PAPER

Integrating Science into the Design of the Tortugas Ecological Reserve

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ABSTRACT

The Tortugas Ecological Reserve, the largest fully protected marine reserve in the U.S.A., was implemented in July 2001 after a successful, three-year collaborative effort. A key facet of this process was the direct involvement of scientists and the acceptance of their information by the various stakeholders collaborating on the reserve's design. This paper describes how scientific information was ultimately influential in the siting and sizing of the reserve. Case studies such as this may benefit those attempting to use science to inform decisions in marine protected area planning.

INTRODUCTION

Marine reserves (called ecological reserves in this paper) are well-defined areas of the ocean fully protected from human disturbance (primarily fishing) for the purpose of biodiversity protection, fisheries enhancement, or protection of some unique feature or artifact (NRC, 2000). They may be independent units or a subset of a larger marine protected area (MPA), an area of the ocean reserved by law or other means to protect part or all of the natural and cultural resources therein (Presidential Executive Order 13158). Marine reserves are increasingly being used around the world as a conservation tool (Gubbay, 1995). However, less than one percent of the world's oceans are protected by marine reserves (Palumbi, 2003). Implementation of marine reserves in the United States has become one of the most contentious environmental issues of the day because of the deeply rooted tradition of treating the oceans as a commons to be exploited with impunity. As an ocean conservation ethic slowly takes hold in the United States and as natural resources become more scarce, acceptance of marine reserves as a legitimate approach to conservation is increasing. However, there are currently few fully protected marine reserves in the U.S.A. that can be used as examples of success, either because they have not been implemented long enough to show positive benefits or they are poorly designed and managed (Jameson et al., 2002).

The Tortugas Ecological Reserve, a fully protected marine reserve that is currently the largest such area in the United States, was recently implemented. The Tortugas Ecological Reserve is part of the Florida Keys National Marine Sanctuary, a multiple-use MPA that uses marine zoning to protect resources while allowing compatible activities. The design and implementation of the Tortugas Ecological Reserve (the reserve) is considered to be a successful example of collaborative decision-making (NRC, 2000). The community-based planning process for the reserve acknowledged the important contributions of the area's users, and in that respect represented a significant departure from government-driven, top-down marine conservation initiatives that are often the norm in developed countries. The inclusion of citizen representatives with an equal voice in the decision-making process was significant. The public involvement aspects of the Tortugas Ecological Reserve process, though critical to its ultimate success, will not be discussed in this paper (see Delaney, 2003).

In addition to unprecedented community involvement, socio-political and economic factors weighed heavily in the outcome of the reserve process, as they do in all resource allocation decisions. Science played a crucial role in balancing short-term economic concerns with potential long-term economic and ecological benefits. Though the integration of scientific data in marine resource planning is not a novel concept (Salm and Clark, 1984, Kenchington and Hudson, 1988, Gubbay, 1995, Mascia, 2001), in the case of the Tortugas Ecological Reserve science significantly influenced the design of the reserve. This paper focuses on the methods used to integrate science into the design process and discusses how various types of data played a critical role in shaping public policy.

BACKGROUND

The Florida Keys form a 356-km island chain located at the southern tip of Florida, in the southeastern United States. The marine environment of the Florida Keys includes mangroves, seagrasses, hardbottom communities, patch reefs, and the third largest bank-barrier coral reef system in the world (Hoffmeister, 1974). Significant degradation of the Keys' marine environment is the result, in part, of dramatic population growth throughout south Florida (USDOC, 1996). Improperly handled wastewater and stormwater contribute to the degradation of nearshore water quality (Kruczynski, 1999), seagrasses and corals are destroyed by boat groundings (Causey et al., 2000), and overfishing of dozens of key species has depleted reef fish biomass and spawning potential (PDT, 1990, Ault et al., 1998). Intensive non-consumptive activities, such as snorkeling and SCUBA diving, also place significant pressures on coral reef resources that are exacerbated by the over three million visitors to the region annually (Leeworthy and Vanasse, 1999).

In an effort to address these many complex threats, to provide comprehensive protection to the region, and to ensure multiple, compatible use of resources, Congress created the Florida Key National Marine Sanctuary (FKNMS or Sanctuary) in 1990 (Florida Keys National Marine Sanctuary and Protection Act, Pub. L. 101-605). The National Oceanic and Atmospheric Administration (NOAA), under the U.S. Department of Commerce, administers this and other National Marine Sanctuaries. The Sanctuary encompasses over 9800 square kilometers (km^2) of coastal and oceanic waters and submerged lands (USDOC, 2000), and is managed under cooperative agreement between the State of Florida and NOAA.

