregation site (for example, black grouper (*Mycteroperca bonaci*)) and potentially other important regional spawning sites yet to be discovered.

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Literature Cited

Ault, J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Harper, D.E., and McClellan, D.B. 2006. Building sustainable fisheries in Florida's coral reef ecosystem: Positive signs in the Dry Tortugas. *Bulletin of Marine Science* 78:633–654.

Burton, M.L., Brennan, K.J., Munoz, R.C., and Parker, R.O., Jr. 2005. Preliminary evidence of increased spawning aggregations of mutton snapper (*Lutjanus analis*) at Riley's Hump two years after establishment of the Tortugas South Ecological Reserve. *Fishery Bulletin* 103:404–410.

Craig, A.K. 1966. Geography of fishing in British Honduras and adjacent coastal waters. Louisiana State University Coastal Studies Laboratory, Baton Rouge, Louisiana.

Farmer, N.A. and Ault, J.S. 2011. Grouper and snapper movements and habitat use in Dry Tortugas, Florida. *Marine Ecology Progress Series* 433:169–184.

Graham, R.T., Carcamo, R., Rhodes, K.L., Roberts, C.M., and Requena, N. 2008. Historical and contemporary evidence of a mutton snapper (*Lutjanus analis* Cuvier, 1828) spawning aggregation fishery in decline. *Coral Reefs* 27:311–319.

Gudger, E.W. 1912. Summary of work done on the fishes of Tortugas. *Carnegie Institute of Washington Yearbook* 11:148–150.

Lindeman, K.C., Pugliese, R., Waugh, G.T., and Ault, J.S. 2000. Development patterns within a multispecies reef fishery: Management applications for essential fish habitats and protected areas. *Bulletin of Marine Science* 66:929–956.

Pratt, H.L., Jr. and Carrier, J.C. 2001. A review of elasmobranch reproductive behavior with a case study on the nurse shark, *Ginglymostoma cirratum*. *Environmental Biology of Fishes* 60:157–188.

Sale P.F., Van Lavieren, H., Ablan Lagman, M.C., Atema, J., Butler, M., Fauvelot, C., Hogan, J.D., Jones, G.P., Lindeman, K.C., Paris, C.B., Steneck, R., and Stewart, H.L. 2010. Preserving Reef Connectivity: A Handbook for Marine Protected Area Managers. Connectivity Working Group, Coral Reef Targeted Research and Capacity Building for Management Program, United Nations University UNU–INWEH.

RNA Performance Topic 2

Chapter 4: Spillover of select reef fish species in and near the Dry Tortugas National Park Research Natural Area

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Project Description

The no-take Research Natural Area (RNA) was implemented within Dry Tortugas National Park (DRTO) in 2007 to preserve marine biodiversity and fishery resources. The RNA is complemented by two no-take marine reserves (NTMRs): Tortugas North and South Ecological Reserves (TNER and TSER). Adjacent to the RNA is the Natural Cultural Zone (NCZ), where recreational hook-and-line fishing is permitted. Due to its upstream location relative to the Florida Current, the Tortugas region is recognized as a source of larval recruitment and is considered the most productive coral reef ecosystem in Florida (Ault et al. 2006). The Tortugas NTMRs were designed to provide critical refuge for the exploited phase of fish stocks, giving fishes the opportunity to reproduce and thereby stimulate regional recruitment. Additionally, NTMRs may contribute to increased fishery yield through direct spillover of fish moving across NTMR boundaries. In this chapter, we summarize information on direct spillover; Chapter 11 summarizes information regarding regional recruitment.

To monitor the immigration and emigration of selected reef fish species in the RNA (RNA Performance Topic 2), two VEMCO (VR2) hydroacoustic arrays were deployed in and around the RNA (Fig. 1). These arrays, one in the southeastern part of the RNA (managed by the Florida Fish and Wildlife Conservation Commission (FWC)) and one along the northwestern RNA boundary (managed by the University of Miami (UM)), were set-up in areas known to support a rich and diverse assemblage of exploited reef fishes. The FWC array of 64 receivers began operation in 2008 and currently encompasses approximately 755 km^2 throughout DRTO and surrounding waters. Thirty-one of those receivers were within DRTO, with 16 receivers located within the RNA. To examine the movement of adult fish from the RNA to fishing grounds (spillover), the FWC array was concentrated along high- and low-relief contiguous reef that traverses RNA boundaries. The FWC array was complemented by six receivers managed by Mote Marine Laboratory (MML). To address fine-scale movements, UM previously had deployed 25 receivers in two grid configurations (16 and 30 km^2) over a representative range of depths and complex coral reef habitats during 2006 and 2007 (Farmer and Ault 2011).

Proximal to the acoustic arrays, selected snappers and groupers were captured by hook and line or fish traps for acoustic tagging from 2006 through 2011. After capture, the abdominal cavities of selected fish were surgically implanted with VEMCO V9 or V16 coded transmitters following aseptic techniques. Fish were held for a short recovery period (5–25 min) and then released at their point of capture. Additionally, from May 2008 to May 2011, FWC conducted stratified-random surveys with chevron traps and hook-and-line gear throughout the southern half (south of 24° 40’ N) of the NCZ and the RNA. As part of these surveys, individual fish were implanted with external dart tags prior to release. Recaptured individuals were then obtained through future sampling efforts or reported by recreational anglers.

Based on acoustic telemetry and conventional tag returns, home range analysis was used to examine fish movements and evaluate spillover between the RNA and other areas of the Dry Tortugas. The results of this analysis will assist in evaluating the design and contribution of NTMRs to the sustainability of marine fisheries resources in the Tortugas.

Results

Acoustic tagging: Southeast RNA

FWC tagged 120 fish from May 2008 through July 2011 with approximately 2.2 million detections recorded during that time. Time-at-liberty (number of days between initial tagging and last detection) for FWC-tagged snappers and groupers ranged from 114 to 1,115 days (d) with a mean (± Standard Error (SE)) of 754 (±35) d for mutton snapper (*Lutjanus analis*) (n=51), 411 (±7) d for yellowtail snapper (*Ocyurus chrysurus*) (n=18), 452 (±47) d for black grouper (*Mycteroperca bonaci*) (n=27), 482 (±237) d for red grouper (*Epinephelus morio*) (n=4), 666 (±292) d for Nassau grouper (*Epinephelus striatus*) (n=3), and 415 (±0) d for goliath grouper (*Epinephelus itajara*) (n=2). Average home ranges for individuals observed on the FWC array (Table 1) were calculated using 95% kernel density estimates (KDE; Animal Movement Extension, ArcView 3.3; see results section of Chapter 3, this volume), examining only

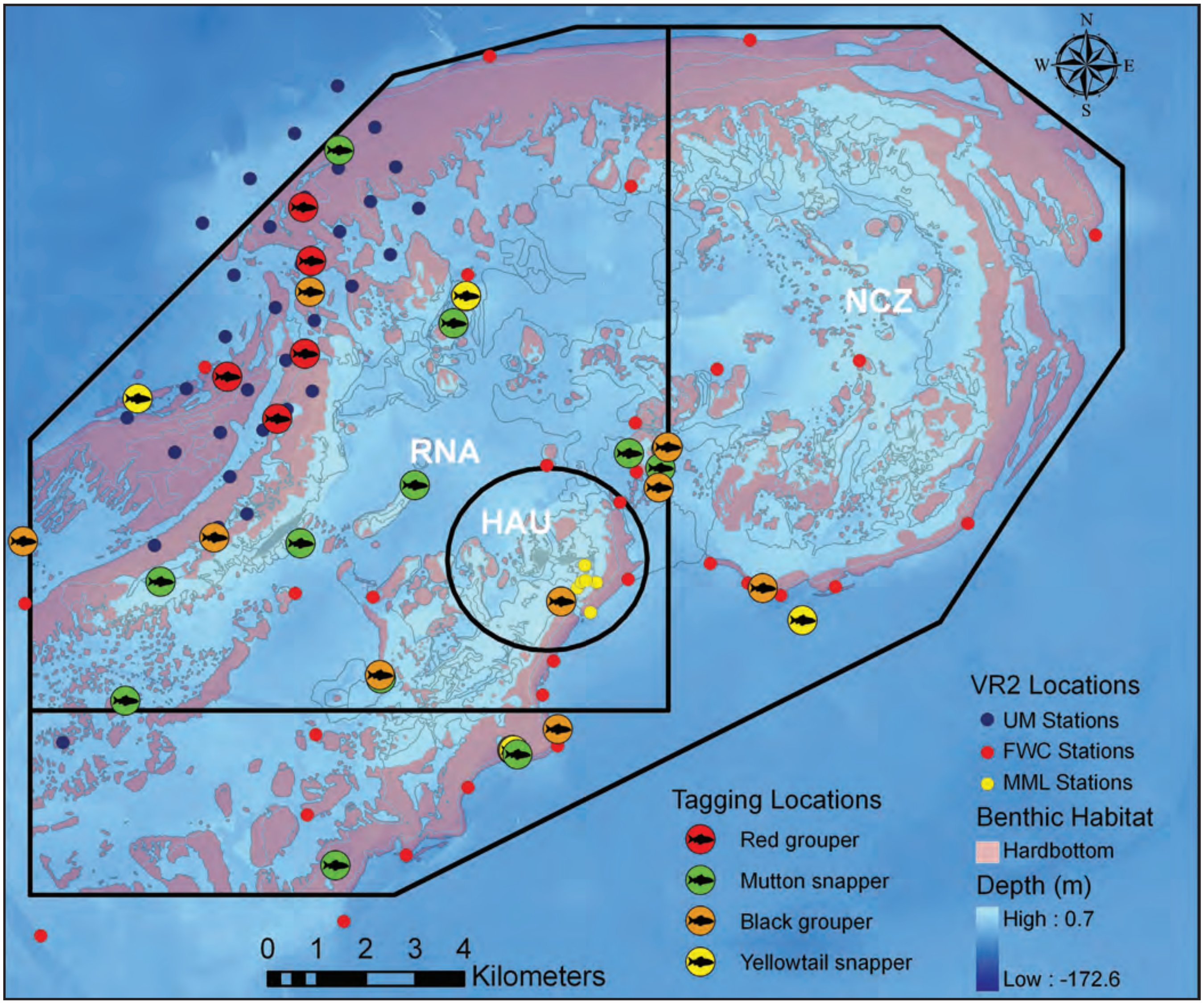

Figure 1. Detailed view of the study area within and near Dry Tortugas National Park showing the location of VR2 receiver stations relative to hard-bottom habitat and management zones (including the recreational fishing only Natural Cultural Zone (NCZ), the recreational fishing only Historic Adaptive Use Zone (HAU), and the no-take Research Natural Area (RNA)). See Figure 1 in Chapter 3 (this volume) for the entire study area. Fish acoustic-tagging locations are represented with each species corresponding to a different color.

Table 1. Home range estimates (± standard error) for tagged fish detected by the Florida Fish and Wildlife Conservation Commission (KDE analysis) and University of Miami (MCP analysis) receiver arrays.

Florida Fish and Wildlife Conservation Commission				University of Miami			
Species	Number tagged	Total length (cm)	KDE home range (km^2)	Species	Number tagged	Total length (cm)	MCP home range (km^2)
Mutton snapper	23	46–90	30.9 ± 10.5	Mutton snapper	1	70	16.1
Yellowtail snapper	10	40–51	1.6 ± 0.9	Yellowtail snapper	5	48–55	4.2 ± 1.8
Black grouper	17	46–122	0.1 ± 0.04	Black grouper	2	57–75	1.4 ± 1.0
				Red grouper	28	44–66	2.1 ± 0.4

fish that were tagged in and around the RNA with a detection period of 2 months or more.

Of the 23 mutton snapper FWC tagged in and around the RNA, 13 (57%) moved between the RNA boundary and other areas. The mean area of home range for these 13 individuals was 54.2 (±16.0) km^2 with 15.0 (±4.6) km^2 of that home range inside the RNA. For mutton snapper crossing the RNA boundary, 30.6 (±7.8)% of their home range was within the RNA. Five mutton snapper tagged within the RNA were never detected outside of its boundaries. Of the 10 yellowtail snappers tagged in and near the RNA, 4 (40%) moved across the RNA boundary. The mean home range for this subset of fish was 3.8 (±0.9) km^2 with 22.9 (±6.5)% of that home range encompassed within the RNA. Seven black grouper tagged in and near the RNA provided more than 2 months of detection data. Of those seven fish, three were tagged just outside of the RNA border but never crossed it. One individual was detected exclusively within the RNA. Two black grouper crossed the RNA boundary briefly, but with insufficient net movement to affect their home range estimate. The remaining black grouper was documented crossing the RNA boundary. The estimated home range for this fish was 0.42 km^2 with 36.1% of this home range within the RNA.

Examples of three fish that demonstrate spillover are presented in Figure 2. One mutton snapper moved southwest outside of the RNA and was detected on receivers throughout the region (Fig. 2A). The yellowtail snapper and black grouper spent a considerable amount of time (see the red portion of the KDE) within the Historic Adaptive Use Zone (HAU), the RNA, and the NCZ to the south of the RNA, demonstrating movement patterns across management zones (Figs. 2B and C).

Acoustic tagging: Northwestern RNA boundary

Between 2006 and 2008, nearly 2.5 million detections from 65 acoustically tagged fish representing 11 species were recorded by the UM array. Time-at-liberty ranged from 2 to 280 d with a mean (± SE) of 135 (±31) d for black grouper (n=3), 92 d for gray snapper (*Lutjanus griseus*) (n=1), 86 (±58) d for mutton snapper (n=3), 111 (±2) d for red grouper (n=45), and 83 (±9) d for yellowtail snapper (n=5). Average home range sizes along the northwestern RNA boundary were estimated by Minimum Convex Polygon (MCP; Animal Movement Extension, Arcview 3.3) analyses (Table 1, see Farmer and Ault (2011) for details).

Even though most of the UM receivers were within the RNA, some spillover was detected. In 2006, 2 of 31 (6%) red grouper were detected moving across the northwestern RNA boundary. In 2007, after reconfiguring the acoustic array to cover a larger area, 4 of 14 (29%) red grouper were detected moving across RNA boundaries into the TNER. No black grouper were detected moving across reserve boundaries in either year; however, this species was not well represented by the tagging study. In general, black grouper home ranges are relatively small (Table 1). One of 5 yellowtail snapper moved across the reserve boundary; this fish crossed the boundary 62 times, but spent less than 2% of its total time in TNER. The 1 tagged gray snapper was detected crossing the boundary 10 times, spending 3.4% of its time in TNER. One of 2 mutton snapper was detected moving across reserve boundaries, but it did so 702 times, spending 9% of its time in TNER. No detections for this fish were recorded within the array during the full moons of June 1 and June 30, 2007. These observations are consistent with the behavior of tagged mutton snapper conducting spawning migrations to Riley's Hump during the summer spawning season (Chapter 3, this volume).

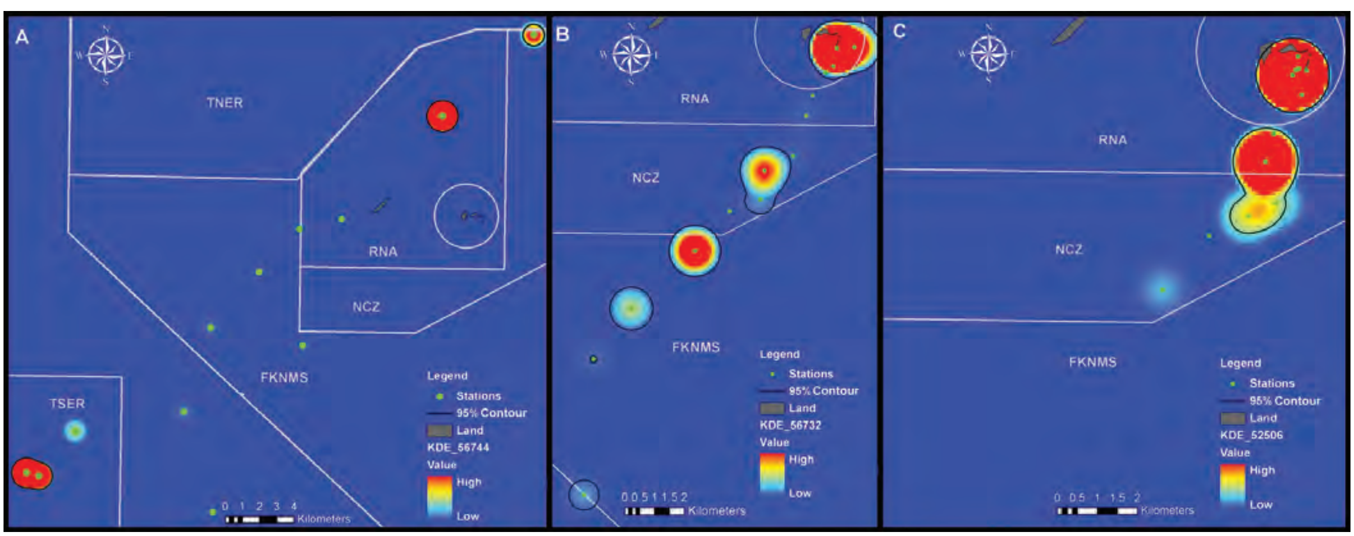

Figure 2. Examples of kernel density estimate (KDE) home range estimates with VR2 stations and 95% volume contour of detections indicated for selected individual (A) mutton snapper, (B) yellowtail snapper, and (C) black grouper relative to management zones. All VR2 stations with a detection of the fish and the relative probabilities of detecting a fish within these areas are indicated by the color gradient. The higher the probability of finding a fish near a certain receiver, the closer to the red spectrum the color becomes.

Conventional tagging

Conventional tagging was a third mechanism used to document spillover between the RNA and other areas. However, due to the relatively low level of fishing activity within the remote Dry Tortugas region, return rates were low and accordingly limited the usefulness of conventional tagging to evaluate spillover associated with the RNA. Although various species were tagged throughout the FWC chevron-trap and hook-and-line study, individuals of only four species were subsequently recaptured: yellowtail snapper, red grouper, gray snapper, and lane snapper (*Lutjanus synagris*). The majority of individuals were recaptured within the management area in which they were originally tagged. The FWC research team made most of these recaptures. Throughout the study, 2,202 yellowtail snapper were tagged in the RNA, of which 6 were recaptured in the RNA, 1 was recaptured in the NCZ, and 1 was recaptured more than 100 km to the east by an angler near Key West. For red grouper, 302 individuals were tagged in the RNA, with 13 recaptured in the RNA and 2 recaptured in the NCZ. No lane snapper or gray snapper tagged within the RNA were ever recaptured. Within the NCZ, 1,703 yellowtail snapper were tagged, of which 6 were recaptured within the NCZ and an additional 2 were recaptured as far as 18.5 km outside DRTO. For red grouper, 386 individuals were tagged and 23 individuals were subsequently recaptured in the NCZ. One hundred and fourteen lane snapper and 78 gray snapper were tagged within the NCZ, and 1 of each species was subsequently recaptured in the NCZ and none was recaptured in the RNA. For white grunt (*Haemulon plumierii*) (n=642), mutton snapper (n=71), and black grouper (n=23), no individuals tagged during this study were ever recaptured.

Performance Measure Evaluation

The results reported here provide a better understanding of the ecology of valuable reef fishes and the first estimates of snapper and grouper movements and home ranges for the Tortugas region. Red grouper and yellowtail moved moderate distances (700–900 m) along the northwestern boundary and conventional tag returns demonstrated red grouper movements (as far as 1 km) across RNA boundaries to and from the NCZ. Conventional tag returns and acoustic movements of yellowtail snapper along the contiguous reef south of Long Key, however, indicate longer-range routine movements (3–18 km), with one fish recaptured more than 100 km east (Key West). Black grouper movements were generally spatially limited and infrequent; although one black grouper (TL=66.7 cm) migrated out of the HAU 1.5 yr after being tagged, and expanded its home range to the contiguous reef south of the RNA (Fig. 2C). Mutton snapper tended to have a central resident habitat and made short, frequent routine movements coupled with repeated long-range (≤32 km) seasonal spawning migrations from the RNA to the TSER. Because of their sensitivity to outliers, MCP analyses generally resulted in less conservative home range estimates relative to KDE calculations. The relatively large mean home range reported for FWC-tagged mutton snapper was due to the greater spatial and temporal scale of the FWC array. This array was distributed across the RNA, NCZ, TSER, TNER, and FKNMS (Florida Keys National Marine Sanctuary) (see Fig. 1 in Chapter 3, this volume).

