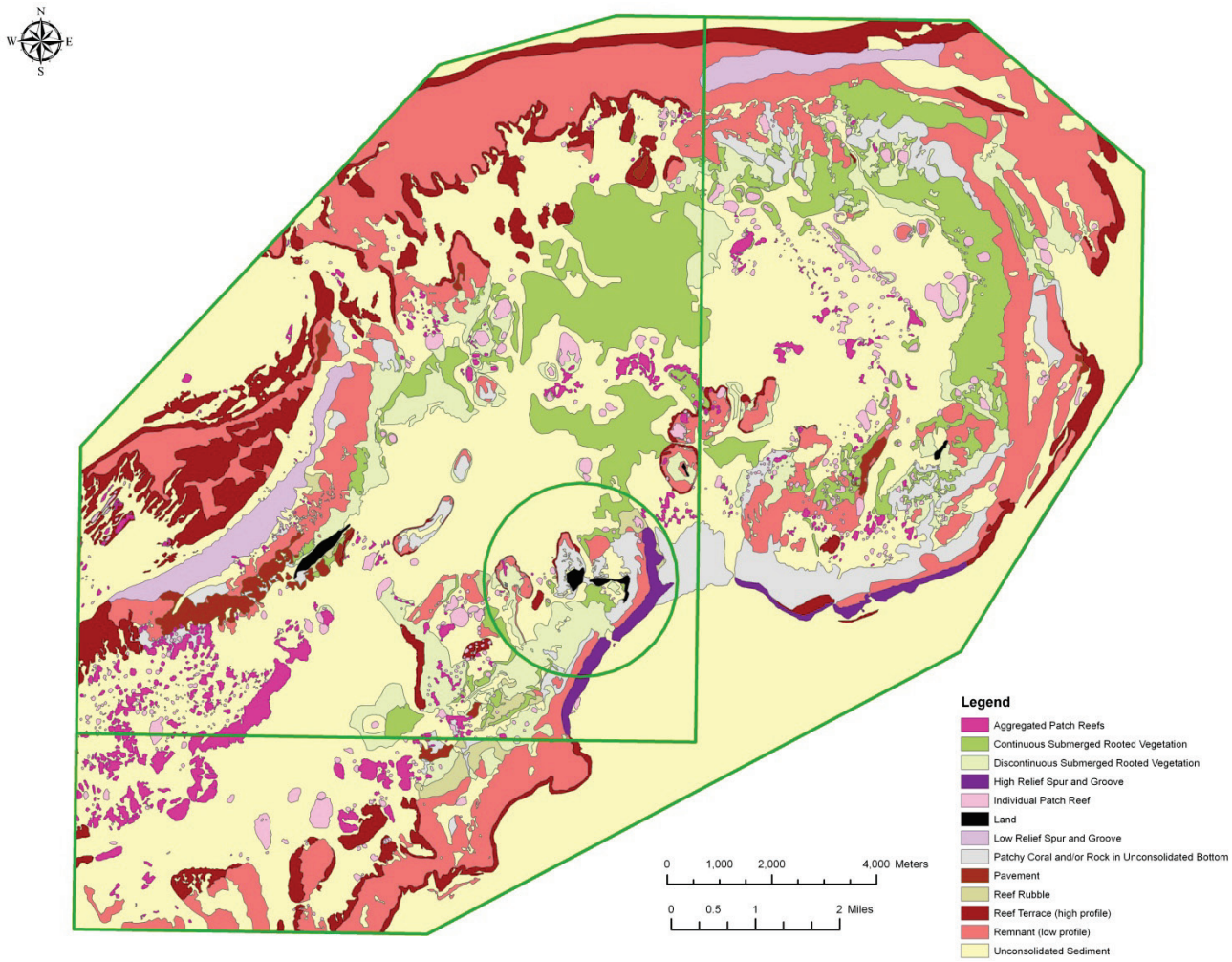
National Park Service
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Natural Resource Stewardship and Science

Development and Policy Applications of the 2010 Benthic Habitat Map for Dry Tortugas National Park

Natural Resource Technical Report NPS/SFCN/NRTR—2011/474



ON THE COVER
The 2010 Benthic Habitat Map for Dry Tortugas National Park.

Development and Policy Applications of the 2010 Benthic Habitat Map for Dry Tortugas National Park

Natural Resource Technical Report NPS/SFCN/NRTR—2011/474

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Fort Collins, Colorado

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Abstract

In 2008 an initial benthic habitat map was completed by the contractor Avineon, Inc. The National Park Service South Florida / Caribbean Network conducted an accuracy assessment of the map and found the overall map classification accuracy to be acceptable (83.2%; lower 90% CL =79.8%). However, upon further inspection, the soft-bottom habitat classifications displayed a relatively high level of accuracy (89.4%; lower 90% CL=85.2%), while the hard-bottom habitats were below an acceptable level (75.2%; lower 90% CL=69.1%). With the acquisition of new higher resolution side scan sonar data and 2,054 field data points from multiple sources, the 2008 map was revised and improved by utilizing these new data sets to produce the 2010 Dry Tortugas benthic habitat map.

The 2010 Dry Tortugas benthic habitat map was developed using 13 mapping classes and 1,709 polygons totaling an area of 26,229 hectares. All "Unknown" areas (10,444 hectares) in the 2008 map were identified, the line work for the hard-bottom areas was fine-tuned, and a mapping layer was developed showing those areas which have a higher potential for fish and benthic biodiversity. In addition, a final bathymetry layer for the park was developed by merging the existing light detection and ranging (LiDAR) and newly acquired side scan sonar/bathymetry data. A subsequent accuracy assessment of the 2010 map found an overall raw accuracy of 89.7% (lower 90% CL=86.0%). The accuracy of hard bottom habitats improved to 88.0% (lower 90% CL=83.4%).

The current management plan for the Dry Tortugas National Park (DRTO) marine areas focuses much of its effort on the no-take Research Natural Area (RNA). The intensive amount of research effort placed on the RNA has also accomplished the research needed for the rest of DRTO because current research and monitoring efforts are split equally between areas of the DRTO that fall within and outside the RNA to make for a balanced comparative study design. In February of 2007, the National Park Service and Florida Fish and Wildlife Conservation Commission developed a science plan to assess conservation effectiveness for the RNA in conjunction with the rest of DRTO and two nearby existing no-take marine reserves.

The new benthic habitat map and corresponding products characterize what types of marine habitats are located in DRTO and provide the ability to track whether management interventions are effectively protecting the environment and associated resources.

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Introduction

Dry Tortugas Benthic Habitat Mapping Project

Accurate benthic habitat maps are important in the establishment of effective and efficient marine monitoring and management programs and assist in park planning. Recent improvements in remote sensing technology such as sonar, and high resolution photography have enabled scientists to map marine habitats with greater detail, accuracy, and to deeper depths. Improvements in benthic maps in turn allowed scientists to decrease sampling effort, but increase data accuracy (Nadon and Stirling, 2006).

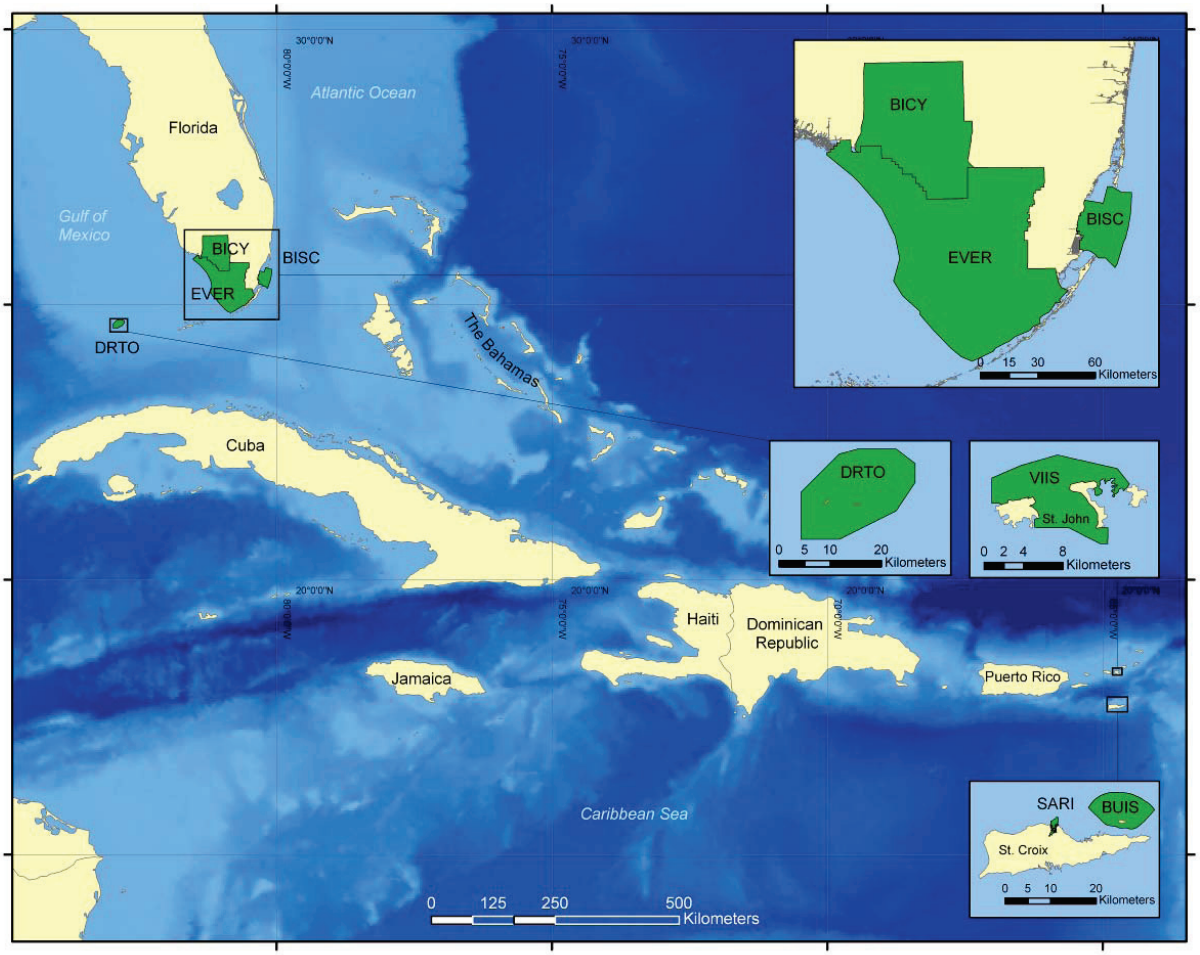


Figure 1. South Florida/ Caribbean Network.

The National Park Service (NPS) South Florida/Caribbean Inventory and Monitoring Network (SFCN) (http://science.nature.nps.gov/im/units/sfcn/) consists of seven NPS units, encompassing 2.5 million acres (Figure 1) and includes Dry Tortugas National Park (DRTO). SFCN is tasked with inventorying and monitoring natural resources within the DRTO and collaborating with partners to do so. This includes benthic habitat mapping and monitoring marine benthic communities, marine fish communities, and exploited invertebrates. The development of an accurate benthic habitat map will help improve the monitoring and management of the DRTO marine resources.

In 2007 the SFCN with funding from National Park Service Geological Resources Division (GRD) entered into a cooperative agreement with the Fish and Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission (FWC) to produce a benthic habitat map for the coral reef ecosystems of DRTO, using the best available technology and appropriate methods. An initial marine benthic habitat map was completed in 2008 by the contractor Avineon, Inc. SFCN decided to take the 2008 mapping project one step further by having the benthic habitat layer developed into a finer scale product by using newly acquired side scan sonar imagery, bathymetry and a large number of field data points acquired from a variety of projects and cooperators.

Dry Tortugas National Park

DRTO is a relatively isolated park located 70 miles west of Key West, Florida. It encompasses seven small islands and 100 square miles of submerged lands at the western end of the Florida Keys coral reef tract whose coral reef ecosystem is considered to be one of the most flourishing and biodiverse within this region. (Ault et al., 2004) (Figure 2). Contained inside this system are some the of largest densities and sizes of grouper, snapper and other game fish species currently observed in the Caribbean (Ault and Bohnsack, 1999). Dry Tortugas is also important as it is upstream of the prevailing ocean currents that reach the Florida Keys National Marine Sanctuary (FKNMS) and Biscayne National Park. This makes it a potential source for planktonic larvae of fish, corals, and other marine species for the Florida Keys and south Florida (McClanahan and Mangi, 2000; Roberts, 1997).

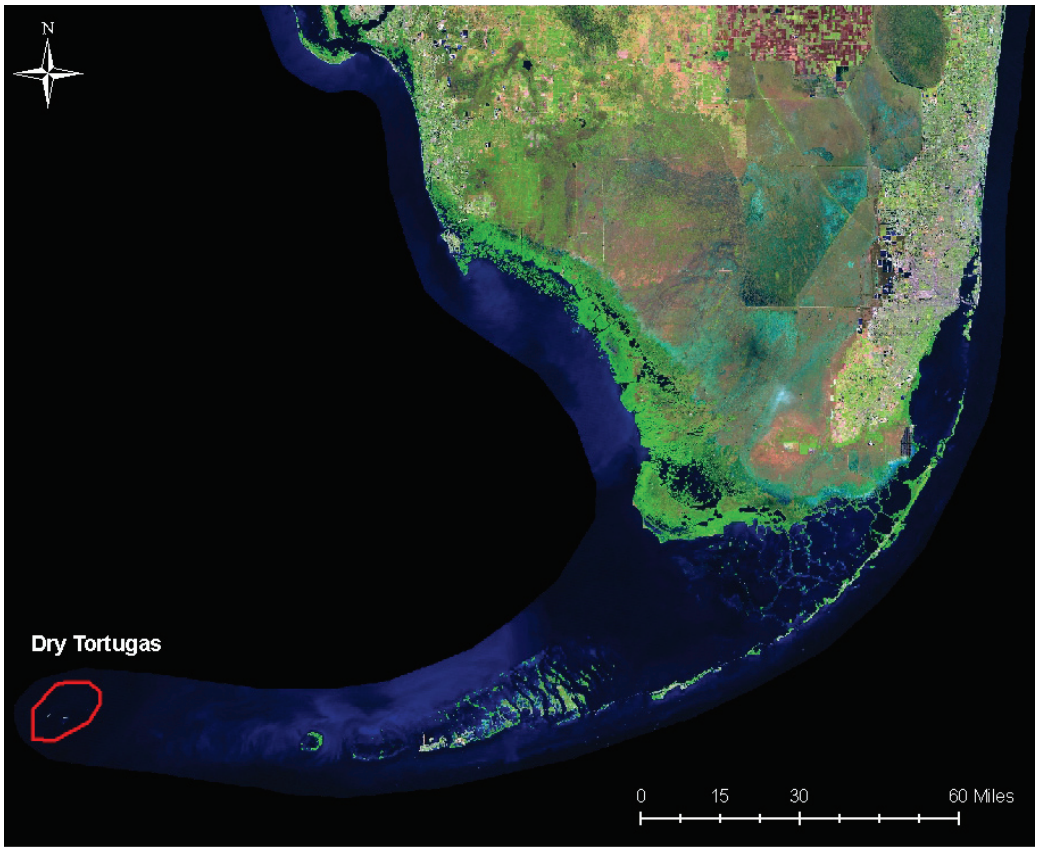


Figure 2. Aerial image of the state of Florida and the location of Dry Tortugas National Park.

DRTO was initially known as the Fort Jefferson National Monument. The Monument was established by a presidential proclamation in 1935 for the purpose of preserving the Dry Tortugas group of islands within the original 1845 federal military reservation of islands, keys, and banks. In 1980, Congress legislatively affirmed the Fort Jefferson National Monument.

In 1992, Congress enacted Public Law 102-525 (16 CFR 1.410, 1992.) abolishing the Fort Jefferson National Monument and establishing DRTO in its place. Congress established the park "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." In addition, Congress directed the Secretary of the Interior to manage the park for the following specific purposes, including:

(1) To protect and interpret a pristine subtropical marine ecosystem, including an intact coral reef community.
(2) To protect populations of fish and wildlife, including (but not limited to) loggerhead and green sea turtles, sooty terns, frigate birds, and numerous migratory bird species.
(3) To protect the pristine natural environment of the Dry Tortugas group of islands.
(4) To protect, stabilize, restore and interpret Fort Jefferson, an outstanding example of nineteenth century masonry fortification.
(5) To preserve and protect submerged cultural resources.
(6) In a manner consistent with paragraphs (1) through (5) above to provide opportunities for scientific research. (16 CFR 1.410, 1992).

Park managers had noticed that there were indications that, despite the park's remote location, rapidly increasing visitor use were negatively impacting the resources and values that make DRTO unique. Visitation to DRTO increased 400 percent from 1994 through 2000, going from 23,000 to 95,000 annual visitors. The resources and infrastructure at the park could not sustain a growth rate of this magnitude while ensuring protection of park resources consistent with the park's legislative mandate (National Park Service, 2001). Scientific studies documented significant declines in the size and abundance of commercially and recreationally important fish species, particularly snapper, grouper, and grunts in DRTO (Ault et al., 2006). These declines threaten the sustainability of reef fish communities both within the park and throughout the Florida Keys. Studies demonstrate that both fish size and abundance in the Tortugas area, including DRTO, are essential to spawning and recruitment for regional fish stocks and the multi-billion dollar fishing and tourism industry in the Florida Keys (Ault et al., 2006).

The population of south Florida is projected to increase from its current level of 6.3 million people to more than 12 million by 2050. With continued technological innovations such as global positioning systems and larger, faster vessels, the increase in population and recreational tourism will likely result in more pressure on the resources in the Tortugas area. In recent years, interest has grown in the commercial sector to provide increased transportation to the park and to conduct additional activities in the park, which would bring many more visitors and greater impacts to park resources.

With this insight the NPS developed the Final General Management Plan Amendment/Environmental Impact Statement (FGMPA/EIS), approved through a Record of Decision (ROD) in July 2001, to comply with its statutory mandate to manage and protect Dry Tortugas National Park, and to respond to pressures from increased visitation and over-

utilization of park resources, which updates the 1983 Fort Jefferson National Monument General Management Plan (National Park Service, 2001).

The FGMPA/EIS addressed specific issues including: (1) protection of near-pristine resources such as coral reefs and sea grasses; (2) protection of fisheries and submerged cultural resources; (3) management of commercial services; and (4) determination of appropriate levels and types of visitor use.

After extensive public involvement and collaboration with state and federal agencies, the NPS selected a management alternative that affords a high level of protection to park resources as well as providing for appropriate types and levels of high quality visitor experiences. This was accomplished by establishing management zones and visitor carrying capacity limits for specific locations in the park, using commercial services to direct and structure visitor use, and instituting a permit system for private as well as commercial boats. A no-take marine reserve, the Research Natural Area (RNA), that encompasses a 46 square-mile area within DRTO, was established to protect a representative range of terrestrial and marine resources that ensures protection of spawning fish and fish diversity and to protect near-pristine habitats and processes to ensure high quality research opportunities. This rule prohibits all extractive activities in the RNA, including fishing. A range of recreational and educational opportunities will be available for visitors as long as appropriate resource conditions are maintained. The quality of visitor experiences will be enhanced by maintaining the quality of resources while expanding visitor access throughout the park.

Management planning process

The current management plan for the DRTO marine areas focuses much of its effort on the RNA. The intensive amount of research effort placed on the RNA also meets the research needs for the greater Tortugas region, since many studies are designed to assess impacts inside the RNA and in nearby surrounding waters adjacent to the RNA.

The establishment of the Dry Tortugas RNA took nine years from its initial proposal in 1998 to its final completion and enactment in 2007. This complex planning project won the 2002 award for the Outstanding Collaborative Planning Project from the American Planning Association's federal planning division. (American Planning Association, 2002).

According to Mascia (2004) in his chapter on Social Dimensions of Marine Reserves, there are ten key principles to follow for successful design of a Marine Reserve or Marine Protected Area (MPA). The planners and managers of the RNA used these principles to direct their design strategy. Included here are each of the principles and corresponding descriptions and summations of how the RNA fits into each. (Mascia, 2004).

(1) ***Share authority for MPA establishment***. *National governments can achieve successful MPA development and establishment by collaborating with local governments, non-governmental organizations (NGO), and resource users.* The Dry Tortugas RNA was designed, developed and established by a 25-member Working Group, composed of commercial and recreational fisherman, divers, scientists, NGO, concerned citizens, stakeholder representatives, Rosenstiel School of Marine and Atmospheric Science (RSMAS) researchers and the FKNMS advisory council members. In addition, various government representatives from the National Oceanic

and Atmospheric Administration (NOAA), FWC, Gulf of Mexico Fisheries Management Council (GMFMC), and NPS were involved in the planning. This Working Group used an "ecosystem approach," and developed models based on scientific principles rather than jurisdictional boundaries (Dry Tortugas National Park – Special Regulations, Final Rule. Federal Register 71(244):76154-76166). This ecosystem approach ensures the greatest chance of success by including all species, life stages, and ecological linkages by encompassing representative portions of all ecologically relevant habitat types (Ballantine, 1997).

(2) ***Share authority for MPA management***. *Management authorities can enhance MPA effectiveness by delegating full or partial responsibility for management to local communities, NGOs, or resource users.* The RNA falls under the Department of the Interior jurisdiction and its regulations. These regulations would be reviewed and evaluated regarding effectiveness and performance of the RNA by the park managers by at least every five years and revisions will be made as necessary. Future revisions to regulations will include opportunities for the public and the Working Groups to review and comment (Dry Tortugas National Park – Special Regulations, Final Rule. Federal Register 71(244):76154-76166).

(3) ***Monitor reserve performance - environmental and social.*** *Tracking the environmental and social dimensions of marine reserve performance provides the basis for adaptive management.* According to the legislation, NPS in collaboration with other federal and state agencies, and universities will implement a research and monitoring program for the marine ecosystem that will provide a status report on the fisheries and benthic communities at least every five years. Additional methods to establish measures for evaluating effectiveness and performance of the RNA will be developed. The incorporation of social sciences into the research and monitoring program will be accomplished by evaluating the performance measures of the users and user groups. There will be extensive analysis of fishing, diving, and boat use data in the RNA and the implementation of an appraisal system to evaluate visitor use and experience correlated with their views regarding RNA effectiveness. There will also be monitoring of RNA law enforcement activity and regulation compliance rates by visitors, businesses, and scientific researchers annually (National Park Service, 2009a).

(4) ***Foster accountability***. *Accountability mechanisms (e.g. elections, consultative sessions, or open meetings) increase the likelihood that decision makers will further constituents' interests rather than personal interests in decision-making processes.* The regulations of the RNA will be reviewed at least every five years, and as seen appropriate, revised and reissued based upon the results of the research and monitoring programs. If there is need for any revisions to the regulations, the public and Working Group will be included in the rulemaking process. The revisions will be contained in the status reports that will be generated and available on the park website: http://www.nps.gov/ever/naturescience/featuredpublication.htm. (Dry Tortugas National Park – Special Regulations, Final Rule. Federal Register 71(244):76154-76166).

(5) ***Clearly define reserve rules and boundaries***. *Clear marine reserve boundaries and rules governing resource use within reserve foster compliance and simplify enforcement.* The RNA will install boundary markers or demarcation buoys at designated points along the boundary line of the RNA. The coordinates and bearings for these demarcation buoys and the delineation of the RNA will be available on mandated navigational charts and current charting software. Through public outreach programs the rules and regulations will be made readily accessible to the

stakeholders, scientists, and any interested parties on various media formats (National Park Service, 2009a).

(6) ***Structure reserve rules so that benefits of resource use are roughly proportional to costs of providing these resources***. *Reserve rules that allocate resource use benefits to users in rough proportion to the costs that these users incur will likely be perceived as more legitimate, and thus enjoy greater compliance, than rules that allocate benefits disproportionate to their costs.* The proportionality of costs to user benefits does not apply to the current RNA. The RNA was set up "to protect and interpret a pristine subtropical marine ecosystem, including an intact coral reef community," meaning the use of the resource by the users is limited and controlled. The RNA has set up a permitting program for all commercial and recreational vessels that want to enter or use the RNA. Boating, snorkeling, scuba diving, and research are regulated through the DRTO permitting system. This was established as a way to set up a system of checks and balances of visitor use to ensure the sustainability of the resource (Culhane, 2002).