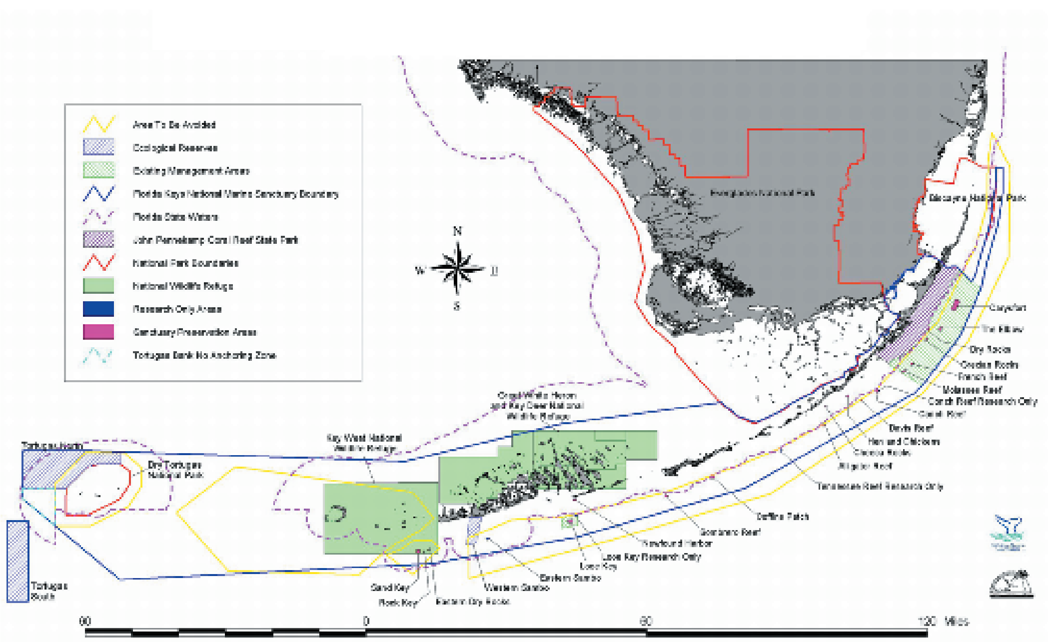
NOAA implemented a comprehensive management plan for the Sanctuary in 1997 that outlined specific marine resource conservation strategies. One of these strategies, marine zoning, is used in the Sanctuary to protect diverse habitats important for maintaining natural resources and ecosystem functions, while allowing compatible activities to continue.

The zoning network established by the Sanctuary was the first of its kind in the U.S.A. (Murray et al., 1999). Five types of zones (Sanctuary Preservation Areas, Research Only Areas, Ecological Reserves, Wildlife Management Areas, and Existing Management Areas) were established and implemented in 1997 (Figure 1). During the draft management plan process (1995) an ecological reserve, one type of fully protected zone, was proposed for the remote Tortugas region of the Sanctuary but was not adopted because of insufficient natural and socioeconomic data and a resulting lack of community acceptance for the proposal. Instead, NOAA committed in the final management plan for the Sanctuary to implement an ecological reserve in the Tortugas region after a thorough review and analysis of the area (USDOC, 1996). To ensure that the unique habitats of the Tortugas were fully protected and to address the myriad of threats in the area, the Florida Keys National Marine Sanctuary initiated the design of the Tortugas Ecological Reserve in 1998. The reserve process was dubbed "Tortugas 2000," and was designed to apply lessons learned and overcome the challenges encountered during the development of the original marine zoning plan for the Sanctuary.

The Design Process

Tortugas 2000 occurred in three phases, beginning in April 1998 and ending in November 2000. Phase I addressed the design of the ecological reserve and culminated in June 1999 with the citizens' Sanctuary Advisory Council (SAC) recommending a preferred boundary for the Tortugas Ecological Reserve

Figure 1. The marine zoning plan for the Florida Keys National Marine Sanctuary. Ecological Reserves, Sanctuary Preservation Areas, and Research Only Areas, labeled below, are fully protected zones (graphic courtesy of Kevin Kirsch/FKNMS).



to NOAA. Phase II (completed by May 2000) incorporated that design into a Draft Supplemental Environmental Impact Statement/Supplemental Management Plan and solicited public comments on the proposal, fulfilling National Environmental Policy Act requirements. During Phase III, NOAA responded to public comments and released a Final Supplemental Environmental Impact Statement/Final Supplemental Management Plan in November 2000. Federal and state rules to implement the reserve were also developed.

Table 1. The Tortugas 2000 Working Group. Research scientists are denoted by a single asterisk and research administrators are denoted with a double asterisk.

Name	Affiliation
Dr. James Bohnsack*	NOAA Fisheries
Dr. Robert Brock**	National Park Service
Mr. John Brownlee	Saltwater Sportsman magazine–recreational fishing
Maj. Bruce Buckson	Florida Marine Patrol
Mr. Billy Causey	Florida Keys National Marine Sanctuary
Dr. Felicia Coleman*	Florida State University and Gulf of Mexico Fishery Management Council
Mr. Ed Conklin	Florida Dept. of Environmental Protection
Mr. Ben Cowie-Haskell	Florida Keys National Marine Sanctuary
Ms. Fran Decker	Citizen
Mr. Don DeMaria	Commercial spearfishermen
Mr. Richard Diaz	Commercial lobster trapper
Dr. Nicholas Funicelli**	U.S. Geological Survey
Mr. Peter Gladding	Commercial handliner
Mr. Andy Griffiths	Commercial charter fishing
Ms. Deborah Harrison	World Wildlife Fund
Mr. David Holtz	The Ocean Conservancy
Mr. Anthony Iarocci	Monroe County Commercial Fishermen, Inc.
Dr. Joseph Kimmel**	NOAA Fisheries
Mr. Don Kincaid	Citizen- recreational diving
Mr. Peter Moffitt	South Atlantic Fishery Management Council
Dr. Erich Mueller*	Mote Marine Laboratory
Dr. Russell Nelson**	Florida Fish and Wildlife Conservation Commission
Mr. Gene Proulx	NOAA Office of Law Enforcement
Mr. Alex Stone	ReefKeeper International- recreational diving
BMC Bob Thomas	U.S. Coast Guard