NTMRs can increase the abundance and size of exploited fish species, which can in turn increase fishery yield due to spillover and increased total reproductive output of protected fish (Watson et al. 2000; Bohnsack 2011). In the case of the RNA, movements across reserve boundaries for all acoustically tagged species demonstrate how the RNA can promote surrounding fisheries in the near-term through spillover into fishable areas. Additionally, the spawning migration movements of mutton snapper illustrate how the RNA can increase long-term fisheries yield by supporting increased spawning stock biomass and consequently greater larval dispersal to surrounding areas (Chapter 11, this volume). The direct and indirect applications of our results benefit fishery habitat management agencies, as well as commercial and recreational anglers. Our findings suggest that movements across the RNA boundary to areas where fishing is permitted occurred consistently. The combination of the protection offered by the RNA and consistent spillover will provide continuous fishing opportunities in nearby open fishing areas and may likely increase fishing yield in the Tortugas region through time.

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Literature Cited

Ault J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Harper, D.E., and McClellan, D.B. 2006. Building sustainable fisheries in Florida's coral reef ecosystem: Positive signs in the Dry Tortugas. *Bulletin of Marine Science* 78(3):633–654.

Bohnsack, J.A. 2011. Impacts of Florida coastal protected areas on recreational world records for spotted seatrout, red drum, black drum, and common snook. *Bulletin of Marine Science* 87(4):939–970.

Farmer, N.A. and Ault, J.S. 2011. Grouper and snapper movements and habitat use in Dry Tortugas, Florida. *Marine Ecology Progress Series* 433: 169–184.

Watson R., Alder, J., and Walters, C. 2000. A dynamic mass-balance model for marine protected areas. *Fish and Fisheries* 1(1):94–98.

RNA Performance Topic 2

Chapter 5: Use of Dry Tortugas National Park by threatened and endangered marine turtles

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Project Description

Dry Tortugas National Park (DRTO) harbors several key benthic habitats that are important for marine turtles. Threatened loggerhead turtles (*Caretta caretta*) forage in hard-bottom areas on spiny lobsters and crabs; endangered hawksbill turtles (*Eretmochelys imbricata*) forage on reefs and consume sponges; and endangered green turtles (*Chelonia mydas*) graze on seagrasses and marine algae. The sandy beaches of DRTO provide suitable nesting habitat for all three species. The majority of nesting activity at DRTO consists of nest construction on East and Loggerhead Keys by loggerhead and green turtles. In order to monitor the immigration and emigration of targeted species in the Research Natural Area (RNA), we characterized the populations of the three sea turtle species in DRTO and quantified the proportion of time individuals spent in the RNA as compared to other areas of the park. We examined turtle data with respect to the RNA and DRTO boundaries.

We initiated our on-going turtle tagging and tracking project in 2008. To distribute capture effort within park boundaries, we captured nesting turtles on East and Loggerhead Keys, and captured turtles in the waters near Bush and Garden Keys, Northkey Harbor, and Pulaski Shoal. Our total area patrolled to catch turtles has expanded over time as determined by suitable turtle capture conditions, with more area being incorporated outside the RNA than inside the RNA. In addition to capture efforts, we recorded sightings of turtles as we patrolled the park by boat and marked the locations with a Global Positioning System (GPS) receiver. Sightings could include one or more turtles at a single location.

USGS researcher K. Hart lifts a subadult hawksbill (*Eretmochelys imbricata*) captured by hand in the Dry Tortugas. The activity depicted was conducted pursuant to National Marine Fisheries Service Permit No. 13307–02. Photo by Kaare Iverson, USGS volunteer.

Turtles were captured by intercepting reproductive females on nesting beaches and catching turtles in the water with rodeo (diving from boat to snorkel-capture turtles), hand-capture, and dip-netting methods. We individually marked each turtle with internal passive integrated transponder (PIT) tags and external flipper tags. We took standard length, width, and mass measurements and obtained blood and tissue samples for genetic, isotopic, and dietary analyses. We attached acoustic and/or satellite-telemetry tags to a subset of turtles.

Seven acoustic receivers were placed by the U.S. Geological Survey (USGS) in the northeastern region of the park; all but one of these were placed outside the RNA. These locations were chosen based on spatial gaps in the network of receivers deployed by the Florida Fish and Wildlife Conservation Commission (FWC) and Mote Marine Laboratory (MML) (see Chapter 4, this volume).We received data from the FWC/MML receiver array, which included more than 80 receivers spread throughout the park in all management areas and outside the park to the southwest.

Using satellite and acoustic telemetry techniques, we determined daily locations and movement patterns for tagged turtles, calculated home ranges and core-use areas, and statistically summarized the extent of overlap of these areas with that of the RNA. We used the kernel density estimation technique (KDE) (Worton 1989; White and Garrott 1990) to determine "hotspots" of turtle activity in the park. KDE is a method used to identify one or more areas of disproportionately heavy use (core-use areas) within a home-range boundary, with appropriate weighting of outlying observations. We also compared the number of turtle-days within and outside the RNA using only days the turtles spent inside the park (DRTO turtle-days). We combined these data sets to determine residence times inside the park and locations of core-use areas for all three species.

It is essential to understand the locations, movements, estimated population size, preferred habitats, and status (for example nesting, foraging, number of juveniles and adults, etc.) of marine turtles within DRTO to effectively manage activities that affect these imperiled species. Our capture and tagging results summarized here can inform decision-makers by providing key information on these population characteristics. Our spatial habitat-use information provides details on locations and areas within and outside the park that turtles select, regardless of capture site.

Results

Captures and Sightings

We captured and marked 145 individual marine turtles in DRTO, including 98 green turtles (67.6%), 41 loggerheads (28.3%), and 6 hawksbills (4.1%) (Fig. 1). Green turtles ranged in size from 22.7 to 109.0 cm straight carapace length (SCL),

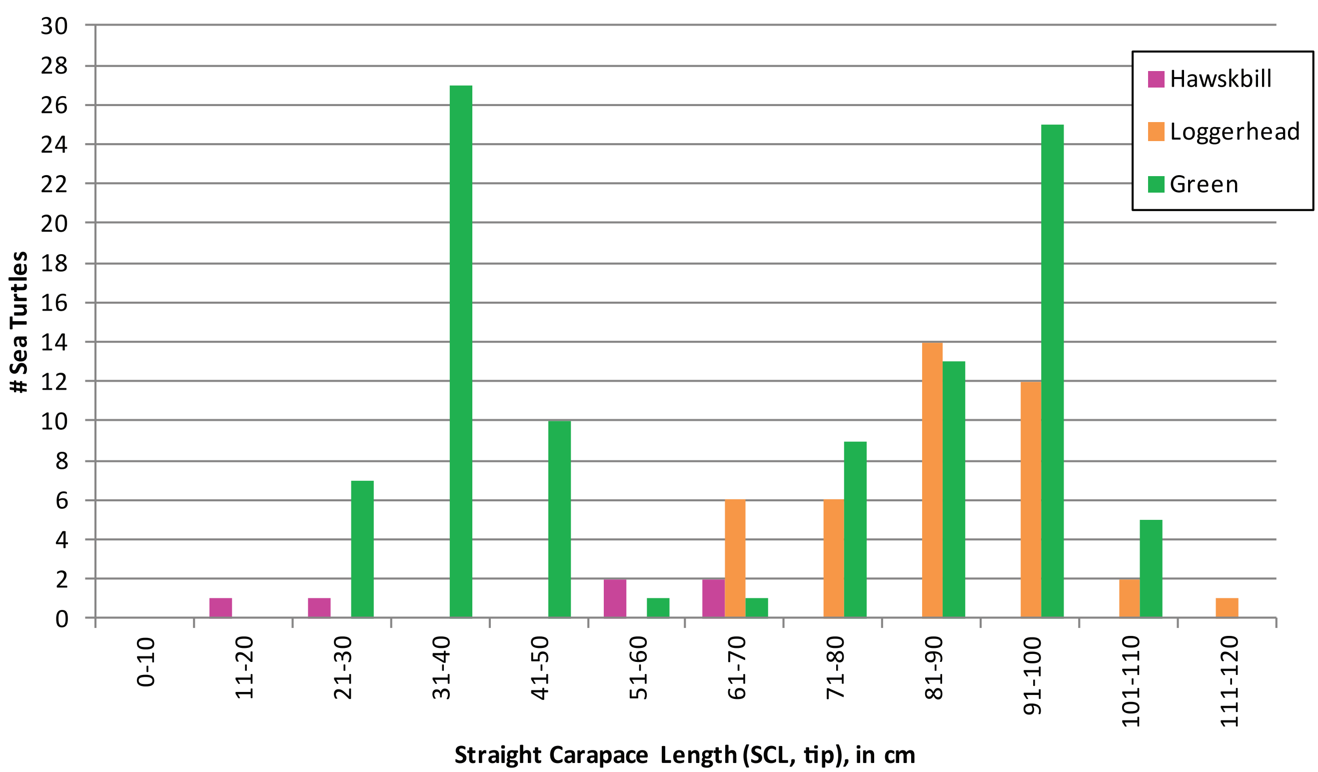

Figure 1. Size distribution of sea turtles captured (N=145) and sampled in DRTO, May 2008–October 2011.

loggerheads ranged in size from 62.5 to 111.6 cm SCL, and hawksbills ranged in size from 16.5 to 69.8 cm SCL (Fig. 1). We captured 41 turtles on nesting beaches (28.3%) and 104 turtles in the water (71.7%) (Fig. 2A). Due to successful recapture of turtles, we had 221 unique capture events between May 2008 and October 2011, with 57.5% in the Historic Adaptive Use Zone (HAU), 34.8% in the Natural Cultural Zone (NCZ), and 7.7% in the RNA.

We have logged 595 sightings, totaling 674 individual turtles in the water within the park (Fig. 2B); a sighting can include multiple turtles at a given point. We may have observed the same individual turtle multiple times. Most sightings were green turtles (81.7%), with fewer sightings of loggerheads (4.5%) and even fewer sightings of hawksbills (1.8%); a portion (11.9%) could not be identified to species, and were coded as "unknown" species. Of these 595 sightings, 529 were in the NCZ, 40 were in the HAU, and 26 were in the RNA.

Acoustic Tagging and Tracking

We outfitted 69 individual turtles with 70 acoustic tags (Vemco V16–4Ls); 1 juvenile green turtle was re-tagged upon recapture. Thirty-five (50.0%) of these 70 tags have been placed on green turtles, 32 (45.7%) on loggerheads, and 3 (4.3%) on hawksbills. We placed acoustic tags on juveniles, subadults, and adult male and female turtles.

On our 7 USGS receivers (Vemco VR2Ws), we logged 207 unique animal/receiver combinations (the combined number of detections at each receiver from unique individuals) (Fig. 3). Of these, 89 (43.0%) were unique turtle/receiver combinations, 105 (50.7%) were unique shark/receiver combinations, and 2 (1.0%) were unique fish/receiver combinations; an additional 11 (5.3%) were unique unknown species/receiver combinations. The total number of detections across all 7 USGS receivers was 28,065 (Fig. 3). Of these, 24,195 (86.2%) were turtles, 3,824 (13.6%) were sharks, and 3 (<0.1%) were fish; an additional 43 (0.2%) detections were unknown. Of the 24,195 turtle detections, 3,714 (15.4%) were detections of green turtles and 20,481 (84.6%) were detections of loggerheads.

Cooperative data sharing among the USGS, FWC, and MML has occurred since the acoustic tracking project began in 2008. On the FWC receivers, there have been 14,475 detections of 51 acoustically tagged turtles (N=22 green turtles; N=28 loggerheads; N=2 hawksbills). Individual turtles were detected on an average of 4 different FWC receivers, and on as many as 17 different FWC receivers. There were an additional 65,535 detections of 6 acoustically tagged turtles (N=3 green turtles; N=1 loggerhead; N=2 hawksbills) on 10 MML receivers. All of these were inside the HAU and five of six individuals had been detected on FWC receivers. Individual turtles were detected on an average of six and on as many as eight different MML receivers.

Overall, the total number of turtle detections in DRTO was 108,075. Across all areas of DRTO, we have 119 unique turtle/receiver combinations in the NCZ, 67 in the RNA, and 58 in the HAU, indicating that turtles are being detected by receivers throughout the park. At least one loggerhead female that we tagged on Loggerhead Key has been detected by a receiver in another array near Tampa, Florida.

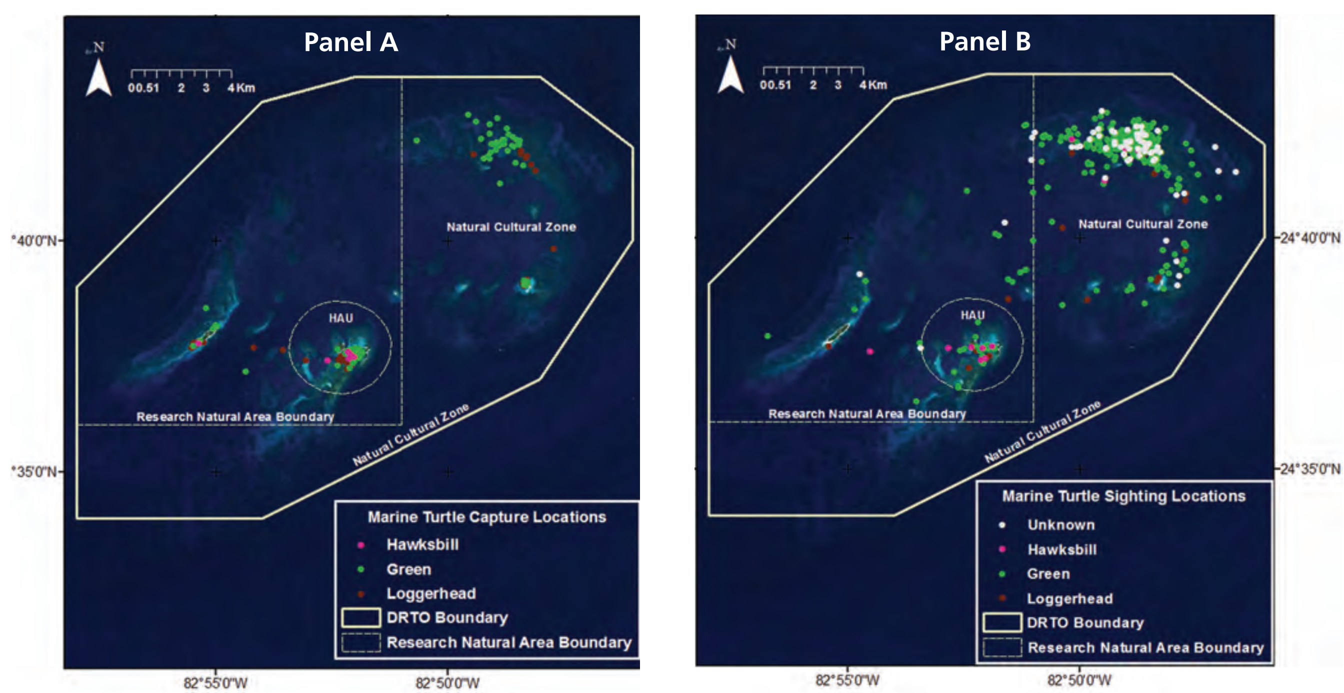

Figure 2. Location of all marine turtle captures (N=221) and sightings (N=595) in DRTO, October 2007–October 2011. Panel A: location of all turtle captures by species; panel B: location of turtle sightings by species (N=674 individuals).

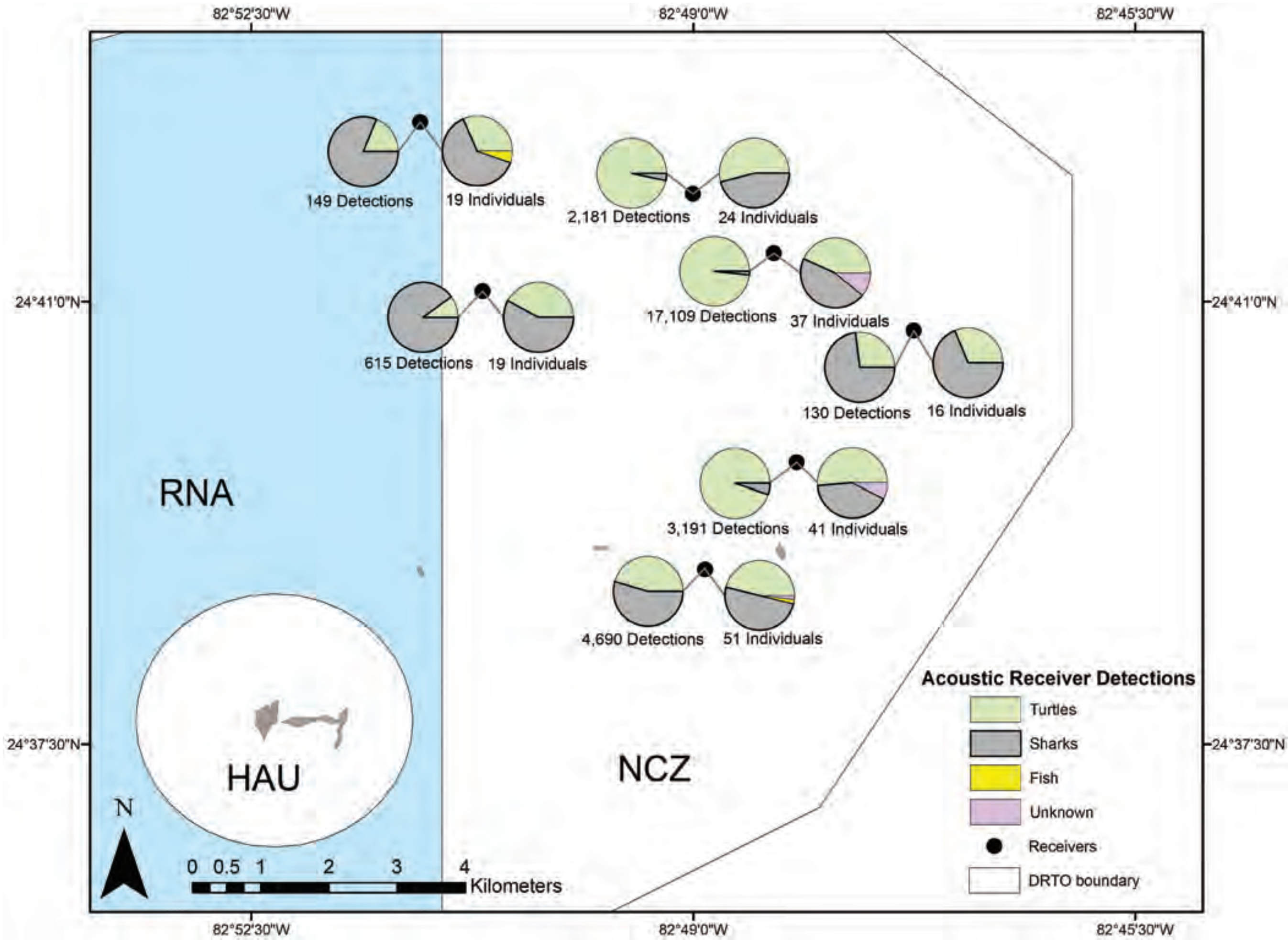

Figure 3. Summary of acoustic detections at each of the seven USGS receivers. Pie charts represent the proportion of the total detections by taxa (number reported to the left of receivers) and the proportion of total individuals detected by taxa (number reported to the right of receivers) detected by each receiver, with overall totals per receiver below the pie charts.

Satellite Tagging and Tracking

We satellite-tagged 51 marine turtles (N=34 nesting turtles, N=17 turtles captured in the water). These included 22 green turtles, 26 loggerheads, and 3 hawksbills. Of these 51 tagged turtles, 44 (86%) were females, and 7 (14%) were males. All individuals were either adults (N=44/51 or 86%) or subadults (N=7/51 or 14%); all subadults were females (N=4 green turtles; N=3 loggerheads). As of November 15, 2011, we documented a total of 11,414 turtle tracking days for the DRTO sea turtle project (http://www.seaturtle.org/tracking/?project_id=402), with a range of 41 to 884 tracking days per individual.