(7) ***Make research and monitoring participatory.*** *Enlisting stakeholders, including resource users, in data collection and analysis educates participants, builds capacity, and fosters trust.* One of the organizations that conduct participatory research in the Dry Tortugas and FKNMS area is the Reef Environmental Education Foundation (REEF). REEF according to their creed is a "grass-roots organization that seeks to conserve marine ecosystems by educating, enlisting and enabling divers and other marine enthusiasts to become active ocean stewards and citizen scientists." (REEF, 2007). REEF was founded in 1990, out of growing concern about the health of the marine environment, and the desire to provide the SCUBA diving community a way to contribute to the understanding and protection of marine populations. REEF achieves this goal primarily through its volunteer fish monitoring program, the REEF Fish Survey Project. Participants in the Project not only learn about the environment they are diving in, but they also produce valuable information. Scientists, marine park staff, and the general public use the data that are collected by REEF volunteers (REEF, 2007).

(8) ***Share monitoring results.*** *Sharing information regarding the environmental and social performance of marine reserves may enhance reserve legitimacy or provide the impetus for necessary policy reform.* The enabling legislation requires a status report on the monitoring activities be produced at least every five years, which will be located on park service website: http://www.nps.gov/ever/naturescience/featuredpublication.htm (Dry Tortugas National Park – Special Regulations, Final Rule. Federal Register 71(244):76154-76166).

(9) ***Share information regarding compliance rates and enforcement actions***. *Broad dissemination of information regarding compliance rates and enforcement actions can enhance reserve legitimacy and foster contingent compliance.* Along with the NPS law enforcement (LE) division, the FWC Sanctuary Enforcement Team Offshore Patrol is the leading enforcement agency patrolling waters of the Dry Tortugas region. Law enforcement activity is monitored and documented in accordance with the DRTO general management plan. The management plan requires a record of all law enforcement activity. These records are then generated into status reports that are for public review, thereby enhancing legitimacy of enforcement presence (National Park Service, 2009a).

10) ***Establish highly accessible conflict resolution mechanisms***. *Highly accessible conflict resolution mechanisms have the potential to provide a vehicle for resolving disputes.* The current method of dispute resolution of the RNA occurs every five years with the interpretation of the status report. At this point the stakeholders, user groups, and others may present their input on regulations and voice the need for any changes during public meetings. All groups have a say on any regulation changes before they are enacted.

Early challenges in and mitigation of planning and review

Many of the issues that occurred in mitigation and planning in DRTO occurred during the development process of the RNA and its final establishment. The following section discusses the major issues and how they were resolved or are being addressed currently.

Establishment issues

During the development of the RNA in DRTO, the state of Florida was reluctant to give the park service all rights to the submerged lands that Monroe county of Florida owned inside the RNA in Dry Tortugas. Through months of debate, a management agreement was settled upon to allow both parties a voice in the protection and establishment of the rules and regulations in this area (State of Florida, 2005).

In addition, during the processing phase of RNA establishment, the RNA plan was made available for public comment. The NPS received over 5000 comments regarding the proposed establishment plan, which consisted of letters, e-mails, and verbal comments. These were processed and compiled into a list of concerns that the NPS addressed. Notably ninety-nine percent of all respondents supported the implementation of the RNA (Dry Tortugas National Park – Special Regulations, Final Rule. Federal Register 71(244):76154-76166).

Those that did not support the RNA were a small group of stakeholders and recreational fisherman. The NPS considered each of the issues that were raised and either adopted the suggestion or rejected it. Each of the concerns were reviewed and then listed along with the reasons for acceptance or rejection. The following are a few of these disputes and their corresponding results and justification for these results.

The science used in RNA decision-making was inadequate because the methodology, assumptions, and data were flawed and the scientists who conducted the studies are biased and inexperienced in fishing and fish habitats. The NPS disagreed with this statement. The original scientific studies were described in detail in a report issued in 1999 that was jointly commissioned by the NPS and the FKNMS. The specific studies of Tortugas reef fish communities and their associated benthic habitats were initially compiled from 1999 to 2004 by an interdisciplinary team of scientists from NPS, NOAA, RSMAS, National Undersea Research Center, UNC Wilmington (NURC), and FWC. This team of scientists has extensive and varied experience in marine ecology, oceanography, fisheries management, and coral reef ecosystems based on their work throughout Florida and the Caribbean, and their site-specific studies over the last 2-3 decades in the Florida reef tract (Ault et al., 2006).

The Research Natural Area is not needed because resources in the Dry Tortugas area (coral reefs, fisheries) are in good shape. Fish stocks are not overfished. The NPS believes that the marine ecological resources within the RNA are not in good shape. The most recent reef game

fish stock assessment concluded that 17 of 18 grouper and snapper species are overfished based on their spawning potential ratio (Ault et al., 2006). The park's coral reefs have similarly experienced substantial declines in the last 30 years. (Science at Dry Tortugas Fact Sheet, 2007). *Acropora palmata* and *Acropora cervicornis* two species recently listed as threatened, are located in the RNA area further necessitating its protection (EPA, 2006).

The NPS should eliminate the rule that states that all fishing gear must be stowed and unavailable when traveling within the RNA zone. The NPS agrees with the stake holders here and accepted their suggestion. The rule now states that for smaller boats with limited space, fishing gear made not available for immediate use would suffice for vessel transport through the RNA. All larger vessels are required to stow all fishing gear appropriately.

Existing regulations and size and bag limits will adequately protect fish stocks. The NPS states that the current recreational fishing regulations are beneficial, but they are not sufficient to protect this important and depleted fishery brooding stock. Although DRTO is an isolated park, its visitation and recreational fishing activities have increased dramatically (Culhane, 2002). This increased fishing activity has caused a significant drop in numbers of the primary game fish stocks, (Ault et al., 2004; Sumaila, 2002). No marine reserves that allow fishing have resulted in long-lasting increases in the abundance, size, and productivity of target fishery (Roberts et al., 2003). Therefore the NPS decided to establish a no-take area or RNA that will provide a refuge for game fish species.

Monitoring issues

With the establishment of the RNA a Memorandum of Understanding (MOU), a formal statement of collaboration of the NPS with the FWC, was created to facilitate the evaluation and monitoring of the performance of the RNA (Hunt et al., 2007). In addition to this new collaborative monitoring effort, preexisting monitoring has been conducted by state, federal and university groups for a multitude of years.

Some of the key problems that occur with all these different groups working in this area are: re-sampling or over sampling of the same sites; different methods of data collection; and lack of data sharing and coordination throughout individually conceived monitoring studies.

The re-sampling or oversampling of the same sites may sound unproblematic; after all, there can never be enough data. However, it results in wasted effort. It was discovered that two of the groups had conducted fish samples in the same locations, in the same month. In regards to benthic monitoring, different agencies have permanent coral monitoring sites located on top of each other on the same reef. Sampling one site multiple times is a good way of checking data, but done in an inefficient unplanned manner will result in wasted energy and prevent the monitoring of additional area.

The use of different methods of data collection happens frequently. Each researcher or monitoring group tends to think they have the "best monitoring method." If methods were standardized throughout the groups, the effort could be spread out throughout the area and this would give more accurate data for determining ecosystems status and trends.

Another problem is the sharing of collected data among the different research groups. Scientists tend to have a sense of ownership over the data they collect; they have a reluctance to share this data, especially unpublished sets. For example, in the federal government according to the Freedom of Information Act (FOIA) all federal agencies are required to disclose records requested in writing by any person, which is interpreted to mean that all data collected by government agencies is public knowledge and anyone can request for it. Requesting often does not result in receiving the data in a timely manner. In the academic world, most of the coral reef ecosystem researchers are in the "publish or perish" scenario. This means that there are consequences if they do not have enough publications in a set period of time. If the project you have been working on needs to have published results in order to receive financial support, not publishing can result in a loss of funding. That being said, the quote that comes to mind is "Why can't we all just get along?" (Rodney King, 1991)

Review and monitoring

In February of 2007, the NPS and FWC developed a science plan to assess conservation effectiveness for the RNA in conjunction with the rest of DRTO and the two nearby existing marine reserves. This examination and assessment included a recent 3-year interim report and anticipates in 2011 a 5-year comprehensive report to assess effectiveness of the RNA according to the current executive summary. The implementation of the science plan has been accomplished through the collaboration and cooperation of federal and state agencies, academic scientists, and NPS. This summary evaluates six performance areas, which according to the 2010 3-year interim report, has 18 projects currently underway.

Performance indicators

The following will briefly review each of the six performance areas and the projects that are underway.

1) "Quantify changes in the abundance and size-structure of exploited species within the RNA relative to adjacent areas."
   Three ongoing projects address this indicator. The first is *Fishery-independent visual assessment of resource status of the reef fish community in DRTO* (Ault et al., 2010b). This project consists of visual underwater surveys conducted by divers in which they are collecting both biological and environmental data. The initial baseline data sets were collected in 2008 and 2009 and additional surveys will be continued for 2010 and 2011. The survey data will be analyzed for changes in the reef fish species. The second is *Examining the efficacy of the newly established RNA for protecting coral reef fishes within DRTO* (Switzer et al., 2010b). This project is a seasonal fish trapping and hook and line survey method that monitors changes in abundance and size structures of exploited fish species located inside and outside the RNA. The project was started in 2008 and will continue through 2011. The third is *Characterization of fish assemblages associated with seagrass within the newly established RNA and adjacent open-use zones at DRTO* (Switzer et al., 2010a). This project uses fish traps in seagrass habitats to collect exploited juvenile fish. This project hopes to catch the early benefits of the RNA by collecting abundance data from the fish at earlier ages in their life cycle. This project was initiated in 2009 and will continue through 2011, which is the timeline for the 5-year report.
2) "Monitor the immigration and emigration of targeted species in the RNA."
   Three projects are currently being implemented to address this indicator. The first is

Fine-scale and net migration patterns of selected reef fish species from the RNA to adjacent fished areas in the DRTO region (Feeley et al., 2010a). This study determines the habitat ranges of selected grouper and snapper species using telemetry data. This projected started in 2008 will determine fish movements inside the RNA and park, thereby may show the spillover benefit of the RNA and DRTO. The second is *Reef fish movements and flux around the RNA* (Farmer and Ault., 2010). This project tracks grouper, snapper and amber jack movements inside and outside the RNA and DRTO through acoustical tacking. The third is *Use of protected areas by threatened and endangered marine turtles in the Dry Tortugas* (Hart, 2010). This project uses acoustical and satellite tags to determine the movements of three species of sea turtles with in the park and their connection to other areas in the Caribbean. The project was established in 2007 and will be a long term monitoring project for the turtles in DRTO.

3) "Monitor changes in species composition and catch rates of exploited species throughout the surrounding region."
   Two projects aim to address this indicator. The first is *Extended creel census development for DRTO* (Ault and Smith., 2010). This project is taking historical creel census data from 1981 to present and improving upon it to estimate fishery statistics. The second is *DRTO vessel permit system* (Walton., 2010a). This system was developed in 2009 to help in quantifying the boating and recreational activities. This data will be used to help in understanding and managing the fishing, diving and social activities in DRTO.
4) "Evaluate the effects of RNA implementation on marine benthic biological communities."
   Four projects address this indicator. The first is *Assessing the effects on corals of SCUBA and snorkeling use at RNA designated (mooring buoy) dive sites* (Morrison et al., 2010). This project will use underwater video to set up a baseline and then assess threw time and damage that may occur due to diving and snorkeling activities. The second project is *Coral reef community monitoring at Bird Key Reef and sites inside and outside the RNA at DRTO* (Miller et al., 2010). This project was established in 2004 and is designed to monitor the benthic habitat through the use of video monitoring. This is a long term monitoring project and will continue for years to come. The third project is *Trophic relationships on coral reefs of DRTO: Inside and outside the RNA* (Kufner et al., 2010). This study is designed to examine the potential impacts of reduced numbers of exploited reef fish species and the effects that occur to the benthic structures. The fourth project is *assessing the effects of creating the RNA no-anchor zone on seagrass beds* (Morrison., 2010). This study is designed to determine the effects of no-anchoring on seagrass habitats.
5) "Assess reproductive potential of exploited species by evaluating egg production and larval dispersal."
   This topic has three projects underway. The first is *Reproductive potential of exploited reef fishes within the newly established Dry Tortugas RNA and adjacent open-use areas* (Switzer et al., 2010c). This study currently is still in its modification process and has not been able to find any reproductive individuals. The second is *Immigration and emigration of selected reef fish species from the RNA to the Tortugas South Ecological Reserve* (Feeley et al., 2010b). This study uses acoustical

tracking to show movements of fish during spawning migrations. The third is *Larval transport modeling form the Dry Tortugas* (Ault et al., 2010a). This study is using a model to show the transport of larval grouper and snapper from the Dry Tortugas area to other areas in the Florida Keys showing a link between them.

6) "Incorporate social sciences into the research and monitoring program." Three projects are currently being implemented to address this indicator. The first is *A survey of visitor demographics, attitudes, perceptions, and experiences in the RNA* (Loomis, 2010). A survey was designed to help managers understand the stakeholders and publics perceptions of DRTO and how improvements can be made. This will help give those individuals a sense of ownership in this area. The second is *Law enforcement in DRTO* (Walton, 2010b). This study shows how law enforcement is being accomplished in DRTO area and how improvements will be accomplished. The third is *Submerged cultural resource condition assessment project* (Conlin et al., 2010). This project is designed to help locate, protect and inform the public of the submerged cultural resources in DRTO.

All projects are currently being implemented in the DRTO and RNA as described in a 3-year interim report. The 5-year comprehensive report will be reviewed by the working group and park managers in 2012 to determine the effectiveness of the RNA and what changes will be needed to the current legislation.

Historical benthic mapping projects

Through the years there have been many benthic mapping projects developed for the Dry Tortugas region. The first was a benthic habitat map developed by Alexander Agassiz in 1882, (Agassiz, 1882) which has been used as a basis for comparing the distribution of marine communities 130 years ago to more recent decades (Davis, 1979). There have been multiple historically significant marine benthic mapping products that were reviewed prior to the development of this product (Table 1), but unfortunately no single effort has provided a comprehensive picture of the marine benthic habitats of DRTO.

Table 1. Historical benthic habitat mapping initiatives that have been developed in the past 100 years.

Principle Investigators	Year	Type of Map	Method	Product	Scale Resolution
Alexander Agassiz	1882	Benthic Habitat Classification	Topographical sketch of the Benthic Habitat	Benthic habitat classification into 10 categories	Unknown
National Geodetic Survey	1971	Benthic Habitat Classification	7.5 minute quad topographic images	Benthic habitat classification into 10 categories	Unknown
Gary Davis	1979	Benthic Habitat Classification	Topographical Sketch but using the NGS base map of 1971.	Benthic habitat classification into 10 categories and sea grass map	Unknown
USFWS and MMS	1983	Benthic Habitat Classification	Aerial Photograph Interpretation using Presence/Absence method	Sea grass and corals inventory	1 :24000
FMRI and NOAA	1998	Benthic Community Characterization	Combined Aerial photography and in situ visual surveys	Detailed inventory and characterization of benthic habitat	1 meter
Jerry Ault et al.	2003	Benthic Habitat Classification and Characterization	Combined Aerial photography, single beam side scan, bathymetric soundings, and in situ visual surveys	Detailed inventory and characterization of benthic habitat	1 meter

Initial Avineon 2008 benthic habitat map.

The 2008 DRTO benthic habitat map (DRTO_Benthic_Map_2008) (Figure 3) was developed by Avineon, Inc. with field and technical support by FWC and the SFCN. Avineon, Inc. is a private contracting firm that, according to their mission statement, offers expert environmental mapping services to clients interested in the acquisition of aerial imagery (analog and digital), field documentation, finished map products, geospatial data, and comprehensive reports aimed at environmental concerns.

Avineon provided the following sets of metadata in their final product. The GIS data layers used were benthic data for DRTO interpreted from IKONOS satellite imagery. The 2008 photointerpretation for the project was accomplished using Avineon's Data Capture System. The classification system was provided by NOAA in the document "A Classification Scheme for Mapping the Shallow-water Coral Ecosystems of Southern Florida" (March 7, 2008). The minimum mapping unit for classification was 0.25 acres (=0.1 hectares).

The goal for Avineon's contracted project was to map the benthic habitats within DRTO with emphasis placed on reef communities. The imagery was also used to identify seagrass, unconsolidated sediment, and other hard-bottom areas. The final mapping product was to be made available to researchers, natural resource managers, law enforcement, and the public in hardcopy and digital forms. The resultant products are stored in perpetuity within the Marine Resources Geographic Information System maintained by the Fish and Wildlife Research Institute (FWRI).

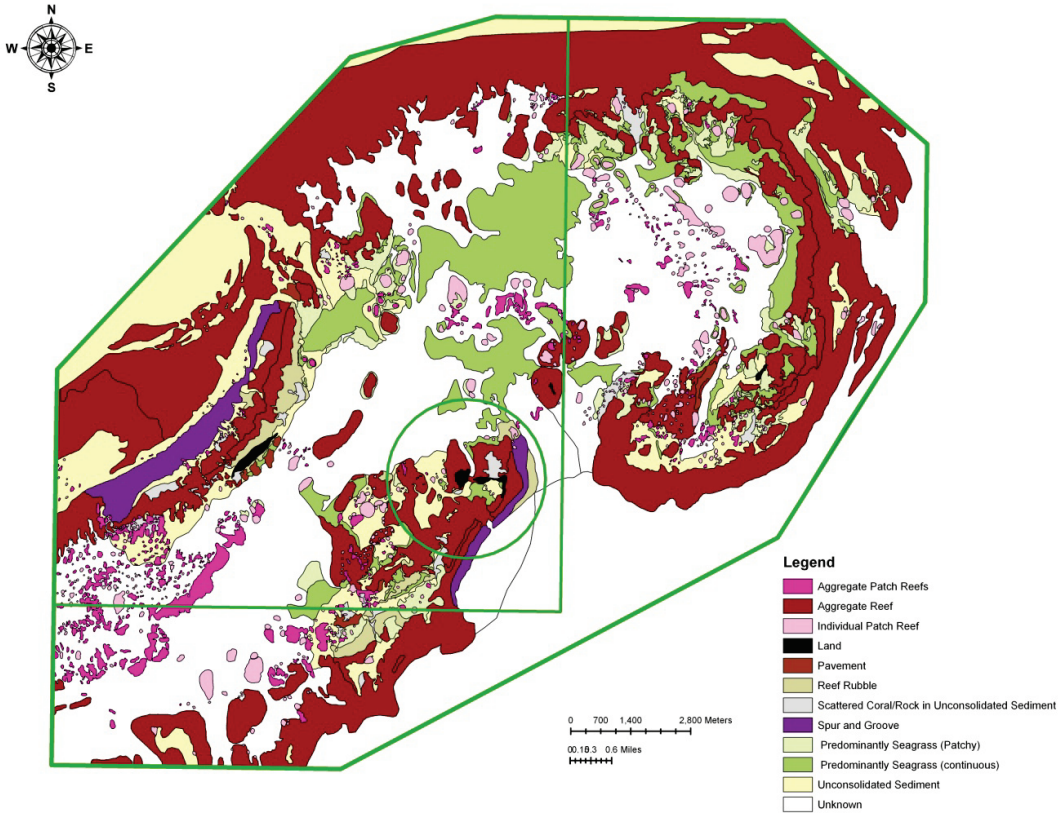


Figure 3. Avineon 2008 Marine Benthic Habitat Map.

Current benthic mapping project objectives

The objectives of this current project were to:

- Assess and analyze the accuracy of the 2008 map through the acquisition of field accuracy assessment data points.
- Update and improve the initial Avineon 2008 benthic habitat map through the use of newly acquired 2009 side scan sonar and bathymetry data sets and additional field data points and create a current, consistent, accurate and reproducible benthic habitat map for the marine ecosystems of DRTO.
- Create a layer that identifies areas that have the potential to contain higher fish and coral reef community biodiversity and abundance for the purpose of helping with the design of future monitoring and management programs.
- Integrate all existing and newly developed spatial and visual data for use in monitoring and performance evaluation of the park and RNA.

Methods

Overview

The 2010 DRTO benthic habitat mapping project was designed by SFCN to take the 2008 benthic habitat map that Avineon, Inc. created and enhance the integrity of this product. This was accomplished, as shown in the schematic in Figure 4 by utilizing newly acquired side scan sonar imagery and bathymetry data sets, historic data and newly acquired field data points. Additional technical support and anecdotal park knowledge came from SFCN, NPS, RSMAS, FWRI, and the University of South Florida (USF).

The general steps used to create the 2010 benthic habitat map for DRTO included the following:

1) An accuracy assessment was performed of the 2008 Avineon, Inc. benthic habitat map.
2) Data sources were assembled that were used to create the 2010 GIS mapping project.
3) Tools were implemented to track changes to the polygons.
4) A layer was developed to check the topology.
5) Raw side scan sonar.xyz data were converted into a raster based data set.
6) A 3-dimensional map was created using ArcScene of the benthic layers.
7) The marine benthic classification was selected.
8) Polygons were modified.
9) The highest potential habitat layer for coral and fish biodiversity was developed.

Step 1) Accuracy assessment of the 2008 Avineon benthic habitat map

Selection of accuracy assessment points.

In 2008 the contractor Avineon, Inc. developed the 2008 benthic habitat map. In order to determine the accuracy of this benthic mapping product and whether it passed the required map accuracy criteria of 80% with 90% confidence, SFCN conducted a field accuracy assessment concurrent with the mapping process.

The concurrent accuracy assessment process differs from the typical post-map completion assessment. A post-map completion assessment includes a stratified random selection of accuracy assessment points that are drawn based upon the completed benthic habitat map. A buffer is established around the edges of polygons preventing the drawing of accuracy assessment (AA) points on or near a polygon edge. A minimum number of points can be forced into rare habitat classes and common habitat classes are not oversampled. However, there were two reasons for not using this process during the DRTO marine benthic accuracy assessment. First, it would have taken over two years to complete the project whereas the method of concurrent AA point collection allowed for the accuracy to be evaluated in a one to two month turn around between the contractor producing the map and the evaluation of the map accuracy, quality and acceptability. A post-map accuracy assessment process would have created an extensive delay between finalization of the map and official acceptance of the quality of the deliverable and payment of the contractor. The second reason was logistical. Due to the distance, weather and time of year the AA points could only be collected during the summer months. The optimal time for collecting AA points in DRTO therefore occurred when SFCN was in the area conducting its annual monitoring of the marine benthic community. This annual monitoring was

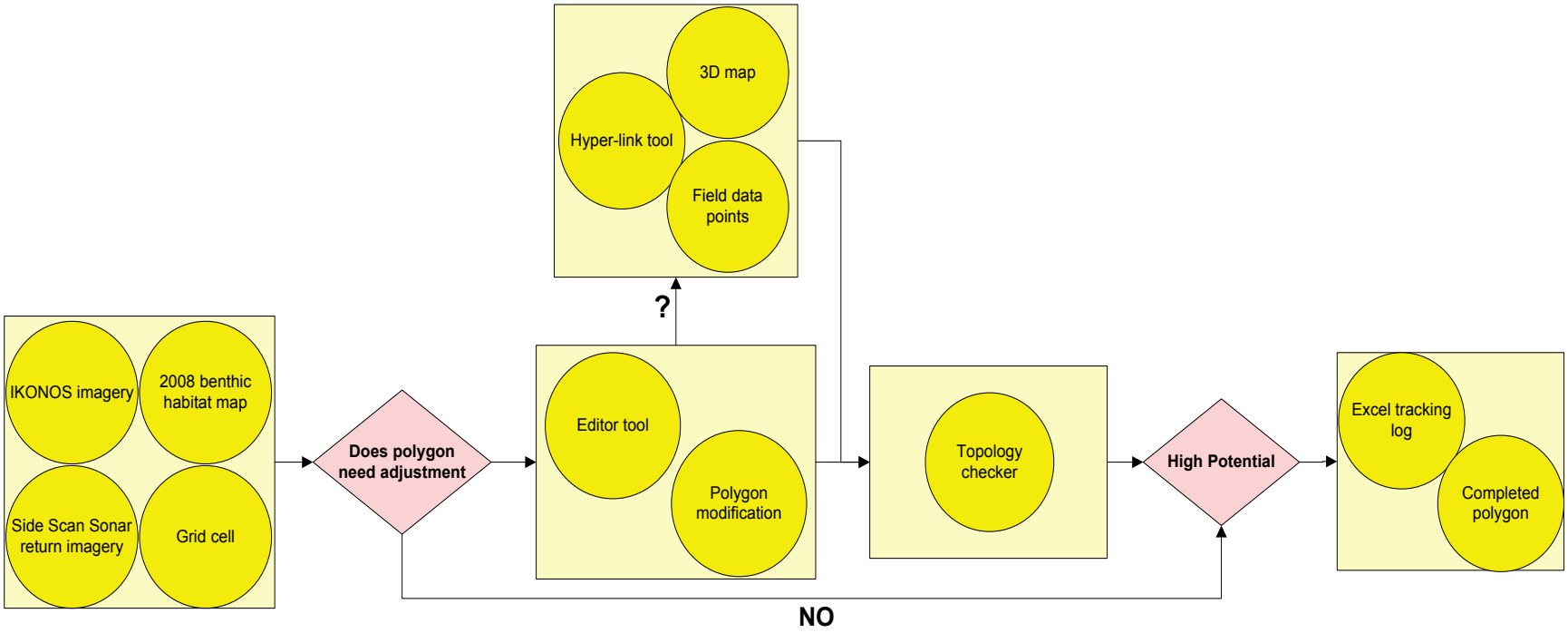


Figure 4. This schematic displays the process of polygon modification.

scheduled before the completion of the map, and so a concurrent accuracy assessment was executed to take advantage of field time.