At the core of Tortugas 2000 was a 25-member working group that included Sanctuary Advisory Council members, stakeholders, and government agency representatives (Table 1). The Working Group ensured that all constituents and agencies with an interest in or concern over activities in the Tortugas were present during the design phase. A key agency partner was the National Park Service due to their trusteeship of the Dry Tortugas National Park, a 259-km^2 park that is surrounded by, but jurisdictionally separate from, the Sanctuary. The Park Service's involvement in the design of the reserve was critical because of the important shallow water coral reef resources found within the park and the connectivity of those resources with surrounding Sanctuary waters (Figure 1).

The Tortugas 2000 Working Group was charged with reviewing available scientific and socioeconomic information and making a recommendation to NOAA on the size, shape, and placement of the Tortugas Ecological Reserve. A professional facilitator guided the Working Group, which over the course of 13 months met five times to define operating goals, agree to ground rules, develop and weight criteria for the reserve, evaluate draft boundaries, and recommend a preferred boundary (Table 2).

METHODS FOR INTEGRATING SCIENCE INTO THE DESIGN PROCESS

The design of the Tortugas Ecological Reserve was an iterative, dynamic process in which the Working Group began with a foundation of knowledge on the Tortugas region and then learned as a group about various attributes of the region as information became available.

Because of its remoteness, there was not a great deal of widely shared knowledge about the Tortugas among the Florida Keys community when the Working Group first convened in April 1998. Two types of information available to the Working Group and public at that time were traditional knowledge from fishermen and scientific knowledge from the few researchers who had worked in the area. Both types of information were valued equally in the design process and were purposefully incorporated into it.

Working Group

The most critical method by which science was integrated into reserve design was through the inclusion of scientists on the Working Group who were both knowledgeable about the Tortugas region and about marine reserves. Two types of scientists were represented on the Working Group: research scientists who worked in the Tortugas and agency scientists who represented their organization's management authority in the region.

The Working Group was structured such that all members, including scientists, had an equal voice in the decision-making process. The Working Group was the sole deliberative body dedicated to designing the reserve and making a recommendation to the SAC; no other advisory bodies made recommendations on any aspect of the reserve. Integrating scientific and traditional knowledge at the Working Group table encouraged accountability of members to the group and to their constituents.

Information provided to the Working Group

White papers

Three white papers were commissioned by NOAA and the National Park Service at the beginning of the reserve process to provide the Working Group (and, through the Tortugas 2000 website, any other interested parties) with a site characterization for the region, including papers on oceanography (Lee et al., 1999), fish and fisheries (Schmidt et al., 1999), and benthic habitats (Jaap et al., 1998). The site characterization synthesized the best available information on the topic and, in the case of the fisheries section, served as a catalyst for developing a unified spatial information system incorporating several disparate datasets. These papers were invaluable in integrating science into reserve design by definitively clarifying questions from the Working Group and public, making facts and imagery about the region widely accessible, and laying the foundation for an Environmental Impact Statement for the reserve.

Informational forums

The Florida Keys National Marine Sanctuary convened two informational forums, the goals of which were to: (1) present to Working Group members and other attendees the best available scientific information on the ecological and socioeconomic aspects of the area, (2) provide an outlet for community members to share their traditional knowledge and experience in the region, and (3) inform the Working Group about the area's uses. For example, the forums highlighted for the Working Group the importance of the Tortugas as a spawning area for several fish and invertebrate species, the exponential increase in fecundity with growth in fish (PDT, 1990), the importance of the Dry Tortugas as a nesting site for pelagic seabirds, the value of the area to shrimpers and dive charter operators, and the excellent water quality of the region as compared to the rest of the Florida Keys. The Working Group then used the information in developing design criteria.

Table 2. Summary of the Working Group meetings to design the reserve (USDOC, 2000).

Date	Purpose
April 1998 (2 days)	Ecological forum and setting ground rules for group process
June 1998 (1 day)	Socioeconomic forum
February 1999 (2 days)	Criteria development
April 1999 (2 days)	Boundary alternative development
May 1999 (1 day)	Selection of preferred alternative