We determined "hotspots" of turtle activity using the KDE technique; locations of core-use areas (the 50% KDE) revealed that turtles used habitat both inside and outside the RNA, in the NCZ, and in the HAU (Figs. 4A, B, and C). Size of core-use areas differed by species and ranged from a minimum of 7.3 km^2 for green turtle males and subadults (Fig. 4B) to a maximum of 32.5 km^2 for loggerhead subadults (Fig. 4A). The size of core-use areas for green turtle nesters (20.0 km^2; Fig. 4B) was remarkably similar to that of loggerhead nesters (20.1 km^2; Fig. 4A). Finally, the size of the core-use area for hawksbills was 10.5 km^2 (Fig. 4C). All turtle species spent a mean 28.2% (standard deviation (SD) 26.0) of their time within the RNA while in DRTO. Loggerheads spent the most time in the RNA (mean 32.2%, SD 29.6), hawksbills spent slightly less time in the RNA (mean 30.9%, SD 1.9), and greens spent even less time in the RNA (mean 24.0%, SD 23.7).

Chi-square test results comparing number of DRTO turtle-days within and outside of the RNA revealed that only 2 of 22 (9.0%) of the satellite-tagged green turtles spent a significant proportion of their time within the RNA while in DRTO. Sixteen of 22 (72.7%) spent a significant proportion of their time ($p<0.05$) outside the RNA. The remaining four green turtles (18.2%) spent approximately equal proportions of their time in both sections of the park. Only 1 of 26 (3.8%) loggerheads spent a significant proportion of its time in the RNA. In contrast, 15 of 26 (57.7%) loggerheads spent a significant proportion of their time outside the RNA and 10 of 26 (38.5%) loggerheads extensively utilized the RNA and NCZ. Hawksbill turtles show a strong preference for the HAU.

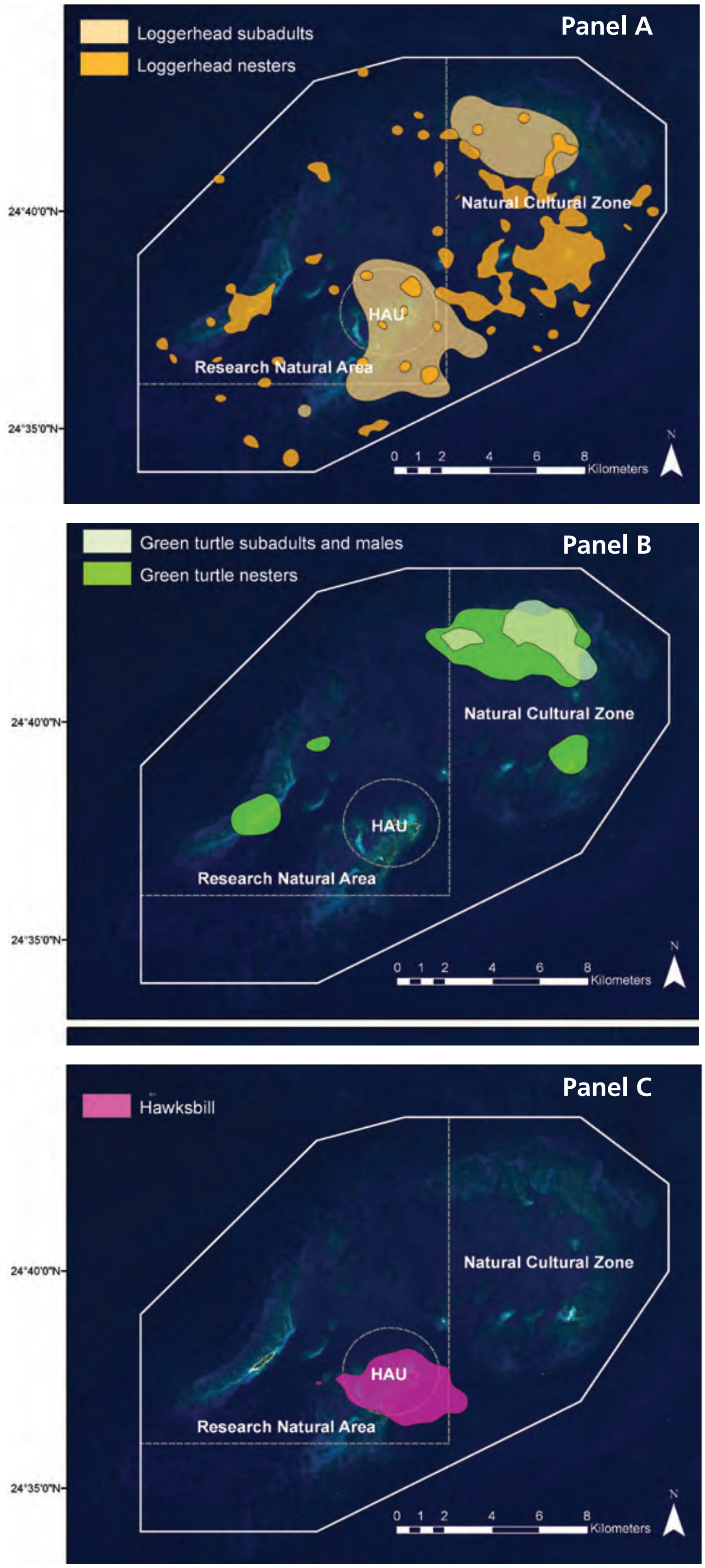

Figure 4. Core-use areas for satellite-tagged marine turtles tagged in Dry Tortugas National Park, May 2008–August 2011. Panel A: Core-use areas for two groups of loggerheads (N=26); Panel B: Core-use areas for two groups of green turtles (N=22); Panel C: Core-use areas for hawksbills (N=3). We grouped daily mean locations for each group of turtles (green turtle males and subadults; green turtle nesters, loggerhead subadults, loggerhead nesters, and hawksbills) for analysis using the kernel density estimation (KDE) technique. The hcv values (the bandwidth, in km, calculated using fixed-kernel least-squares cross validation) were as follows: green turtle males and subadults = 0.258; green turtle nesters = 0.364, hawksbills = 0.398; loggerhead nesters = 0.220, and loggerhead subadults = 0.804.

Performance Measure Evaluation

The RNA represented a small proportion of the area utilized by the turtles in this study; this was demonstrated through both our acoustic and satellite-tracking results. The majority of our captures and sightings occurred outside the RNA (Fig. 2), primarily because of chosen locations of capture and tagging efforts. Capture efforts were not concentrated within the RNA, except on the Loggerhead Key nesting beach. Consequently, we are not yet able to definitively assess the suitability of the RNA for marine turtles; however, we highlight important turtle-use areas within the boundary of DRTO that are not designated as restricted-use areas. Results indicate that turtles captured outside the RNA rarely ventured into that area, and that, at least for most tagged turtles, the RNA is likely not preferred habitat.

Acoustic and satellite telemetry allowed us to track turtles to assess their preferred foraging and nesting areas; we documented turtle movements away from capture locations and for long periods of time (as long as ~2.4 years). Across all areas of DRTO, we have 119 unique turtle/receiver combinations in the NCZ, 67 in the RNA, and 58 in the HAU, indicating that turtles are being detected by receivers throughout the park. Only 27% of acoustic detections for all tagged turtles have occurred inside the RNA, demonstrating that the majority of our tagged turtles are not spending time in the RNA. Satellite-telemetry results support these acoustic results, as the majority of our satellite-tagged turtles' core-use areas also were outside the RNA. Further, the main core-use areas that were inside the RNA were in close proximity to Loggerhead Key, indicating that the primary useful habitat within the RNA is restricted to the area immediately around this nesting area.

Across multiple tracking years, we have observed consistency in core-use areas (Hart et al. 2010), suggesting that the RNA will likely not become preferred core-use area for these tagged turtles in the future. However, additional tracking of DRTO turtles captured on nesting beaches and in the water will illuminate the longer-term spatial habitat-use patterns of DRTO marine turtles and will continue to provide insight into the effectiveness of the RNA for protecting threatened and endangered marine turtles and their requisite habitats. This will contribute toward the development of more effective decision-support tools to adaptively manage protected areas.

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Literature Cited

Coyne, M.S. and Godley, B.J. 2005. Satellite Tracking and Analysis Tool (STAT): An integrated system for archiving, analyzing and mapping animal tracking data. *Marine Ecology Progress Series* 301:1–7.

Hart, K.M., Zawada, D.G., Fujisaki, I., and Lidz, B.H. 2010. Inter-nesting habitat-use patterns of loggerhead sea turtles: Enhancing satellite tracking with benthic mapping. *Aquatic Biology* 11:77–90.

White, G.C. and Garrott, R.A. 1990. Analysis of wildlife radio-tracking data. Academic Press, New York, New York.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70:164–168.

USGS researchers and volunteers waiting for epoxy to dry on a satellite- and acoustic-tagged loggerhead (*Caretta caretta*) female, Loggerhead Key, Dry Tortugas National Park. All marine turtle images taken in Florida were obtained with the approval of the U.S. Fish and Wildlife Service and the Florida Fish and Wildlife Conservation Commission (FWC MTP #11–176) under conditions not harmful to this or other turtles. Photo by Kaare Iverson, USGS volunteer.

RNA Performance Topic 3

Chapter 6: Status of the development and implementation of a creel survey and vessel permit system at Dry Tortugas National Park

Investigators

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Project Description

The Research Natural Area (RNA) at Dry Tortugas National Park (DRTO) was established in 2007 and serves as a no-take marine reserve (NTMR) that complements the Florida Keys National Marine Sanctuary ecological reserves. One outcome of protecting marine resources in these collective reserves may be to enhance fisheries in proximate areas, such as the adjacent Natural Cultural Zone (NCZ) of DRTO, which is open to recreational fishing. Fish tagging studies associated with the RNA have demonstrated that spillover of fish across the RNA boundary is occurring (Chapters 3 and 4, this volume). The system by which recreational anglers in DRTO are directly surveyed is being redesigned to provide a better estimate of potential fishery effects of the RNA and associated NTMRs in the region (Performance Topic 3).

To support monitoring of changes in species composition and catch rates of exploited species throughout the Tortugas region, National Park Service (NPS) staff members have been working with University of Miami (UM) fisheries scientists to develop an improved creel census for DRTO (Ault et al. 2011). Creel surveys estimate angler effort and harvest in areas within the park that are open to fishing. Once implemented, the data collected through the creel survey will be used to calculate reef fish catch per unit effort (CPUE), a fishery-dependent measure of fish abundance. We will be able to compare these data to the fishery-independent data from the reef visual census (Chapter 1, this volume) as they relate to the RNA.

NPS staff will interview anglers that are fishing on Garden Key and anglers on anchored boats within the Garden Key anchorage. A typical survey will ask basic questions regarding how long the anglers were fishing, what species of fish were caught, and how many were kept or released. Additionally, fish length measurements will be taken by the survey clerk. Interviewees will be shown a map of the park and asked to identify by region where their fishing activity occurred. UM scientists have developed a new spatial map of fishing zones to incorporate the no-take RNA (Fig. 1). The new map divides DRTO into four fishing areas that are comparable to the fisheries independent surveys (Chapter 1, this volume).

Commercial fishing vessels anchored in the harbor near Garden Key, Dry Tortugas National Park. NPS photo by Joy Brunk.

Creel survey data will be used to calculate CPUE for exploited fisheries species. An estimate of CPUE can help provide an estimate of species abundance during a given time period, whereas the estimate of exploited phase species length can provide a measure of fishing intensity. For example, DRTO staff collected creel surveys during 1981–1984 and 2000–2004. This historical data set was used to calculate CPUE for species of interest, as well as the average length in the exploited phase of fish species of interest. However, DRTO managers are missing information that is critical to understanding the status of the fishery. The park needs to obtain estimates of total effort (total number of hours fished) and total species catch in DRTO waters that are open to fishing. This new survey design will help gather that missing information.

In order to estimate total fishing effort, we need to know how many vessels are engaged in fishing within the park. To address this issue, DRTO implemented a vessel permit system in 2011. This permit system will provide managers with consistent information about public use in the park including the number of vessels that are engaged in fishing. Anglers will soon be required to provide fishing activity and catch data as a component of this permit system. Once the creel survey is fully implemented within the park, the statistics from the vessel permit system will contribute to fishery dependent surveys.

Another purpose of the DRTO vessel permit system is to protect resources, minimize human impacts, monitor visitor use, and increase awareness of the RNA. The permit system achieves this goal by providing reliable information to the public about the delicate resources within the park, the significance of the RNA, and appropriate regulations for RNA visitation. The permit system also enhances safe boating practices through a greater level of staff and visitor interaction. This, in turn, is expected to lead to a reduction in the number of violations and incidents within the park.

Law enforcement rangers are implementing the vessel permit system at DRTO. When visitors come to the park aboard a vessel, a ranger contacts the vessel via VHF radio, requesting that the visitors come to Garden Key to obtain a permit. The permit application identifies park users and the

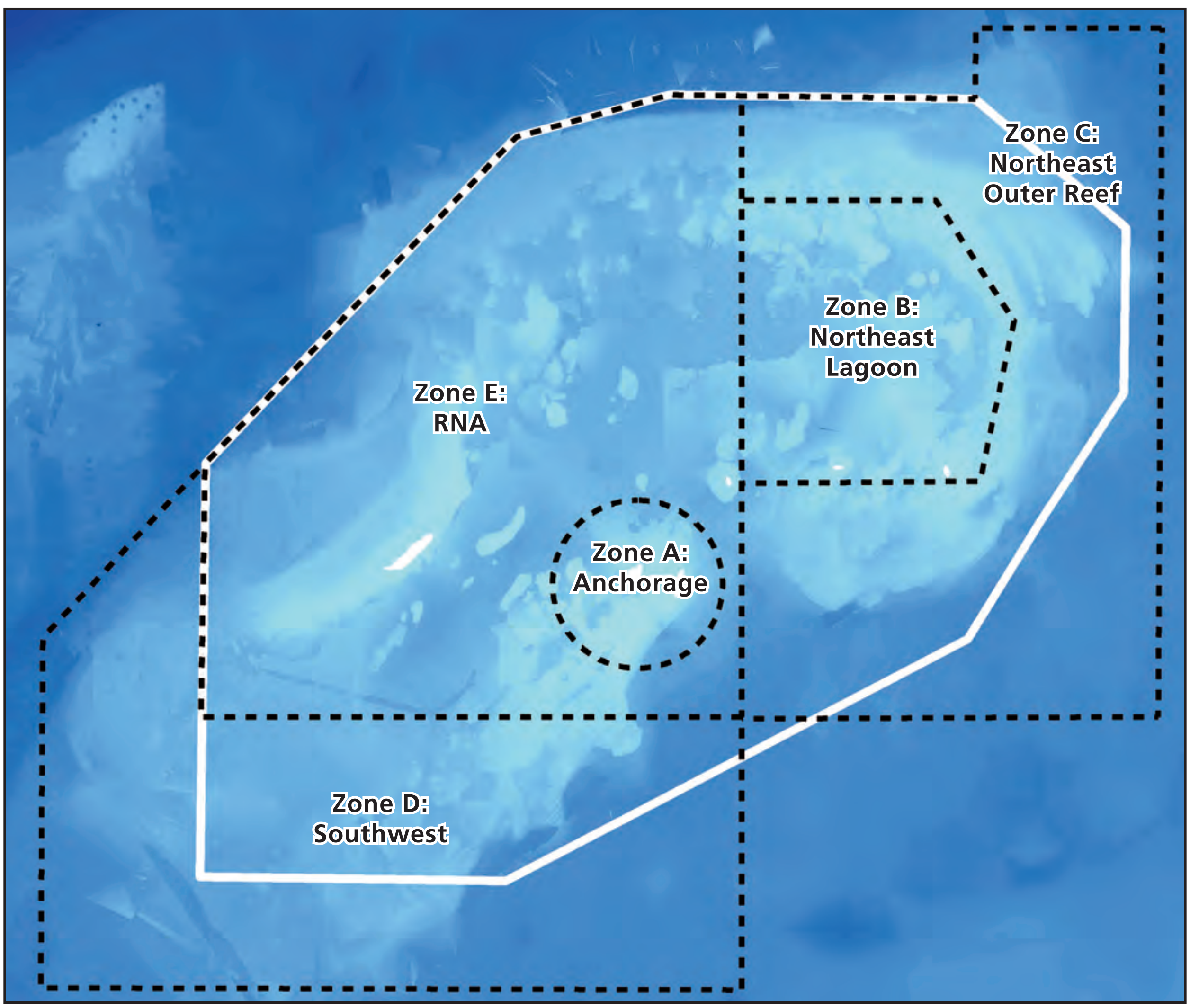

Figure 1. Map of the proposed new spatial fishing zones for the creel survey. (Bathymetry: lighter areas are shallower, darker areas are deeper.)

Recreational sailboats were the most popular vessel to visit the park, followed by recreational motor vessels. NPS photo.

activities they intend to participate in during their visit. Every permit holder is given a packet of park brochures that specify park regulations and includes a map of the park and the RNA. The ranger explains the pertinent rules and regulations to the visitor during this contact. Permits apply to all recreational vessels, commercial vessels, and vessels operating under a Commercial Use Authorization. DRTO staff compiles all the information from permits into a database. Activity categories include fishing, snorkeling, SCUBA diving, camping, kayaking, visiting Loggerhead and Bush Keys, and mooring ball use within the RNA.

Results

DRTO staff issued a total of 3,082 boat permits in 2011. Of these, 2,479 were recreational vessel boat permits. Recreational sailboats were the most popular vessel to visit the park, followed by recreational motor vessels (Fig. 2). Permits were issued to kayaks independently of motor and sailing vessels. Staff also collected boat permits from 603 commercial and law enforcement vessels. Most visitors arriving by recreational vessel came to the park for sightseeing (Fig. 3). Fishing, snorkeling, and visiting Loggerhead Key were the next three most common visitor activities.

Performance Measure Evaluation

The creel survey for DRTO is still a work in progress. DRTO recently hired a fisheries biologist to assist with the implementation of the creel survey at the park. The new survey design developed by UM includes recommendations for a 2-year study to optimize the creel survey specifically for the Tortugas region. This study will be the first step in helping to estimate total fishing effort in the park and, when combined with interview sampling, will allow park staff to estimate total catch for exploited fish species. These statistics are necessary to evaluate the performance measure of monitoring changes in species composition and catch rates of exploited species in the Tortugas region.

Several recreational and commercial fisheries dependent monitoring programs exist for the Tortugas region. For example, the National Marine Fisheries Service (NMFS) has been collecting fishing activity from chartered “head boats” since 1981 using a logbook system. These existing data sets could be used to evaluate the effects of RNA implementation on fisheries outside of DTRO.

The DRTO vessel permit system is in its introductory phase of operation. The vessel permit system allows NPS staff to maintain statistics of visitor use. The information gathered from the vessel permit system will also allow managers to determine the carrying capacity of recreational dive and snorkel sites, including mooring ball use. DRTO staff members are currently working on an electronic version of the permit application that will be added to the DRTO website. Eventually, anglers in the park will be required to declare their intended fishing activity in order to obtain a permit. Anglers will then be required to return a completed angler survey to DRTO staff on Garden Key in person, by U.S. mail, or by internet. These survey data will then be used to calculate CPUE and record the size of reef fish. This survey method will be used in concert with the in-person creel interview surveys to help assess the effects of RNA implementation on recreational fishing areas surrounding the RNA.

Literature Cited

Ault, J.S., Smith, S.G., Zurcher, N., McClellan, D.B., Bohnsack, J.A., Luo, J., and Vaughan, N. 2011. Assessment of coral reef multispecies fishery resources and RNA performance in Dry Tortugas National Park, 1999–2010. National Park Service Final Report.