To conduct the concurrent accuracy assessment, 300 random points were selected across the park. This random generation process was accomplished using a GIS program called Alaska pack. Due to time constraints, only 250 AA points were visited in the field.

Field method for checking accuracy assessment points

Once the AA points were generated, they were uploaded into the Garmin 5212 chart plotter. Using the chart plotter the SFCN team navigated to the appropriate AA point. Then to mark the AA point, a soft weighted buoy was deployed gently on the benthos. Depending on weather conditions, visibility, depth and the complexity of the habitat, one of three methods was used to assess the habitat: scuba, snorkel, or drop camera.

The drop camera method was the most frequently used and efficient assessment method. Effective use of the drop camera required habitats of low to moderate complexity, low swell/chop, and a minimum of 20ft of horizontal visibility through the water column. After deploying the weighted float, the boat was navigated to the buoy slowly and a SeaViewer 950 color drop camera on a 150 ft. cable was deployed to several meters above the habitat and video of the habitat was recorded (Figure 5).

The video stream from the drop camera was captured to a Sony DV recorder while observers simultaneously reviewed the video in real time for 2-5 minutes. Streaming time increased with habitat complexity and decreased visibility. The AA data sheets (Appendix D) were filled in with the habitat type directly under the landing spot of the weight as were all habitat type/densities within the visible range of one to ten meters.



Figure 5. Counterclockwise from upper left: the NPS vessel used for operations, drop camera above a reef habitat, and the Sony DV recorder on board.



Figure 6. Snorkelers conducting habitat assessment and an example of photos from 4 cardinal directions.

In cases of poorer weather/visibility or sites which required a more in depth investigation, 2-3 snorkelers or SCUBA divers were deployed near the float. Diver verification was typically used on sites with depths greater than 40ft or too shallow for the boat to reach safely and when conditions were not favorable for the use of the drop camera.

The *in situ* observers classified the habitat type directly under the landing spot of the weight and all habitat types/densities within the visible range of 2 to 20 meters depending on water clarity. The observers then captured photographs in four cardinal directions of the benthos from a fish-eye view using a Sony DSC T900 in a Sony TPK Marine Pack (Figure 6).

Snorkelers returned to the boat and came to an agreement on the benthic classification based on the direct site survey and completed the AA data sheet by following the NOAA classification scheme, Geostructure was evaluated for all points. Biocover (Submerged Rooted Vegetation and Submerged Aquatic Vegetation) was only evaluated for unconsolidated sediment (Appendix D).

Evaluation of "acceptability" of map class based upon field data

Post-field evaluation of the AA points was needed in order to determine if a point whose field classification was not an exact match to the map classification was still acceptable as a correctly identified polygon on the map.

To conduct the evaluation of the AA points, two ArcGIS 9.3 layers were developed. The first was an ArcGIS layer that hyperlinked the field photos and video to the corresponding AA points. The AA field data was displayed at the same time by using the Information tool in ArcGIS 9.3. The second layer joined the AA data and the map attributes so comparison of the field classification and map annotations could be made. In order to record the data, three additional

columns were added for exact match (yes/no), acceptable match (yes/no) and reasons for points being accepted.

Each of the AA points were evaluated to determine if the field classification was an exact match to the map classification or deemed acceptable after review. Although *Geomorphic Structure* and *Coral Ecosystem Biological Cover* were classified separately for the softbottom and seagrass habitats in the 2008 benthic map, these were combined into map classes for the AA evaluation. Thus the final map classifications tested were:

- *Aggregate Patch Reefs*
- *Individual Patch Reef*
- *Aggregate Reef*
- *Spur and Groove*
- *Pavement*
- *Reef Rubble*
- *Scattered Coral/Rock in Unconsolidated Sediment*
- *Unconsolidated Sediment - Predominantly Seagrass (continuous)*
- *Unconsolidated Sediment - Predominantly Seagrass (Patchy)*
- *Unconsolidated Sediment – Unknown*

Reasons for classifying points as acceptable that were not an exact match:

- ***Classification Scale***- The habitat classification is spatial-scale and landscape context dependent. This creates a difficulty for *in situ* field classification in the absence of either a map context or imagery as the area a diver can evaluate in a timely manner was much smaller than what the actual minimum mapping unit (MMU) appeared to be for the map (the actual versus the stated MMU is discussed later). For example determining the difference between individual and aggregate patch reefs or between unconsolidated sediment and discontinuous submerged rooted vegetation can be difficult in the field without accompanying imagery. A specific example is shown in Figure 7 where a small area within a larger polygon may be classified differently than the rest of the polygon. If the size of this small area is smaller than the minimum mapping unit, the mapped polygon annotation may be acceptable. This would only be found in the post-field review.
- ***Pavement/Aggregate Reef Misidentified***- During the AA point identification process *Aggregate Reef* was consistently misidentified by some field personnel as pavement according to the videos and photos. This was due to a misunderstanding of the definition and field crews not having the established Scheme and corresponding pictures to help in the habitat identification. Pavement by definition from the FMRI SCHEME has little to no real structure with minimal growth upon it. While Aggregate Reef consists of coral and hard-bottom features such as sponges and gorgonians.
- ***Equivalent class***- A field classification of *Submerged Aquatic Vegetation* (typically macroalgae) was considered an equivalent class to *Unconsolidated Sediment* as the contractor was not required to map macroalgae and the imagery could not determine the difference between classifications.

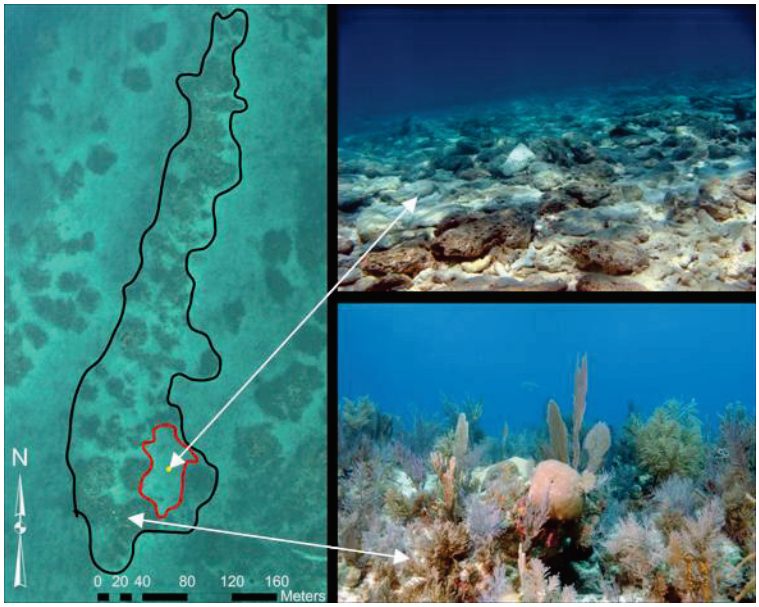


Figure 7. Examples of photointerpretation and diver field classification difficulties. Shown here in the area circled in red is where the AA point landed. The diver originally assessed the area as *Pavement*, but upon post-field evaluation the point was part of a *Polygon* designated as *Aggregate Patch Reef*.

- ***Polygon edge***- The polygon was determined acceptable when the AA point landed within 3 m of the edge between two different polygon habitats and one of the polygons matched the AA point.
- ***On edge between classification definitions***- If the field data and video/photos showed the habitat was in between classification definitions and the map annotation was felt to be reasonable, the point was declared acceptable. For example, a field AA point landed on an area of very sparse reef rubble overlying unconsolidated sediment. The field classification was reef rubble but the map annotation of unconsolidated sediment was determined acceptable.
- ***AA error*** –A few points upon review of the video and/or photos and field data appeared to have an error in field classification. These were then changed to the proper field classification and the polygon declared acceptable if it then matched.

Statistical methods

The overall benthic map class classification accuracy assessment was calculated as the number of accuracy assessment points considered "acceptable" divided by the total number of points. "Acceptable" points included both those that a) had a complete match between the map annotation and the field assessment, and b) those for which the map annotation was different but deemed acceptable by SFCN staff as described above. The lower 1-tailed 90% confidence interval was calculated using confidence limits for population proportions as described in (Zar 1999, p. 527). The NPS Vegetation Inventory Program has a standard of 80% classification accuracy with 90% confidence. As standards have not been created for benthic maps, this standard was used as a benchmark for this product.

In addition to an overall level of accuracy assessment, calculations of accuracy within hard-bottom habitats and within soft-bottom habitats were also conducted separately. Calculations were also made by map classification.

Step 2) Assemble the data sources that were used to create the 2010 GIS mapping project.

The following were the layers, imagery, field data points and locations of the more in-depth metadata that were used in the development of the 2010 DRTO benthic habitat map.

Benthic habitat maps

- ***DRTO_Benthic _Map_1998***
  This layer was developed by NOAA as a descriptor to the various benthic habitats that are associated with the area in DRTO. The in depth metadata on where the naming convention, delineations and various other attributes associated with this layer can be found in the metadata text file DRTO_Benthic_Map_1998_metadata**.**
- ***DRTO_Benthic_Map_2008***
  This layer was developed by a contract between FWC and Avineon, Inc. with money given by SFCN to produce a new benthic habitat map.
  DRTO_Benthic_Map_2008_metadata text file explains how this layer was developed and what data sets were used for it.

Imagery

- ***DRTO_2006_IKONOS_RGB_4m.jp2***
  This imagery is IKONOS which is a commercial earth observation satellite, and is publicly available high-resolution imagery at 1- and 4-meter resolution including multispectral (MS) and panchromatic (PAN) imagery. This imagery was taken for the Dry Tortugas National Park in 2006. NOTE: No Metadata was available for this data set.
- ***DRTO_2006_IKONOS_blue_band_4m.tif***
  This imagery is **"**IKONOS**,** which is a commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. It offers multispectral (MS) and panchromatic (PAN) imagery." This imagery was taken for the Dry Tortugas National Park in 2006. This imagery is using the blue band which gives a better resolution for deeper water environments. NOTE: No Metadata was available for this data set.
- ***DRTO_2007_NAIP_RGB_1m***
  This imagery was developed by the National Agriculture Imagery Program with a horizontal resolution of 1meter, but due to the reflection off the water and the return of light due to the wave action and surface movements during the imaging process the imagery is not of high quality in all areas of the park. The metadata for this layer is located in the metadata file located in the product.
- ***Raw Geotiff imagery from the side scan returns***
  This is the raw imagery collected from the returns of the side scan sonar were collected by Stanley D. Locker, Ph.D. and others from the College of Marine Science of the University of South Florida in 2008 with a horizontal resolution of 30cm. The following are the layers that were sent to SFCN and were broken up into 7 different images because of their size. The following were the images used:

  3x3_LFSS_r03_c01
  3x3_LFSS_r03_c02
  3x3_LFSS_r02_c03

3x3_LFSS_r02_c01
3x3_LFSS_r01_c03
3x3_LFSS_r01_c02
3x3_LFSS_r01_c01

Bathymetry

- ***DRTO_DEM_2004_LIDAR***
  This data set flown by the Experimental Advanced Airborne Research LiDar (EAARL) gives the topography for the shallow water environments <15m deep in Dry Tortugas National Park. The resolution for this data set is 1m. The metadata for this layer is located in the layer itself.
- ***DRTO_2010_LIDAR_SS_merge_1m***
  This data layer is a merged layer of 2004 LIDAR and 2009 Side Scan bathymetry into one filtered data set. The horizontal resolution for this layer is 1m. This layer was clipped from the full LIDAR and side scan sonar bathymetry set and merged to fit the DRTO boundary.
- ***2009 Raw Side Scan Bathymetry data***
  These are the original bathymetry layers that were collected by Stanley D. Locker, Ph.D. and others from the College of Marine Science of the University of South Florida in 2008 and were converted from the original .xyz data sets that the side scan sonar had collected.

  r01_c01_terr_1m.tiff
  r01_c02_terr_1m.tiff
  r01_c03_terr_1m.tiff
  r02_c01_terr_1m.tiff
  r03_c01_terr_1m.tiff
  r03_c02_terr_1m.tiff
  newr2c2c3_t1.tiff

Field data sets

- ***DRTO_RVC_0408_points***
  This layer is from the Reef fish Visual Census (RVC) sites provided by a collaboration of NOAA and RSMAS for the years 2004, 2006 and 2008. This data set contains the benthic data collected during the fish surveys and photos that were taken in four cardinal directions at each point used to confirm the benthic habitat descriptor recorded during the RVC.
- ***DRTO_RVC_2009_points***
  This layer is from the Reef fish Visual Census (RVC) sites provided by a collaboration of NOAA, SFCN and RSMAS for the year 2009. This data set contains the benthic data collected during the fish surveys and photos that were taken in four cardinal directions at each point used to confirm the benthic habitat descriptor recorded during the RVC.
- ***DRTO_RHA_2008***
  This layer is from the data that was collected by SFCN during their assessment of potential marine benthic monitoring sites. This data set also has photos that were taken in four cardinal directions at each point that were used to confirm the descriptor.

- ***Extensive Coral Monitoring Sites***
  These are SFCN's long-term benthic monitoring sites that were established in 2008. Data collected at each point included rugosity, video, and yearly benthic coral cover estimates.
- ***DRTO_AA_2008***
  This data set contains information on the habitat collected by SFCN at 254 random points selected in DRTO. These data were collected to be used for conducting map accuracy assessment of the 2008 benthic habitat map developed by Avineon. The data also has corresponding photos in four cardinal directions or video.

The field data sets were brought together from a multitude of different research projects and through the cooperation and collaboration of Federal, State and University groups. It was possible to use the data as field data points to give a small scale, but fine detail to the habitat description. The total field data points are shown in Figure 8.

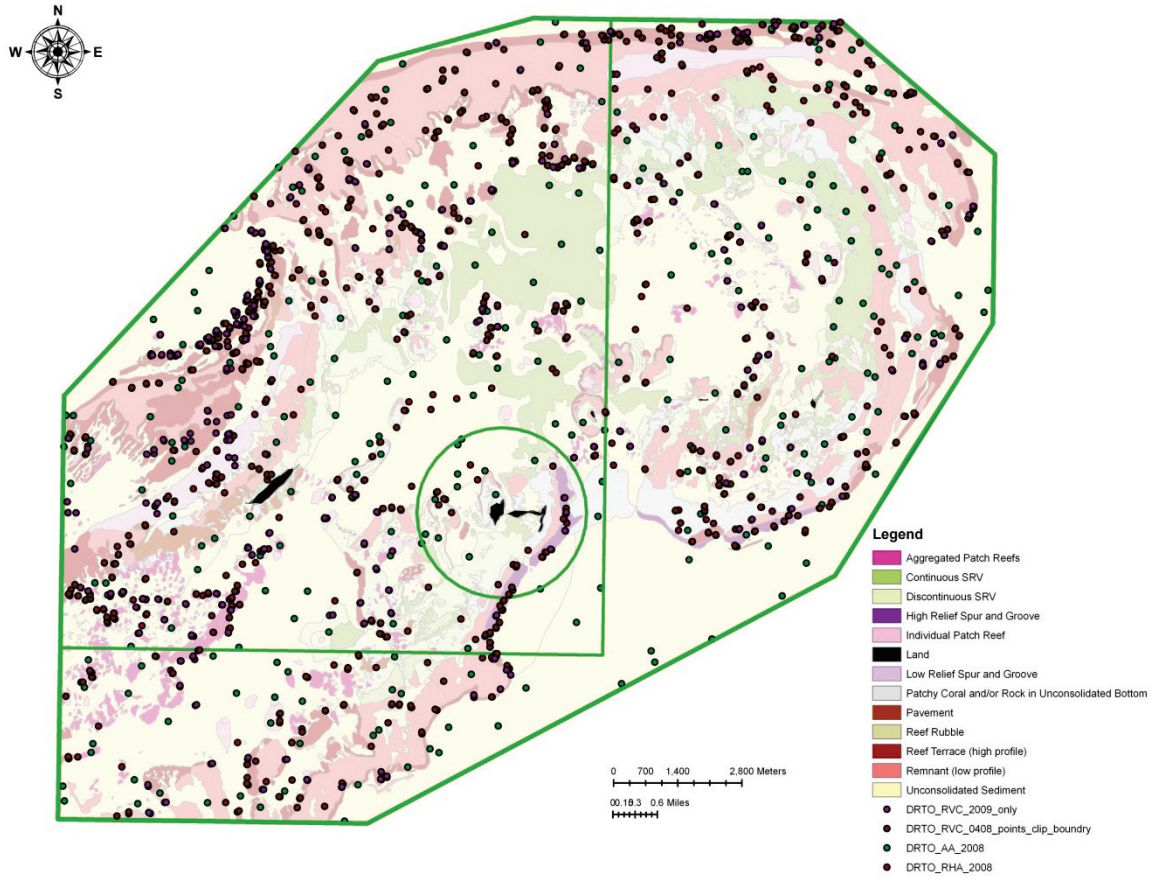


Figure 8. Map of all field data points used.

Each of these projects included data on the benthos, but varied slightly in their data collection process. The RVC fish monitoring project started its fish data collecting for the entire Dry Tortugas in 2000 and has continued to survey bi-annually in this region. In 2009 the same group also conducted an intensive fish census of only DRTO. The method and type of data that were collected for the benthic collection component can be found in Appendix A. This habitat dataset

is extensive enough to use the points as field data points for the polygons' benthic habitat identification. Also each of these points has corresponding photos of four cardinal directions so that if there is a question concerning the observer's identifications, the photos can be used to confirm the benthic data collected (Brandt et al., 2009).

Step 3) Implement tools to track changes.

Three tools were created to help in tracking and organizing of the adjustments to the polygons in the new benthic layer. These tools were the grid cell layer, completed polygon layer and an Excel tracking log.

Grid Cell Layer

The grid cell layer is a simple polygon layer that was developed in AlaskaPak to place a grid over the top of the mapping area (NPS AlaskaPak V2.2 2010). This layer sets up 99 2 km x 2 km manageable grid cells in which each grid cell has a corresponding identification number so that when the polygons are augmented they can be documented to their location on the GIS map. This layer not only helped in keeping track of where these polygons were, but also what polygons still needed to be examined or adjusted.

Completed Polygons

The completed polygon layer was developed so that there was a way of tracking the individual polygons that were adjusted in the 2010 benthic habitat layer. This layer was designed so that once a polygon had been examined or adjusted it would become a predetermined contrasting color to the other polygons. This enabled the observer to keep track of what was worked on and what was still in need of examination as they went from polygon to polygon.

A column was also added to the 2010 benthic mapping layer attribute table,"DRTO_2010_Benthic_Map", called Date_checked. Each time a polygon was checked and adjustments completed, the date of when its completion was put into the Date_checked column. The completed polygon layer was developed by taking a copied layer from the 2010 benthic mapping layer that was being worked on, and a rule was added in the definition query which stated," [Date_checked] is not null". In the symbology field an appropriate color was picked in the single symbol feature so that it did not match any of the color schemes being used to determine the benthic habitat. The definition query was then activated and the chosen color for the completed layer filled in those polygons.

Excel Tracking Log

An excel spreadsheet was developed to help track the changes of the polygons and Table 2 provides the table layout.

Table 2. Tracking changes log column labels.

Excel Column Label	Description
Park	This is for the park identification Ex. DRTO (Dry Tortugas National Park)
Grid ID	The grid cell number is placed here to identify which cell the polygon change is taking place.
Polygon ID	The polygon number of the adjusted or examined polygon from the attribute table is placed here to allow for identification of the polygon that was changed.
Modification type	Describes what type of modification was made to the polygon. • Line Modification — Adjustment of the line work of the polygon. • Attribute change — Change the name of the polygon. • New polygon — Draw a new polygon • Deleted polygon — Remove the polygon • Move polygon — Adjust the polygon over the correct feature. • Merge — Combining of like polygons • None — Inspection of the polygon, but with no adjustment needed
Image used	This identifies what image or combination of images that were used to make the polygon change. The following are the codes used for each image: • Side scan — The raw 30cm side scan return data from the side scan sonar. • Bathymetry — The raw side scans converted .xyz data sets • LiDAR — The 2004 LIDAR data set • IKONOS — The 2006 4m IKONOS blue band imagery • IKONOS RGB — The 2006 4m IKONOS imagery
High Potential	This delineates the areas that during the investigation process were determined to have higher potential habitats for coral and reef fish.
AA points used	This delineates the polygons that field data points were used to confirm the polygon's identification.
Obvious correct polygon	This category was marked when the polygon change or identification is determined with a higher certainty.
Notes	This was used for any notable issues that occurred with the polygons.

Step 4) Develop a layer to check topology

Maintaining topology was one of the more difficult procedural challenges of this project. Topology is the study of those properties of geometric objects that remain constant under certain transformations such as cutting or expanding (Chang, 2007). Topology checks were conducted to detect errors, such as polygons that were not closed, had gaps or polygons that overlapped as shown in (Figure 9). These errors can occur during polygon line adjustment, creation and deletion processes. These kinds of errors must be corrected to avoid incomplete features and to ensure data integrity (Chang, 2007).

In order to use the topology feature in ArcGIS 9.3, a geodatabase was created and a feature data set was created within it. From this feature data set, a "feature class single" was imported (NOTE: This is the layer on which adjustments to the line work were made). With the feature data set highlighted, again in the drop down menu topology was selected, and then add rules where in the rules "must not overlap" and "must not have gaps" were selected. If there were errors, this topology checker helped to find them and through the use of the editor tool, the errors were fixed.