Additional information

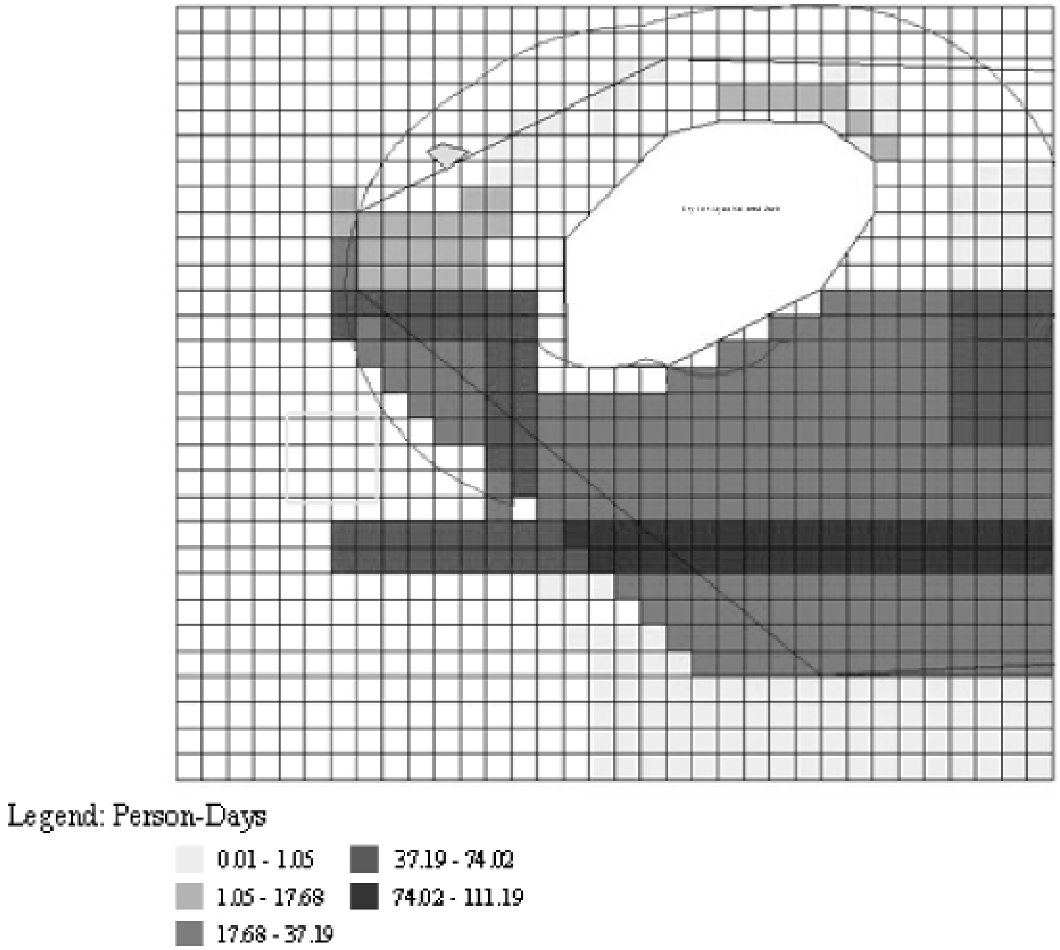
Sanctuary staff also provided each Working Group member with information relevant to reserve design throughout the process. This included peer-reviewed science papers, definition and regulations for an ecological reserve from the FKNMS management plan (USDOC, 1996), color GIS maps, design criteria, newspaper articles on the Tortugas process, and meeting summaries.

Geographic Information Systems

During the design process several types of spatial data from the region were being compiled simultaneously by different investigators. For example, while biologists were collecting fish distribution and benthic habitat data the economists were collecting data on human uses. Geographic Information Systems (GIS) data served a critical role by integrating these datasets into maps of the same scale (Franklin et al., 2001). A uniform framework was established using a spatial grid of approximately one square nautical mile (1 degree latitude by 1 degree longitude). This cell size was chosen because it adequately captured the scale of human activity and ecological phenomena (Figure 2). Digital versions of NOAA nautical charts were used as base layers in GIS maps, displaying the relevant data in a familiar context for fishermen and other Tortugas users.

This framework proved very useful for a number of reasons. First and most importantly, manipulating grid cells or raster data in GIS for drafting boundary scenarios was easy and straightforward as compared to manipulations of polygons or vector data. Secondly, because the grid cell framework was aligned with meridians, the reserve alternatives were also, resulting in straight-edged boundaries that would facilitate compliance with and enforcement of the reserve. Lastly, the one square nautical mile grid cell was a common mapping unit that most Working Group members were familiar with,

Figure 2. Example of a user map showing the location of recreational fishing effort in the Tortugas Ecological Reserve study area . Also depicted is the one-degree latitude by one-degree longitude grid cell framework used as a tool in the design of the reserve (USDOC, 2000).



providing a comfortable frame of reference for quickly judging distances or the spatial extent of a proposal.