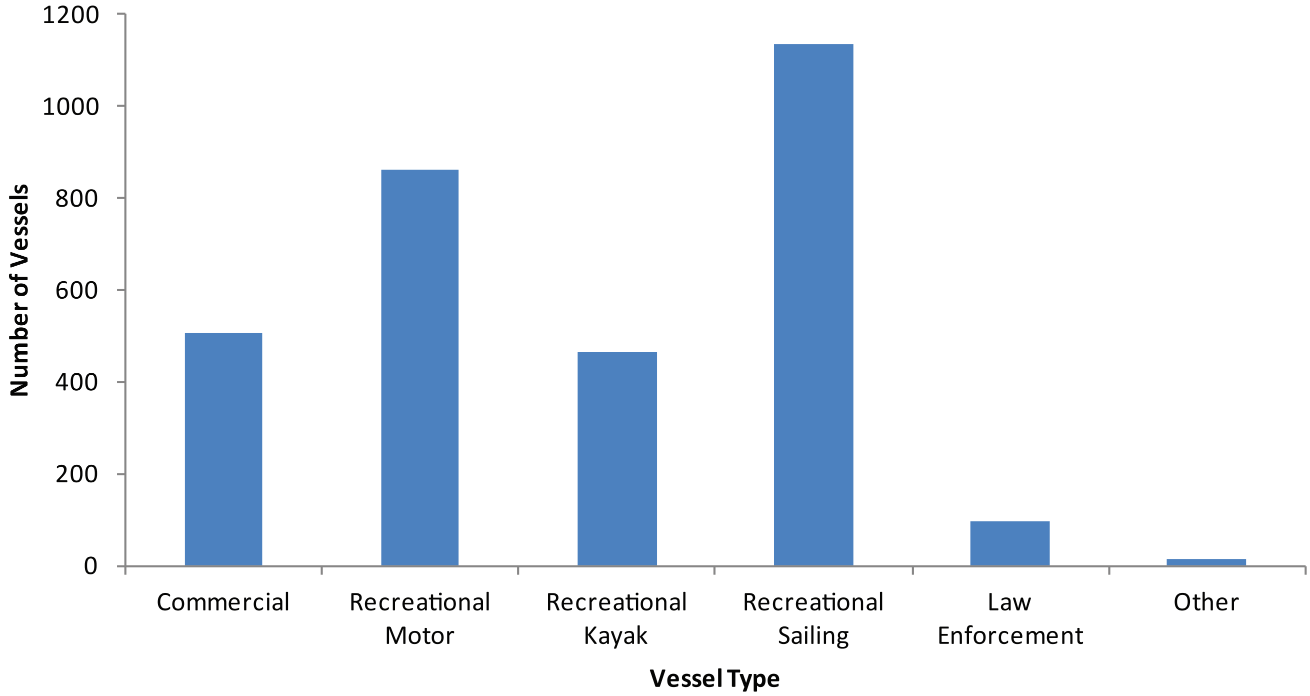

Figure 2. Number of vessels by type from permits at DRTO in 2011.

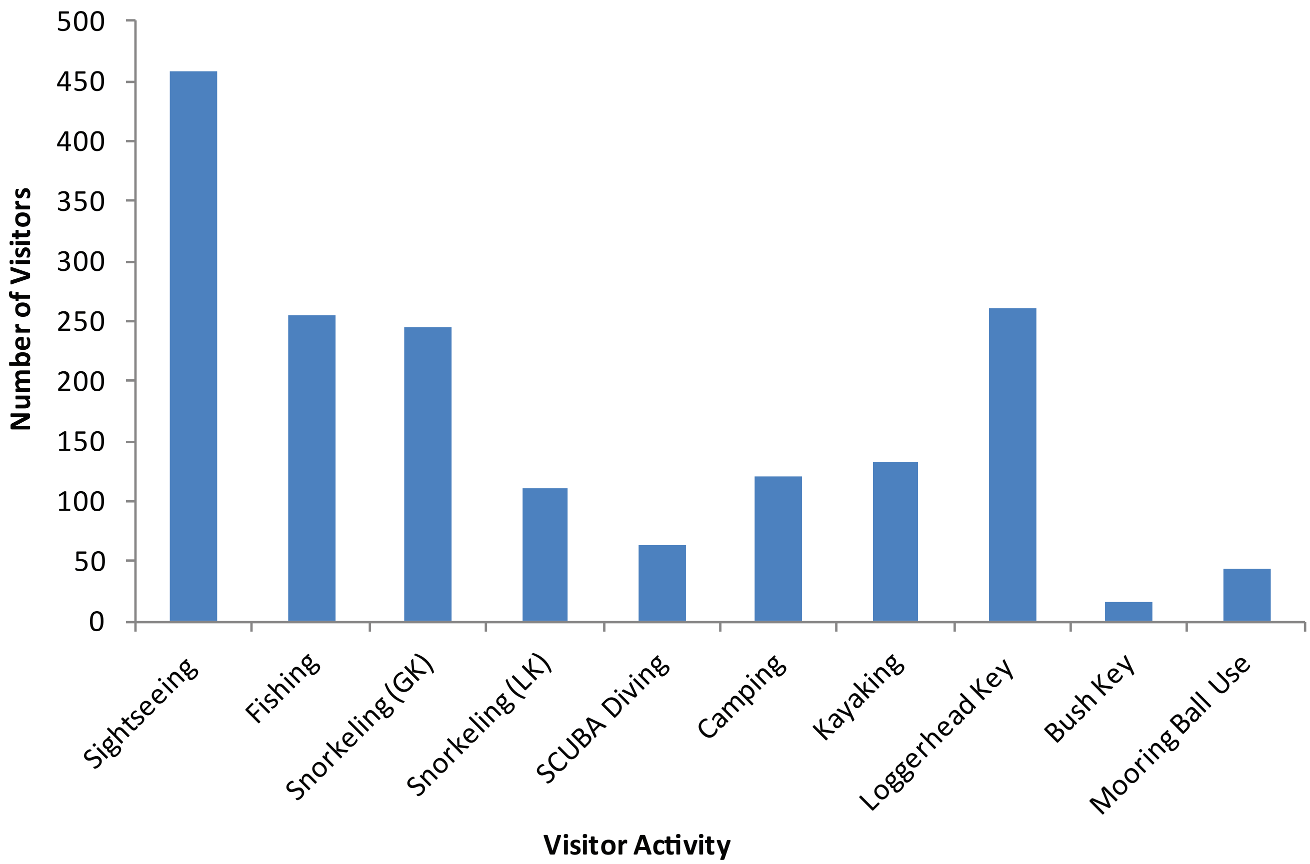

Figure 3. Visitor activity from recreational vessel permits at DRTO in 2011. GK, Garden Key; LK, Loggerhead Key.

RNA Performance Topic 4

Chapter 7: Assessing the effects of diving activities on coral communities at designated dive sites within the Dry Tortugas National Park Research Natural Area

Investigators

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Project Description

Implementation of the Dry Tortugas National Park (DRTO) Research Natural Area (RNA) prohibited boat anchoring within RNA boundaries and established designated dive sites with mooring buoys for diving and snorkeling activities within the RNA. This is a potential concern for DRTO because concentrating diving activities at sites with mooring buoys can have adverse effects on coral reef communities. Multiple studies from around the world have found that intensive SCUBA diving activity can negatively impact coral reefs (Tratalos and Austin 2001; Zakai and Chadwick-Furman 2002). Recreational divers can unintentionally harm corals by kicking, abrading, or dusting them with sediment and this has led some coral reef managers to institute diver "carrying capacities" so that the incidence of diver-induced damage can be minimized (Luna et al. 2009).

An RNA resource stewardship goal is to have no long-term effects of diving activities on corals (Performance Topic 4). The primary performance measures are damage to and loss of stony corals, including the federally listed *Acroporid* species. Secondary performance measures focus on damage to and loss of sponges, branching soft corals, and other benthic taxa (such as zoanthids). A fully replicated Before-After-Reference-Impact sampling design was established to compare changes in coral communities at RNA dive sites and equivalent reference sites with no or little diving activity. In 2009, permanent monitoring stations were installed at Texas Rock, Davis Rock, and The Maze (Fig. 1), all pinnacle reefs and RNA dive sites. Two pinnacle reefs, Mayer's Peak and Temptation Rock, were selected as the reference sites. To monitor specifically for damage to *Acropora cervicornis*, another RNA dive site (Off-Ramp) and a reference site (Perfection) were selected at two shallow reefs where *A. cervicornis* is common. The location of all RNA dive sites with mooring buoys and those used for reference sites is shown in Figure 1. This project is part of a long-term benthic monitoring and assessment program conducted by the Coral Reef Evaluation and Monitoring Project

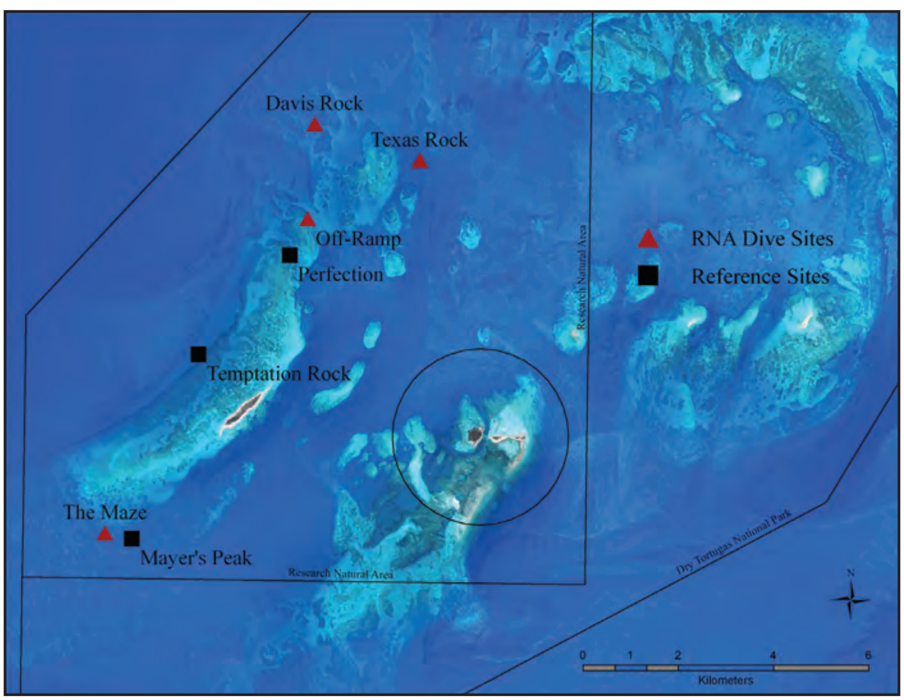

Figure 1. Location of RNA dive sites and equivalent reference sites.

(CREMP) via cooperative agreement between the Florida Fish and Wildlife Conservation Commission and the National Park Service.

It is often challenging to differentiate accurately between coral damage inflicted by divers as opposed to damage caused by other stressors (such as storms). As a result, a combined approach, using short-term measures of stress (such as bleaching and damage) and longer-term measures of population density and benthic cover, was used to assess benthic community change at the pinnacle reef RNA dive sites and reference sites. If impacts by divers were greater at the RNA dive sites than at the reference sites, it would be anticipated that the frequency of stress would be higher at the RNA dive sites and lead to larger declines in density and benthic cover.

Four stations were surveyed at each site. Benthic cover of stony corals, octocorals, sponges, and zoanthids was determined from image analysis acquired through video or still camera transects (Ruzicka et al. 2010). At each station, three 22-m x 40-cm fixed location transects were filmed annually. Images were analyzed using a custom software package, Point Count '99, and between 200 and 250 abutting images were overlaid with 15 random points per image, resulting in about 3,000 points counted for each station. Coral density was estimated by recording all stony corals ≥4 cm in diameter or height at each 22-m x 2-m survey station by divers. To quantify coral stress, 10-m x 1-m belt-transects were conducted at each station. The maximum width; the presence of disease, bleaching, and damage; and the percentage of estimated tissue mortality were recorded for each stony coral colony ≥4 cm in diameter. An entirely different methodology was used at Off-Ramp and Perfection because the surveys were specifically designed to study the highly dynamic coral, *A. cervicornis*. Radial plots, 7 m in diameter, were established in lieu of traditional 22-m x 2-m sampling stations used by CREMP. Within each radial plot, all *A. cervicornis* colonies were mapped and a subset tracked for estimates of disease and damage.

Results for benthic cover and stony coral density are reported here and were calculated by averaging the station values for the three RNA dive sites (N=12) and two reference sites (N=8). Baseline estimates of coral stress and damage were completed in 2009 and included in the DRTO RNA 3-year report (Hallac and Hunt 2010). The radial plots to assess the condition of *A. cervicornis* were first established in 2011. The radial plots will be surveyed a minimum of three times annually.

Results

Benthic cover data were collected in 2009 and 2010 and stony coral density data were collected in 2010 at the pinnacle reef RNA dive sites and reference sites. There were no significant differences in the cover of stony corals, octocorals, sponges, or zoanthids between years at the RNA dive sites or reference

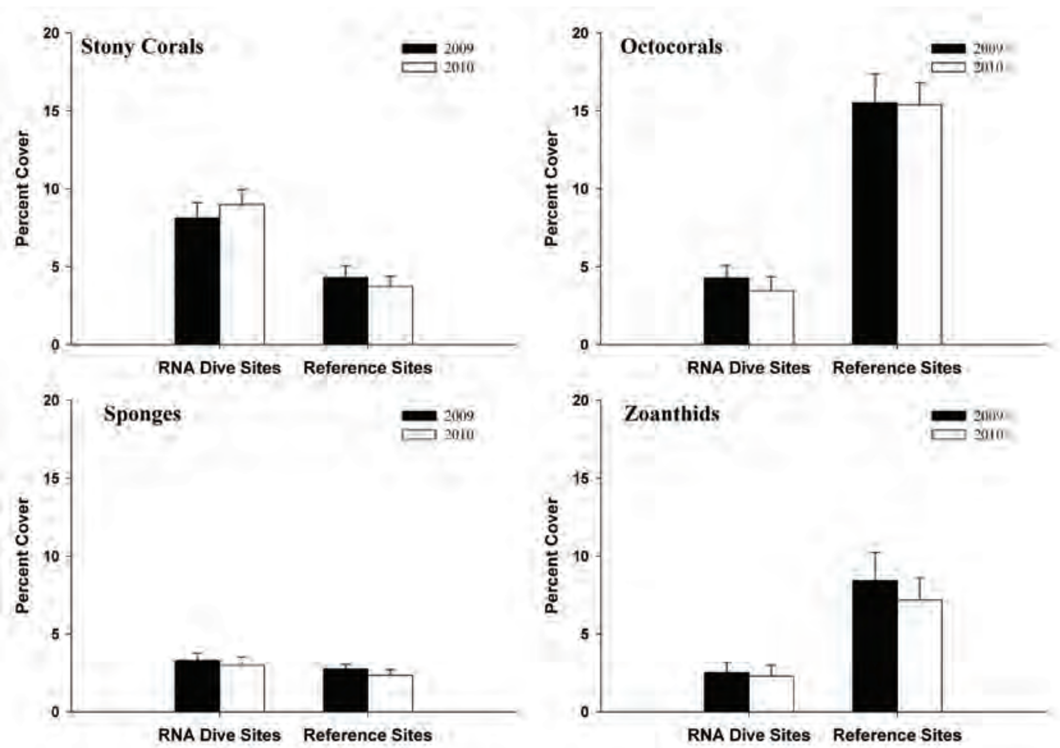

Figure 2. Percent cover (±SE) cover of stony corals, octocorals, sponges, and zoanthids at three RNA dive sites (Davis Rock, Texas Rock, The Maze) and two reference sites (Mayer's Peak and Temptation Rock). No significant differences in benthic cover were detected for any taxonomic group between years. N=12 for RNA dive sites and N=8 for two reference sites.

sites (Fig. 2). The RNA dive sites had higher stony coral and sponge cover than the reference sites (Fig. 2). Octocoral and zoanthid cover was greater at the reference sites than at the RNA dive sites (Fig. 2). Overall stony coral density (number of corals per m^2) was higher at the RNA dive sites in comparison to the reference sites (Table 1). The density of foliose/plating, massive/encrusting, and solitary corals was higher for each category at the RNA dive sites than at reference sites (Table 1). Only the density of branching coral species was greater at the reference sites compared to the RNA dive sites (Table 1).

Although the installation of mooring buoys was anticipated to occur in 2010, installation was not complete until 2011. As a result, the first assessment of diver impacts at the RNA dive sites has not yet occurred. However, the results from the 2009 and 2010 surveys provide excellent baseline information on benthic community structure prior to any impacts associated with diving activities. Additionally, the delay in mooring buoy

Table 1. Stony coral density (number of corals per m^2) at three RNA dive sites (Davis Rock, Texas Rock, and The Maze) and two reference sites (Mayer's Peak and Temptation Rock). N=12 for RNA dive sites and N=8 for reference sites. ± value is standard error.

	RNA Dive Sites		Reference Sites	
Branching	**0.179**	**± 0.036**	**0.342**	**± 0.080**
Acropora cervicornis	0.002	± 0.002	0.026	± 0.017
Oculina diffusa	0.012	± 0.006	0.031	± 0.021
Eusimilia fastigiata	0.037	± 0.011	0.016	± 0.006
Mussa angulosa	0.012	± 0.005	0.006	± 0.004
Porites porites	0.116	± 0.034	0.264	± 0.084
Foliose/Plating	**0.188**	**± 0.039**	**0.154**	**± 0.030**
Agaricia agaricites (complex)	0.068	± 0.016	0.077	± 0.022
Agaricia fragilis	0.049	± 0.017	0.029	± 0.016
Agaricia lamarcki	0.005	± 0.003	0.000	± 0.000
Leptoseris cucullata	0.002	± 0.002	0.000	± 0.000
Mycetophyllia aliciae	0.044	± 0.013	0.009	± 0.004
Mycetophyllia ferox	0.011	± 0.005	0.006	± 0.004
Mycetophyllia lamarckiana	0.009	± 0.004	0.034	± 0.009
Massive/Encrusting	**3.084**	**± 0.259**	**2.409**	**± 0.287**
Montastraea annularis (complex)	0.367	± 0.043	0.118	± 0.025
Montastraea cavernosa	0.715	± 0.087	0.250	± 0.055
Colpophyllia natans	0.135	± 0.023	0.061	± 0.019
Dichocoenia stokesii	0.017	± 0.006	0.058	± 0.019
Diploria labyrinthiformis	0.009	± 0.005	0.029	± 0.008
Diploria strigosa	0.072	± 0.015	0.097	± 0.016
Madracis decactis	0.139	± 0.046	0.052	± 0.022
Madracis pharensis	0.002	± 0.002	0.000	± 0.000
Meandrina meandrites	0.040	± 0.010	0.051	± 0.011
Porites astreoides	0.615	± 0.067	0.561	± 0.064
Siderastrea radians	0.003	± 0.002	0.007	± 0.004
Siderastrea siderea	0.635	± 0.073	0.702	± 0.092
Solenastrea bournoni	0.002	± 0.002	0.003	± 0.003
Stephanocoenia michelinii	0.332	± 0.047	0.392	± 0.075
Manicina areolata	0.000	± 0.000	0.025	± 0.013
Isophyllia sinuosa	0.000	± 0.000	0.004	± 0.004
Solitary	**0.006**	**± 0.003**	**0.001**	**± 0.001**
Phyllangia americana	0.002	± 0.002	0.000	± 0.000
Scolymia cubensis	0.004	± 0.002	0.001	± 0.001
Total	**3.456**	**± 0.264**	**2.906**	**± 0.276**

installation allowed for a revision to the monitoring protocol used for assessing damage to *A. cervicornis* at the Off-Ramp and Perfection sites.

Performance Measure Evaluation

The surveys conducted in 2009 and 2010 provide an excellent baseline against which to evaluate the impacts that diving activities may have on coral communities at the RNA dive sites. Benthic cover estimates were consistent across years and stony coral density surveys encompassed a minimum of 150 m^2 at each of the RNA dive and reference sites. The combination of these long-term measures coupled with previously reported estimates of coral stress will serve as reliable indicators to assess the long-term condition of coral communities at these sites and assist in determining if diver related impacts are the cause of any detectable differences between the RNA dive sites and reference sites.