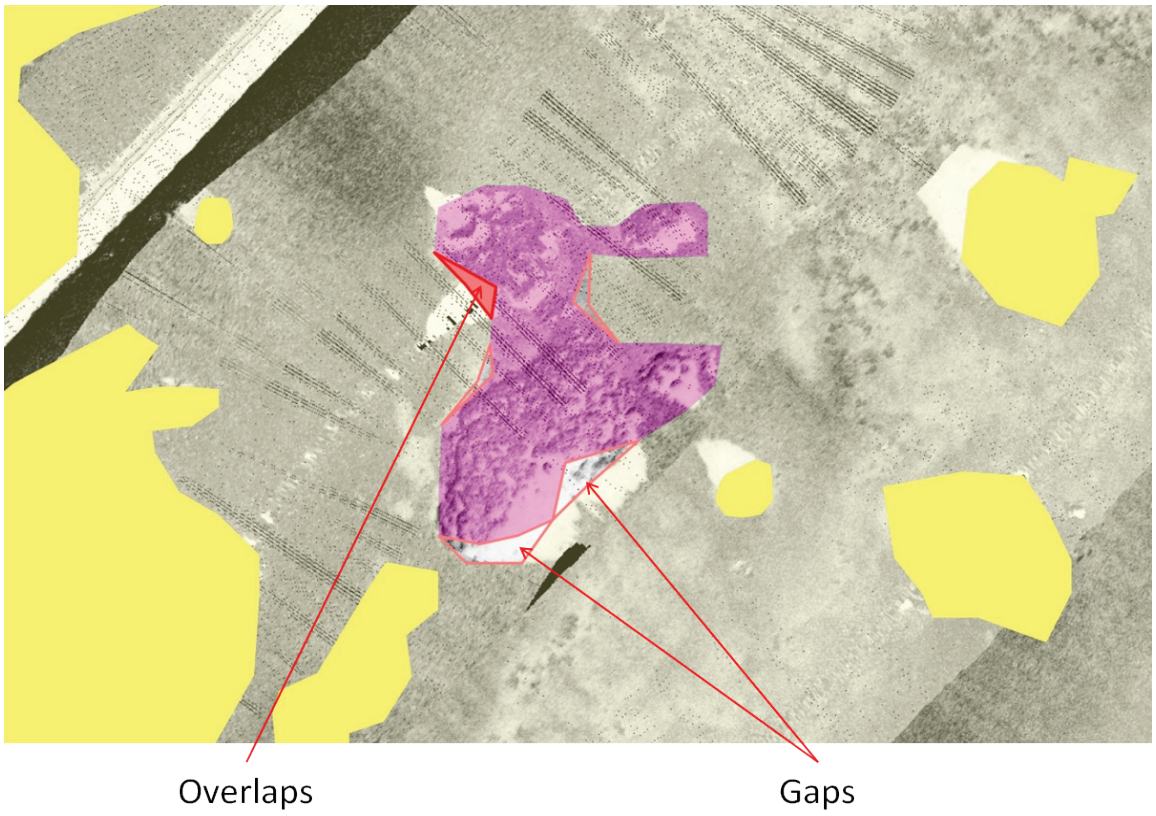


Figure 9. Shown here is an example of the overlaps and gaps that topology checker displays when run.

Step 5) Convert the newly acquired raw side scan sonar.xyz data into a raster based data set.

Acquisition of side scan sonar data

While aerial and satellite imagery along with LiDAR bathymetric data are widely used in the discrimination and mapping of marine habitats, these techniques have a limited application to shallow waters (usually <15 m) (Kenny et al., 2003). Thus the acquisition of side scan sonar data provided critical information for mapping of deeper or more turbid areas of the park.

For environments deeper than 15m, side scan sonar and corresponding bathymetric data were collected by Stanley D. Locker, Ph.D. and others from the College of Marine Science of the University of South Florida in 2008. Side scan sonar is defined as an acoustic imaging device that provides a high-resolution picture of the seabed.

The equipment that Locker's group used was the Teledyne-Benthos C3D Sonar System. This system is a fully integrated sonar system that acquires high resolution side scan sonar imagery combined with swath bathymetry to produce an accurate 3D map of the ocean floor. The parameters that Locker's group used for their side scan sonar data collection were:

- Side scan was 200kHz.
- Acquired at a range of 100m (200m swath), but to achieve overlap the survey line spacing was reduced to 120m giving a 65-70 m range.
- Raw bathymetry resolution was around 5-6 cm per data point.
- Side scan was about 5cm.
- Since track resolution varied as a function of ship speed, the vessel speed was 3.5-4.5 kts with a corresponding ping rate of 8 pings per second.
- Side scan gain balancing was done using Angle Varying Gain.
- The raw bathymetry was down sampled initially to mimic a 0.1 degree multibeam. This meant that the raw data brought into processing had increasing data point separation with range.
- Final geotif and xyz bathymetry was output at 1 m resolution.
- At the 90 m range the bathymetry data points were at 50 cm spacing. Then at the range of 60-70 meters the bathymetry point spacing was around 25cm.

The side scan sonar produced two products. The first was a set of raw 2-dimensional images produced by side scan backscatter with a resolution of 30cm. The second was a raw swath bathymetry data layer. The post processing and filtering of the final bathymetry data was accomplished with the program Cleansweep (OIC Cleansweep, 2009). This program provides an interface to all data streams for post-processing of both side scan and bathymetry data. It also converts the raw .xyz data into contour, 3D surface, 3D wireframe, vector, image, shaded relief, and post maps. Once the post processing was completed for this large side scan data set, the final merged LiDAR and newly acquired bathymetry data layer was created by using ARC maps mosaic tool. This new bathymetry merged layer had a horizontal resolution of 1m and covered over 90% of the park. The final side scan bathymetry and LiDAR merged layer was reviewed by NPS underwater archaeologists from the submerged resource center (SRC) to ensure this data set did not give away locations of Submerged Cultural Resources with potential portable artifacts.

Conversion of raw side scan sonar data

The bathymetry data files from the side scan sonar came in .xyz format which was converted into a Raster format in order for ArcGIS 9.3 to be able to interpret these .xyz files. This process consisted of four conversion steps:

1. A personnel geodatabase was created.
2. The .xyz file was converted to a "feature class" using ArcGIS 9.3 toolbox's 3D analyst tools.
3. The "feature class" was converted to a Terrain file.
4. The file was converted from a "terrain format" to a raster.

Once this was accomplished, ArcGIS 9.3 could use this tiff raster file for bathymetry since it has a z axis (vertical characteristic).

Step 6) Create a 3-dimensional map of the benthic layers.

Through the use of ArcScene, the benthic areas were converted into a 3-dimensional (3D) format. The raster formatted side scan sonar files as described in step 4 and the LiDAR data were uploaded into the ArcScene program. These benthic layers have a z dimension to them or depth parameter, which with ArcScene was converted into a 3D map (Figure 10).

Then inside ArcScene a couple of adjustments were made to the properties of the bathymetry files to give the optimal view of the 3D layer file. The first was to adjust the z unit conversion or exaggerate it to give more dimensions to the layer. The second was to set the rendering to the highest quality. This gave the highest resolution of the layer thereby giving finer detail to the image. The ArcScene program allowed navigation around the layer giving different views that were used to determine edges and rugosity of the benthic layers.

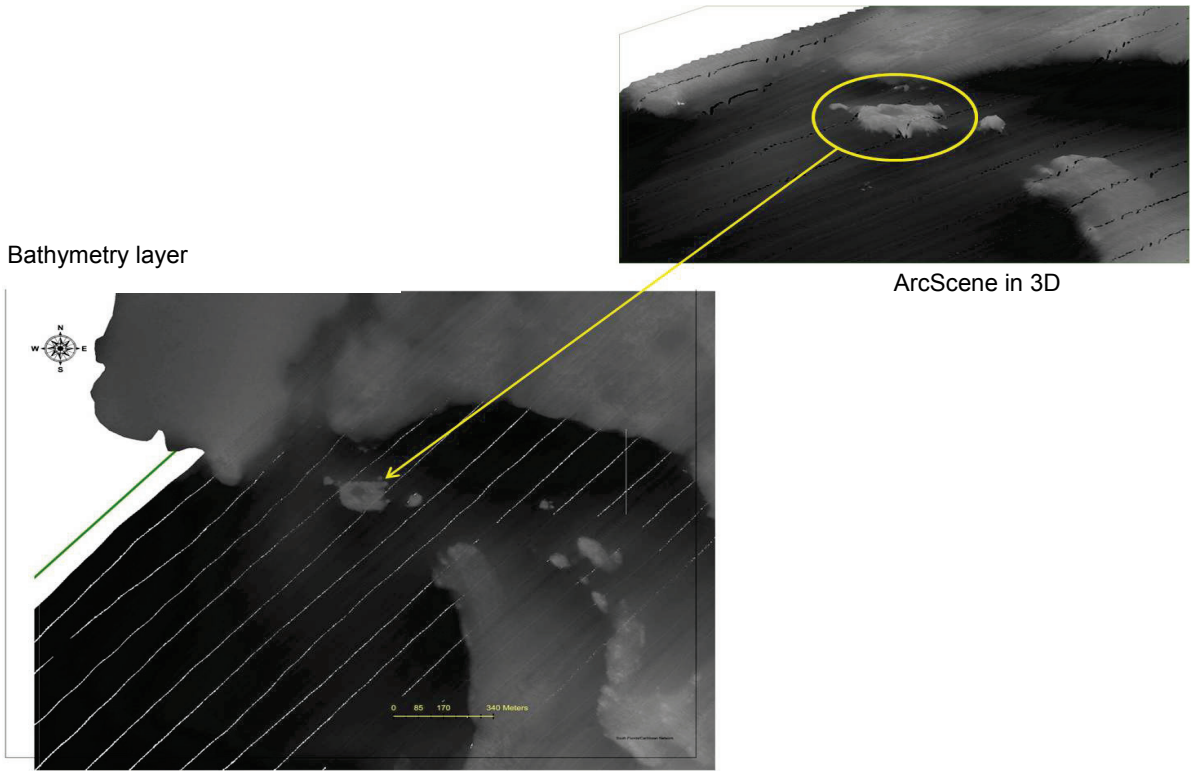


Figure 10. Images showing side scan imagery and corresponding 3D image in ArcScene.

Step 7) Select the marine benthic classification

The 2008 benthic habitat map used the National Oceanic and Atmospheric Administration (NOAA) hierarchical classification scheme to classify the benthic habitats (Appendix B). However, the final 2010 map was classified according to FWRI's System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) (Table 3 and Appendix C). The change to the SCHEME classification system was made because:

a) The SCHEME benthic habitat classification contained important reef sub-classes (Low vs. High Relief Spur and Groove; Reef Terrace vs. Reef Remnant) that were not available in the NOAA classification scheme and which were felt to be important because they were ecologically distinct and useful for future resource management in determining where the most ecologically sensitive areas are located and allow for protection or monitoring of these habitats. (Brock et al., 2006), (Wilson et al., 2007), (Wedding et al., 2008), (Veron, 2000);
b) The NOAA classification was already cross-walked to the SCHEME classification;
c) The NOAA hierarchical classification scheme draft is currently being worked on.

The NOAA hierarchical classification system is maintained in the 2010 map database, however the 2010 map products use the SCHEME classification.

Table 3. Abbreviated classification scheme from Madley et al (2002) SCHEME used in the creation of the Dry Tortugas National Park benthic habitat map. For detailed classification definitions see Appendix C. (*) = map class

1. Unconsolidated Sediments (*)
2. Submersed Aquatic Vegetation (SAV)
    21. Submersed Rooted Vascular Plants (SRV) (i.e. seagrasses and oligohaline grasses)
        211. Continuous SRV (*)
        212. Discontinuous SRV (*)
3. Reef/Hardbottom
    31. Coral Reef
        311. Platform Reef (also bank reef)
            3111. Linear Reef
                31111. Reef Terrace (high profile) (*)
                31112. Remnant (low profile) (*)
            3112. Spur and Groove
                31121. High Relief Spur and Groove (*)
                31122. Low Relief Spur and Groove (*)
            3113. Reef Rubble (*)
        312. Patch Reefs
            3121. Individual Patch Reef (*)
            3124. Aggregated Patch Reefs (*)
        313. Patchy Coral and/or Rock in Unconsolidated Bottom (*)
    34. Hardbottom
        Pavement (i.e. low relief hardbottom) (*)
6. Land (*)
A. Artificial (*)

Step 8) Modify polygons

Polygon modification consisted of the adjustment and creation of the new benthic mapping layer. This step used all of the corresponding layers, field data points, and the 3D ArcScene map to determine what adjustments were made to the polygons.

The method used for the polygon adjustments was a modified version of the interactive, or "heads up," digitization. Using this method, an aerial photograph, satellite image, or orthophotograph was displayed onscreen as a basemap and then a polygon layer (in this case the 2008 benthic habitat map) was displayed over the top of the base map, which allowed for the basemap to be seen through the 2008 benthic map. This allowed for tracing or redrawing of features, such as seagrass beds, patch reefs and reef and sand interfaces (Figure 11). The 2008 benthic mapping layer or base map upon the completion of the modifications became the new updated 2010 benthic habitat map.

To help with the defining and tracking of the polygons, additional data were entered into the attribute table of the new 2010 benthic habitat map. The following attribute columns were added:

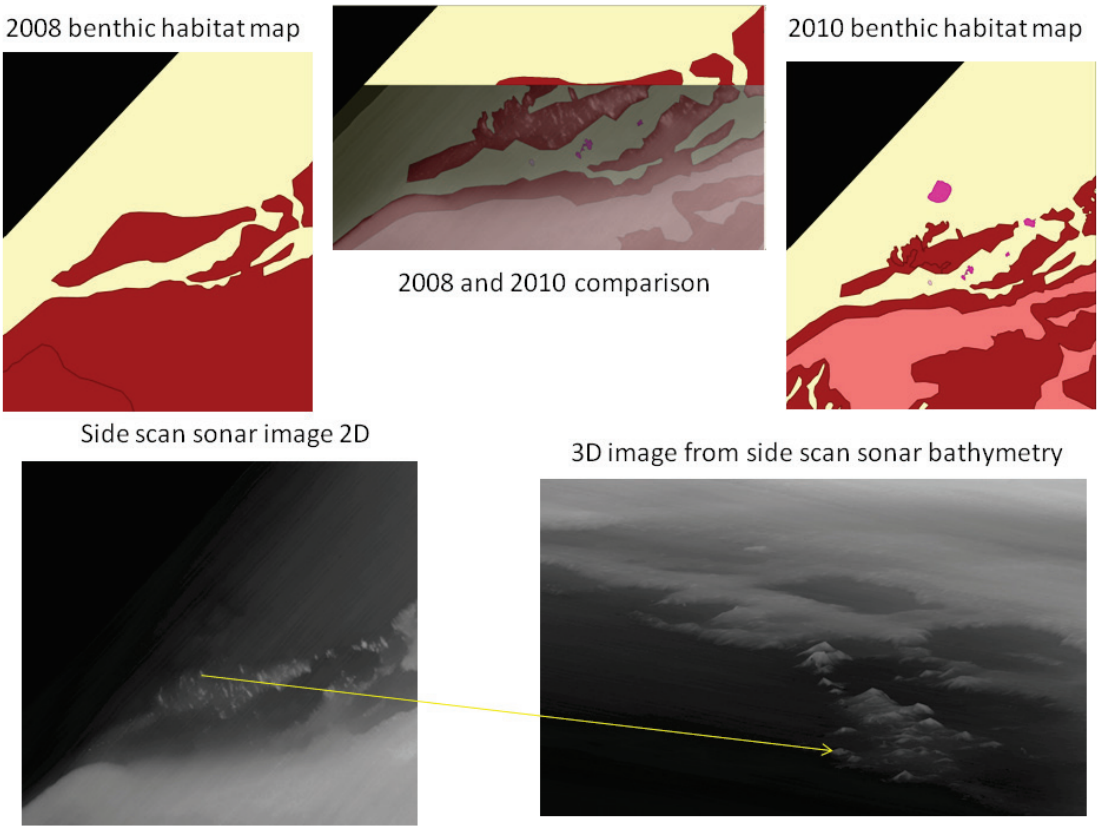


Figure 11. Example of area before and after adjustments with side scan sonar 2D and 3D images.

Column name	Purpose
Reef_Edge	This column was marked with a “y” or “n” to determine if the polygon being worked on was a reef edge. Reef edges have a higher potential for coral cover and fish numbers.
Date_check	The date when the polygon was created or adjusted.
High_poten	This column was marked with a “y” or “n” to determine if the polygon being worked on was of higher potential for coral cover and reef fish habitat.
GEO_MODIFI	This column was where the subclasses of Low Relief Spur and Groove and Remnant Reef are documented in a manner that maintains a format that the terms can be related to in the NOAA classification.

Polygon modifications occurred once the required layers were assembled and the new 2010 benthic layer was created.

The polygon modification process was started by activating the ArcGIS 9.3 Editor toolbar, which allowed for the editing of features and geometries in the 2010 marine benthic map layer (Figure 12). Once the editor toolbar was turned on and the appropriate layer was selected (DRTO_Benthic_Map_2010**)** adjustments or editing were completed.

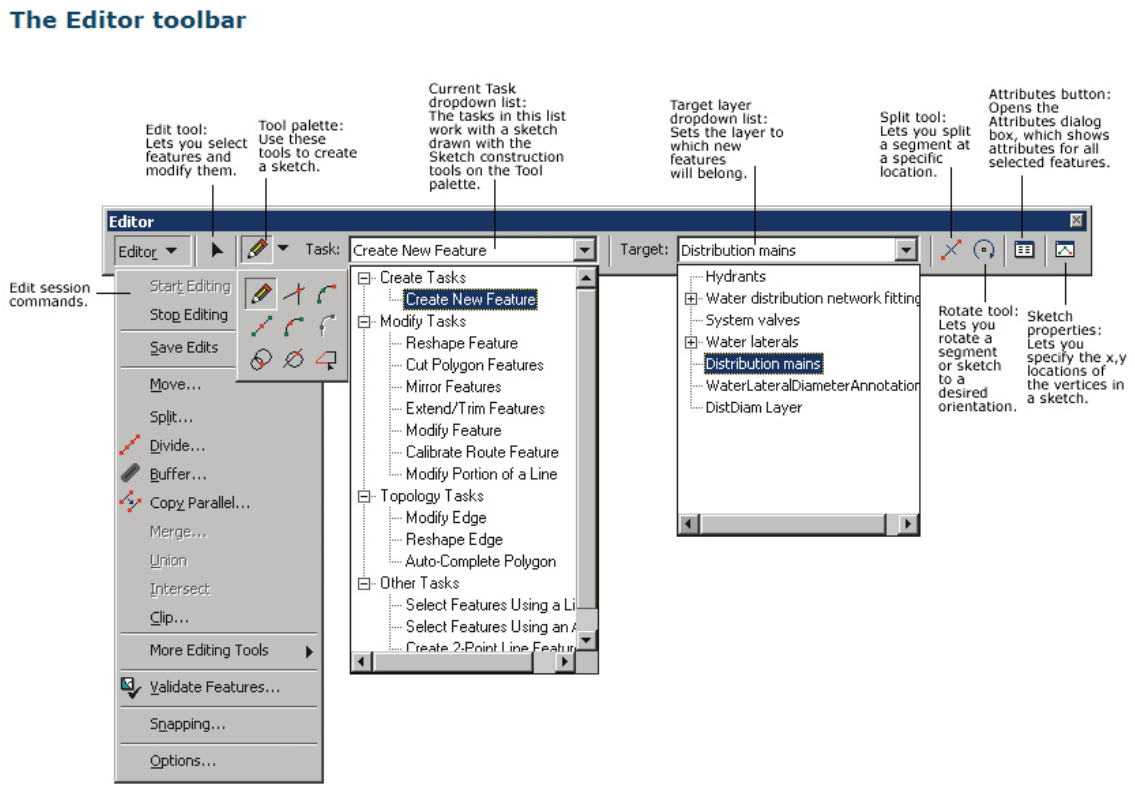


Figure 12. ArcMap editor tool bar.

Editing a polygon was a straight forward process if the appropriate tools in the editor were selected. The following tools caused issues in topology when they were used in the editor. The "create new feature" tool was used to draw over the feature that was seen in the basemap, but it caused overlap in the topology. The other was the "modify feature" tool which was used to move vertices of the polygon to match the base map feature, but in the working layer it caused overlaps or produced holes. During the polygon adjustment process these two tools caused the most errors in the topology of the benthic map. The topology editing layer was used to repair the errors that occurred during the editing process.

Individual Patch Reefs

The process of editing polygons was started by picking a grid cell that contained multiple patch reefs. Patch reefs were chosen because they were easier to determine what line work was needed and what adjustments to make to the benthic layer shape file.

Each patch reef was pulled into view in the ArcGIS project with the base map imagery and 2010 benthic map overlay. The patch reef was observed in all four base map images and the one that produced the best image of the patch reef was left in the forefront. Then one of the two ArcScene 3D maps with the patch reef in was turned on and displayed. There were two ArcScene 3D maps since the filtering process of the side scan and its merge with the LIDAR data did not occurr initially.

The appropriate adjustments were made to the patch reef polygon. The attribute table in the 2010 benthic map was updated to reflect the polygon evaluation and changes. The attribute table update caused the completed polygon layer to update and turn the completed patch reef polygon yellow. The adjustments were recorded in the excel log file. Then the save edits was activated in the Editor tool and the polygon adjustment was saved. This process was continued until all polygons in that grid cell had been completed. The Minimum Mapping Unit (MMU) for the 2010 map was 0.5 hectares, but the patch reefs in the 2010 benthic map were frequently mapped to a much smaller size.

Aggregate Patch Reefs

The aggregate patch reefs were evaluated along with the individual patch reefs. During the aggregate patch reef modifications as much of the non-reef structure was edited out of the aggregate patch reef polygon as reasonably possible. In addition, many of the patch reefs located in the Aggregate Patch Reefs polygons were separated and reclassified into Individual Patch Reefs depending on the photointerpretation.

Linear Reef, Spur and Groove, and Unconsolidated Sediment

Reviewing and editing the larger polygons of Linear Reef (Aggregate Reef in NOAA classification), Spur and Groove, and Unconsolidated Sediment included examining and adjusting the line work of the hard bottom (reef) and unconsolidated sediment (sand) interface. This was accomplished by using the same steps that were used in the patch reef polygon work. Then the interfaces that occurred within the larger polygon were evaluated and mapped, which were typically sand patches, rubble and hard bottom interfaces.

Remnant, Reef Terrace, High Relief Spur and Groove and Low Relief Spur and Groove

The most difficult portion of the polygon modification process was the dividing up and identification of Linear Reef (Aggregate Reef) into Remnant and Reef Terrace and of Spur and

Groove into High Relief and Low Relief Spur and Groove. The same procedures used in the other habitat category adjustments were conducted, but the field data points and 3D ArcScene maps played more of a critical role in the final editing process. After conducting the photointerpretation, the interface between these sub-categories were much harder to differentiate. However, the 3D ArcScene map was able to show the amount of relief which is the critical distinguishing feature in these sub-categories and coupled with the base map data and field data points allowed the sub-division and classification of these polygons.

Unknown Polygon Adjustments

The 2008 benthic habitat map had five polygons that were classified as "unknown". However, newly acquired field data points, raw side scan imagery and bathymetry data that were not available during the development of the 2008 benthic habitat map allowed the previously unknown polygons to be classified.

After conducting photo-interpretation of all of DRTO using all data sets including the side scan bathymetry and return imagery, there were no significant structures found in these previously unknown areas. In addition, there were a total of 101 field data points from the 2008 AA assessment data of which 83.2% of the points were a 100% match to Unconsolidated Sediment. For a description of the other 12 points see Table 4. The Scattered Coral Rock in Unconsolidated Sediment classification is similar in structure to the Unconsolidated Sediment classification and is close in structure and image return. Five field data points landed near or on the edges of the polygons. There was also one point classified as pavement in the Unknown areas that the imagery could not reach because of depth constraints and the side scan did not return a signature of pavement, but rather Unconsolidated Sediment.

Taking all of this data into account, it was decided that there was enough information to identify the previous unknown polygons as Unconsolidated Sediment. However map users should be aware that there may be some small areas of these other categories within it. These five unknown polygons added 10,443.8 hectares to the Unconsolidated Sediment category and produced a complete habitat map for the Dry Tortugas National Park.

Table 4. Field data point description corresponding to the Unknown polygon area in the 2008 map.

Habitat description	Number of Field data points	Notes regarding similarity to Unconsolidated Sediment
Unconsolidated Sediment	84	100% match
Scattered Coral Rock in Unconsolidated Sediment	6	Similar category
Pavement	3	Points fell on boundary between categories or were too deep to be detected by imagery
Reef Rubble	1	
Aggregate Reef	1	
Aggregate Patch Reef	1	

Final topology check

Once all the adjustments were made to the benthic map polygon features a final topology check was done to clean up any slivers or small polygons that could be merged into an existing and adjacent polygon. The geodatabase topology feature in ArcGIS locates slivers and then allows the features to be merged into the adjacent matching polygons. In addition, by sorting the attribute table by area all polygons smaller than 200m^2 were investigated to determine if they were real benthic features or artifacts of the editing process.

Step 9) Develop highest potential habitat layer for coral and fish biodiversity

An additional ArcGIS layer created as part of the 2010 benthic habitat map product was the development of a "higher potential" layer (Figure 13). The layer was developed to show those areas in the park that were expected to have a greater potential for biodiversity and abundant coral reef and reef fish habitats. It has been shown that rugosity and complexity are correlated to coral recruitment (Carleton and Sammarco, 1987), (Dana, 1976), coral species richness (Kuffner et al., 2008), (Tomansick, 1991), (Brock et al., 2006), (Wilson et al., 2007), and fish assemblages (Wedding and Friedlander, 2008), (Wedding et al., 2008). So this layer included all patch reefs and aggregate patch reefs, along with those reef edges or those areas that displayed higher rugosity or complexity.