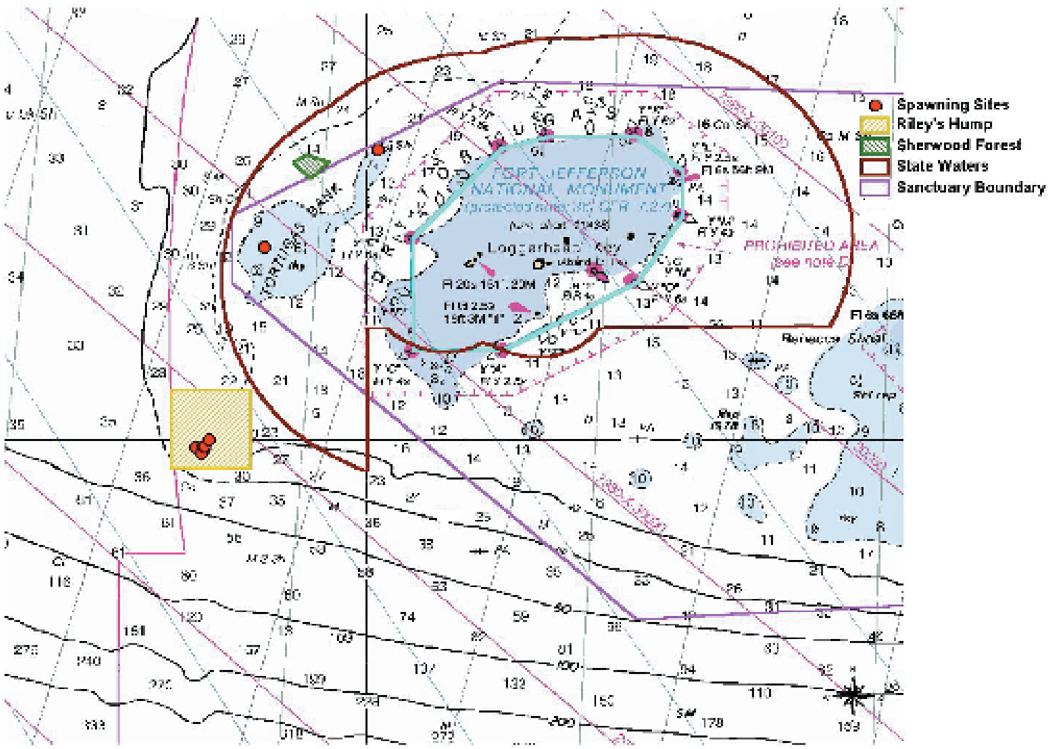
An example of the utility of GIS in this process was the mapping of fish spawning sites. The Tortugas region, particularly Riley's Hump, has long been known to fishermen as a site of several fish spawning aggregations. Some of these sites were disclosed to researchers and subsequently mapped for the first time for use in the Tortugas 2000 process (Figure 3). These sites are further described in the results section of this paper.

RESULTS OF THE SCIENCE-DRIVEN RESERVE DESIGN PROCESS

The final outcome of the Tortugas 2000 process was the implementation of the Tortugas Ecological Reserve in July 2001. The Tortugas Ecological Reserve is located 225 km west of Key West, Florida, at the western terminus of the Florida Keys archipelago and abutting the Dry Tortugas National Park (Figure 1). The reserve is comprised of two sections: Tortugas North at 312 km^2, and Tortugas South at 206 km^2, with a total area of 518 km^2. Tortugas North protects a deepwater (30–50m) coral bank called Tortugas Bank, a portion of which was dubbed Sherwood Forest because of the abundant mushroom-shaped coral heads found there (Figure 4). Tortugas South protects Riley's Hump, a low relief coral bank that serves as a spawning aggregation site for several fish species and some deepwater habitat (50–600m) important to a variety of ecologically and commercially important fishes and invertebrates.

All of the available scientific information on the Tortugas was given to the Working Group and made publicly available through the methods described above. An interesting result of widely sharing scientific data and information among the Working Group members and public was that some of the scientific information proved to be more influential in the reserve

Figure 3. Location of several fish spawning sites in the Tortugas region (denoted by dark gray circles). A NOAA nautical chart forms the base layer for the map, hence the extraneous data depicted (data courtesy of K. Lindeman).



design process than other information. In this context we will use the term cornerstone science to refer to scientific information that is persuasive and therefore readily influences public policy. In developing criteria and objectives for the reserve, the steps of which are described later in this section, Working Group members reiterated what science was most important to their decision-making. The authors additionally received feedback from the Working Group when the information was presented.

Cornerstone science resulting from the reserve process fell into several broad categories, each with varying influence on the ultimate design of the area protected. Following are specific descriptions of cornerstone science used throughout the design process, with an explanation of why each was particularly persuasive in the public debate over creating the reserve.

Oceanographic Information

Satellite-tracked drifters

Dr. Tom Lee of the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences has been studying the Florida Current and related gyres for decades (Lee et al., 1994). One of his primary techniques for doing this is through the monthly deployment of a battery-powered drifter from one of several locations along the Southwest Florida coast. Current-driven movements of each drifter are tracked by satellite for several months, providing a time-series plot of regional circulation patterns. The drifter track data provided a powerful visual aid for demonstrating the oceanographic connectivity of the Tortugas region with not only the Florida Keys, but also with the southwest coast of Florida and the southeast coast of the U.S.A. (Figure 5).