Identifying the diver carrying capacity at the RNA sites is critical if RNA resource stewardship goals are to be achieved. Estimating an acceptable diver capacity at intensively used dive sites can be difficult and previous attempts from reefs around the world have varied widely, ranging from 5,000 to 50,000 divers per site per year (Luna et al. 2009). Many factors such as the biological and physical characteristics of the dive site, the presence of other anthropogenic stressors, the frequency of large-scale natural disturbances, and the education and competence of the divers all play a role in estimating diver carrying capacity. With installation of the mooring field completed, data on diver activity at the RNA sites can now be obtained through the DRTO vessel permit system (Chapter 6, this volume). Most likely RNA dive sites will be visited by fewer than 6,000 divers per year, a level generally accepted as non-detrimental to coral reef communities (Hawkins et al. 1999). Conservative diver thresholds are typically applied to dive sites where branching corals are the most dominant constituent because branching corals are more vulnerable to diver-inflicted damage (Hawkins et al. 1999). At the RNA pinnacle reef dive sites, however, massive/encrusting stony corals and octocorals represent a large proportion of the reef community and this may increase the number of divers that can visit these sites without causing any discernible impacts.

Acknowledgements

All monitoring activities in 2009 and 2010 were jointly performed with DRTO under monitoring permits DRTO–2009–SCI–0002 and DRTO–2010–SCI–0017. All activities were funded by cooperative agreement #H2117 08 3732, task agreement #J5299 08 9502, between the National Park Service and the Fish and Wildlife Research Institute (FWRI). We would like to thank multiple DRTO staff who made this work possible including Dr. Doug Morrison, Dr. Tracy Ziegler, and Kayla Nimmo. We also need to extend our sincere gratitude to FWRI employees Dr. Dave Palandro and Dave Eaken whose assistance was invaluable for completing the installation of the new survey stations at three RNA sites.

Literature Cited

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

Hawkins, J.P., Roberts, C.M., Van'T Hof, T., De Meyer, K., Tratalos, J.A., and Aldam, C. 1999. Effects of Recreational Scuba Diving on Caribbean Coral and Fish Communities. *Conservation Biology* 13:888–897.

Luna, B., Valle Pérez, C., and Sánchez-Lizaso, J.L. 2009. Benthic impacts of recreational divers in a Mediterranean Marine Protected Area. *ICES Journal of Marine Science* 66:517–523.

Ruzicka R, Semon, K., Colella, M.A., Brinkhuis, V., Morrison, J., Macaulay, K., Kidney, J., Porter, J., Meyers, M., Christman, M., and Colee, J. 2010. Coral Reef Evaluation and Monitoring Project 2009 Final Report. Fish and Wildlife Research Institute/Florida Fish and Wildlife Conservation Commission, Saint Petersburg, FL, 110 pp.

Tratalos, J.A. and Austin, T.J.. 2001. Impacts of recreational scuba diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation* 102:67–75.

Zakai, D. and Chadwick-Furman, N.E., 2002. Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. *Biological Conservation* 105:179–187.

RNA Performance Topic 4

Chapter 8: Baseline surveys to detect trophic changes in shallow hard-bottom communities induced by the Dry Tortugas National Park Research Natural Area

Investigators

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Project Description

This chapter addresses the performance of the Dry Tortugas National Park (DRTO) Research Natural Area (RNA) in restoring coral reef ecological processes, including recovery of coral abundance and cover, coral recruitment, herbivory by fishes, and abundance of key species (Performance Topic 4). Like other reefs in the south Florida and Caribbean regions, Dry Tortugas communities have experienced significant degradation in the form of decreases in exploited species, reduced live coral, and increases in fleshy macroalgae. It remains to be determined to what extent humans are responsible for the decline in live coral coverage, as meteorological events are known to have contributed. Alexander Agassiz mapped the Dry Tortugas benthos in 1881, showing tens of hectares of *Acropora palmata*, but drilling has revealed that this species was not responsible for reef accretion in the Dry Tortugas (Shinn et al. 1977). In 1976, a comprehensive habitat map was created to examine change since the Agassiz map was prepared; the map showed that *A. palmata* had virtually disappeared and that *Acropora cervicornis* coverage was vast (Davis 1982). In January 1977, a severe cold front killed most of the *A. cervicornis* reefs. Populations have not recovered on patch reefs they once dominated in the early 1970s; in fact, a representative site showed steady decline due to bleaching and disease from 1999 to 2005 (Beaver et al. 2005). Regardless of what forces are responsible for the present state of reefs, there is some evidence that protecting reefs from any harvesting may help restore coral populations by restoring the balance among all trophic levels (Mumby et al. 2006).

The purpose of our study was to document the status of reef resources across multiple trophic groups in DRTO, both inside the RNA and in the adjacent Natural Cultural Zone (NCZ), with particular focus on the important reef process of herbivory. We investigated trophic cascades by examining the distribution and abundance of herbivores, the macroalgae they eat, and the stony corals that provide shelter for most reef organisms. Because of our focus on herbivory and trophic functioning, and because other monitoring programs (National Park Service, South Florida and Caribbean Network (SFCN); National Oceanic and Atmospheric Administration; and Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute) have focused on habitat deeper than 6 m, we chose to focus our study on the shallow (<6 m) reef environment. We focused specifically on low-relief, hard-bottom habitat (equivalent to remnant low profile and patch reef categories as categorized by SFCN, see Chapter 9, this volume) because it is the most abundant biological community habitat class within DRTO (Franklin et al. 2003).

We randomly selected 18 sites for surveys conducted during October 2007, 9 within the RNA and 9 within the NCZ (Fig. 1). We conducted species-level surveys of macroalgae, scleractinian and gorgonian corals, herbivorous and game fishes, and sea urchins (Fig. 2), and also assessed substratum composition and quantified rugosity. Three 15-m transects were laid out radially from each Global Positioning System (GPS) location at bearings of 0°, 120°, and 240°. One reef fish visual census (7.5-m-radius cylinder with stationary observer) was conducted on each transect line (Bohnsack and Bannerot 1986; Brandt et al. 2009) with a downsized species list to reflect our objectives (for example, small benthic fishes were not included). The benthic community was assessed using n=4 quadrats (0.0625 m^2 with line demarking 25 equal boxes) per transect by visually estimating percent cover of taxa within the quadrat, and urchins and damselfish were counted in a 2-m-wide belt along each transect line. Rugosity was estimated by repeatedly draping a 1-m chain (3-cm link size) on the substratum underneath each transect line, giving the ratio between contoured and linear distance. Gorgonian and scleractinian diversity at each site was determined by recording all species observed throughout the approximately 1-hour-long dive in the proximity of the three transect lines (~700 m^2 area). The “game fish” category used here included grouper (*Epinephelus*, *Mycteroperca*, *Cephalopholis*) but excluded the small-bodied hamlets (*Hypoplectrus*), jacks (*Caranx*), snapper (*Lutjanus* and *Ocyurus*), and hogfish (*Lachnolaimus maximus*). Details on calculation of fish biomass are available in Kuffner et al. (2009).

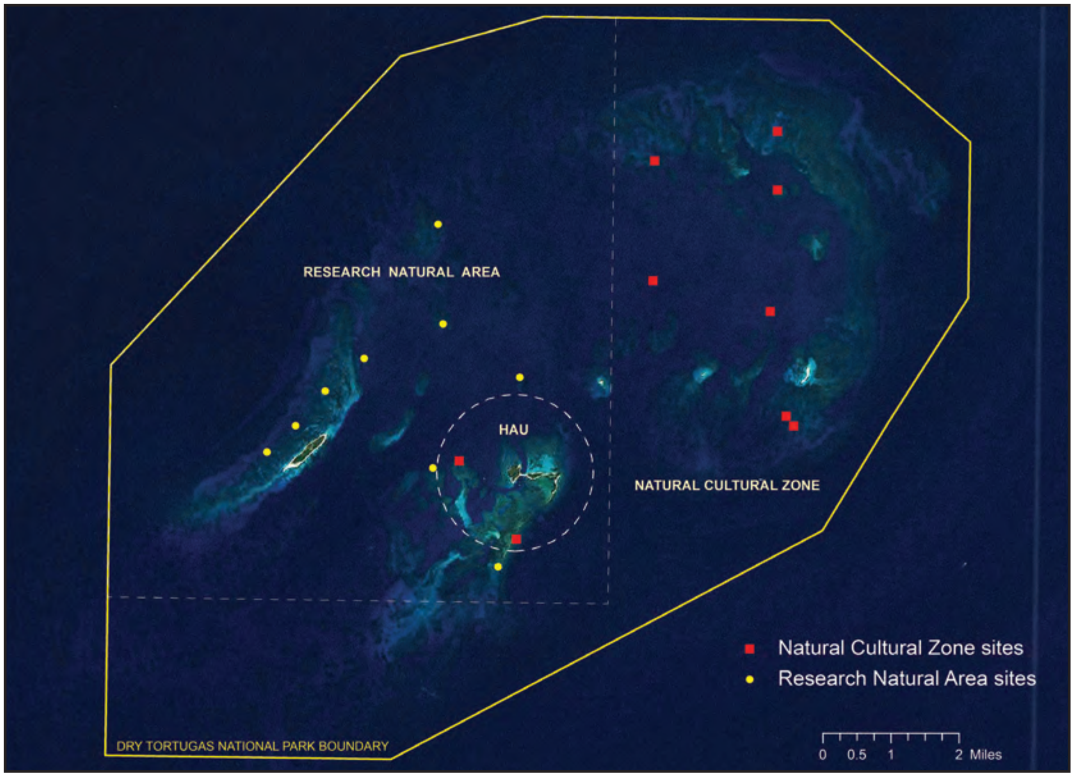

Figure 1. IKONOS satellite mosaic of Dry Tortugas National Park showing the location of 18 randomly selected sites where in-situ surveys were conducted during October 2007.

Results

Our surveys revealed that no variables measured were significantly different within the RNA vs. within the NCZ (Table 1; Kuffner et al. 2009). Game fish, particularly red grouper (*Epinephelus morio*), were abundant compared to sites of similar habitat in Virgin Islands National Park (data not shown). We counted a total of 19 *E. morio* during 54 censuses at the 18 sites throughout the park. Initial-phase hogfish (*Lachnolaimus maximus*), which are important predators of benthic invertebrates including sea urchins, were recorded at 6 of the 18 sites. The long-spined urchin (*Diadema antillarum*) was present and fairly evenly distributed at all 18 sites. Mean densities ranged from 0.01 to 0.54 individuals m^{-2}, with 11 of the 18 sites having densities above 0.10 individuals m^{-2}. Mean percent of the substratum covered by macroalgae across all sites was 34% and dominated by brown algae (*Dictyota* spp.). *D. antillarum* density, scleractinian-coral species richness, scarid (parrotfish) abundance and biomass, and damselfish (*Stegastes* spp.) abundance were positively related to rugosity of the substratum. *D. antillarum* density also was positively related to percentage of the substratum composed of *A. cervicornis* rubble, and the amount of variance explained increased (adjusted R^2=0.49) when both the rugosity and rubble variables were included in a multiple linear regression model. Small (<1-m-diameter), live colonies of *A. cervicornis* (Fig. 3) were noted at 12 of the 18 sites, evenly distributed across the RNA and the NCZ.

Performance Measure Evaluation

Can resource managers expect to reverse the decline in live coral coverage through the establishment and enforcement of the RNA? To have realistic expectations for the RNA's efficacy with respect to benthic communities, it is necessary to take stock of initial conditions and to understand what forces drive coral population levels. Our data provide an important baseline that can be used to evaluate change with respect to the establishment of the RNA. A key element of our dataset is that no pre-existing differences exist among sites within the RNA vs. within the NCZ in any of the variables measured.

Although there are too few ecological data to determine if the Caribbean-wide mortality of the key herbivore, *Diadema antillarum*, played a role in coral decline at this location since the early 1980s, the recent increases in this population could potentially enhance coral recruitment through the removal of *Dictyota* spp. and other algae from otherwise suitable substrata (Kuffner et al. 2006; Paul et al. 2011). Also, our data indicate that testing the hypothesis that *A. cervicornis* rubble acts as nursery habitat for *D. antillarum* would be worthwhile. We suggest the possibility of a positive feedback mechanism between these two recovering species.

No-take areas are considered an important tool in managing for reef resilience (Bellwood et al. 2004), and there is a growing body of evidence that no-take areas facilitate the recovery of key ecological processes like coral recruitment

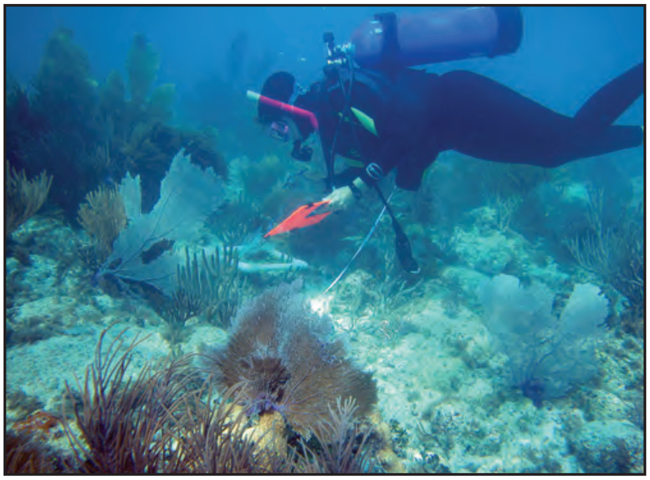

Figure 2. Valerie Paul conducting benthic community surveys in shallow, low-relief, hard-bottom habitat typical of the sites we surveyed in Dry Tortugas National Park. Photo by Raphael Ritson-Williams, Smithsonian.

Figure 3. The threatened staghorn coral (*Acropora cervicornis)* on substrata mainly occupied by weedy brown algae in the genus *Dictyota.* Photo by Raphael Ritson-Williams, Smithsonian.

Table 1. Variables measured during in-situ surveys in Dry Tortugas National Park, October 16 – 20, 2007. Means, standard errors (SE), and p values of two-tailed two-sample t-tests are reported for variables comparing sites within the RNA and NCZ. The sites within the NCZ are still within the national park boundary where there are limited restrictions on resource use, including a ban on spear fishing.

	RNA (n=9)		NCZ (n=9)		T-test
	Mean	SE	Mean	SE	P value
Rugosity	1.33	0.04	1.29	0.03	0.49
No. of coral species	14.1	0.9	12.2	1.0	0.19
No. of gorgonian taxa	13.3	1.0	14.9	0.8	0.23
Diadema antillarum (no. m^{-2})	0.18	0.05	0.16	0.06	0.79
Acanthurids (no. $cylinder^{-1}$)	4.4	0.85	2.4	0.72	0.09
Acanthurid biomass (g $cylinder^{-1}$)	151	34	143	85	[1]0.93
Scarids (no. $cylinder^{-1}$)	14.4	3.2	13.9	2.9	0.91
Scarid biomass (g $cylinder^{-1}$)	418	105	283	152	0.48
Stegastes spp. (no. m^{-2})	0.66	0.04	0.7	0.13	[1]0.74
Game fish (no. $cylinder^{-1}$)	5.3	1.6	5.2	1.9	0.96
Crustose coralline algae (% cover)	33.9	4.7	24.8	2.9	0.12
Total calcified macroalgae (% cover)	9.0	1.1	9.0	0.44	[1]1.00
Total fleshy macroalgae (% cover)	32.9	3.8	34.3	2.6	0.80
Halimeda tuna (% cover)	6.2	1.0	6.8	0.5	[1]0.59
Dictyota spp. (% cover)	25.1	3.0	23.0	3.6	0.66
Encrusting invertebrates[2] (% cover)	3.6	1.0	5.5	1.2	0.26

[1] T-test assuming unequal variance using Satterthwait's method as reported by Statistix© 9 software.
[2] "Encrusting invertebrates" includes only *Briareum asbestinum*, *Erythropodium caribaeorum*, and *Palythoa caribaeorum*.

and herbivory (Hughes et al. 2007). If enforcement of the new RNA management regime persists, DRTO presents a unique case study of no-take area efficacy with minimal underlying problems of land-based pollution present in the adjacent inhabited Florida Keys. Recent studies have shown that the calcification (growth) rate of at least one species of coral is 30% faster in DRTO compared to three other sites throughout the Florida Keys (Kuffner, unpublished data). Nonetheless, it is important that realistic expectations are set for the RNA with regards to benthic community change. To achieve this, we need to appreciate regional and global-scale trends in coral mortality, as well as recognize the impacts of localized disturbances such as hurricanes and cold events. Changes in the resource illustrating the efficacy of the RNA in meeting the goal of restoring benthic communities are thus expected to be subtle and slow to occur.

Acknowledgements

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Literature Cited

Beaver, C., Brooke, S., Callahan, M., Wade, S., Johnson, D., Kupfner, S., and Kidney, J. 2005. Long-term monitoring of selected coral reef sites at the Dry Tortugas National Park. Fish and Wildlife Research Institute, St. Petersburg, Florida.

Bellwood, D.R., Hughes, T.P., Folke, C., and Nystrom, M. 2004. Confronting the coral reef crisis. *Nature* 429:827–833.

Bohnsack, J.A. and Bannerot, S.P. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. National Oceanic and Atmospheric Administration Technical Report 41.

Brandt, M.E., Zurcher, N., Acosta, A., Ault, J.S., Bohnsack, J.A., Feeley, M.W., Harper, D.E., Hunt, J.H., Kellison, T., McClellan, D.B., Patterson, M.E., and Smith, S.G. 2009. A cooperative multi-agency reef fish monitoring protocol for the Florida Keys coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR–2009/150. National Park Service, Fort Collins, Colorado.

Davis, G.E. 1982. A century of natural change in coral distribution at the Dry Tortugas: A comparison of reef maps from 1881 and 1976. *Bulletin of Marine Science* 32:608–623.

Franklin, E.C., Ault, J.S., Smith, S.G., Luo, J., Meester, G.A., Diaz, G.A., Chiappone, M., Swanson, D.W., Miller, S.L., and Bohnsack, J.A. 2003. Benthic habitat mapping in the Tortugas region, Florida. *Marine Geodesy* 26:19–34.

Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L.J., Moltschaniwskyj, N., Pratchett, M.S., Steneck, R.S., and Willis, B. 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology* 17:360–365.

Kuffner, I.B., Paul, V.J., Ritson-Williams, R., Hickey, T.D., and Walters, L.J. 2009. Reef communities in the Dry Tortugas (Florida, USA): Baseline surveys for the new no-take area. Proceedings of the 11th International Coral Reef Symposium: 311–315.

Kuffner, I.B., Walters, L.J., Becerro, M.A., Paul, V.J., Ritson-Williams, R., and Beach, K.S. 2006. Inhibition of coral recruitment by macroalgae and cyanobacteria. *Marine Ecology Progress Series* 323:107–117.

Mumby, P.J., Dahlgren, C.P., Harborne, A.R., Kappel, C.V., Micheli, F., Brumbaugh, D.R., Holmes, K.E., Mendes, J.M., Broad, K., Sanchirico, J.N., Buch, K., Box, S., Stoffle, R.W., and Gill, A.B. 2006. Fishing, trophic cascades, and the process of grazing on coral reefs. *Science* 311:98–101.

Paul, V.J., Kuffner, I.B., Walters, L.J., Ritson-Williams, R., Beach, K.S., and Becerro, M.A. 2011. Chemically mediated interactions between macroalgae *Dictyota* spp. and multiple life-history stages of the coral *Porites astreoides*. *Marine Ecology Progress Series* 426:161–170.

Shinn, E.A., Hudson, J.H., Halley, R.B., and Lidz, B. 1977. Topographic control and accumulation rate of some Holocene coral reefs: South Florida and Dry Tortugas. Proceedings of the 3rd International Coral Reef Symposium 2:1–7.

RNA Performance Topic 4

Chapter 9: Eight years of coral reef community monitoring: Results from inside and outside the Dry Tortugas National Park Research Natural Area

Investigators

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Project Description

The South Florida/Caribbean Network (SFCN) of the National Park Service (NPS) Inventory and Monitoring Program is monitoring coral reef communities within Dry Tortugas National Park (DRTO) to evaluate trends in cover of key benthic community indicators from selected coral reef sites both inside and outside the Research Natural Area (RNA). This monitoring addresses the need identified in Performance Topic 4 to evaluate the effects of RNA implementation on marine benthic biological communities.