To determine the reef edges and other reef habitats that had higher rugosity and complexity the 3D ArcScene maps and field data points were used by having them displayed in two separate ArcMap projects and then using photointerpretation the areas were drawn out and saved to produce this high potential layer. The high potential areas on the reef edge tended to be 20 to 50m from the sand interface up the reef edge till the habitat became more gorgonian or soft coral dominated with less rugostiy and complexity.

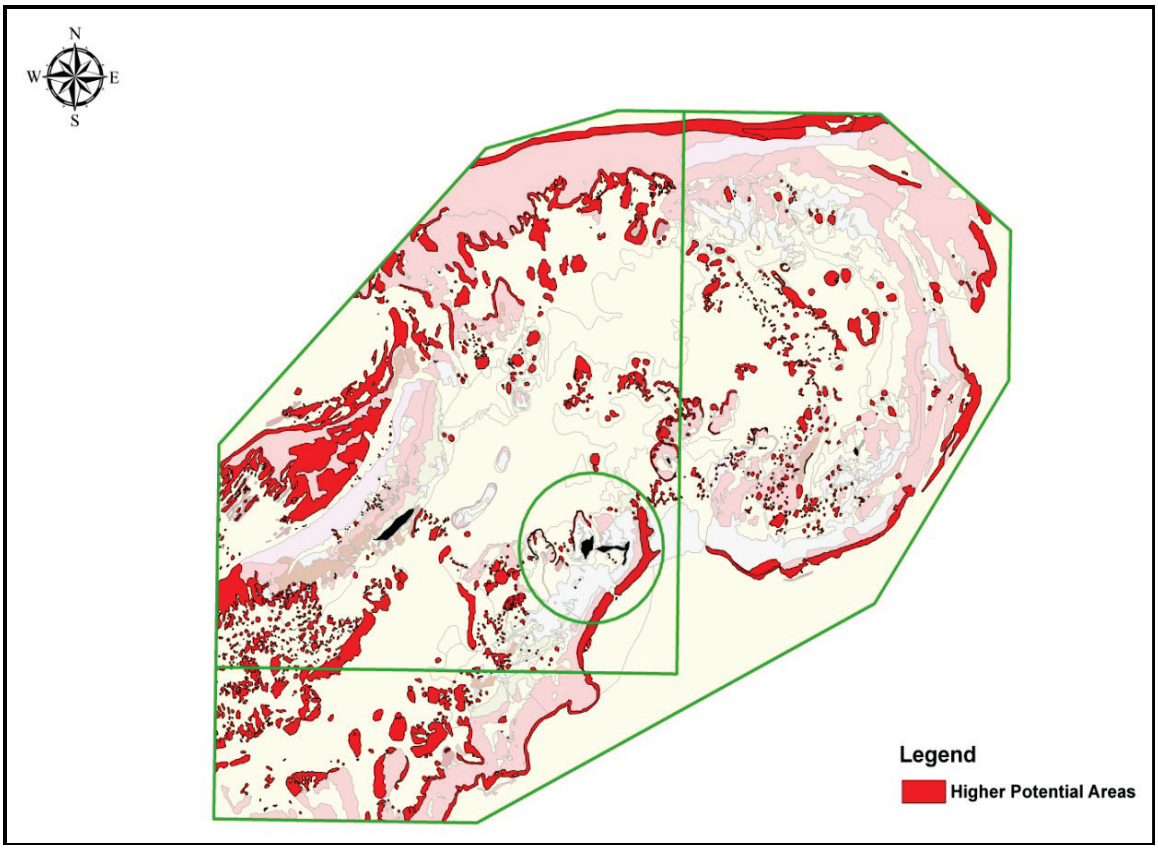


Figure 13. Higher potential areas.

Results

This project produced several new data sets. The following provides details regarding each data set, the details of the data collection, analysis, and final deliverable. These lists are not exhaustive, but illustrative for those who are not familiar with this type of data.

The 2008 DRTO Marine Benthic Map Accuracy Assessment

2008 Avineon benthic habitat map classification accuracy assessment

Of the 300 points initially randomly selected, 250 were visited in the field due to time constraints and logistics. There was an exact match between the field classification and the map classification for 100 of the 250 points. Then upon review and analysis of the points as described above, an additional 108 points were considered acceptable map classifications giving a final map classification accuracy of 83.2% with a lower 90% confidence level of 79.8%. The distribution of the acceptable and unacceptable points is shown in Figure 14. Since there was no marine benthic habitat mapping accuracy assessment standards established during the development of the benthic habitat map, it was decided to use the assessment standards used by the NPS Vegetation Mapping Inventory Program. Their standards of map classification are 80% accuracy with 90% confidence.

The most common reason an accuracy assessment point was considered acceptable despite not being an exact match to the field classification involved issues of classification scale. For example, points that were field classified as Aggregate Patch

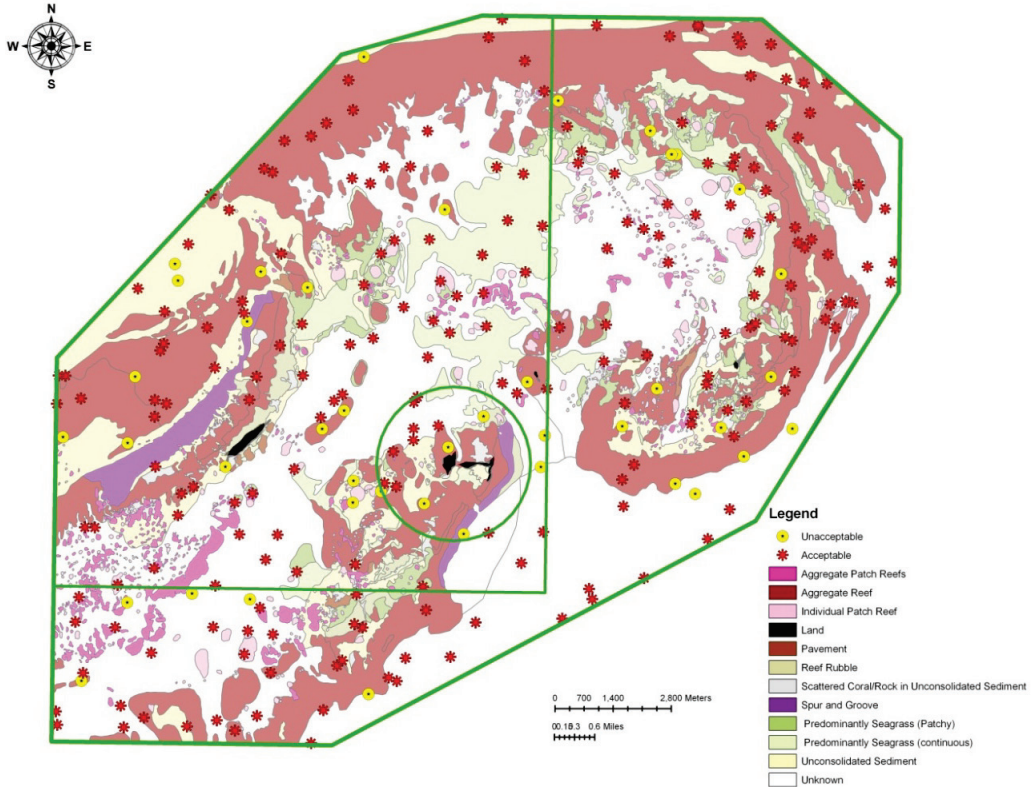


Figure 14. Distribution of acceptable and unacceptable accuracy assessment points.

Reefs but were classified on the map as Individual Patch Reefs were considered acceptable. The misclassification of Aggregate Reef as Pavement was the second largest issue and could also be considered in part an issue of classification scale (Table 5). Eight points fell within 3m of a polygon edge that was a matching classification.

Analysis of benthic classification errors

Tables 6 and 7 show a breakdown of the errors by map class and field class, respectively. When hard bottom and soft bottom habitats were analyzed separately, the hard bottom habitats had an accuracy of 75.2% with a 90% lower confidence level of 69.1% while the soft bottom habitat had a much higher accuracy of 89.4% with a lower 90% confidence level of 85.2%. Thus, the accuracy of the hard bottom habitat in the 2008 map had room for improvement, providing the justification to update the map using the side scan sonar and other data.

When examined on a class by class basis, the class of greatest concern in the 2008 map appeared to be Spur and Groove. For all four times that the AA points were field classified as Spur and Groove, none were classified as Spur and Groove on the map and in only one case was the map class considered acceptable. Thus Spur and Groove may be under represented in the 2008 benthic habitat map. Although the field classes of Pavement, Reef Rubble, Scattered Coral Rock and Unconsolidated Sediment, and Aggregate Patch Reef rarely matched the exact map classification it was determined that in most cases the map classification was acceptable. The main reason for the differences was classification scale and accurate definitions of the field class. Tables 6 and 7 summarize the accuracy assessment results.

Table 5. Summary of reasons an accuracy assessment point was considered acceptable when it was not a 100% match to the field definition.

Acceptance Rationale	# AA Points
AA error (see video)	5
Classification Scale	29
Classification Scale/On Edge between Class definitions	12
Equivalent class	13
On Edge between Class definitions	11
On Edge between Class definitions/Polygon edge	2
Pavement/Aggregate Reef Cutoff	30
Polygon edge	6
Grand Total	108

Table 6. Accuracy assessment of 2008 Avenion benthic habitat map by mapping class.

2008 Map Geological Classification	2008 Map Biological Cover Classification	Accuracy Assessment Field Classification	Acceptable		Grand Total	Raw 100% accuracy	Acceptable accuracy	Lower 90% Confidence Interval
			No	Yes				
Aggregate Patch Reefs	Unclassified	Aggregate Patch Reefs		2	2			
		Pavement		1	1			
		Reef Rubble		2	2			
		Scattered Coral Rock in Unconsol Sed	1	1	2			
	Total		1	6	7	29%	85.7%	
Aggregate Reef	Unclassified	Aggregate Patch Reefs	2	5	7			
		Aggregate Reef		6	6			
		Individual Patch Reefs		1	1			
		Pavement		32	32			
		Reef Rubble	5	3	8			
		Sand	2	2	4			
		Scattered Coral Rock in Unconsol Sed	5	12	17			
		Spur and Groove		1	1			
		SRV	7		7			
	Total		21	62	83	7.2%	74.7%	
Individual Patch Reef	Unclassified	Aggregate Patch Reefs		3	3			
		Pavement		3	3			
		Reef Rubble		1	1			
		SAV		1	1			
		SRV		1	1			
	Total			9	9	0%	100.0%	
Pavement	Unclassified	Spur and Groove	1		1			
		SRV	1		1			
	Total		2		2	0%	0.0%	
Reef Rubble	Unclassified	Pavement		1	1			
		SAV		1	1			
		Spur and Groove	2		2			
	Total		2	2	4	0%	50.0%	
Scattered Coral/Rock in Unconsolidated Sediment	Unclassified	Pavement		1	1			
		Reef Rubble		1	1			
		Sand	1	1	2			
	Total		1	3	4	0%	75.0%	
Total Hardbottom			27	82	109	7.3%	75.2%	69.1%
Unconsolidated Sediment	Predominantly Seagrass (continuous)	Sand	1	4	5			
		SAV		1	1			
		SRV		16	16			
		Total	1	21	22	72.7%	95.5%	
	Predominantly Seagrass (Patchy)	Reef Rubble		1	1			
		Sand		2	2			
		SRV		4	4			
		Total	0	7	7	57.1%	100%	
	Unknown	Aggregate Patch Reefs	1		1			
		Aggregate Reef	2		2			
		Pavement	3	1	4			
		Reef Rubble		5	5			
		Sand		72	72			
		SAV		13	13			
		Scattered Coral Rock in Unconsol Sed	3	4	7			
		SRV	5	3	8			
		Total	14	98	112	64.3%	87.5%	
Total Unconsolidated Sediment			15	126	141	81.6%	89.4%	85.2%
Grand Total			42	208	250	40.0%	83.2%	79.8%

Table 7. Accuracy assessment of 2008 Avenion benthic habitat map by field class.

Accuracy Assessment Field Classification	2008 Map Geological Classification	2008 Map Biological Cover Classification	Acceptable		Grand Total	Raw 100% accuracy	Acceptable accuracy
			No	Yes			
Aggregate Patch Reefs	Aggregate Patch Reefs	Unclassified		2	2		
	Aggregate Reef	Unclassified	2	5	7		
	Individual Patch Reef	Unclassified		3	3		
	Unconsolidated Sediment	Unknown	1		1		
	Total		3	10	13	15.4%	76.9%
Aggregate Reef	Aggregate Reef	Unclassified		6	6		
	Unconsolidated Sediment	Unknown	2		2		
	Total		2	6	8	75.0%	75.0%
Individual Patch Reefs	Aggregate Reef	Unclassified		1	1		
	Total			1	1	100.0%	100.0%
Pavement	Aggregate Patch Reefs	Unclassified		1	1		
	Aggregate Reef	Unclassified		32	32		
	Individual Patch Reef	Unclassified		3	3		
	Reef Rubble	Unclassified		1	1		
	Scattered Coral/Rock in Unconsolidated Sediment	Unclassified		1	1		
	Unconsolidated Sediment	Unknown	3	1	4		
	Total		3	39	42	0.0%	92.9%
Reef Rubble	Aggregate Patch Reefs	Unclassified		2	2		
	Aggregate Reef	Unclassified	5	3	8		
	Individual Patch Reef	Unclassified		1	1		
	Scattered Coral/Rock in Unconsolidated Sediment	Unclassified		1	1		
	Unconsolidated Sediment	Predominantly Seagrass (Patchy)		1	1		
		Unknown		5	5		
	Total		5	13	18	0.0%	72.2%
Sand	Aggregate Reef	Unclassified	2	2	4		
	Scattered Coral/Rock in Unconsolidated Sediment	Unclassified	1	1	2		
	Unconsolidated Sediment	Predominantly Seagrass (continuous)	1	4	5		
		Predominantly Seagrass (Patchy)		2	2		
		Unknown		72	72		
	Total		4	81	85	84.7%	95.3%
SAV	Individual Patch Reef	Unclassified		1	1		
	Reef Rubble	Unclassified		1	1		
	Unconsolidated Sediment	Predominantly Seagrass (continuous)		1	1		
		Unknown		13	13		
	Total			16	16	0.0%	100.0%
Scattered Coral Rock in Unconsol Sed	Aggregate Patch Reefs	Unclassified	1	1	2		
	Aggregate Reef	Unclassified	5	12	17		
	Unconsolidated Sediment	Unknown	3	4	7		
	Total		9	17	26	0.0%	65.4%
Spur and Groove	Aggregate Reef	Unclassified		1	1		
	Pavement	Unclassified	1		1		
	Reef Rubble	Unclassified	2		2		
	Total		3	1	4	0.0%	25.0%
SRV	Aggregate Reef	Unclassified	7		7		
	Individual Patch Reef	Unclassified		1	1		
	Pavement	Unclassified	1		1		
	Unconsolidated Sediment	Predominantly Seagrass (continuous)		16	16		
		Predominantly Seagrass (Patchy)		4	4		
		Unknown	5	3	8		
	Total		13	24	37	54.1%	64.9%
Grand Total			42	208	250	40.4%	83.2%

Development of a photo hyper-linking tool

During the analysis and development of the new benthic habitat map, a new tool was developed in ArcGIS for evaluating the accuracy assessment (AA) data and was invaluable for visualizing the assortment of habitats that the AA points fell upon. This tool hyperlinked photos and/or videos that were collected with each of the AA points allowing these images and/or videos to be accessible at each point together with the data it was clicked upon in ArcGIS. Therefore, as each point was re-analyzed during the post-field evaluation, the observer would look at the imagery and /or video together with the data, imagery, and map classification and determine whether the map classification was acceptable.



Figure 15. Example of side scan imagery, 3D image and corresponding photos from the AA data point

The 2010 DRTO Marine Benthic Map.

Description of the revised 2010 benthic habitat map

The 2010 DRTO benthic habitat map (Figure 16) was developed by enhancing the 2008 benthic habitat map created by the contractor Avineon, Inc. with a combination of satellite and aerial imagery, newly acquired side scan sonar data, bathymetry data, and field observations from a number of research projects. The map was projected in Universe Trans Mercator (UTM), zone 17N, North American Datum 1983 (NAD83), with a Minimum Mapping Unit (MMU) for all feature class polygons of 0.5 hectares. However, where possible patch reefs and the soft and hard-bottom interfaces where mapped to greater detail. The bathymetry data was a composite

data set, starting with the 2004 LIDAR data set which had 1m horizontal resolution joined with the 2009 raw side scan bathymetry data. Aerial imagery used were the 2006 IKONOS satellite imagery blue band – 4m spatial resolution, 2006 IKONOS satellite imagery RGB – 4m spatial resolution, 2007 National Agriculture Imagery Program (NAIP)-1m spatial resolution and the raw geotiff imagery from the side scan returns-30cm spatial resolution**.** The field data points or polygon ground truthing points came from (254) 2008 SFCN accuracy assessment points, (1,624) 2004, 2006, 2008, and 2009 reef fish visual census (RVC) benthic data points, (158) 2008 rapid habitat assessment points and (18) SFCN extensive monitoring sites giving a total of 2,054 field data points. The final 2010 benthic mapping product has a total of 13 mapping classes and 1,709 polygons and has eliminated all unknown polygon areas (Table 8).

The identification and renaming of the habitat polygons required the use of a standardized classification scheme. The 2008 benthic habitat map created by Avineon, Inc. used the NOAA hierarchical classification scheme to classify the benthic habitats (Appendix B). However the final 2010 map was classified according to FWRIs' SCHEME (Appendix C). The change to the SCHEME classification system was made because A) The SCHEME had categories already in place for ecologically important subclasses that were not available in the NOAA classification; B) The NOAA classification was already cross-walked to the SCHEME classification; C) The NOAA hierarchical classification scheme draft is still being worked on. The NOAA hierarchical classification system is still maintained in the database; however the 2010 map products use the SCHEME classification.

As the accuracy assessment of the 2008 map showed an overall classification accuracy of 79.8% with 90% confidence, which was very close to being acceptable to passing the required criteria. The 2010 project improved the detail of the line work and corrected classification deficiencies based upon the newly acquired data sets. SFCN and FWC decided a second accuracy assessment was unobtainable in the near future and the initial accuracy assessment results were largely sufficient for the 2010 map as well as the 2008 map. However map users should be aware that the accuracy of the sub-categories of High Relief Spur and Groove, Low Relief Spur and Groove, Reef Terrace, and Remnant reef have not been tested and consequently the accuracy of the High Potential layer has yet to be tested as well.

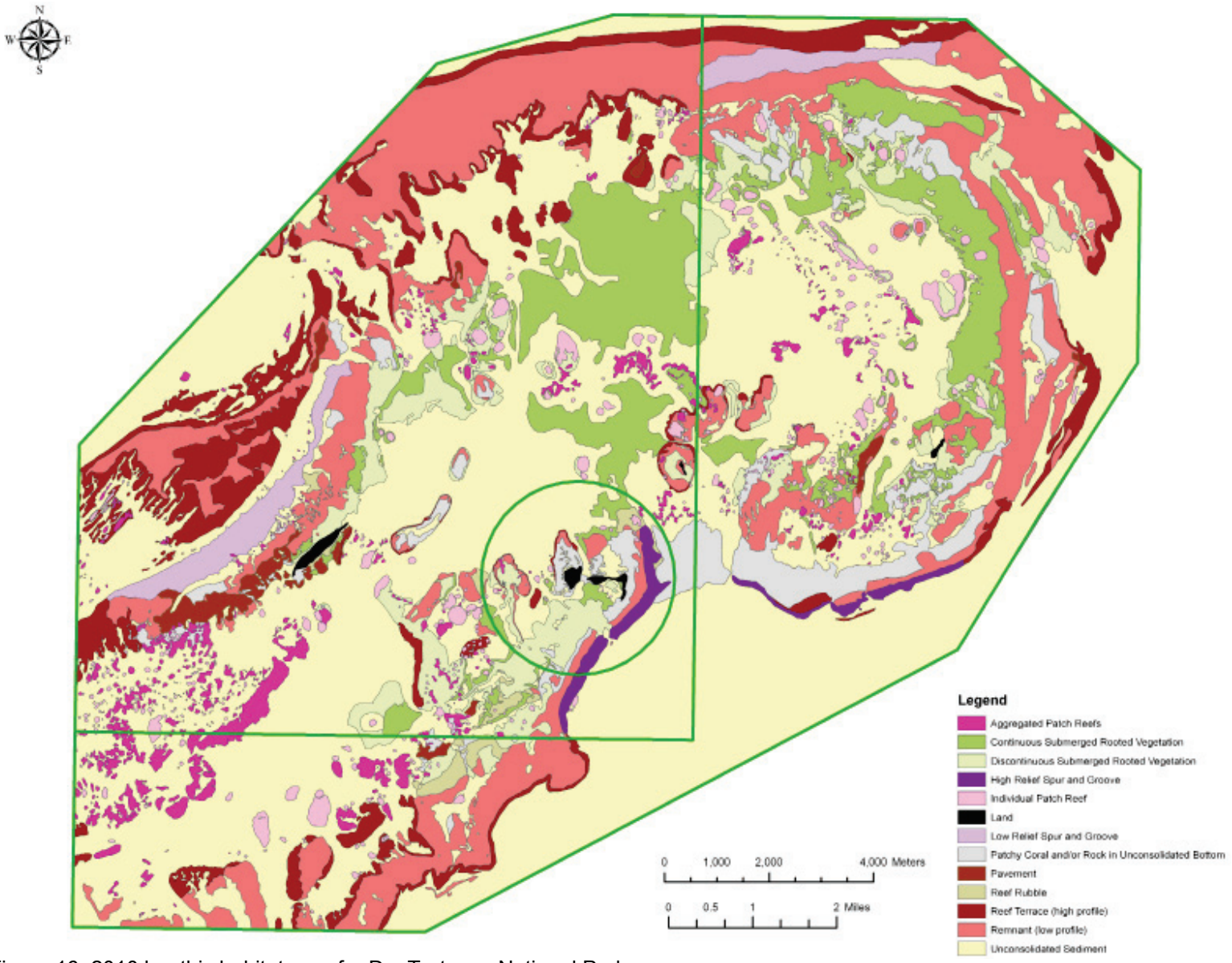


Figure 16. 2010 benthic habitat map for Dry Tortugas National Park.

Table 8. 2010 benthic habitat map summary of statistics by map class.

Map Class (Geological Structure)	Number Polygons	Total Area (ha)	Minimum Area (Ha)	Maximum Area (Ha)	Field Data Points				
					Reef Visual Census	Rapid Habitat Assessment	2008 Accuracy Assessment	SFCN Extensive Sites	Total
Aggregate Patch Reefs	404	633.0	0.029	80.6	200	6	7	1	213
Reef Terrace (high profile)	83	1871.6	0.177	506.52	681	21	15	11	729
Remnant (low profile)	75	4263.6	0.024	2472.76	178	61	50	5	294
Individual Patch Reef	736	525.6	0.013	29.5	171	5	13	1	190
Land	5	46.9	1.201	22.0	0	0	0	0	0
Pavement	16	207.5	0.416	119.59	2	4	1		7
Reef Rubble	14	128.1	0.028	34.36	0	3	2		5
Patchy Coral/or Rock in Unconsolidated Sediment	43	1011.5	0.058	264.35	28	17	12		59
High Relief Spur and Groove	4	155.6	17.561	57.1	79	1	3		83
Low Relief Spur and Groove	2	417.7	170.285	247.5	32	5	1		38
Unconsolidated Sediment	153	13244.5	0.051	12334.45	199	28	110		337
Continuous SRV	106	2267.7	0.032	777.31	17	9	28		54
Discontinuous SRV	68	1455.4	0.391	179.2	40	3	11		54

Vetting process for the 2010 benthic habitat map.