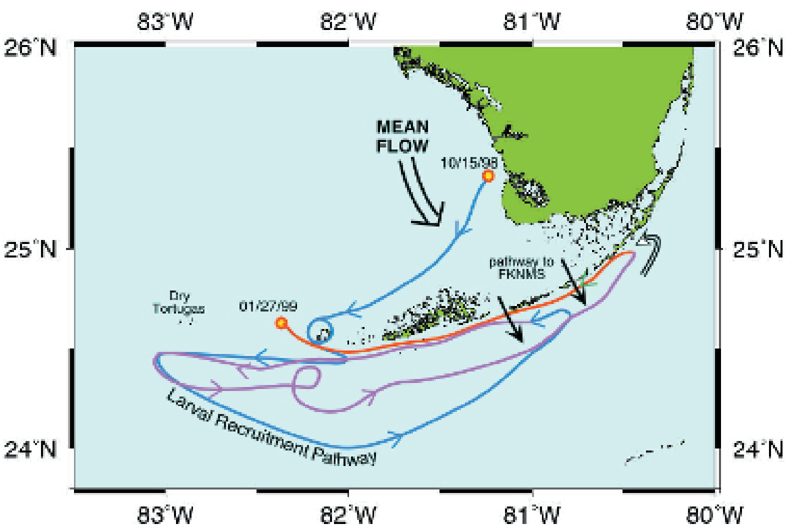
The implication of this connectivity was the potential for advective transport of fish and invertebrate larvae to vast areas downstream and upstream of the Tortugas. It was especially important to demonstrate to Tortugas fishermen the potential for larval transport, as they were faced with the possibility of giving up productive fishing grounds through the creation of the reserve.

Drifter vials

Also reinforcing the Tortugas' potential as a source area for fish larvae was a drift bottle study by Domeier and colleagues, where 1000 small glass vials were released on Riley's Hump during a full moon in May 1999 to coincide with mutton snapper spawning (Domeier, 1999). The vials were weighted slightly to float just below the surface, acting as crude proxies for snapper larvae, and contained instructions

Figure 4. Underwater photograph showing the unique plate-like and mushroom-like coral morphology of Tortugas Bank (USDOC, 2000).

Figure 5. Track showing path of drifter #23113 that was launched in October 1998 along the southwest coast of Florida by the University of Miami. The drifter was entrained by the Tortugas gyre and the coastal countercurrent for three full cycles before running out of battery power in January 1999 (image courtesy of T. Lee/Univ. of Miami).



for the finder on how to report vial recovery. A total of 114 returns enabled the scientists to map the terminal location of the vials, providing a rough picture of larval dispersal potential (Figure 6). The majority of the recoveries were from the middle Florida Keys, 390 km east of the Tortugas, and some recoveries were reported from as far away as 1500 km. The duration of time between deployment and recovery roughly approximated the planktonic larval duration of mutton snapper (~30 days) (Lindeman et al., 2000). This simple study further bolstered evidence that the Tortugas may serve as a source of fish larvae.

Fish Spawning Aggregations

Several species of commercially and recreationally important reef fish aggregate to spawn at specific times of the year in the Florida Keys and Tortugas, particularly snappers and groupers (Lindeman et al., 2000). The locations and timing of these events are well known by some fishermen, who often target the aggregations in order to increase their catch (Lindeman et al., 2000). In some cases, aggregations have been decimated for so long they no longer exist (P. Gladding, pers. comm.). The snapper and grouper spawning aggregations that still occur in the Tortugas are likely due to the area's remoteness and possibly the seasonal fishing restrictions that have existed at Riley's Hump for several species since the mid-1990s. Historically, fishermen have been reluctant to reveal the location and timing of these events. However, after seeing aggregations diminish despite fishing restrictions in the area, several leading fishermen revealed the existence of known sites to scientists in an effort to help protect them (Figure 3). These data reinforced drifter track data, providing a useful image of the reserve's potential to serve as a source of larvae to surrounding regions. These data also revealed that seasonal protection of Riley's Hump was not enough, and that continuous protection with a reserve was needed as several spawning aggregations were still being heavily fished.

Fish Distribution and Abundance

Science showing the consequences of overfishing also influenced public opinion in the reserve design process. Dr. James Bohnsack (NOAA Fisheries), a member of the Working Group, and Dr. Jerry Ault (University of Miami) shared their research on the status of the snapper-grouper complex (73 species managed by the South Atlantic Fishery Management Council) in the Florida Keys. The data showed that the majority of the snapper/grouper complex (13 of 16 grouper species, 7 of 12 snapper species, and 2 of 5 grunt species) were below the 30 percent spawning potential ratio federal standard - a sign of serial overfishing (Ault et al., 1998). During the formulation of the reserve, Ault and Bohnsack conducted fishery-independent diver surveys in the Tortugas to ascertain the status of fish stocks specific to that region. Their results confirmed for the Working Group that stocks were healthier in the Tortugas than in the remaining Florida Keys, but were still in an overfished state (Schmidt et al., 1999).

Benthic Habitat Maps and Photographs

Photographs of benthic habitats, particularly coral banks, were perhaps the most visually influential data presented to the

Working Group. These photographs documented very high coral cover (>30 percent), excellent water clarity (>100'), rare corals (*Antipathes spp.*), and unique coral morphologies (Figure 4). The actual extent of this rich habitat was unknown during the Working Group's deliberations. Subsequently, using benthic habitat data from a variety of sources including side scan sonar and diver surveys (Franklin et al., in press), it became clear that the extent of this deep coral bank habitat was much larger than the one square nautical mile portrayed in early planning maps. These data furthered knowledge that the reserve study area contained fragile coral habitats unique to the Florida Keys.