We began monitoring during 2004 at Bird Key Reef (study site termed "Bird Key"; area = 19,765m^2), adding an adjacent site in 2005 ("Bird Key North"; 25,642m^2) (Fig. 1). The Bird Key Reef sites are situated within a 2-km long, high-relief spur-and-groove habitat. These sites were selected for management interest in human activities in and around Fort Jefferson, and for comparison with historical monitoring results. Each site consists of 20 permanent, randomly selected 10-m transects that are monitored with a high-definition video camera. Percent cover by benthic groups/categories is quantified by visual identification of 10 random dots placed on 30–35 non-overlapping video images (per transect). Benthic categories

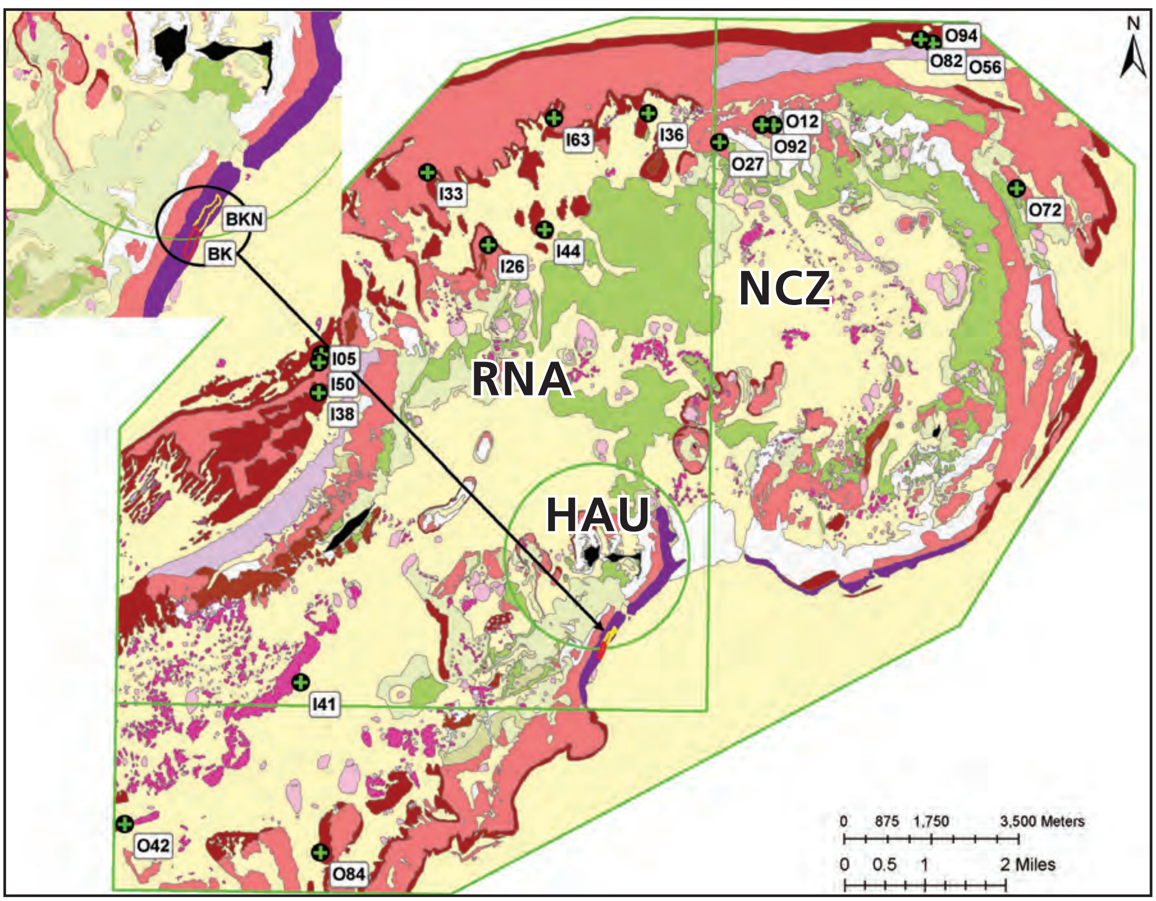

Figure 1. The 2010 Dry Tortugas National Park benthic habitat map showing habitat classifications and location of coral monitoring sites at Bird Key (BK), Bird Key North (BKN), nine sites (labeled with "I" prefix) inside the Research Natural Area (RNA) and nine sites (labeled with "O" prefix) inside the Natural Cultural Zone (NCZ). Refer to Table 1 for the habitat legend.

include living coral by species, macroalgae, turf algae, crustose coralline algae, octocorals, and sponges. Additional field data are collected on coral disease, abundance of long-spined sea urchins (an important algal grazer), stony coral species diversity, rugosity, and reef-depth water temperature. The Bird Key sites straddle the Historic Adaptive Use Zone (HAU) boundary (see map on inside front cover), where 12 of the 40 combined transects fall within the RNA and 28 in the HAU, which may allow a future analysis of boundary effects.

We expanded benthic monitoring in 2008 to include additional randomly selected sites that increased the spatial scale of benthic sampling in DRTO. More than 150 hard-bottom habitat sites were evaluated (2–20 m depth range), which led to 18 sites (termed "extensive" sites; 9 inside the RNA and 9 inside the Natural Cultural Zone (NCZ)) that met the criteria of having >5% stony coral cover (see site locations in Fig. 1). Each site consists of four 10-m video transects and the same data are collected as described at the Bird Key sites. Monitoring of all sites by SFCN staff has continued annually.

In 2007, we entered into a cooperative agreement with the Florida Fish and Wildlife Conservation Commission (FWC) to produce a benthic habitat map for the coral reef ecosystems of DRTO. An initial benthic habitat map was completed in 2008 by the contractor, Avineon, Inc. Acquisition of new higher resolution side scan sonar data and 2,054 field data points from multiple sources (SFCN, National Oceanic and Atmospheric Administration, and University of Miami) allowed SFCN to correct classification deficiencies in the 2008 map and improve the detail level of the line work to produce the 2010 DRTO benthic habitat map (Fig. 1, Table 1; Waara et al. 2011).

Table 1. The 2010 Dry Tortugas National Park benthic habitat map classifications with corresponding color scheme and the areas (in hectares) inside the Research Natural Area (RNA) and the Natural Cultural Zone (NCZ) along with the area totals for Dry Tortugas National Park.

Map Classification	Color	RNA (ha)	NCZ (ha)	DRTO Total (ha)
Aggregate Patch Reefs		326.08	306.97	633.06
Continuous Submerged Rooted Vegetation (SRV)		1,242.18	1,025.6	2,267.78
Discontinuous SRV		672.16	783.9	1,456.06
High Relief Spur and Groove		21.54	134.06	155.59
Individual Patch Reefs		200.78	324.82	525.6
Land		23.18	16.19	39.37
Low Relief Spur and Groove		249.84	167.91	417.75
Patchy Coral or Rock in Unconsolidated Sediment		200.79	812.94	1,013.73
Pavement		170.85	36.61	207.46
Reef Rubble		47.3	80.85	128.15
Reef Terrace (high profile)		1,226.84	655.91	1,882.75
Remnant (low profile)		1,879.03	2,389.03	4,268.05
Unconsolidated Sediment		5,738.22	7,495.31	13,233.53

Results

Bird Key Reef: Monitoring from 2004 through 2011 indicated a significant decrease in stony coral cover at the Bird Key site (13.2% to 10.6%; $p<0.0001$). This decrease primarily occurred from 2004 through 2007 and then appeared to stabilize. Bird Key North, initiated in 2005, did not show a significant overall trend (Fig. 2). Octocoral cover (such as sea fans, sea plumes, etc.) showed a significant 1-year decline at both Bird Key Reef sites from an average of 20.0% in 2005 to 8.9% cover in 2006 ($p<0.0001$) followed by an increase through 2011. This trend is likely the result of four hurricanes passing over DRTO during the extremely active hurricane season of 2005.

Extensive sites: Results of annual monitoring at the 18 extensive sites showed that stony coral cover had no significant trends at these sites during 2008–11. Two sites located within the RNA in Loggerhead Forest (105, 150), had exceptionally high stony coral cover (105 : 4-year mean = 31.0% [Standard Error (SE)=0.5]; 150: 4-year mean = 20.1% [SE=1.3]). This finding is notable because in June and July of 2008, SFCN staff observed an outbreak of the coral disease white plague in DRTO, much of it located in the Loggerhead Forest area. This outbreak was investigated again in July 2008 by a team of coral disease specialists from the U.S. Coral Disease and Health Consortium and George Mason University. Loggerhead Forest sites (105, 150) were resurveyed and tissue samples were collected (results pending) but by the time of the resurvey, the outbreak had subsided. Cover by macroalgae varied throughout the study and was inversely related to the turf algae category. Macroalgal cover was ephemeral; when present, cover of turf algae and other substrate categories (sand, for example) decreased as they were replaced or became covered by macroalgae.

Temperature: Analyses of reef-depth water temperature data indicated that benthic communities in DRTO were subject to large variations in water temperature, both seasonally and episodically. Daily average temperatures in the summer regularly exceeded the theoretical 30.5°C bleaching threshold; however, NPS staff stationed at the park did not report widespread coral bleaching, possibly indicating that the bleaching threshold at DRTO may be higher. Daily average temperatures during the winters of 2009, 2010, and 2011 fell below 19.5°C (Fig. 3), with 2009 and 2011 temperatures even lower than those experienced in DRTO during Florida's deadly cold-water event in 2010 (Lirman et al. 2011). Cold-water events also were recorded in the summers of 2009, 2010 and 2011, when temperatures at several monitoring sites (primarily Loggerhead Forest) rapidly dropped 4–8°C in a matter of days, remaining well below temperatures recorded at other DRTO locations for days to weeks. Although these cold temperatures were above the 16°C minimum temperature stress threshold, they demonstrate that benthic communities are exposed to wide fluctuations in temperature, at times exceeding 10°C.

Benthic Habitat Map: We conducted an accuracy assessment of the 2008 Avineon, Inc. DRTO benthic habitat map and found the overall classification accuracy to be acceptable (83.2%; lower 90% Confidence Interval (CI)=79.8%). However, upon closer evaluation, the soft-bottom habitat classifications displayed a relatively high level of accuracy (89.4%; lower 90% CI=85.2%), whereas the hard-bottom habitat classifications were below an acceptable level (75.2%; lower 90% CI=69.1%). All unknown areas (10,444 ha) in the 2008 map were identified, and the line work for the hard-bottom areas

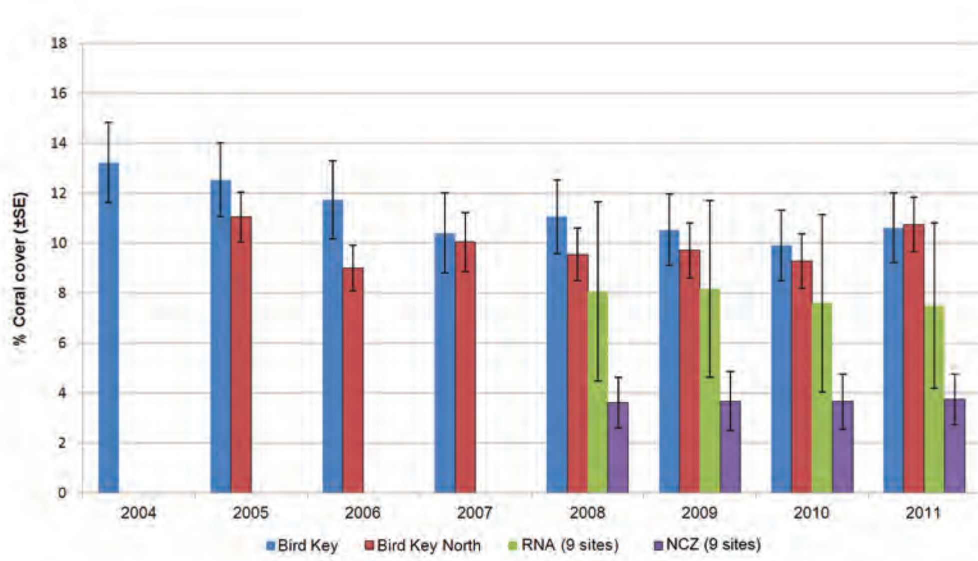

Figure 2. Trends in average percent cover of stony corals at coral monitoring sites grouped into Bird Key, Bird Key North, inside the Research Natural Area (RNA), and the Natural Cultural Zone (NCZ) strata.

was fine-tuned in the 2010 DRTO benthic habitat map (Waara et al. 2011). The overall accuracy assessment of the redrawn 2010 DRTO benthic habitat map was 89.7% (lower 90% CI=86.0%). The accuracy of hard-bottom habitats improved to 88.0% (lower 90% CI=83.4%). The 2010 map consists of 13 mapping classes and 1,709 polygons totaling an area of 26,229 ha. A map layer also was developed to identify areas that have a higher potential for fish and benthic biodiversity. In addition, a final bathymetry layer for the park was created by merging the 2004 Light Detection and Ranging (LiDAR) data and newly acquired side scan sonar bathymetry data. To facilitate visualization of underwater sites, a hyperlink tool was developed that displays photos and videos together with field data when a point is selected in ArcGIS.

Performance Measure Evaluation

The SFCN benthic monitoring program at DRTO was developed, in part, to address the need identified in RNA Performance Topic 4. The program will continue to be a useful tool to evaluate the effectiveness of the RNA in the years to come.

Bird Key Reef: Although trends observed at this site are not necessarily representative of park-wide DRTO trends, SFCN monitoring conducted at this site can be evaluated within a valuable historical context. In 1975, coral cover on this site, measured at 11 transects with a line transect method, ranged from 17.9% to 63.9% (mean: 42.3% [SE=4.3]; Jaap et al. 1989). Additionally, monitoring conducted by the FWC at 12 stations in DRTO (including 4 at Bird Key Reef) during 1999–2008 reported a significant decrease in coral cover ($p<0.001$; Ruzicka et al. 2009). Thus, although methods differ, we are concerned that the current decrease in coral cover during 2004–2011 may be part of a longer downward trend at Bird Key Reef. The observations of very large toppled coral boulders and distinct patches of coral mortality suggest that hurricanes and coral diseases are the likely causes of these dramatic declines in coral cover. Given this context, monitoring of benthic communities is important not only for determining effects of the RNA on this aspect of the ecosystem, but also for correctly interpreting results of other performance measures that could be tied to benthic community health, such as fish abundance and size structure (RNA Performance Topic 1).

Extensive Sites: The development of a DRTO GIS-based benthic habitat map has facilitated management-based sample designs in benthic monitoring. In 2008, we installed four benthic monitoring transects at nine randomly selected sites inside the RNA and NCZ with the purpose of tracking changes in the benthic community. Despite the white plague disease outbreak in June 2008, no appreciable coral loss was subsequently observed (Brandt et al. in review). Results of video monitoring during 2008–2011 showed no change in stony coral cover at the nine RNA sites (2011 mean cover: 7.5% [SE=3.3]) or the nine NCZ sites (2011 mean cover 3.8% [SE=1.0]). Although mean stony coral cover in the RNA appears higher than outside, this was driven by the exceptional coral cover at the two previously mentioned sites located within the high profile reef terrace in the northwestern part of the RNA (Loggerhead Forest). This area has relatively high coral species richness and high rugosity, and may contain the highest remaining living stony coral cover within DRTO. During the study period, stony coral species richness remained relatively constant at sites in the RNA and NCZ, with higher diversity at sites in the RNA, again primarily reflecting the high diversity of coral spe-

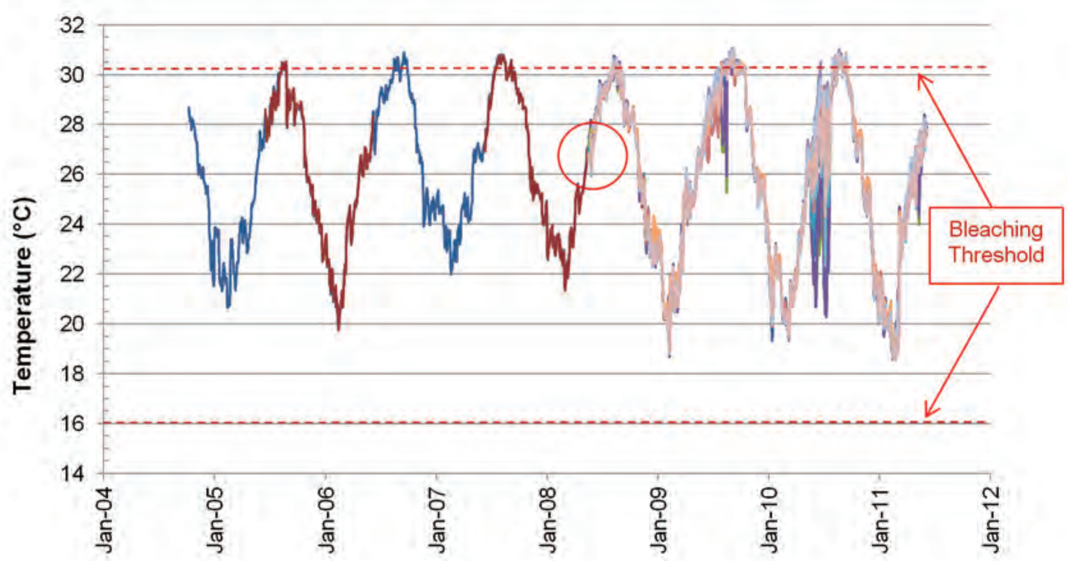

Figure 3. Water temperature measured at coral monitoring sites in Dry Tortugas National Park, 2004–2011. Prior to the introduction of 18 extensive monitoring sites in 2008 (indicated by red circle), temperature was recorded only at Bird Key (blue) and Bird Key North (red). Cold-water stress threshold of 16°C and bleaching threshold of 30.5°C are shown.

cies in Loggerhead Forest. Cover by sponges, octocorals, macroalgae, and turf algae was not significantly different between the two management zones, with macroalgae being the most abundant benthic community group.

Benthic Habitat Map: The greater accuracy and detail of the 2010 DRTO benthic habitat map as well as the new bathymetry layer should facilitate both monitoring and management planning. As an example, the proportions of different habitats can be shown for the management zones. Soft-bottom habitats (such as unconsolidated sediment, continuous or discontinuous submerged rooted vegetation, or reef rubble) comprise 65.8% of the area in the RNA and 71.7% in the NCZ. In both management zones, remnant reef (low profile) is the dominant hard-bottom component, followed by reef terrace (high profile). However, there is more than twice the amount of reef terrace inside the RNA than inside the NCZ. Patch reefs are common features in both strata, comprising 12.9% of the hard bottom in the RNA and 15.7% in the NCZ; while the area of individual and aggregate patch reefs are nearly equal in the NCZ (324.8 ha vs. 306.9 ha, respectively), there are fewer individual patch reefs in the RNA (200.8-ha vs. 326.1-ha aggregate patch). Spur-and-groove reefs are moderately abundant hard-bottom features in DRTO. In the RNA, the majority are low relief (249.8 ha low relief vs. 21.5 ha high relief); distribution is more equal in the NCZ (167.9 ha low vs. 134.1 ha high).

The additional habitat delineated in the 2010 map includes areas with potential for high coral cover, diversity, and rugosity, primarily in the northeastern and southwestern sections of DRTO (for example, low- and high-relief spur and groove, and reef terrace). We are currently considering revising our extensive-site study design to include these areas in the survey domain. Monitoring for status and trends in the benthic community, specifically coral cover, requires a well-designed monitoring program. Declines in coral cover can occur rapidly (such as from hurricane effects or disease outbreaks) or be prolonged (for example, from climate change). Given the very slow rate of coral growth, quantifying increases in coral cover takes many years if not decades. We are structuring our monitoring program to capture declines and increases in coral cover and growth.

Monitoring of coral cover and other benthic communities is important not only for determining effects of the RNA on the ecosystem, but also for correctly interpreting results of other performance measures that could be tied to benthic community health, such as fish abundance and size structure. Photo by the South Florida/Caribbean Inventory and Monitoring Network, NPS.