The 2010 marine benthic habitat map and its corresponding report have gone through multiple individuals for its vetting process. The first of these is an in-house review by SFCN staff. The GIS specialist reviewed the benthic map for topology errors and reviewed the attributes to confirm that they all match in description and any other mistakes that may have been made. The SFCN statistician confirmed the accuracy assessment results and data analysis. Second the benthic habitat map was sent to the GRD for review and was included in their project concerning the geology and structure of the marine environment in DRTO. The third group that reviewed this document was a committee of professors from the University of Miami's RSMAS each with varying degrees of expertise. First Dr. Marilyn Brandt-Smith whose expertise is in marine benthic ecosystems reviewed the scientific aspect of the document. Second Dr. Liana McManus, whose has an extensive knowledge of management and policy, reviewed the document for its overall use by managers and potential in policy development. Third Maria Estevanez is an expert in GIS and her review was of the mapping product and overall project development. Each committee member also reviewed the document for its overall structure and cohesiveness. The final review came from Dave Hallac, the biological branch chief for Everglades National Park and DRTO, who reviewed the document in its entirety. The DVDs of the final product and all corresponding layers that were used in its development will be available to the public. Any imagery and the hyper-link program, which was too big for the DVD package, will be hosted on the SFCN website. The benthic map is a living document that will be modified and updated as it is used and improvements are identified.

A standardized color scheme for benthic habitat mapping.

Standardizing a color scheme for habitats will help in clarifying map interpretations and prevent mistakes in classification. This type of standardization has been used for other mapping initiatives to help in maintaining consistency (Jeer, 1997). A suggested standardized color scheme is presented in (Figure 17).

Polygon Attribute	Color Scheme Name	Color
Aggregate Patch Reefs	Ginger Pink	
Continuous SRV	Medium Olivenite	
Discontinuous SRV	Olivine Yellow	
High Relief Spur and Groove	Dark Amethyst	
Individual Patch Reefs	Rhodolite Rose	
Land	Black	
Low Relief Spur and Groove	Lepidolite Lilac	
Patchy Coral/or Rock in Unconsolidated Sediment	Gray 10%	
Pavement	Cherry Cola	
Reef Rubble	Lime Dust	
Reef Terrace (high profile)	Tuscan Red	
Remnant (low profile)	Medium Coral	
Unconsolidated Sediment	Yucca Yellow	

Figure 17. Benthic habitat classification color scheme

Summary of changes between 2010 and 2008 benthic habitat maps

Modifications to over 1100 polygons were made during the course of this project as summarized in Table 9. An example of the changes in line work in the polygons between the 2008 benthic map and the 2010 benthic habitat maps are shown in Figure 18.

Table 9. Type and number of polygon modifications.

Modification Type	Number of polygons changed
Line Modification	622
Line Modification/Merge/Rename	21
Attribute Change	41
New Polygon	378
New Polygon/Merge	20
Delete Polygon	4
Move Polygon	6
Rename	8
Merge	31
None	41

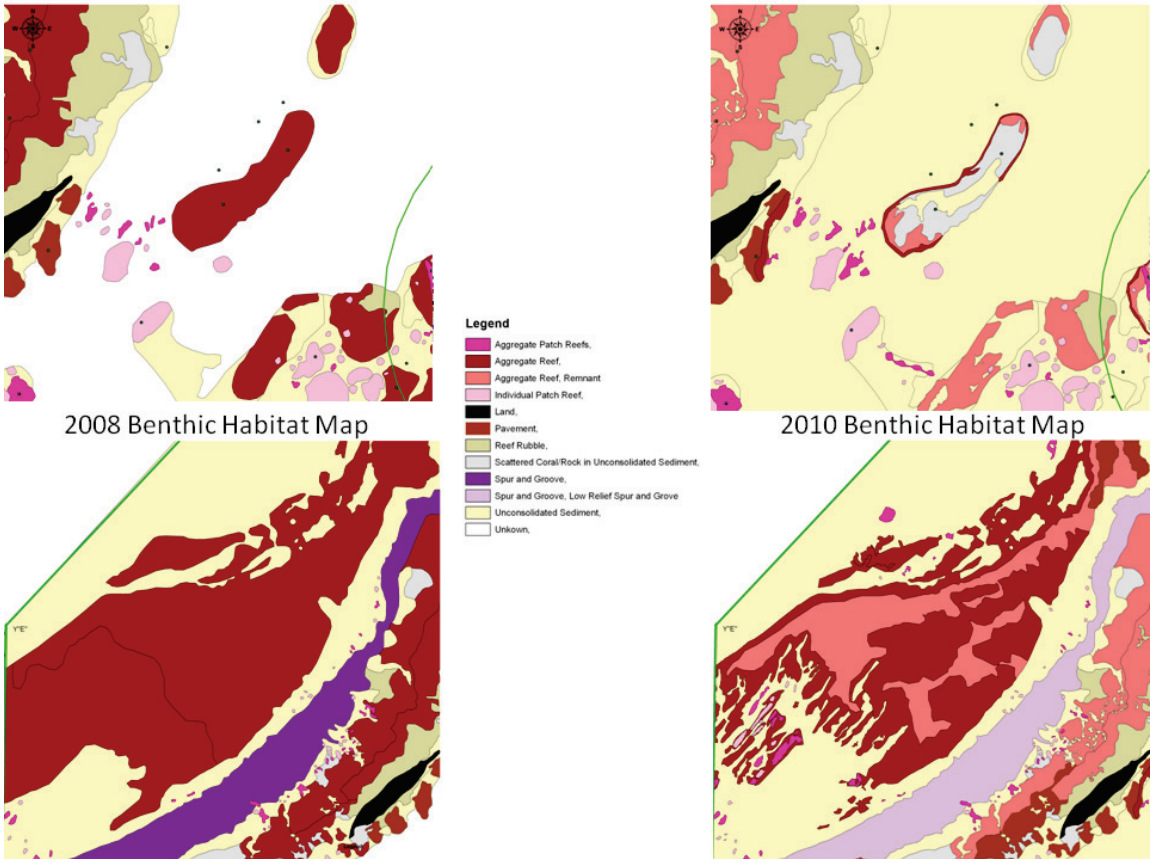


Figure 18. Comparisons between 2008 and 2010 habitat maps.

Tables 10 and 11 summarize the changes between the 2008 and 2010 maps by map class with a more detailed discussion provided below:

- ***Aggregate Patch Reefs***- There was a decrease in the number of polygons and an increase in area from the 2008 to 2010 benthic habitat maps. This was due to the dividing out of the Individual Patch Reefs from the Aggregate Patch Reefs because of the more accurate polygon delineation and increased resolution from the new data. There was an increase in Aggregate Patch Reef area due to the drawing in of previously unknown small patch reef structures into the already existing polygons. This was due to the increased resolution of the data and the ability of this data to show what the deeper and more turbid water environments contained.
- ***Linear Reef (Aggregate Reef)-*** From the comparisons of the cross-walked categories of Linear Reef and Aggregate Reef there was an increase in polygons, but a decrease in area from the 2008 to 2010 due to the following reasons. First, there more accurate polygon delineation from higher resolution data from the side scan sonar surveys, which reduced the overall area of the polygons. Second there was the establishment of the Low Relief Spur and Groove polygons in the Aggregate Reef areas that were originally in the 2008 marine benthic habitat map. These polygons were created because of the side scan sonar data and corresponding field data points indicated a difference in habitat structure. In addition, the Linear Reef category was split into two subclasses that were used in the 2010 map development Reef Terrace (high profile) and Remnant (low profile).
- ***Individual Patch Reefs***- There was an increase of individual patch reefs, but a decrease in total individual patch reef area. The side scan sonar data allowed for the location and more accurate drawing of the individual patch reefs so the numbers increased, but there was a drop in total area because the line work was drawn much more accurately thereby separating the non-hard bottom from the patch reef.
- ***Pavement -*** There was an increase of polygon numbers and increase of area. This was due to the finer line work drawing and the drawing in of patch like areas of pavement inside the Aggregate Reef polygons.
- ***Reef Rubble -*** There was no change in polygon number, but a decrease in area. This was due to the finer line work drawing of these polygons.
- ***Patchy Coral/or Rock in Unconsolidated Sediment -*** There was both an increase in polygon number and increase in area. This was due to the finer line work drawing and the drawing in of patch like areas of Scattered Coral Rock in Unconsolidated Sediment in the larger Aggregate Reef polygons. There were areas that were previously too deep to classify in the 2008 benthic habitat map, but the side scan sonar data and field data points allowed for these areas to be identified and mapped.
- ***Spur and Groove -*** This category increased both in polygon number and area. This was partly due to the redrawing of a new Spur and Groove area, but mainly because of the establishments of 2 new Low Relief Spur and Groove polygons and 1 new High Relief Spur and Groove polygon located inside the Aggregate Reef polygon classification in the 2008 habitat map. These polygons were created because of the side scan sonar data and corresponding field data points indicated a difference in structure and fit into the two descriptors in the Spur and Groove class from the Madley (et al., 2002) document. These subclasses were High Relief Spur and Groove and Low Relief Spur and Groove.

Table 10. Benthic habitat classes and comparisons between the 3 benthic habitat maps.

	2010		2008		1998		
Map Class (Geological structure)	**Number Polygons**	**Total Area (Ha)**	**Number Polygons**	**Total Area (Ha)**	**Map Class**	**Number Polygons**	**Total Area (Ha)**
Aggregate Reef/Linear Reef	158	6135.2	99	8085.4	Reef/Patch Reef Remnant	132	4515.3
Reef Terrace (high profile)	83	1871.6					
Remnant (low profile)	75	4263.6					
Pavement	16	207.5	8	59.2			
					Hardbottom/Perceptible Seagrass	1	2.3
Aggregate Patch Reefs	404	633.1	410	599.2	Reef/Patch Reef (Aggregated)	30	230.8
Individual Patch Reef	736	525.6	664	567.2	Reef/Patch Reef (Individual)	399	449.9
					Reef/Patch Reef and Halo (Individual)	35	19.1
Spur and Groove	6	573.3	3	375.6	Reef/Patch Reef Drowned Spur and Groove	6	1137.8
High Relief Spur and Groove	4	155.6					
Low Relief Spur and Groove	2	417.7					
Reef Rubble	14	128.1	13	245.8	Hardbottom/Reef Rubble	59	125.7
Patchy Coral and/or Rock in Unconsolidated Sediment // Scattered Coral/Rock in Unconsolidated Sediment	43	1011.5	26	194.4	Reef/Coral Patches in bare sand	28	2179.3
Unconsolidated Sediment	174	13244.5	244	5537.1	<Unconsolidated Sediment>	203	4546.4
Continuous SRV / Predominantly Seagrass (continuous)	106	2267.7	109	2073.7	Seagrass/Continuous	72	1656.9
					Seagrass/Continuous (Banks)	2	4.3
					Seagrass/Continuous (Blowouts)	79	2230.1
Discontinuous SRV/Predominantly Seagrass (Patchy)	68	1455.4	54	718.9	Seagrass/Patchy/<50%	50	453.1
Sand & unmapped seagrass	0	0	0	0	Sand	26	196.0
					Sand banks	2	6.0
Unknown	0	0	5	10443.8	Unknown	10	12912.3
Land	5	46.9	5	46.9	Land	6	35.7
Total	1709.0	26228.9	1477	26154.6	Total	937	26154.6

Table 11. Map class changes between 2010 and 2008 benthic habitats with corresponding reasons for these changes.

Map Class (Geological Structure)	Polygon Difference (2010 - 2008 maps)	Area difference in hectares (2010-2008 map)	Major changes
Aggregate Patch Reefs	-4.0	33.9	Line work improvement, dividing of Aggregate Patch Reef into Individual Patch Reef, Additional smaller reefs brought into Aggregate Patch Reef category, which was discovered due to side scan data sets.
Linear Reef (Aggregate Reef)	59.0	-1950.2	Line work redrawing, division of Aggregate Reef category into a new subclass polygon
Individual Patch Reef	72.0	-41.6	Line work redrawing, increased resolution allowed for Individual Patch Reefs to be drawn
Land	0.0	0.0	No change
Pavement	8.0	148.3	Line work improvement
Reef Rubble	1	-117.7	Line work improvement
Patchy Coral/or Rock in Unconsolidated Sediment	17.0	817.0	Line work improvement
Spur and Groove	3.0	197.7	Line work improvement, additional Low Relief Spur and Groove category and an additional area of Spur and Groove was mapped
Unconsolidated Sediment	-93	10500.0	Line work redrawing, Identification or Unknown areas that were determined to be Unconsolidated Sediment
Continuous SRV/Predominantly Seagrass (Continuous)	-3	194.0	Line work improvement
Discontinuous SRV/Predominantly Seagrass (Patchy)	14	736.5	Line work improvement
Unknown	-5	-10443.8	Due to new data sets in side scan sonar and field data sets the Unknown area were identified

- ***Unconsolidated Sediment*** **-** This habitat category increased substantially because of the identification and elimination of the previously Unknown classified area in the 2010 benthic map that was present in the 2008 benthic map (Figure 19). The 2008 Avineon benthic habitat map had 5 large polygons, which contained 31% of the park that were classified as Unknown. Based upon field data and the new 2009 side scan sonar/ bathymetry data, these 5 unknown polygons were able to be classified as Unconsolidated Sediment adding 10,444 classified hectares and producing a complete habitat map for the Dry Tortugas National Park. Now if the Unknown areas are removed from the equation and corresponding polygons from the 2010 benthic habitat map, there was still an increase in the number of polygons and area in the Unconsolidated Sediment category. These increases were due to the increased resolution imagery produced by the side scan data, which allowed for redrawing of finer line work both on the edges and inside of the hard-bottom habitats. NOTE: The new line work redrawing resulted in both increases and decreases of the unconsolidated sediment polygon. The boundaries and between polygon line work that was originally drawn were including extra none-hard bottom areas but also had been identifying areas that are hard bottom as soft bottom habitats.
- ***Continuous SRV*** **–** This habitat category increased in both polygon number and area. This was due to the redrawing of the line work and fine tuning of the polygons.
- ***Discontinuous SRV*** **-** This habitat category increased in both polygon number and area. This was due to the redrawing of the line work and fine tuning of the polygons.

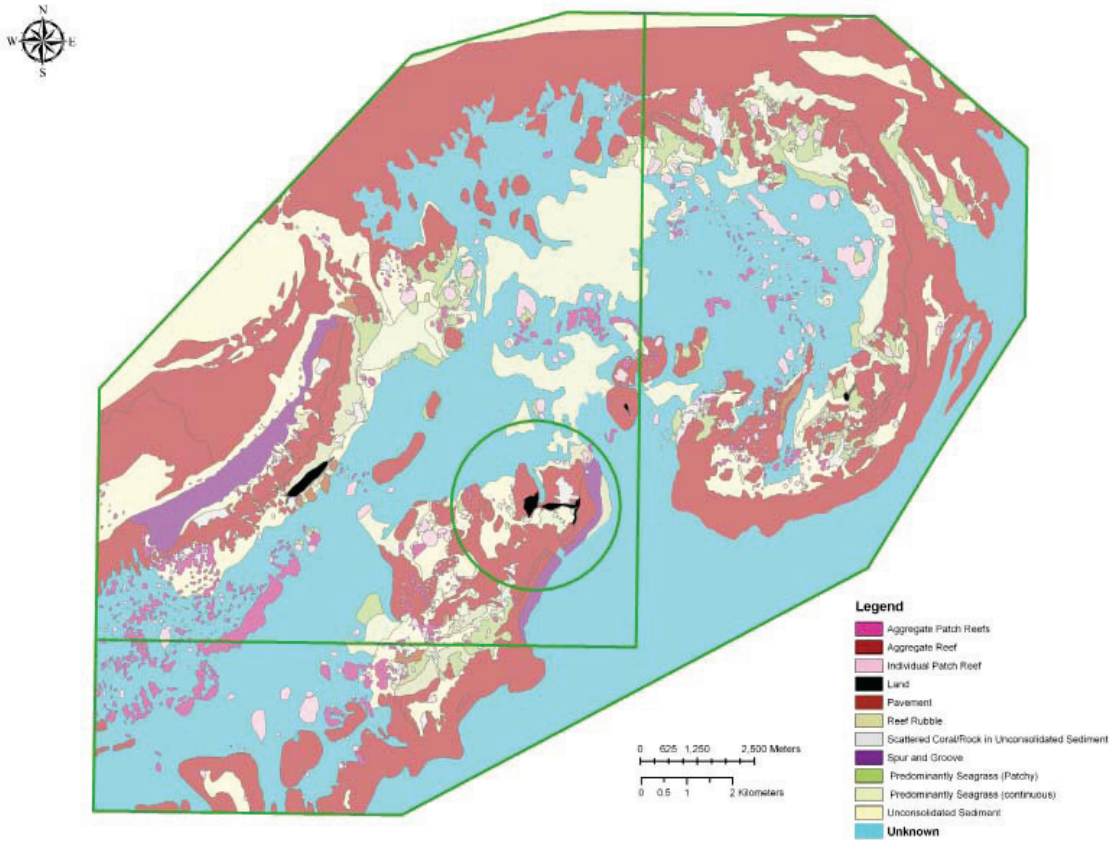


Figure 19. Area classified as "Unknown" in the 2008 benthic habitat map. These areas (shown in blue) were classified as "Unconsolidated Sediment" based upon field data in the 2010 benthic map.

The accuracy assessment data were used to update the 2010 benthic habitat map in both the hardbottom and softbottom areas. However, as shown in Table 12, there were seven AA points that were summarized and considered unacceptable in the 2008 map that were not able to be updated in the 2010 map. In each case the imagery and side scan sonar data did not reach to the depth of these points and it was impossible to draw a polygon to match the field data. In addition, it was impossible to determine whether the field data indicated an area larger than the minimum mapping unit. Thus, users of this map should be aware that although the unconsolidated areas are at least 85.2% correct with 90% confidence there may be areas in the deeper regions of the park of pavement or seagrass that are not correct in the 2010 map.

Table 12. Field points that did not match in the 2010 benthic habitat map.

2010 Map Class	AA Field Classification	# point unable to be updated
Unconsolidated sediment	Pavement	2
	Patchy Coral Rock in Unconsolidated Sediment	1
	SRV	4
Total		7

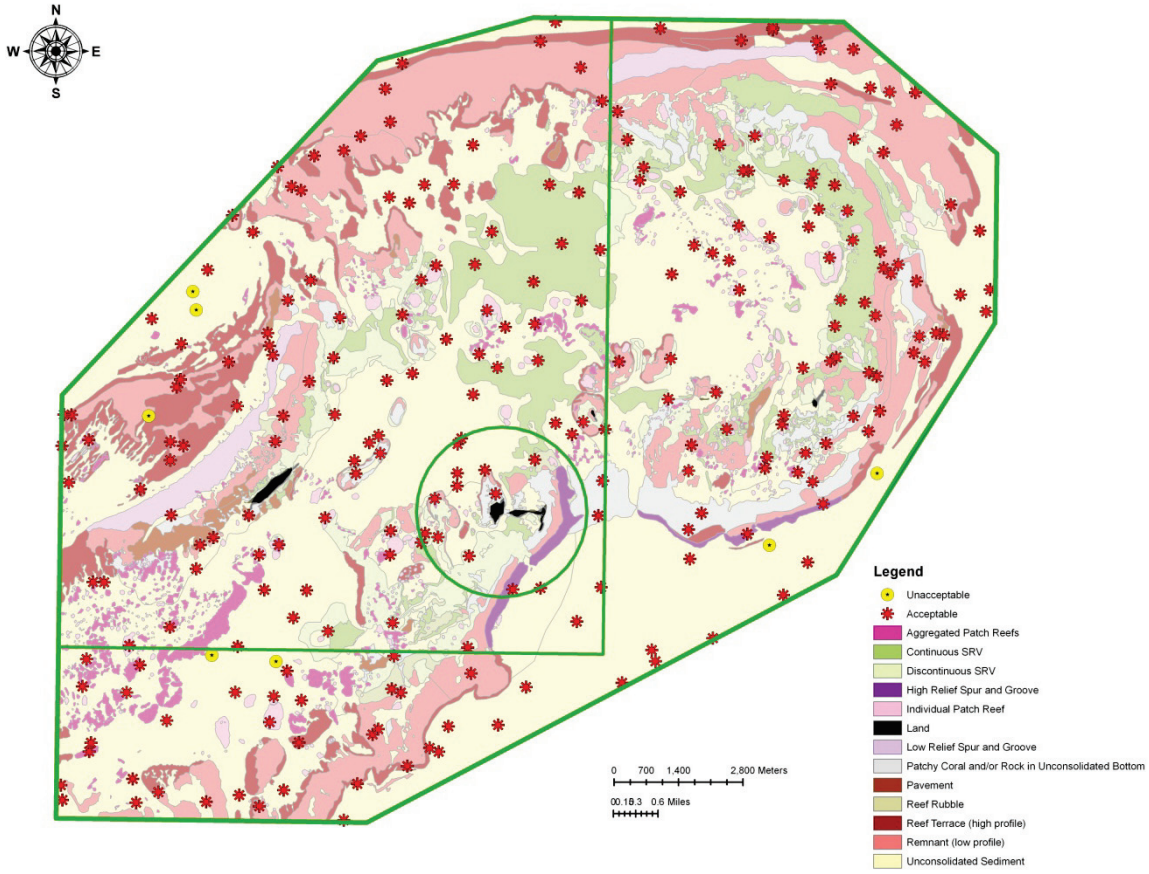


Figure 20. Points that did and did not match in the 2010 benthic habitat map.

MMU differences between the 2010 and 2008 benthic maps.

Upon the completion of the 2010 marine benthic habitat map, it was determined that the MMU most appropriate for the map was 0.5 hectares. The MMU represents how large something must be before it is represented separately on the map. The line work for those areas such as patch reefs and hard and soft bottom interfaces were drawn to a much finer scale (Figure 21).

The metadata for the 2008 benthic habitat map stated that the MMU used for the 2008 benthic habitat map was 0.1 hectares. Thus, at first glance the 2010 map appears to be a less-detailed product. However, after working with the 2008 map product, this MMU appears unreasonable and inaccurate. A comparison was done between the 2010 and 2008 benthic maps shown in (Figures 21 and 22). The 2008 map appeared to contain many features in the range of 0.5 – 1 ha and even larger that were not mapped separately. In addition a histogram was developed to show the polygon size distribution for both the 2010 and 2008 benthic maps (Figure 23). This graph indicated that few of the polygons for the 2008 map fell into the 0.05-0.25 hectare bin, but rather they were in the 0.25 to 1 hectare bin classes. These 3 figures show that the MMU of 0.1 hectare claimed in the metadata by Avineon, Inc. for the 2008 benthic habitat map appears to be over reaching for their mapping initiative. The actual MMU for the 2008 benthic habitat map seems to be on a more coarse scale of perhaps 1 hectare or even larger according to the hectare comparisons in (Figures 21 and 22).