Socioeconomics

Dr. Vernon Leeworthy, chief economist for the National Marine Sanctuary Program, and his colleagues designed and implemented a socioeconomic survey of all users of the Tortugas study area. Through fishing license databases they identified a population of 110 commercial fishermen who used the Tortugas region as their primary fishing grounds. Leeworthy then contracted two experts already known to the fishermen to conduct the surveys. They were able to obtain confidential data from approximately 95 of the 110 fishermen on the location and quantity of catch by species, fishing costs, and their socioeconomic profile (Leeworthy and Wiley, 2000). Using these data, detailed maps were produced in GIS that showed the location of various uses and the level of use in terms of pounds of catch or person-days of time (as possible maximum values for each cell versus absolute values) (Figure 2).

The data and user maps were accepted by the Working Group and fishermen to be accurate reflections of their activities for the given year. These data and maps were extremely important in the reserve design process because they quantified the potential impact of any given proposal on each user group.

THE INFLUENCE OF SCIENCE ON RESERVE DESIGN CRITERIA AND BOUNDARY SELECTION

Based on the scientific information available to them, the Working Group developed a set of criteria for defining the objectives of the reserve and to aid in the selection of reserve boundaries. Table 3 lists the final criteria with their objectives. Four of the six criteria had ecological objectives that clearly reflected the cornerstone science made available to the Working Group.

The Working Group then weighted the criteria through a consensus exercise. Table 4 shows the resulting three criteria profiles with their assigned weighting. Of interest is that all of the criteria profiles included ecological objectives in their top four criteria, despite being developed by different interests seated at the Working Group table.

Figure 6. Recovery locations of vials released on Riley's Hump in May 1999. These vials served as proxies for mutton snapper larvae (image courtesy of M. Domeier/Pfleger Institute of Environmental Research).

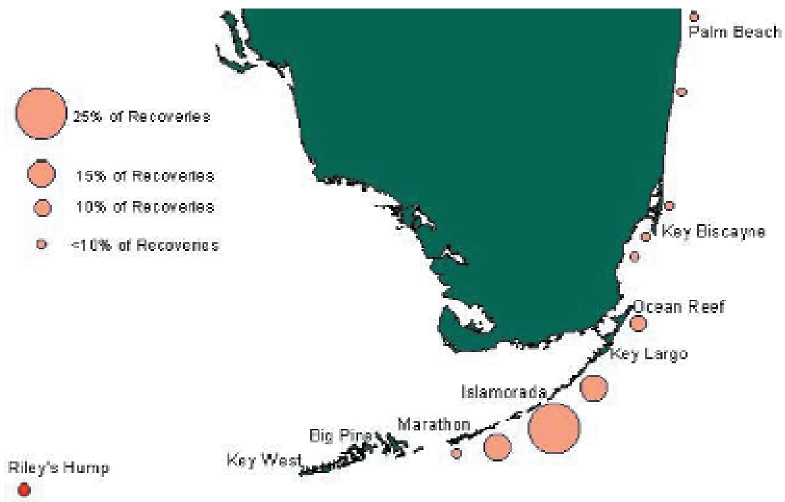


Table 3. Final design criteria developed by the Working Group (USDOC, 2000).

Criterion	Objective
Biodiversity and habitat	Try to choose an area that would contain the greatest level of biological diversity and wider range of contiguous habitats.
Fisheries sustainability	Try to choose an area that would provide the greatest benefit in protecting and enhancing important fish species, especially those that are rare, threatened, or depleted.
- spawning sites	Try to choose an area that would include significant fish spawning aggregation sites.
- full life cycles	Try to choose an area that would encompass all the habitats required to support the full life cycle of commercially and recreationally important fish.
Sufficient size	Try to choose a boundary that would encompass an area that is large enough to meet the criteria listed above and to achieve the potential benefits and goals of an ecological reserve.
Socioeconomic impacts	Try to choose an area and craft recommendations that would serve to minimize adverse socio-economic impacts on established users of resources in the area.
Reference area/monitoring	Try to choose an area that would serve as a reference or control area to facilitate the monitoring of anthropogenic impacts and to evaluate the consequences of establishing the ecological reserve.
Enforcement/compliance	Try to choose a boundary and craft regulations that would facilitate enforcement and encourage compliance.

Table 4. Three criteria weighting profiles developed by the Working Group (USDOC, 2000).

Criteria Weighting Profile "A" **Mid-range Consensus**	**Criteria Weighting Profile "B"** **Less Protective**	**Criteria Weighting Profile "C"** **More Protective**
Biodiversity and Habitat 27%	Fisheries Sustainability 25%	Sufficient Size 50%
Fisheries Sustainability 26%	Socioeconomic Impacts 25%	Fisheries Sustainability 20%
Enforcement & Compliance 17%	Enforcement & Compliance 20%	Biodiversity and Habitat 15%
Sufficient Size 16%	Biodiversity and Habitat 15%	Reference Area and Monitoring 5%
Socioeconomic Impacts 9%	Reference Area and Monitoring 10%	Enforcement & Compliance 5%
Reference Area and Monitoring 5%	Sufficient Size 5%	Socioeconomic Impacts 5%
Total 100%	Total 100%	Total 100%

Table 5. The relative importance of science to various aspects of the reserve design.