Literature Cited

Brandt, M.E., Ruttenberg, B.I., Waara, R., Miller, J., Witcher, B., Estep, A.J., and Patterson, M.. In review. Dynamics of an acute coral disease outbreak associated with the macroalgae *Dictyota* spp. in Dry Tortugas National Park, Florida, U.S.A. *Bulletin of Marine Science*.

Jaap, W.C., Lyons, W.G., Dustan, P., and Halas, J.C. 1989. Stony coral (Scleractinia and Milleporina) community structure at Bird Key Reef, Ft. Jefferson National Monument, Dry Tortugas, Florida. Florida Marine Research Publication. No. 46. Florida Marine Research Institute, St. Petersburg, Florida.

Lirman, D., Schopmeyer, S., Manzello, D., Gramer, L.J., Precht, W.F., Muller-Karger, F., Banks, K., Barnes, B., Bartels, E., Bourque, A., Byrne, J., Donahue, S., Duquesnel, J., Fisher, L., Gilliam, D., Hendee, J., Johnson, M., Maxwell, K., McDevitt, E., Monty, J., Rueda, D., Ruzicka, R., and Thanner, S. 2011. Severe 2010 cold-water event caused unprecedented mortality to corals of the Florida reef tract and reversed previous survivorship patterns. *Public Library of Science One* 6(8):1–10.

Ruzicka, R., Semon, K., Colella, M., Brinkluis, V., Kidney, J., Morrison, J., Macaulay, K., Porter, J., Meyers, M., Christman, M., and Colee, J. 2009. Coral Reef Evaluation and Monitoring Project: 2009 Annual Report. Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute, Funded by US EPA and NOAA, USEPA Grant award X7–97468002–8, 110 pages.

Waara, R.J., Patterson, J.M., Atkinson, A.J., and Estep, A.J. 2011. Development and policy applications of the 2010 benthic habitat map for DRTO. Natural Resource Technical Report NPS/SFCN/NRTR–2011/474. NPS, Fort Collins, Colorado.

RNA Performance Topic 4

Chapter 10: Evaluation of submerged cultural resource conditions within Dry Tortugas National Park

Investigators

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Project Description

The National Park Service (NPS), including staff from Dry Tortugas National Park (DRTO) and the Submerged Resources Center (SRC), with additional assistance and support from Biscayne National Park staff, conducted condition assessments on the known submerged archeological sites throughout DRTO from July 2009 to July 2011.

Goals of the project were to reconcile the existing archeological site database with accurate site location information and current conditions, and to develop a monitoring plan to prioritize future assessment work in the park. Condition assessments were completed of all known sites that had been recorded over decades but were not monitored. This project has provided a baseline from which sites within the Research Natural Area (RNA), established inside the park in 2007, can be compared to sites outside of the RNA to evaluate the effectiveness of the management strategy for the protection of submerged cultural resources. As a part of the ongoing fieldwork, a supplemental goal is the discovery of previously unknown sites.

The condition assessment information collected is tracked in the Archeological Sites Management Information System (ASMIS) database, which is an NPS-wide repository of archeological data. Use of this standardized database to collect a consistent basic dataset across researchers and research designs allows for monitoring of basic site data as well as long-term condition trends within the park and in comparison to

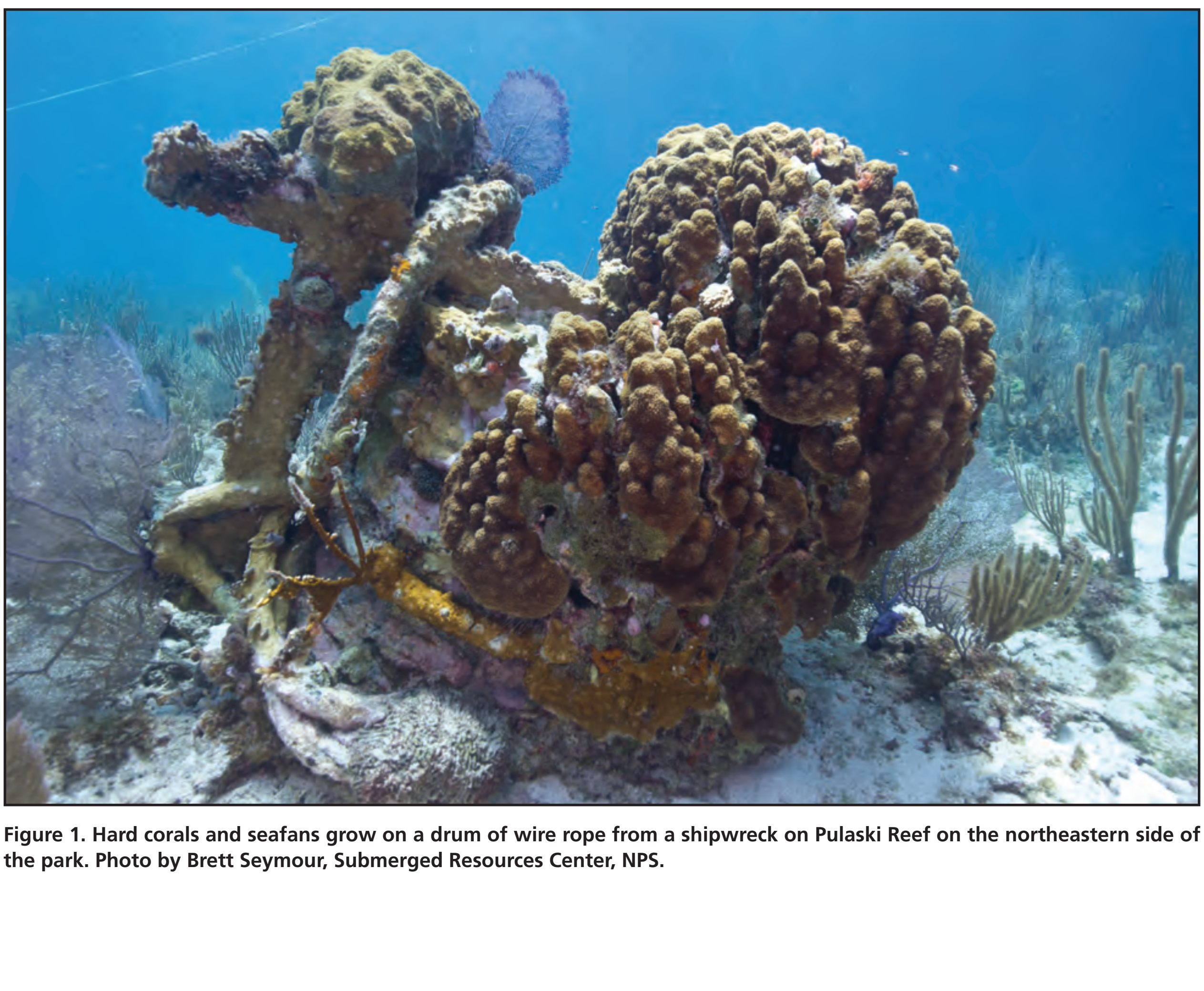

Figure 1. Hard corals and seafans grow on a drum of wire rope from a shipwreck on Pulaski Reef on the northeastern side of the park. Photo by Brett Seymour, Submerged Resources Center, NPS.

other units of the national park system. Because submerged cultural resources often provide good substrate for thriving benthic communities, protection of cultural resources in the park also serves to enhance natural resources (Fig. 1).

The methodology of a condition assessment of a submerged archeological site consists of a review of known information about the site, including initial site documentation, photographs, maps, and previous condition assessments, and includes visiting the site and noting any difference since the last visit (Fig. 2). If new discoveries have been made or if significant change has occurred, new measurements are taken and added to the site map. Qualitative data, such as observed impacts or threats, also are interpreted and documented. Together, these observations are expressed as a condition designation of good/fair/poor/destroyed/not relocated/unknown in the ASMIS database (National Park Service 2007). All known sites at DRTO have been determined to be in good or fair condition. As defined by ASMIS, a good site is defined as:

> "The site, at the first condition assessment or during the time interval since its last condition assessment, shows no evidence of noticeable deterioration by natural forces and/or human activities. The site is considered currently stable and its present archaeological values are not threatened. No adjustments to the currently prescribed site treatments are required in the near future to maintain the site's present condition."

A fair designation is:

> "The site, at the first condition assessment or during the time interval since its last condition assessment, shows evidence of deterioration by natural forces and/or human activities. If the identified impacts continue without the appropriate corrective treatment, the site will degrade to a poor condition and the site's data potential for historical or scientific research will be lowered."

According to NPS policy, sites that have been designated in fair condition require that corrective action take place to either stabilize or improve the condition of the site. Treatment of a site found in fair condition may include increased monitoring, archeological data recovery, site closure, or other management action. Monitoring may include regular site visitations by trained archeologists or increased law enforcement patrols in the area. Archeological data recovery would include the creation or update of a site plan, and/or intensive still and video imaging, or recovery of sensitive artifacts.

Results

The SRC spent a substantial amount of time during the early 1990s locating, mapping, and interpreting DRTO submerged cultural resources. This work resulted in site maps for 11 shipwreck sites and hundreds of individual photographs and vid-

Figure 2. National Park Service diver John Spade records information about a cultural resource near Garden Key, Dry Tortugas National Park. Photo by Brett Seymour, Submerged Resources Center, NPS.

eo images (Murphy 1993). An additional site was mapped in July of 2010. Together these site documentations serve as strong baseline data to track changes to submerged cultural resources in subsequent years.

Along with the work that was conducted from 2009 through 2011, a supplemental goal was met in the development of the capability of park staff to conduct condition assessments of submerged archeological sites. In 2011, seven submerged archeological sites were assessed by park staff. Six of the sites assessed were determined to be in good condition. One site, the Cement Barrel Site, was assessed to be in fair condition.

The Cement Barrel Site, located on South Loggerhead Reef, has maintained a fair condition since its assessment in July of 2009, despite its continuous impact by dynamic natural forces. Further monitoring of the site, as well as the completion of an updated site map from information collected during the 2009 field season, will aid researchers in the understanding of the forces that are affecting this site.

When conducting ongoing condition assessments, remote sensing targets identified from survey efforts in the early 1990s by the SRC were investigated when time allowed. The investigation of these targets resulted in the addition of 15 previously unrecorded sites. With condition assessments completed in 2011, the NPS will now develop a monitoring and management plan in 2012.

Performance Measure Evaluation

This chapter documents the classification of submerged archeological site condition assessments as a performance measure for Performance Topic 4, to evaluate the effects of RNA implementation on marine benthic biological communities. Cultural resources of DRTO support important natural resources. Whether intentional or inadvertent, human disturbance to submerged cultural resources threatens both the integrity of the historic resource and the marine benthic biological communities that they support. The first 5 years of the RNA at DRTO revealed that of the 50 submerged cultural resources surveyed in the park, both inside and outside of the RNA, 49 of them were determined to be in good condition, and 1 in fair condition. This consistent baseline will provide an outstanding opportunity to compare long-term effects of the RNA through monitoring these resources.

The buoyed Windjammer site on South Loggerhead Key is a prime example of a site that should be studied to determine the effects of RNA implementation. On August 21, 2011, the site was assessed and it was documented that the ship's structure continues to serve as substrate for coral, which appears to be growing well. Such observations present the opportunity for collaborative studies with biologists to study the health and size of coral communities associated with submerged cultural resources. An example of a suitable control site is the East Key Construction Wreck. This site is outside the RNA, is visited, and has not been buoyed. The site is also marked on marine charts and park literature, revealing its location and attracting visitation.

In addition, submerged cultural resources in DRTO are desirable habitat for invasive lionfish (*Pterois volitans)*. Collaborative studies regarding impacts of lionfish on cultural resources, as well as the potential impacts of lionfish eradication activities on cultural resources, also are recommended.

Ideally, performance goals for cultural resources should have their own topic in the RNA Science Plan. This topic should be developed by the NPS in collaboration with the Florida Bureau of Archeological Research, Florida Department of State.

Literature Cited

Murphy, L.E., editor. 1993. Dry Tortugas National Park: Submerged Cultural Resources Assessment. Submerged Resources Center Professional Report No. 13. National Park Service, Santa Fe, New Mexico.

National Park Service. 2007. Data Dictionary: Archeological Information Management System 3.01. Department of the Interior, Washington, DC.

NPS archeologist Andres Diaz inspects the propeller of the Bird Key Wreck, Dry Tortugas National Park. Photo by Brett Seymour, Submerged Resources Center, NPS.

RNA Performance Topic 5

Chapter 11: Larval Transport Modeling to Assess the Reproductive Potential of Reef Fish Spawning in the Tortugas Region

Investigators

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Project Description

The goal of this study was to assess the reproductive potential of exploited reef fish species by evaluating the expected physical transport and fate of fish eggs and larvae spawned in the Tortugas region to the adjacent waters of the south Florida coral reef ecosystem (Performance Topic 5). Species in the snapper-grouper complex utilize a mosaic of cross-shelf habitats and oceanographic features over their life spans (Lindeman et al. 2000; Ault et al. 2005). Most adults spawn on the barrier reefs, where they sometimes form large spawning aggregations (Domeier and Colin 1997). Eggs and developing larvae are transported from spawning sites along the barrier reef tract by a combination of water currents and unique animal behaviors. Eventually they settle as young juveniles in a variety of in-shore benthic habitats (Lee et al. 1994; Ault et al. 1999). Some of the most important nursery habitats are located in near-shore areas (Lindeman et al. 2000; Ault et al. 2001). The Tortugas region, in particular, contains numerous known spawning aggregation sites for reef fishes (Schmidt et al. 1999; Chapter 4, this volume). The Dry Tortugas also is where the Loop Current in the southeastern Gulf of Mexico merges with the Florida Current and then flows parallel to the barrier reef through the Straits of Florida toward Miami. These factors indicate that the Tortugas region may be an important source of newborn fish that replenish reef fish populations in the Florida Keys.

This project was designed to complement concurrent intensive field studies in the Tortugas region: (1) fishery-independent surveys providing abundance metrics of reef fishes, including juveniles and spawning adults (Chapters 1 and 2, this volume); and (2) acoustic tagging providing information on adult fish movements and spawning migrations (Chapters 3 and 4, this volume). Our research utilized a physical oceanographic model known as the Hybrid Miami Isopycnal Coordinate Ocean Model (HYCOM) and high-performance computational resources, along with detailed demographic information on spawning and larval life history characteristics of key snapper and grouper reef fish species. We developed a computer interface to link the HYCOM model (Kourafalou et al. 2009) with a particle flux model to simulate larval transport. The model domain was the northern Caribbean Sea, Gulf of Mexico, and southeastern United States with a grid spacing of 4 km. The model utilized meteorological and oceanographic data that allowed "real time" simulations of transport. HYCOM model year 2008 was used for the simulations. Biological information, including the timing and duration of spawning and larval phase duration, was compiled for principal snapper and grouper species.

A factorial experimental design for the simulation analyses was developed for three principal factors. The first factor was Spawning Season, defined as either winter (February 1 release date) or summer (July 15 release date). The second factor was Spawning Location, which was either Riley's Hump (located inside Tortugas South Ecological Reserve) or Sherwood Forest (located inside Tortugas North Ecological Reserve). The third factor was the Depth Layer (m), which we defined as either 0 m (surface), 10 m, 20 m, or 30 m deep. The timing of egg and larval release corresponded to the general spawning seasons for groupers (winter) and snappers (summer). The two spawning locations were chosen on the basis of numerous field observations of spawning aggregations of various reef-associated and coastal pelagic species, including mutton snapper (Riley's Hump; Chapter 3, this volume) and permit (Sherwood Forest; Ault et al. 2006 and Fig. 1). Depth layers represent the range of conditions for the buoyancy of larval particles: positively buoyant (surface, 0 m depth), neutrally buoyant at the substrate depth of the spawning location (30 m), and neutrally buoyant at two intermediate spawning depths (10 m and 20 m).

A separate simulation experiment was conducted for each combination of season, location, and depth. Each experiment entailed continuous tracking in time and space of thousands of passive larval particles for 30 days, approximating the larval duration of snappers and groupers. The principal metric was the percentage of released particles that could have potentially settled in a coastal environment on the *i*th day from the start of the simulation. Results are provided for days from start i=10, 15, 20, 25, and 30. Particles located in environments with substrate depths shallower than 50 m on the *i*th day were considered to be successful with respect to potential settlement.

Figure 1. Spawning aggregations of permit (*Trachinotus falcatus*) observed during fishery-independent visual surveys in the Dry Tortugas (west Tortugas Bank) in (A) June 2010 (photo by J. Luo, UM RSMAS) and (B) June 2004 (photo by D. Bryan, UM RSMAS). In (B), note the dark patches behind the dorsal fins that are only present during spawning for this species.

Results

Lagrangian simulation results of larval drift patterns by season, location, and depth are summarized in Table 1. The highest percent settlement generally occurred for particles spawned at the surface depth layer irrespective of season and location. Relatively higher settlement also occurred for particles spawned at the substrate depth layer of 30 m for most seasons and locations, with the lowest percent settlement for particles spawned at depth layers of 10 m and 20 m. A general seasonal trend in settlement success also was observed, with winter having higher overall percent settlement compared to summer, irrespective of spawning location.

Spatial patterns of larval drift were evaluated with respect to three general areas presented in Figure 2. Area 1 is defined as southern Florida, including the Florida Keys and greater Tortugas region; Area 2 is the West Florida Shelf; and Area 3 is the east coast of Florida and the South Atlantic Bight (Fig. 2). The location of larval particles (day 25 at depth layer 0 m) for two spawning locations and two seasons is shown in Figure 3. Our results suggest that larval spatial distribution patterns may be dependent on the spawning season (Table 1). During winter, successful settlement was concentrated in south Florida (Area 1) and the east coast of Florida (Area 3), with very little settlement occurring on the West Florida Shelf (Area 2). In contrast, during summer, settlement was concentrated in south Florida and the West Florida Shelf, with very little settlement occurring along the east coast of Florida.

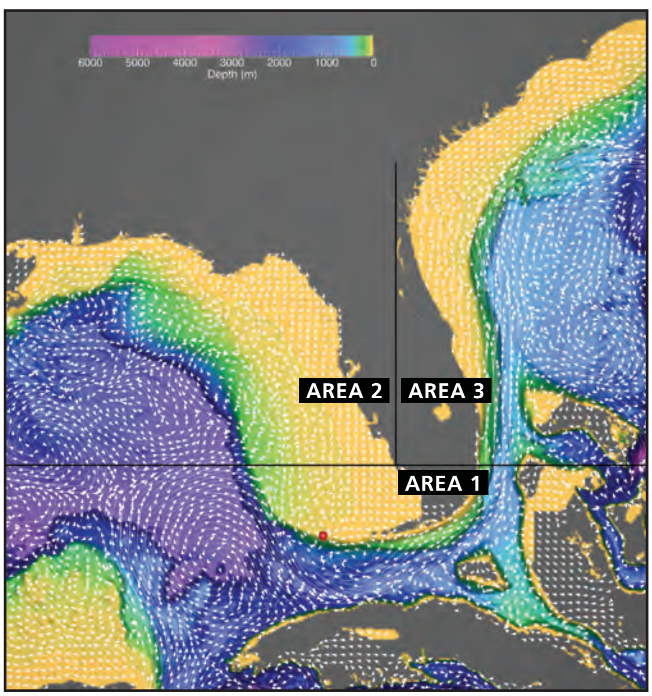

Figure 2. Three general areas denoting the spatial distribution of passive larval particles: Area 1 (southern Florida), Area 2 (West Florida Shelf), and Area 3 (east coast of Florida and South Atlantic Bight).

Performance Measure Evaluation

We developed a general south Florida marine ecosystems model that can be used to simulate the larval drift of any marine organism for any start time and period of duration. Our simulation results indicate that spawning in the Tortugas region is likely supplying newborn recruits to reef fish populations throughout southern Florida, including the Dry Tortugas and Florida Keys reef tract, coastal bays along the West Florida Shelf, and along the east coast of Florida north of Miami. Our results also suggest that the potential success of larval settlement and the ensuing spatial distribution may be dependent upon the spawning season.