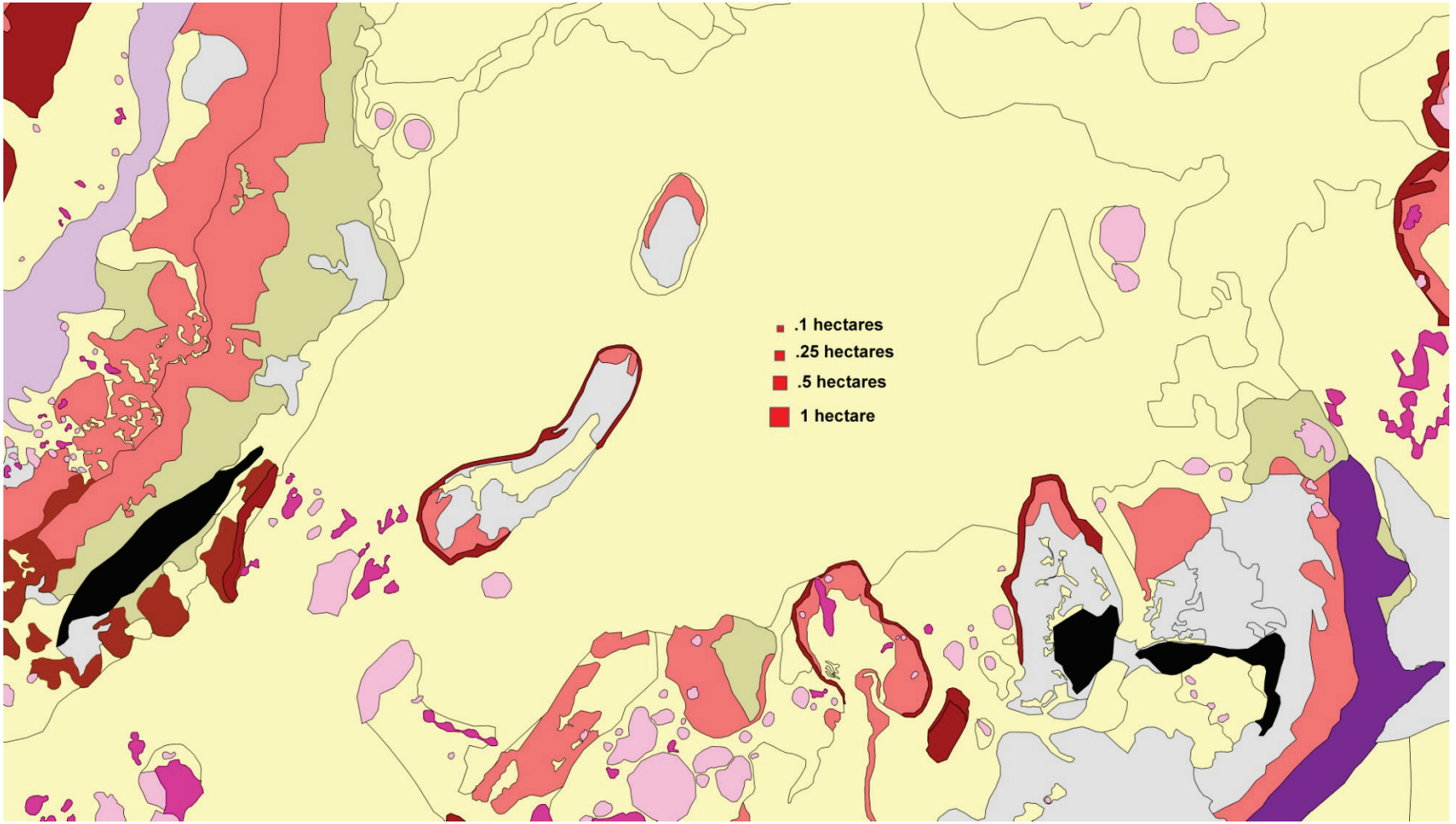


Figure 21. 2010 benthic map showing the changes in the line work drawn as compared to hectare sizes.

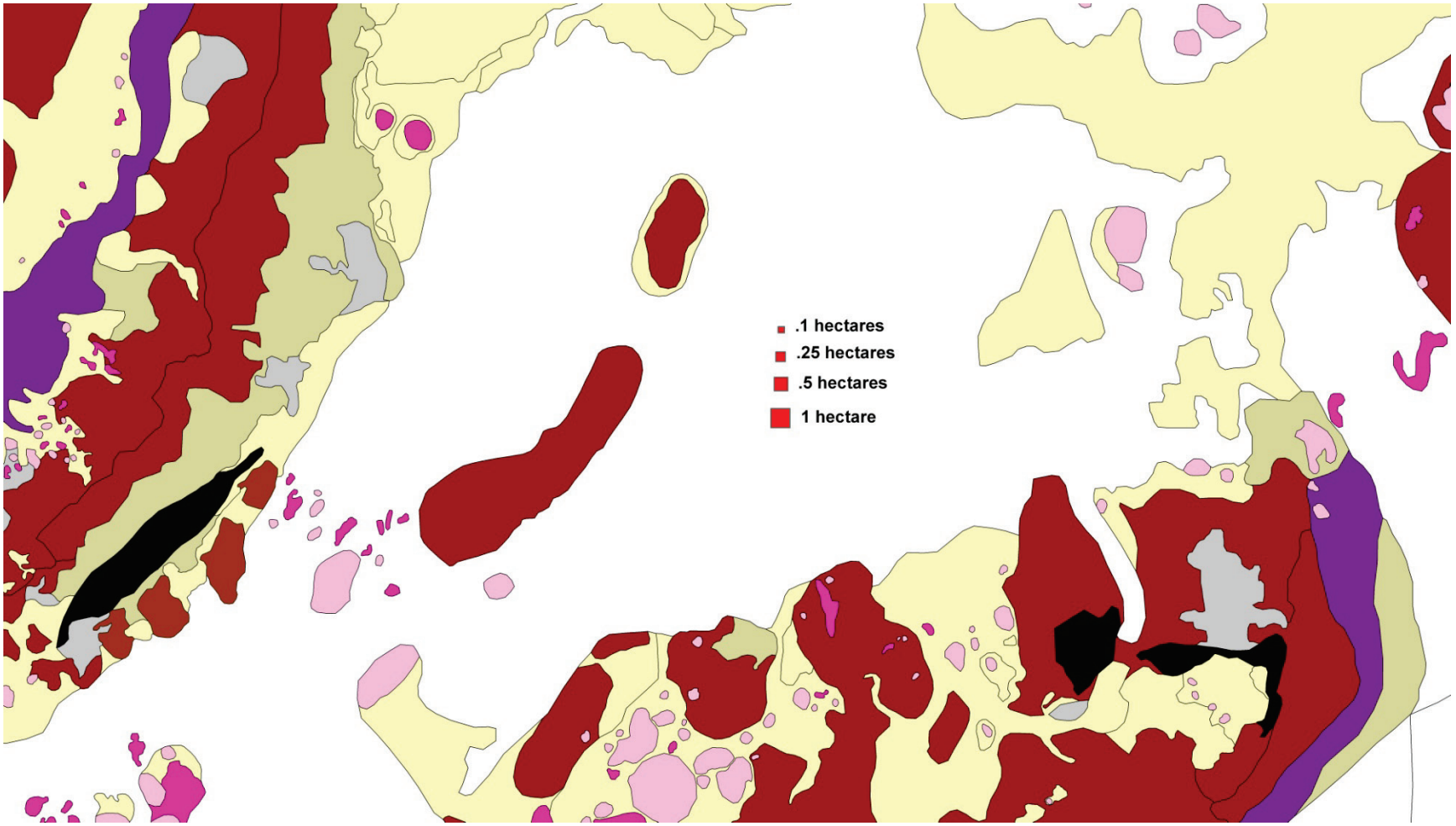


Figure 22. 2008 benthic map showing the changes in the line work drawn as compared to hectare sizes.

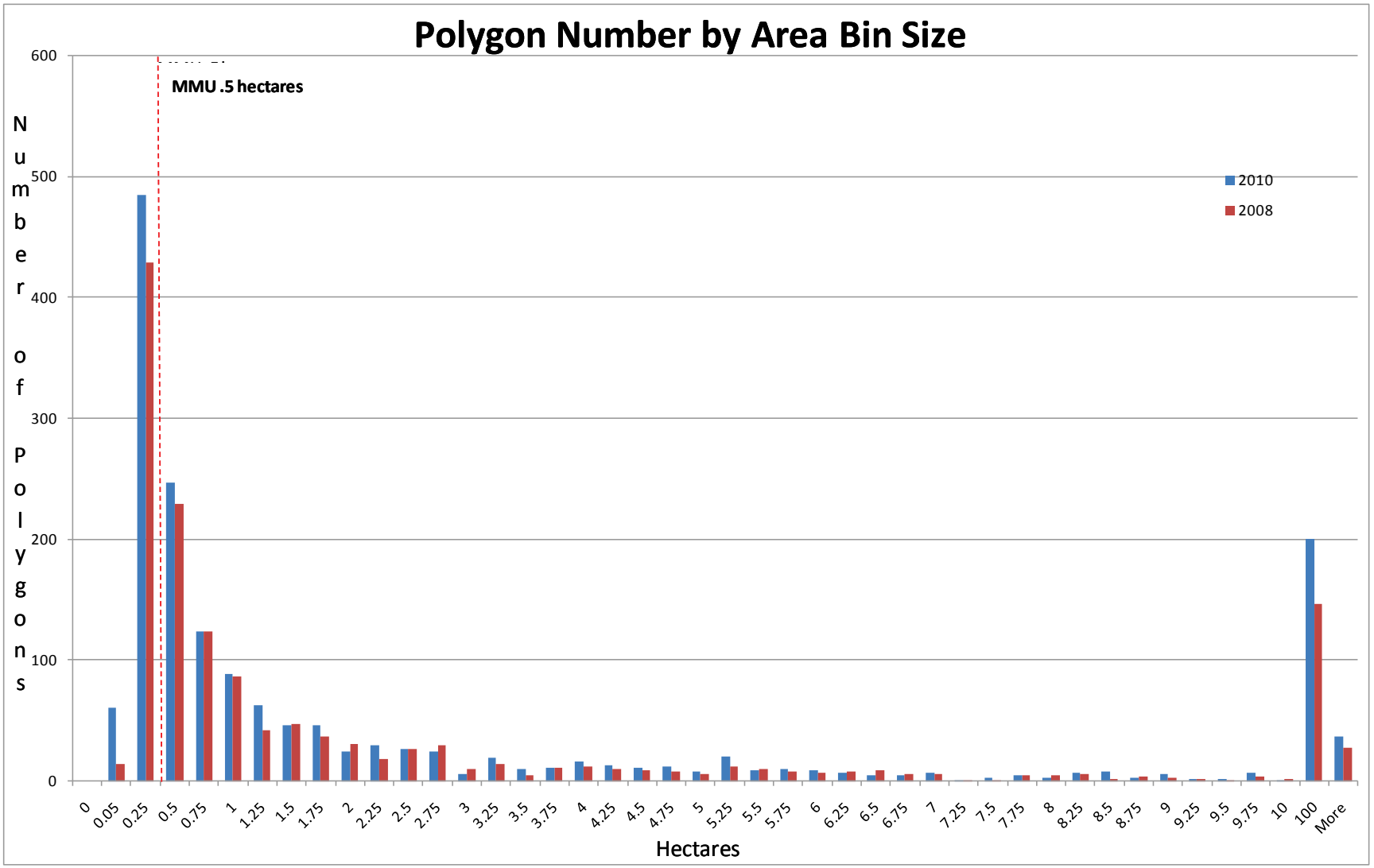


Figure 23. This graph shows the distribution of polygons by hectare.

Comparison between the 2010 benthic habitat map and the 1998 benthic habitat map. An additional comparison was made between the 2010 benthic habitat map and the 1998 NOAA benthic habitat map. The comparison statistics and differences between all the attributes in the 2010 benthic map and the 1998 (and 2008) benthic maps are located in Table 12. These two maps were placed over each other as shown in Figure 24 Image A. Then the change of area between them was calculated. The results are as follows: In the 1998 benthic map there was a total of 2943.5 hectares of hard bottom habitat that was not mapped, but was included in the new 2010 benthic habitat map. While the inverse of the map placement, as shown in Figure 23 Image B indicated from the 1998 map there was a total of 3322.2 hectares of previously classified hard bottom habitat that was changed to the Unconsolidated Sediment, Reef Rubble or Scattered Coral/Rock in Unconsolidated Sediment classifications in the 2010 benthic habitat map.

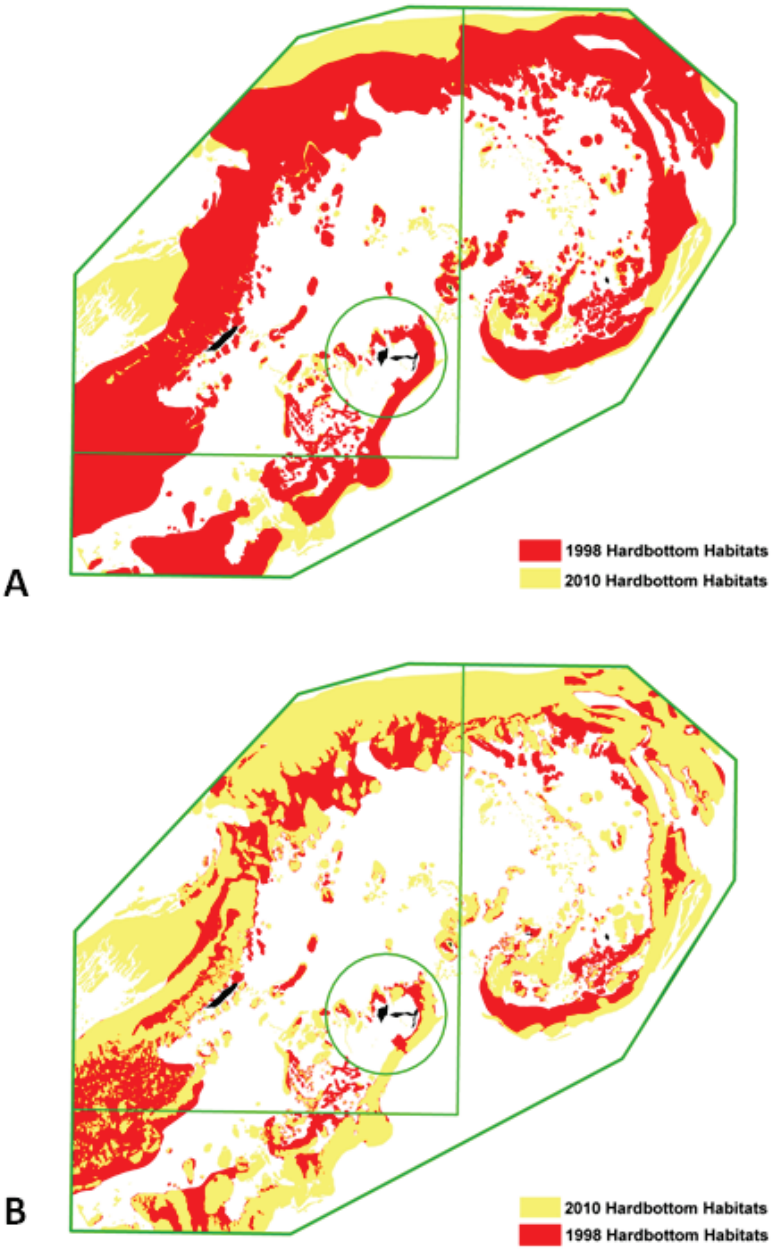


Figure 24. Image A shows the hard-bottom areas that the 1998 benthic habitat map classified as soft-bottom as compared to the 2010 benthic map. Image B shows the areas that the 1998 benthic map called hard-bottom that the 2010 benthic map classified as soft-bottom.

Creation of a data layer that contains the higher potential sites for fish and scleractinian corals.

An additional data layer that was developed from the 2010 benthic habitat map was the higher potential layer (Figure 25). This layer was developed to show those areas in the park that had the potential for increased biodiversity and abundance of coral reef and reef fish. This data layer contains all patch reefs, aggregate patch reefs and those areas that showed higher rugosity or complexity totaling 3,186 hectares. As these areas tend to have higher coral cover and fish densities based on numerous field observations, this benthic layer will be useful for both park managers and researchers. Park managers will have a better spatial understanding as to where to establish protective areas and moorings, while coral reef and reef fish researchers will be able to determine what habitats will have the highest potential for species diversity and abundance. This may reduce project costs and duration by focusing effort towards these more biologically rich areas. Table 13 shows the habitat classifications, number of polygons per class, total area for each habitat class and the percentage of that class that were included in the higher potential sites.

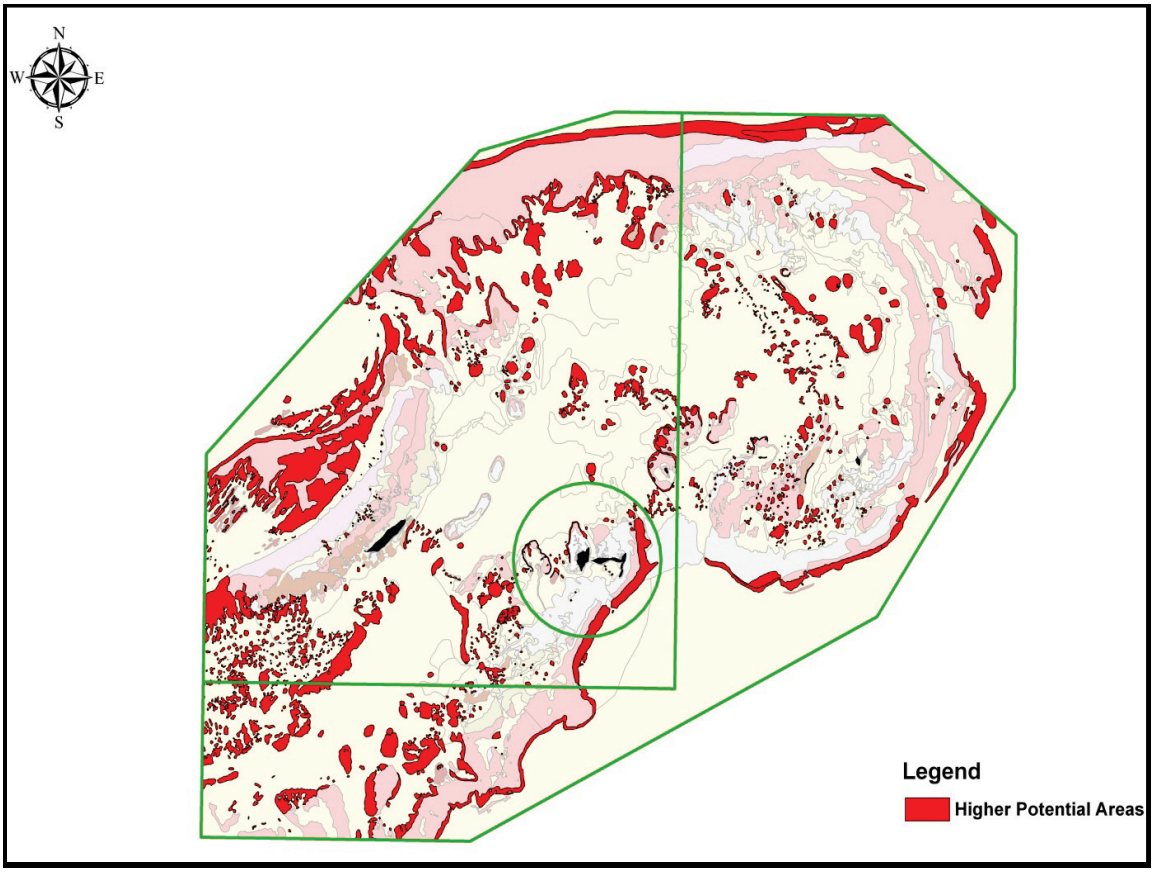


Figure 25. Higher potential areas.

Table 13. Areas with higher potential for fish and coral abundance and biodiversity.

2010 Map Class (Geological structure)	Number of polygons	Area (ha)	Percent of total area
Individual Patch Reef	736	525.6	100%
Aggregate Patch Reefs	404	633.1	100%
Reef Terrace	83	1871.6	100%
High Relief Spur and Groove	4	155.6	100%
Totals	1227	3185.9	
Hardbottom			38%

A more complete bathymetry map for the Dry Tortugas National Park.

The merging and interpolating of the new 2010 side scan sonar bathymetry set and the existing 2004 LiDAR data resulted in a more complete bathymetry map for DRTO. DRTO's shallow submerged resources were initially mapped in 2004 by the NASA Experimental Airborne Advanced Research LiDar (EAARL), which provides the ability to survey near-shore and shallow water (< 15m) benthic habitats (Figure 26). This left the areas deeper then 15m with little to no high resolution benthic data. For the deep water environments or those below the 15m range, acoustic data was collected using a combination of side scan sonar and corresponding bathymetric data for DRTO by the C3D Side Scan Sonar Imaging System, which produced raw data sets that were in .xyz format. The post processing and filtering of the .xyz data to produce the final bathymetry data was accomplished with the program SURFER®. The side scan raw bathymetry data with a horizontal resolution of 30 cm covered a total of 10507.63 hectares of the park that was previously charted by a coarser scaled opportunistic bathymetry readings from the Geophysical Data Management System (GEODAS) data sets. The total area that LiDAR bathymetry with a 1m horizontal resolution covers is 13370.4 hectares of the park. This layer merged to the non-interpolated raw side scan bathymetry data produced a bathymetry map that encompasses 23878.03 hectares of the park. The final merged side scan sonar / LiDAR bathymetry data set is a filtered and interpolated raster image with 1m horizontal resolution covering over 90% of the parks submerged resource.

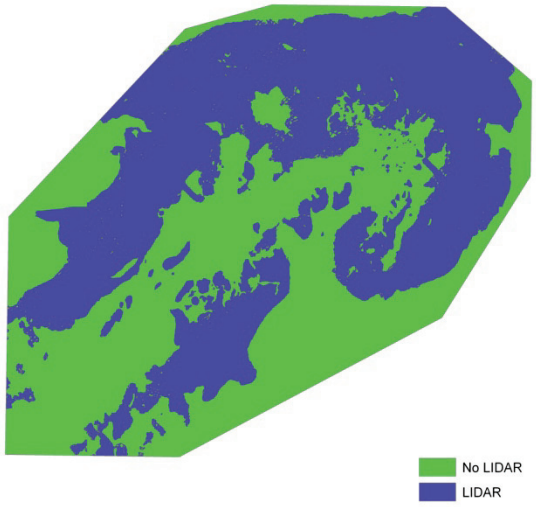


Figure 26. Area of the park covered by LiDar imagery.

The final merged LiDAR and newly acquired bathymetry data layer was created by using ArcGIS 9.3 mosaic tool. This new bathymetry merged layer has a horizontal resolution of 1m

and covers over 90% of the park. The final side scan bathymetry and LiDAR merged layer was reviewed by NPS underwater archaeologists from the submerged resource center (SRC) to ensure this data set did not give away locations of submerged cultural resources with potential portable artifacts.

Discussion

Upon the completion of the new benthic habitat map the following are potential management products that can be developed allowing park management decisions to be made with more certainty based on information instead of assumptions.

Benthic maps application for the performance indicators

The following will briefly review each of the six performance areas and how the new marine benthic habitat map and corresponding products will be of value in each area in the final 5-year comprehensive report and continued monitoring and research:

1. "Quantify changes in the abundance and size-structure of exploited species within the RNA relative to adjacent areas". Each of the current projects underway in the RNA uses a benthic map to stratify their sampling regime. This new benthic map has eliminated all of the unknown areas and has fine tuned the benthic classifications and line work. The sampling universe can now be stratified to much more accurate benthic classification, thereby eliminating wasted time in finding out that the sample point is not on the desired benthic structure.
2. "Monitor the immigration and emigration of targeted species in the RNA". The projects underway in this area use a benthic map to determine where to set up acoustic receivers to track fish and turtle movements in and out to the RNA. The new benthic map will help in determining where to install these receivers according to the correct benthic areas and show what types of habitats the animals are moving in and out of with higher degree of accuracy.
3. "Monitor changes in species composition and catch rates of exploited species throughout the surrounding region." The two projects currently under way in this topic pertain to creel census data and permitting. The benthic map has no real relevant use in these two areas.
4. "Evaluate the effects of RNA implementation on marine benthic biological communities." The three research projects underway in this topic will greatly benefit from the new benthic map. The new fine tuned map will help in the establishment of new coral monitoring sites and help in tracking changes in seagrass densities from a spatial extent.
5. "Assess reproductive potential of exploited species by evaluating egg production and larval dispersal." The new benthic map will be of use for the project that involves hook and line fishing for fish sampling. The map will give a better indicator as to where to fish for targeted species. There is a project involving acoustical tracking of species. As stated in an earlier topic the new benthic map can provide a better understanding of where the desired habitats are for acoustical tracker establishment.
6. "Incorporate social sciences into the research and monitoring program."The final report will be available for the public who in turn will be able to have a better understanding of the habitats of the DRTO. This knowledge will give the visitor a better feeling of what is actually out in the park and how precious the ecosystem really is. The new map will also allow help with submerged cultural resources by allowing the managers to integrate these resource sites into this mapping product.

User Map

A user map is a mapping product that can be developed in ArcGIS that displays how stakeholders and other entities use an area, such as a national park or reserve. DRTO and the RNA would greatly benefit from the development of a user mapping product that could aid with management of fragile marine resources.

With the development of the new benthic habitat map and bathymetric data set, along with the current data that is available, an ArcGIS project or *user map* could be developed to show usage patterns of stakeholders and other public and commercial entities within DRTO and the RNA. As stated previously the Dry Tortugas RNA has six performance indicators that will be used to determine the effectiveness of this protected area. The last indicator pertains to incorporating social sciences into the research and monitoring. This indicator would most benefit from the development of a user map.