Cornerstone science (• specific study)	**Importance for design**	**Importance in influencing public opinion**
Benthic habitats • GIS maps of habitat extent • underwater photographs of coral habitat	Location of coral banks	Beauty and fragility of coral Presence of rare corals and other invertebrates
Fish • fish larvae dispersal • fish spawning aggregations • fish distribution	Location of spawning aggregations	Absence of large fish Potential for future benefits from spillover and larval dispersal
Oceanography • satellite tracked drifters • satellite imagery	Area of greatest advective potential	Connectivity between regions indicating potential for future benefits from spillover and larval dispersal
Socio-economics	Where uses occur	Potential impacts

The three criteria profiles were used to develop a set of boundary alternatives for the reserve. In this step of the design process, Working Group members again revisited the scientific information and traditional knowledge available to them. The Working Group relied heavily on the GIS-based map products, described previously in this paper, to visualize borders and estimate to what extent each alternative met the reserve criteria. Initially twelve boundary alternatives were crafted by the Working Group, with two alternatives then selected as a point of departure for further discussions. These discussions led to the final selection of a compromise alternative that sufficiently addressed all of the criteria and addressed the needs of both the extractive and non-extractive users on the Working Group. The Working Group adopted the compromise alternative by consensus as the recommended preferred alternative for the Tortugas Ecological Reserve, and forwarded this recommendation to the FKNMS for consideration.

Clearly, the criteria the Working Group members chose to design the reserve and, more importantly, the weighting they assigned to those criteria, reflected the quality of scientific and traditional information made available to them during the process. These criteria led to the selection of a final boundary for the reserve that was rooted in the best available data on the Tortugas region, thereby maximizing the potential for successful implementation of the reserve. The Working Group's consensus agreement on a recommended preferred alternative set the stage for the many approvals required from the seven state and federal agencies that would oversee the implementation of differing jurisdictional components of the reserve. Full implementation of the reserve occurred on July 1, 2001.

DISCUSSION AND CONCLUSION

As the architect of the Tortugas 2000 process, it was the Sanctuary's goal to thoroughly integrate science into reserve design to ensure that the various decisions made by Working Group members were based on accurate knowledge. Cornerstone science played two key roles in the reserve process: (1) it influenced where lines were drawn on maps, and (2) it influenced the opinion of the broader public not directly involved in the Working Group deliberations (Table 5). Oceanographic information was extremely beneficial in demonstrating the connectivity between regions and the potential for accrual of downstream benefits in terms of increased fish catches and improved species diversity; however, because of its dynamic nature, it was not particularly helpful in the precise siting of the reserve. Benthic habitat maps were critical for ensuring that draft boundaries captured the extent of the most sensitive coral habitat. Underwater photographs of coral colonies were highly influential in that they demonstrated the beauty, fragility, and uniqueness of the deepwater corals of the region. Data on fish distribution was helpful on a broad scale in identifying the relative importance of the Tortugas region to the entire Florida Keys archipelago. Maps of spawning aggregations were critical to the fishing representatives on the Working Group, as they wanted to ensure that these sites were protected. This data, in conjunction with the map of drifter vial recoveries, also influenced public opinion by demonstrating the potential for dispersal of fish larvae to surrounding fishing grounds. Socioeconomic information proved vital at several levels. First, it debunked rumors about excessive economic costs of the proposed reserve and put those costs in perspective relative to the value of other economic sectors and fisheries. Secondly, the high-resolution data showed exactly where uses were occurring, allowing Working Group members to avoid heavy-use areas when drafting boundaries.

Several valuable lessons were learned as a result of the Tortugas Ecological Reserve process about the importance of integrating science into management decisions. First and foremost, it was essential to begin the design process with a common foundation of knowledge among all decision-makers. Secondly, making the same knowledge available to the local community and the general public enhanced interest in and support for the eventual decisions made about the reserve. Internet posting of technical papers, maps, and other visual data was particularly useful in this regard; however, the more significant vehicle by which the Sanctuary shared scientific and traditional knowledge was through the informational forums that were held at the beginning of the design phase. Given the broad dissemination of scientific information related to reserve design it was important for the data to be easily interpreted and understood by a variety of audiences. GIS maps based on familiar units and scales were extremely helpful for visualizing reserve boundaries and determining how alternatives would meet specific criteria and affect certain users. Lastly, it was important that science experts were seated at the table with other relevant stakeholders from project inception. Scientific data and research results are important to a reserve design process, but should be considered alongside traditional knowledge provided by users of the area. Also, when scientific experts participate directly in the process they are able to answer questions and advise on technical matters as needed. This direct exchange of information serves to build trust and engenders a sense of accountability among the Working Group members and the public.

In the contentious debate over marine reserves, policymakers will increasingly demand that decisions be based on the best available science. The success of the Tortugas Ecological Reserve process demonstrates that science can play a pivotal role in the design of a marine reserve by a multi-stakeholder group.

ACKNOWLEDGEMENTS

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