While the Tortugas region is a known spawning area for reef fishes (Schmidt et al. 1999), it also appears to be an important spawning area for other economically important coastal marine species. The permit (*Trachinotus falcatus*) is a prized gamefish most often associated with inshore shallow-water sport fisheries for bonefish and tarpon, some of the most economically important species in Florida (Ault 2008). Large aggregations of permit (hundreds to thousands of fishes; Fig. 1A) possessing "spawning marks" (Fig. 1B; Graham and Castellanos 2005) have been encountered during each visual survey conducted on Tortugas Bank since 2004 (Ault et al. 2006; Smith et al. 2011; Chapter 1, this volume). These surveys occurred during the spring-summer spawning season for permit in Florida (Crabtree et al. 2002). Early juvenile permit have been captured in netting studies in shallow, inshore habitats ranging from Charlotte Harbor on the west coast of Florida, through the Florida Keys in the south, to the coastal areas north of Miami (Adams et al. 2006; Snodgrass and Harndon 2009). This corresponds very well to the spatial distribution of larval settlement predicted by the simulation model for the summer spawning months (Fig. 3).

Our analyses of reproductive potential via larval transport modeling, combined with results from fishery-independent surveys (Chapters 1 and 2, this volume) and tagging studies (Chapters 3 and 4, this volume), shed some light on the ecological importance of DRTO and the Tortugas region in sustaining the productivity of coral reef and coastal marine fisheries in southern Florida. DRTO harbors from one-third to one-half of the adult spawners of principal snapper-grouper species in the south Florida coral reef ecosystem (Chapter 1, this volume), and provides a home base for migrations to and from spawning aggregation sites such as Riley's Hump (Chapter 3, this volume). Eggs spawned at these locations have a wide geographic distribution in terms of potential larval settlement (Fig. 3). The relatively small geographic area of DRTO appears to contain some of the most valuable marine habitat in the southern Florida ecosystem. The area provides newborn recruits to populations of principal coral reef and coastal marine fishery species in the Tortugas region (Chapter 2, this volume), the Florida Keys reef tract, the West Florida shelf, and along the east coast of Florida north of Miami.

Table 1. Percent potential settlement of passive larval particles at simulation day 10, 15, 20, 25, and 30 by spawning location, date, and depth. Areas are described in Figure 2.

				Percent Potential Settlement			
Spawning Location	Spawning Date	Depth (m)	Days from start	Overall	Area 1	Area 2	Area 3
Riley's Hump	Feb 1	0	10	93.9	53.6	0.0	40.3
Riley's Hump	Feb 1	0	15	90.5	48.9	0.0	41.6
Riley's Hump	Feb 1	0	20	91.5	47.5	0.0	44.0
Riley's Hump	Feb 1	0	25	90.8	46.5	0.0	44.3
Riley's Hump	Feb 1	0	30	92.3	46.0	0.0	46.3
Riley's Hump	Feb 1	30	10	24.6	19.1	0.0	5.5
Riley's Hump	Feb 1	30	15	35.1	19.2	0.0	15.9
Riley's Hump	Feb 1	30	20	30.4	19.2	0.0	11.2
Riley's Hump	Feb 1	30	25	37.7	19.2	0.0	18.5
Riley's Hump	Feb 1	30	30	46.7	19.2	0.0	27.5
Riley's Hump	Jul 15	0	10	21.5	21.5	0.0	0.0
Riley's Hump	Jul 15	0	15	26.9	25.2	1.7	0.0
Riley's Hump	Jul 15	0	20	33.0	30.4	2.6	0.0
Riley's Hump	Jul 15	0	25	41.3	28.8	10.6	1.9
Riley's Hump	Jul 15	0	30	42.3	35.0	3.2	4.1
Riley's Hump	Jul 15	30	10	26.5	26.5	0.0	0.0
Riley's Hump	Jul 15	30	15	29.0	28.6	0.0	0.4
Riley's Hump	Jul 15	30	20	35.1	32.7	0.1	2.3
Riley's Hump	Jul 15	30	25	40.3	34.1	0.7	5.5
Riley's Hump	Jul 15	30	30	44.1	34.8	0.9	8.4
Sherwood Forest	Feb 1	0	10	88.8	88.8	0.0	0.0
Sherwood Forest	Feb 1	0	15	88.9	88.0	0.0	0.9
Sherwood Forest	Feb 1	0	20	80.0	75.5	0.0	4.5
Sherwood Forest	Feb 1	0	25	83.2	72.4	0.0	10.8
Sherwood Forest	Feb 1	0	30	80.8	71.3	0.0	9.5
Sherwood Forest	Feb 1	30	10	60.6	60.6	0.0	0.0
Sherwood Forest	Feb 1	30	15	64.5	63.0	0.0	1.5
Sherwood Forest	Feb 1	30	20	65.7	63.8	0.0	1.9
Sherwood Forest	Feb 1	30	25	72.8	63.9	0.0	8.9
Sherwood Forest	Feb 1	30	30	79.5	63.9	0.0	15.6
Sherwood Forest	Jul 15	0	10	27.6	27.5	0.1	0.0
Sherwood Forest	Jul 15	0	15	38.0	25.0	13.0	0.0
Sherwood Forest	Jul 15	0	20	43.4	27.6	15.8	0.0
Sherwood Forest	Jul 15	0	25	54.5	29.9	23.2	1.4
Sherwood Forest	Jul 15	0	30	55.0	36.1	16.5	2.4
Sherwood Forest	Jul 15	30	10	34.0	34.0	0.0	0.0
Sherwood Forest	Jul 15	30	15	35.2	35.2	0.0	0.0
Sherwood Forest	Jul 15	30	20	37.6	37.5	0.1	0.0
Sherwood Forest	Jul 15	30	25	42.6	39.9	0.5	2.2
Sherwood Forest	Jul 15	30	30	49.1	40.0	1.5	7.6

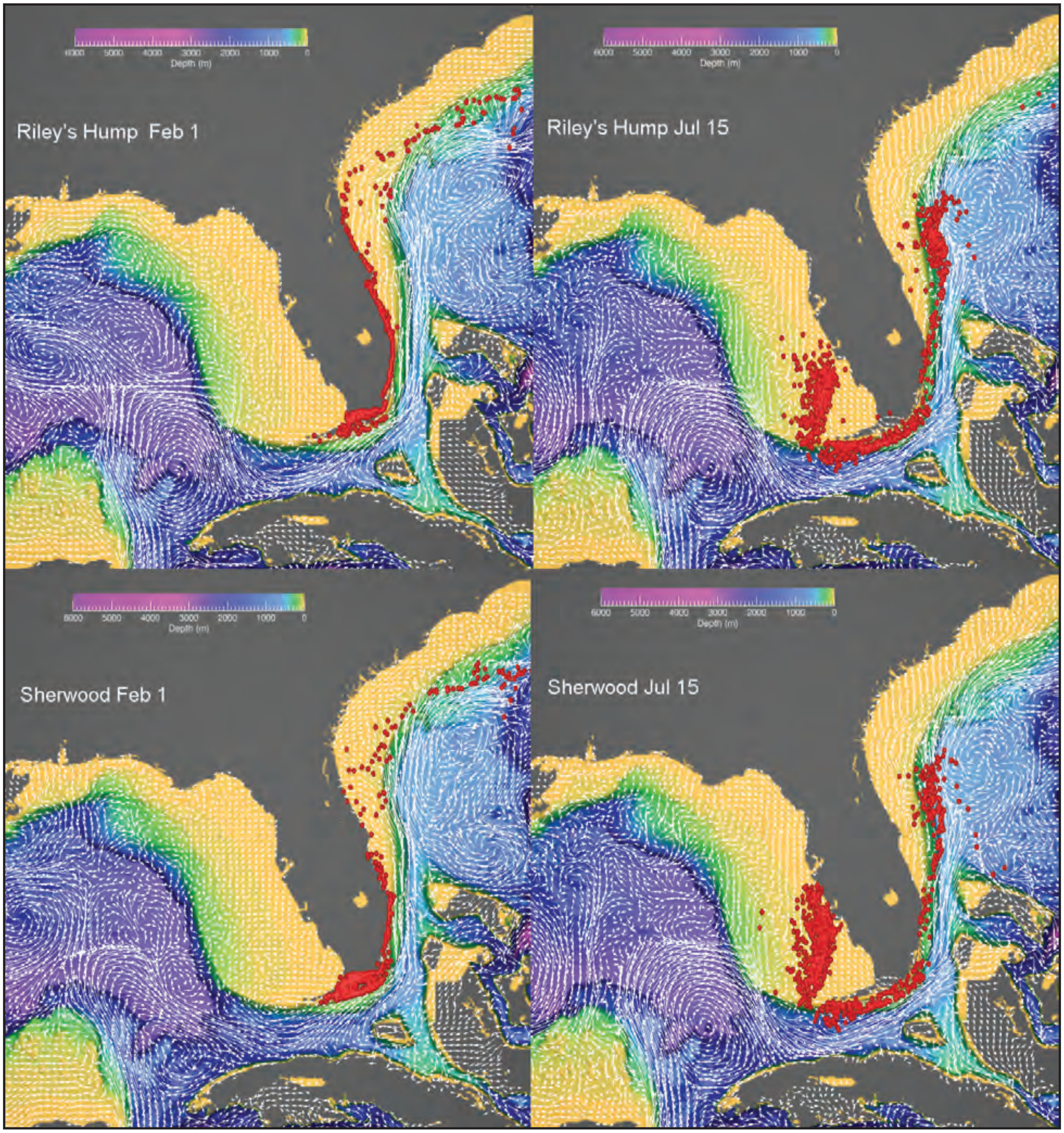

Figure 3. Spatial distribution of larval particles (red) at 25 days after spawning at the surface depth layer simulated with HYCOM model current vectors (model year 2008) for two spawning seasons and locations.

Literature Cited

Adams, A.J., Wolfe, R.K., Kellison, G.T., and Victor, B.C. 2006. Patterns of juvenile habitat use and seasonality by permit, *Trachinotus falcatus*. *Environmental Biology of Fishes* 75:209–217.

Ault, J.S., ed. 2008. Biology and management of the world tarpon and bonefish fisheries. CRC Press/Taylor and Francis Group, Boca Raton, Florida.

Ault, J.S., Bohnsack, J.A., Smith, S.G., Luo, J. 2005. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. *Bulletin of Marine Science* 76:595–622.

Ault, J.S., Diaz, G.A., Smith, S.G., Luo, J., and Serafy, J.E. 1999. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. *North American Journal of Fisheries Management* 19:696–712.

Ault, J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Harper, D.E., and McClellan, D.B. 2006. Building sustainable fisheries in the Florida coral reef ecosystem: Positive signs in the Dry Tortugas. *Bulletin of Marine Science* 78:633–654.

Ault, J.S., Smith, S.G., Meester, G.A., Luo, J., and Bohnsack, J.A. 2001. Site characterization for Biscayne National Park: Assessment of fisheries and habitats. NOAA Technical Memorandum NMFS–SEFSC–468.

Crabtree, R.E., Hood, P.B., and Snodgrass, D. 2002. Age, growth, and reproduction of permit (*Trachinotus falcatus*). *Fishery Bulletin* 100:26–34.

Domeier, M.L. and Colin, P.L. 1997. Tropical reef fish spawning aggregations: Defined and reviewed. *Bulletin of Marine Science* 60:698–726.

Graham, R.T. and Castellanos, D.W. 2005. Courtship and spawning behaviors of Carangid species in Belize. *Fishery Bulletin* 103:426–432.

Kourafalou V.H., Peng, G., Kang., H., Hogan, P.J., Smedstad, O.M., and Weisberg, R.H. 2009. Evaluation of Global Ocean Data Assimilation Experiment products on south Florida nested simulations with the Hybrid Coordinate Ocean Model. *Ocean Dynamics* 59:47–66.

Lee, T.N., Clarke, M.E., Williams, E., Szmant, A.F., and Berger, T. 1994. Evolution of the Tortugas Gyre and its influence on recruitment in the Florida Keys. *Bulletin of Marine Science* 54:621–646.

Lindeman, K.C., Pugliese, R., Waugh, G.T., and Ault, J.S. 2000. Developmental pathways within a multispecies reef fishery: Management applications for essential fish habitats and protected areas. *Bulletin of Marine Science* 66:929–956.

Schmidt, T.W., Ault, J.S. and Bohnsack, J.A. 1999. Site characterization for the Dry Tortugas region: Fisheries and essential habitats. Report to the Florida Keys National Marine Sanctuary and National Park Service. Homestead, Florida.

Smith, S.G., Ault, J.S., Bohnsack, J.A., Harper, D.E., Luo, J., and McClellan, D.B. 2011. Multispecies survey design for assessing reef fish stocks, spatially explicit management performance, and ecosystem condition. *Fisheries Research* 109:25–41.

Snodgrass, D. and Harndon, C.W. 2009. Composition of fish species on ocean-side beach habitats in the Florida Keys. *Florida Scientist* 72:153–170.

RNA Performance Topic 6

Chapter 12: A survey of visitor demographics, attitudes, perceptions, and experiences at Dry Tortugas National Park

Investigators

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Project Description

This project will survey visitor demographics, attitudes, perceptions, and experiences of park resources among visitors who enjoy recreational boating, fishing, SCUBA diving, snorkeling, and other activities within Dry Tortugas National Park (DRTO), with emphasis on understanding the use of the Research Natural Area (RNA) (Performance Topic 6). In addition, surveys will include a geospatial assessment of geographic locations of these uses. The RNA science plan identifies the need to understand the behaviors and actions of park visitors, which have significant impacts on resources and the success of the RNA. Better understanding of the human dimension will greatly inform adaptive management efforts by the National Park Service (NPS) and the Florida Fish and Wildlife Conservation Commission (FWC) to evaluate the RNA and other park management zones. By characterizing visitors' ecological knowledge and perceptions, NPS and FWC will improve education and outreach messages, encourage compliance with fishing and anchoring regulations, and enable visitors to protect the resources they enjoy. The survey questions will help elucidate heavily utilized areas within the park as well as highlight possible areas of user-group conflicts. Finally, NPS also seeks to measure visitor satisfaction and enjoyment after RNA implementation. The project is funded by the NPS service-wide recreational fee program and coordinated by the NPS Ocean and Coastal Resources Branch of the Natural Resource Program Center and DRTO.

Survey data will be collected through visitor contact, plus mail and electronic surveys. Separate surveys will be administered to visitors arriving either by commercial ferry or by private boat. Visitors will be contacted on-site and those agreeing to participate will complete a brief on-site contact sheet. The main survey questionnaire will be sent to these identified individuals within one month of being contacted and will be completed either by mail or electronically.

Results

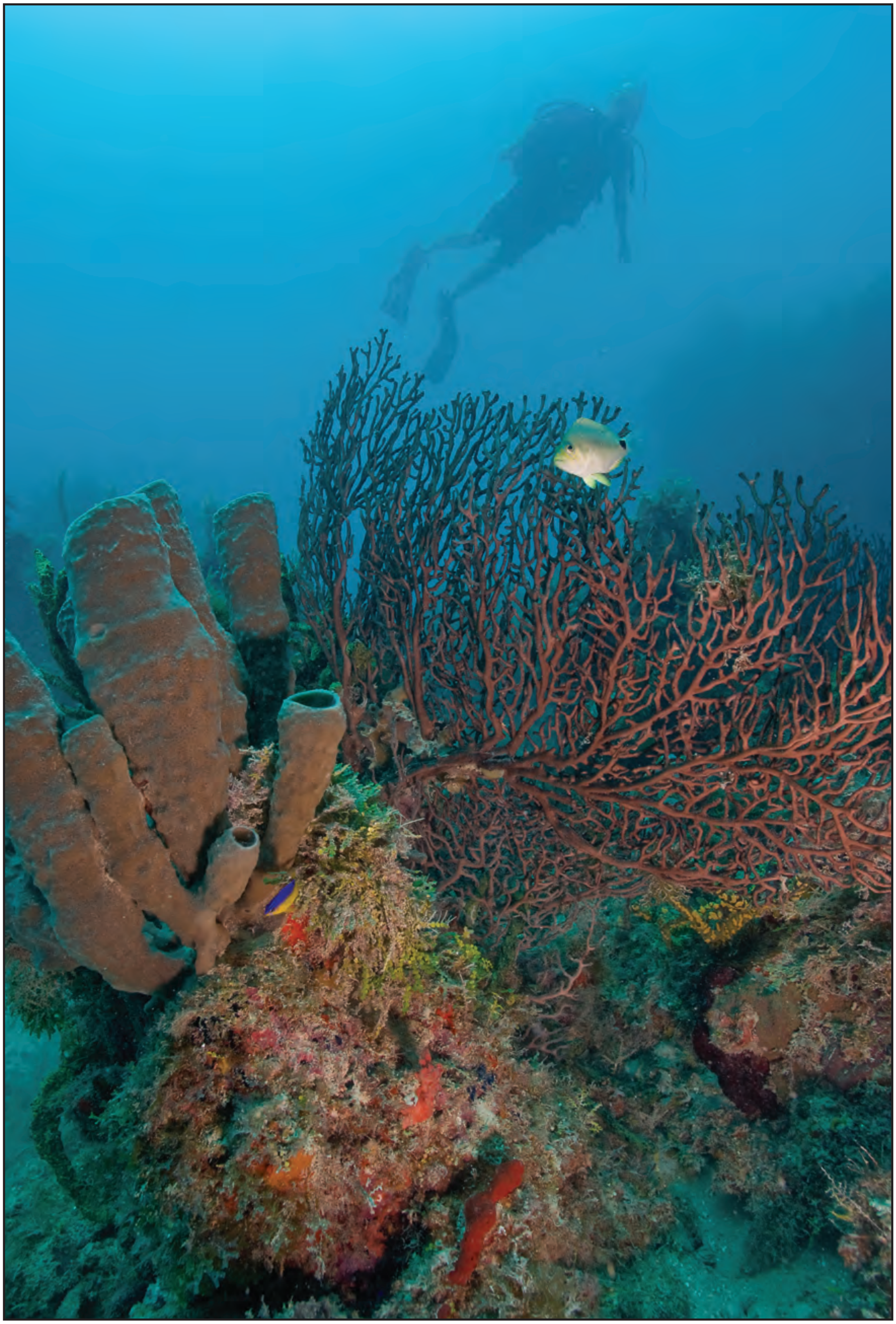
East Carolina University and NPS collaborated to develop the quantitative survey questionnaires and methodology. Development of the two survey questionnaires has been completed. Separate survey questionnaires were designed for ferry passengers and for private boat operators. Prior research drawn from a wide array of social science literature, and discussions with park management, informed the design and format of specific questions.

Regulations under the Paperwork Reduction Act require review by the Office of Management and Budget (OMB) on social science surveys as well as two opportunities for public notice and comment. The initial public notice was published in the Federal Register on May 6, 2009, with only one comment received during the 60-day comment period. The investigator working with NPS staff then submitted justifications and copies of the survey questionnaires as required by OMB. The Department of the Interior and OMB must review these materials before publication of the second and final 30-day opportunity for public notice and comment in the Federal Register and final approval. This process was recently completed and the final justifications and survey questionnaires have been submitted to OMB. Upon approval, the questionnaires will be ready for distribution at the park.

Performance Measure Evaluation

Each survey instrument is unique because of differences in opportunities for visitors arriving by ferry at Garden Key and arriving on private boats with greater access to marine resources. Each has an identical set of core questions followed by questions specific to primary recreational activity and location. The survey questionnaires will provide basic demographic information on the respondents; the frequency and extent to which respondents engage in different types of recreational activities; respondent experience level as anglers, divers, or in other activities; respondent perceptions of the RNA; respondent views on the ecological health of resources and the relative impacts of environmental stressors and recreational activities; respondents' preferred sources of information; and factors such as ecological health and visitor crowding that diminish respondent enjoyment.

Data collection will begin during the spring of 2012 and continue through November 2012. Our team will have a final report completed by October 2013.



This project will survey demographics, attitudes, perceptions, and experiences of park resources among visitors who enjoy recreational boating, fishing, SCUBA diving, snorkeling, and other activities within Dry Tortugas National Park, with emphasis on understanding the use of the Research Natural Area. Photo by Brett Seymour, Submerged Resources Center, NPS.


TORTUGAS NORTH ECOLOGICAL RESERVE
RESEARCH NATURAL AREA
TORTUGAS BANK OPEN USE AREA
TORTUGAS SOUTH ECOLOGICAL RESERVE
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Naples
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Area of Detail
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