This ArcGIS project would be developed by those individuals of the Dry Tortugas or Everglades National Park that have the skill set to manage ArcGIS. If these individuals are not available SFCN, could develop the appropriate ArcMap project with corresponding layers. This dynamic ArcMap project will allow for the ability to adjust, manipulate or add data depending upon the needs of the park. Currently there is no such data product.

An example of what this DRTO map product would look like is shown here. The public user groups would consist of commercial and recreational fishers, diving and snorkel charter boats, and other recreational boaters.

- ***Commercial fishers***- As of current regulation there is no commercial fishing in the park, but the commercial shrimpers do anchor just on the northeast border of the park. Now the shrimpers clean their nets and dump bycatch overboard in this area, which will attract multiple fish species to this area of excess food. This in turn increases fish numbers and can cause a spillover effect into and out of the park (Harris and Painer., 1991). This change in the normal behavior patterns can cause a bias in the fish counts that scientists and managers use to estimate the populations contained in the park. A user map of the numbers, amounts and movement patterns of the shrimp boats will help account for this anomaly in the data.
- ***Recreational and charter fishers***- Recreational and charter fishing is allowed in the park, but not in the RNA. The development of an ArcGIS product showing where fishing is taking place in the park and those areas just outside the park boundaries will help in giving an understanding of what amount of fishing pressure is being put on the resource. This will help in the development of a better monitoring scheme for fish populations by quantifying recreational fishing pressure and accounting for it in data analysis, which in turn determines the effectiveness of the regulations for this resource.
- ***Private and commercial diving/ snorkeling*** -Currently there have been 5 recreational moorings established in the park. According to the Buoy and Aids to Navigation Management Plan for Dry Tortugas National Park, 2009, the second phase of the mooring establishment states the need for additional recreational mooring buoys for the RNA that meet the requirements of the General Management Plan Amendment (GMPA). These locations will be based upon input from the public, commercial tour operators, science cooperators and park staff. The 2010 benthic habitat and the new

bathymetry layer will be able to give a much more definitive description of the habitats in the park allowing for better decision making to guide the new mooring establishments. Figure 27 shows the current dive moorings and sites where the captain of the recreational dive vessel SPREE stated good dive locations are located.

- ***Boating and sailing***- Dry Tortugas is a destination site for sailing and power boats. There currently is a fee program in place that monitors the numbers of vessels that stay in the park. Those that do venture to this location have a safe harbor to anchor, but the harbor has areas that will allow a vessel to drag or move during times of high winds. There is a need for a more integrated map of where these unsafe anchorages are located. There is also another solution to this problem and that is the installation of overnight moorings. Currently the park is establishing a mooring program to maintain the boundary, marker and dive moorings in the park and RNA. The addition of moorings in the harbor will help make a safer anchorage, thereby increasing the user experience and will not overly tax the park resources since the mooring programs are already going to be developed.

The new products will allow mangers, research groups and different agencies to accomplish those tasks that they were mandated to fulfill. In addition stakeholder groups such as dive charter companies will be able to use these mapping products along with their own knowledge of the area to help in establishing additional dive/snorkel moorings in the RNA and DRTO. Examples of potential uses of these new products are shown in Figure 27.

Develop an ESRI ArcMap™ to track monitoring and research.

This ArcMap project was established using all the images, data sets and layers from the 2010 benthic map product. Additional data sets are included from benthic and fish monitoring and research projects that are or have been conducted within the park boundaries. However it is recommended to establish a map of where work is currently or has historically taken place. This will be useful for park managers to have a better spatial understanding as to where to establish protective areas and moorings, while coral reef and reef fish researchers will be able to determine what habitats will have the highest potential for species diversity and abundance. This may reduce project costs and duration by focusing effort towards these more biologically rich areas.

In addition some benthic monitoring sites are sensitive to intrusive activities, such as drilling into the benthos. A mapping product that shows where these sites are located, allows others to avoid these areas so as not to bias data or alter long term monitoring sites. Park managers will be able to upload into this ArcMap mapping product any submerged cultural resources that are located within the park. This will help, for example, in showing where not to establish a long term coral monitoring site that involves drilling, altering or movement of the benthic habitat. Examples of such maps from this map product are shown in Figure 28 for fish and in Figure 29 for benthic work.

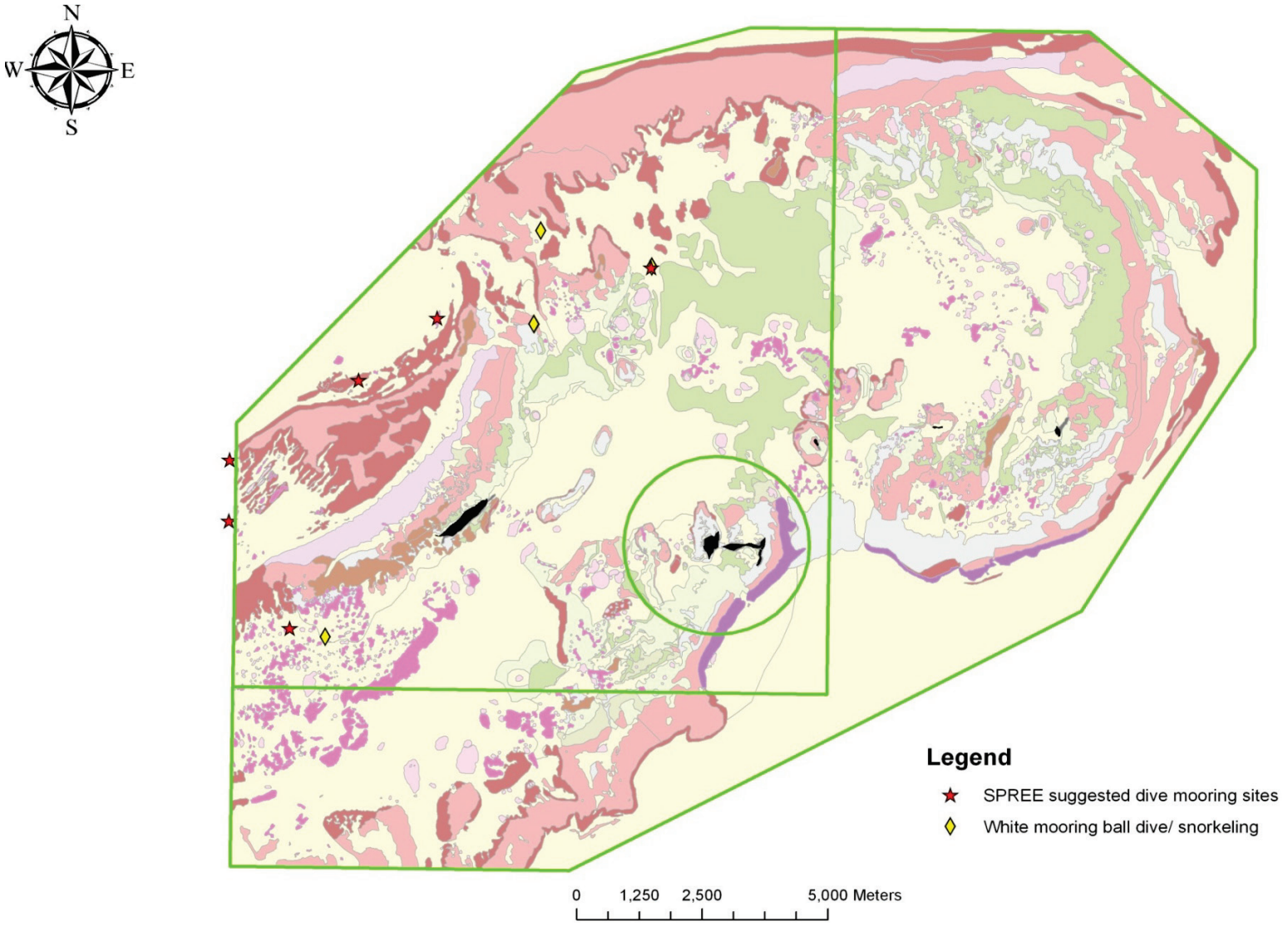


Figure 27. Dive/snorkel moorings current and suggested.

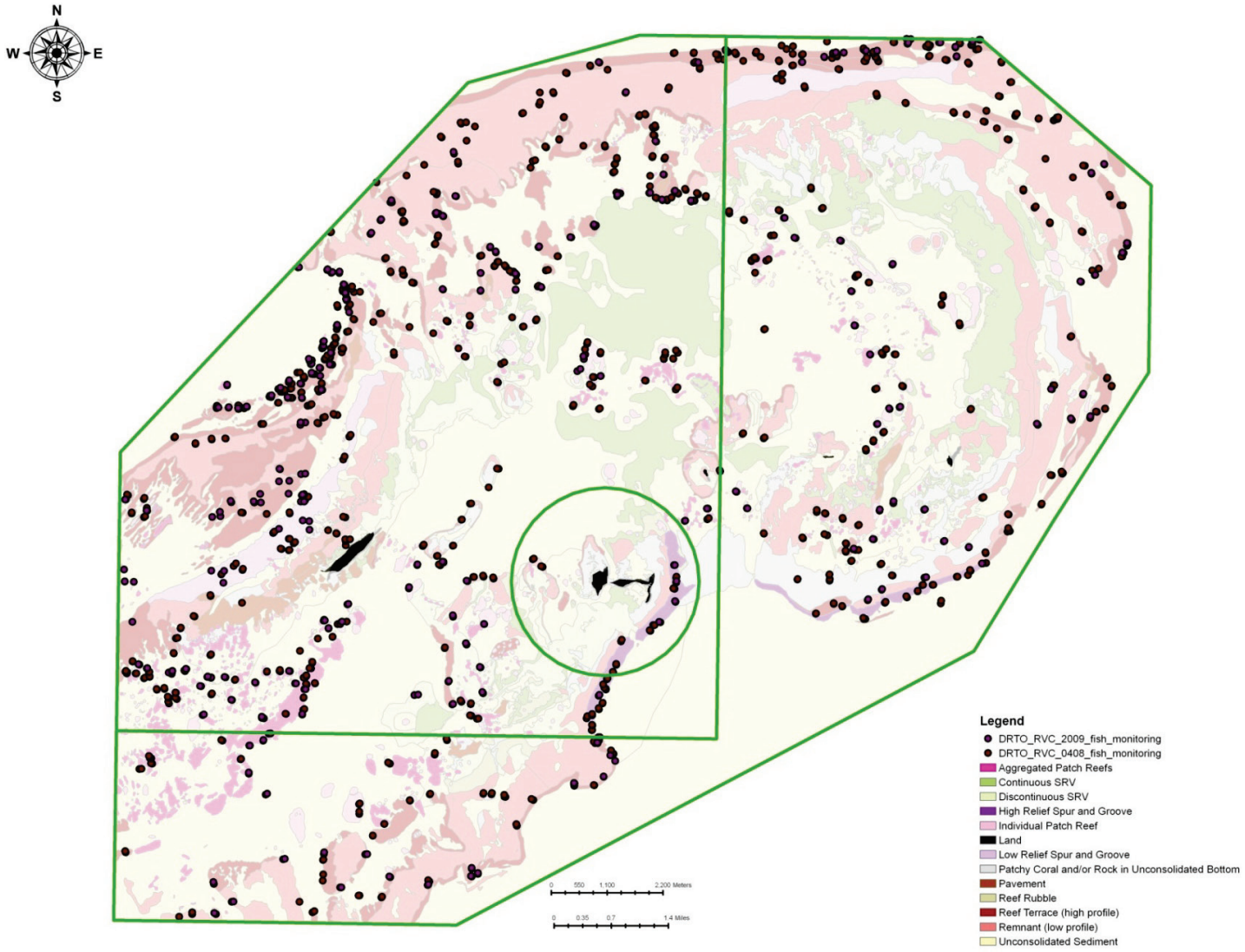


Figure 28. Reef fish monitoring sites from 2004 - 2009.

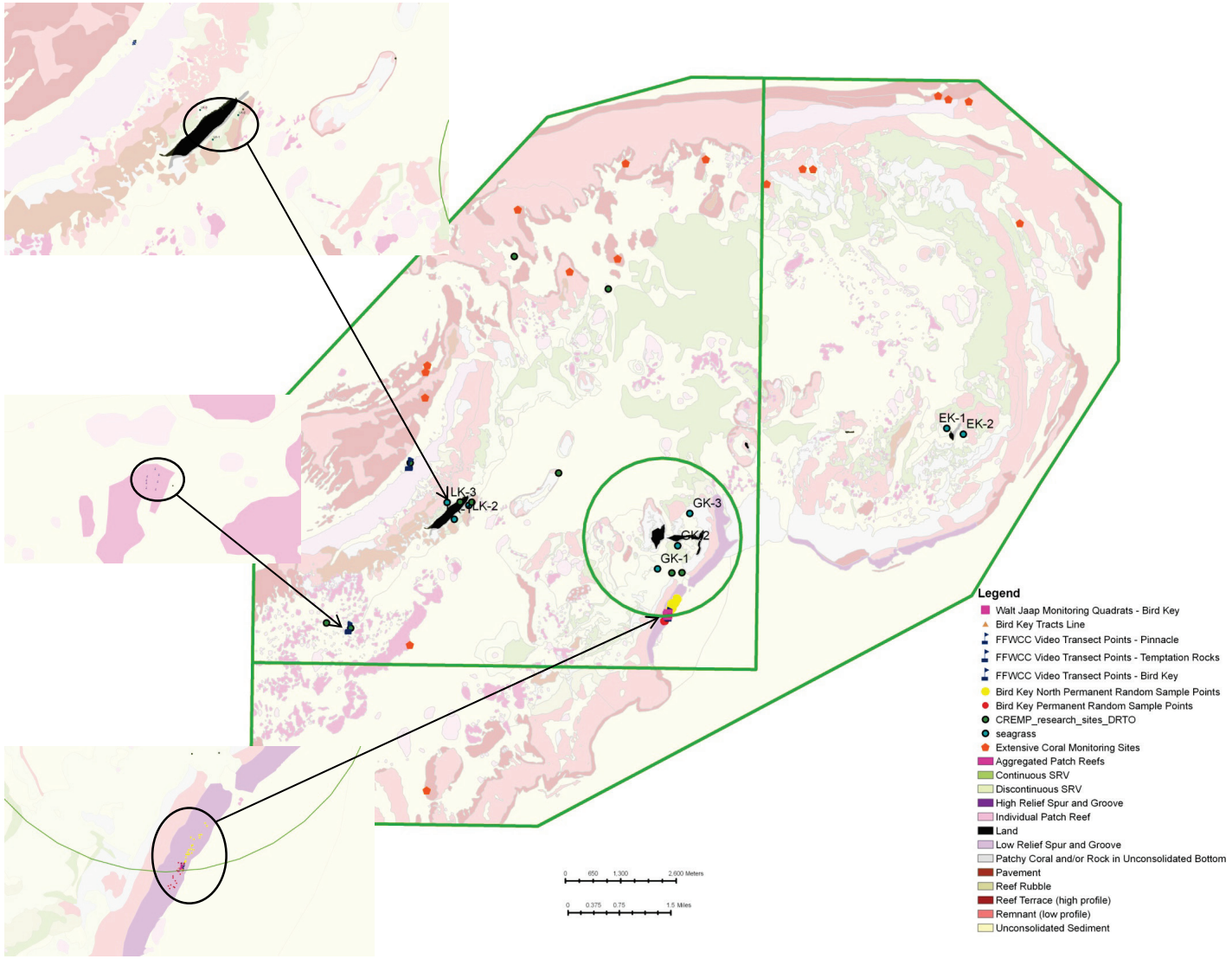


Figure 29. Current benthic monitoring occurring in DRTO.

Invasive Lionfish Sightings

A new recent development is the invasive lionfish spreading throughout the Caribbean, Florida and Dry Tortugas. This fish has the potential to cause serious harm to the marine ecosystem. This new benthic map and corresponding ARCGIS 9.3 product can be used to show not only where in the park the lionfish are being spotted, but also show what type of habitats and corresponding depths these invasive fish are being found (Figure 30) (Morris and Whitfied, 2009).

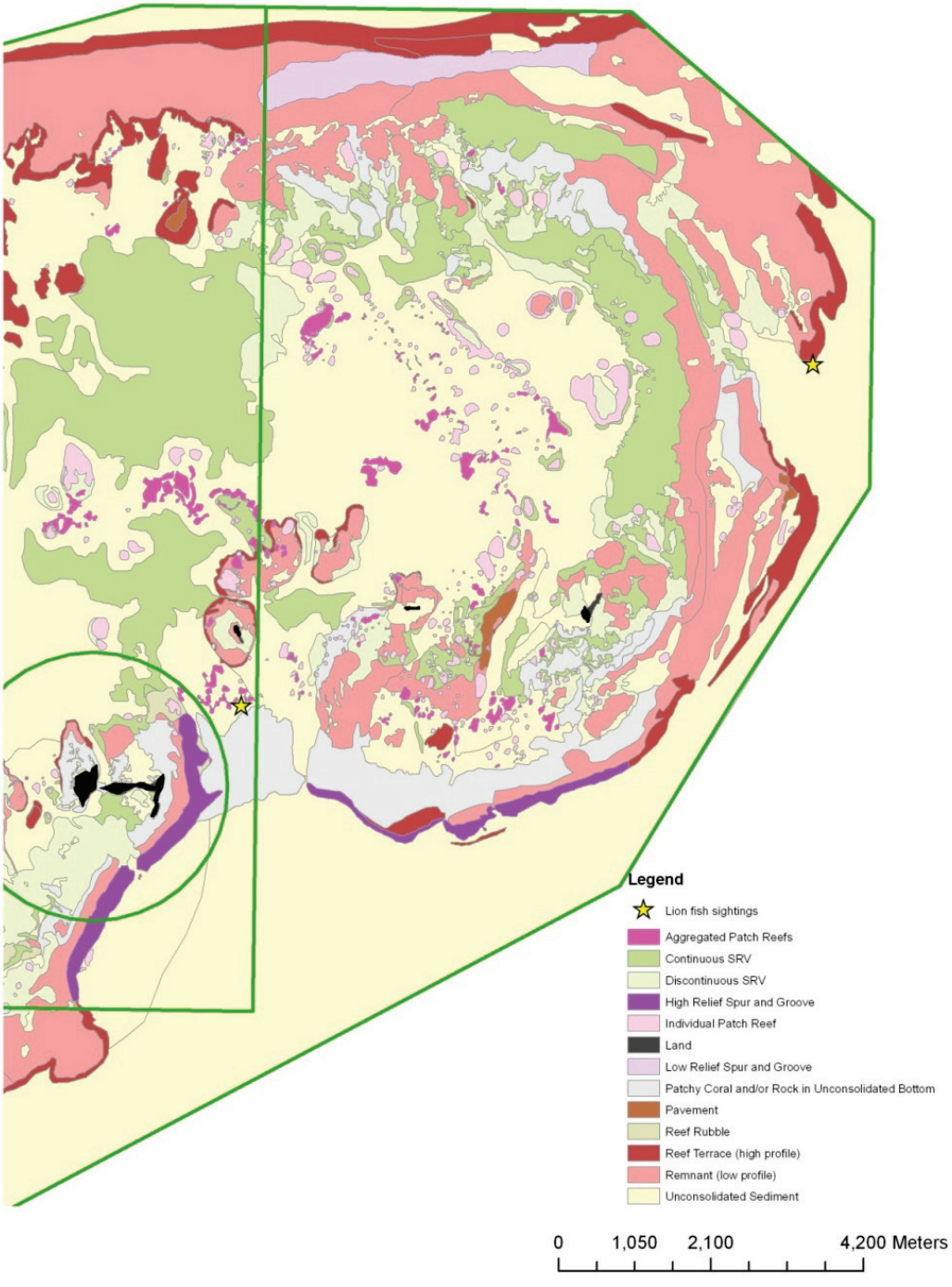


Figure 30. Lionfish sightings from 2010 in the park.

Current and proposed buoys and marine special protection zones

According to the Buoy and Aids to Navigation Management Plan, DRTO managers are to develop a plan for the installation and management of necessary and appropriate buoys and other aids to navigation (ATONS) in DRTO. The following are the management objectives (Morrison, 2009).

- Establish buoys to implement the General Management Plan (GMPA) decisions and new Special Regulations.
- Establish Special Protection Zone boundary buoys around Long Key.
- Utilize GMPA decisions, DRTO Special Regulations, Threatened and Endangered species, culturally sensitive areas and public input to evaluate and decide on proposed buoy locations at natural and cultural resources
- Identify all existing ATONS and incorporate into Park asset inventory.
- Obtain USCG and other necessary permits.
- Provide new buoy coordinates on the park web site.
- Establish a boating permit system to monitor use.
- Establish a natural and cultural resource monitoring program to ensure resource protection at designated dive sites**.**

With these management objectives in mind the new benthic map and bathymetry layer will help in associating the habitats and related depths as to where these buoys and protected areas will be established (Figures 31 and 32). The following is a ArcGIS project map that when all corresponding data sets are brought into this project, decisions on, for example depths and types of habitat that the buoys will be installed can be made with the most recent and accurate information available.

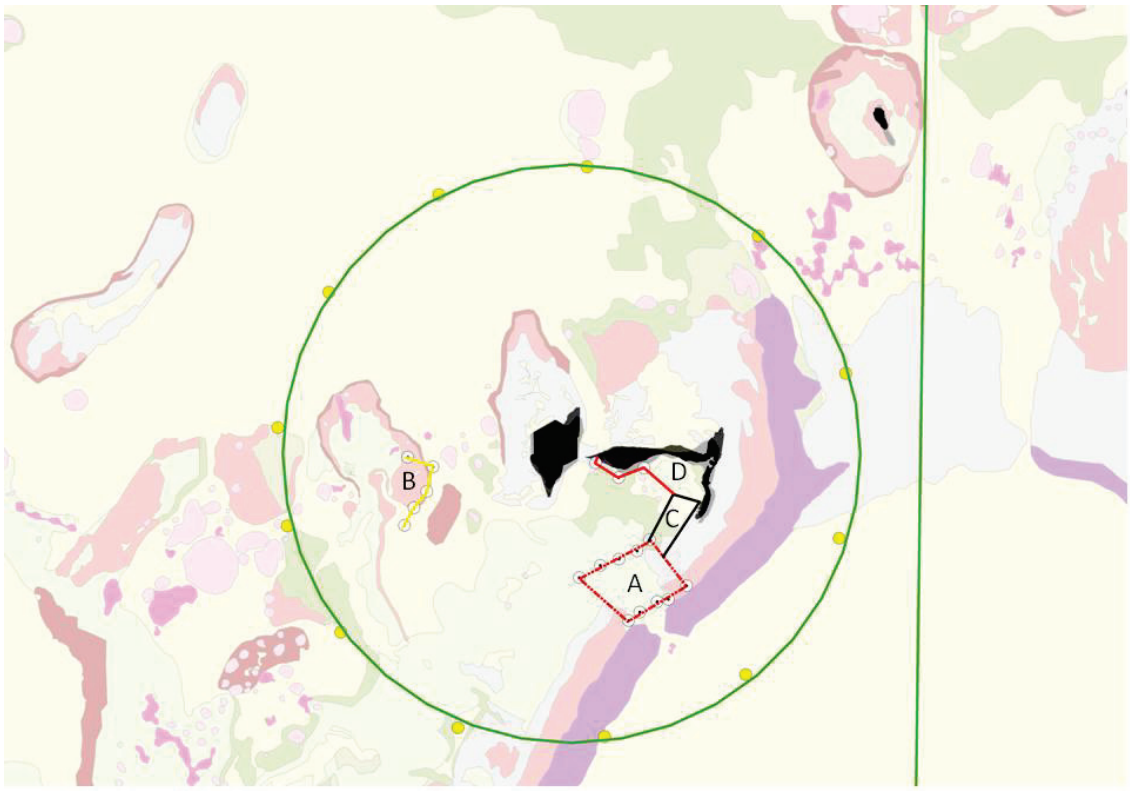


Figure 31. Special protective zones for A) *Acropora prolifera*, B) *Acropora palmata*, C) Nurse shark mating area and D) Long Key closure area.

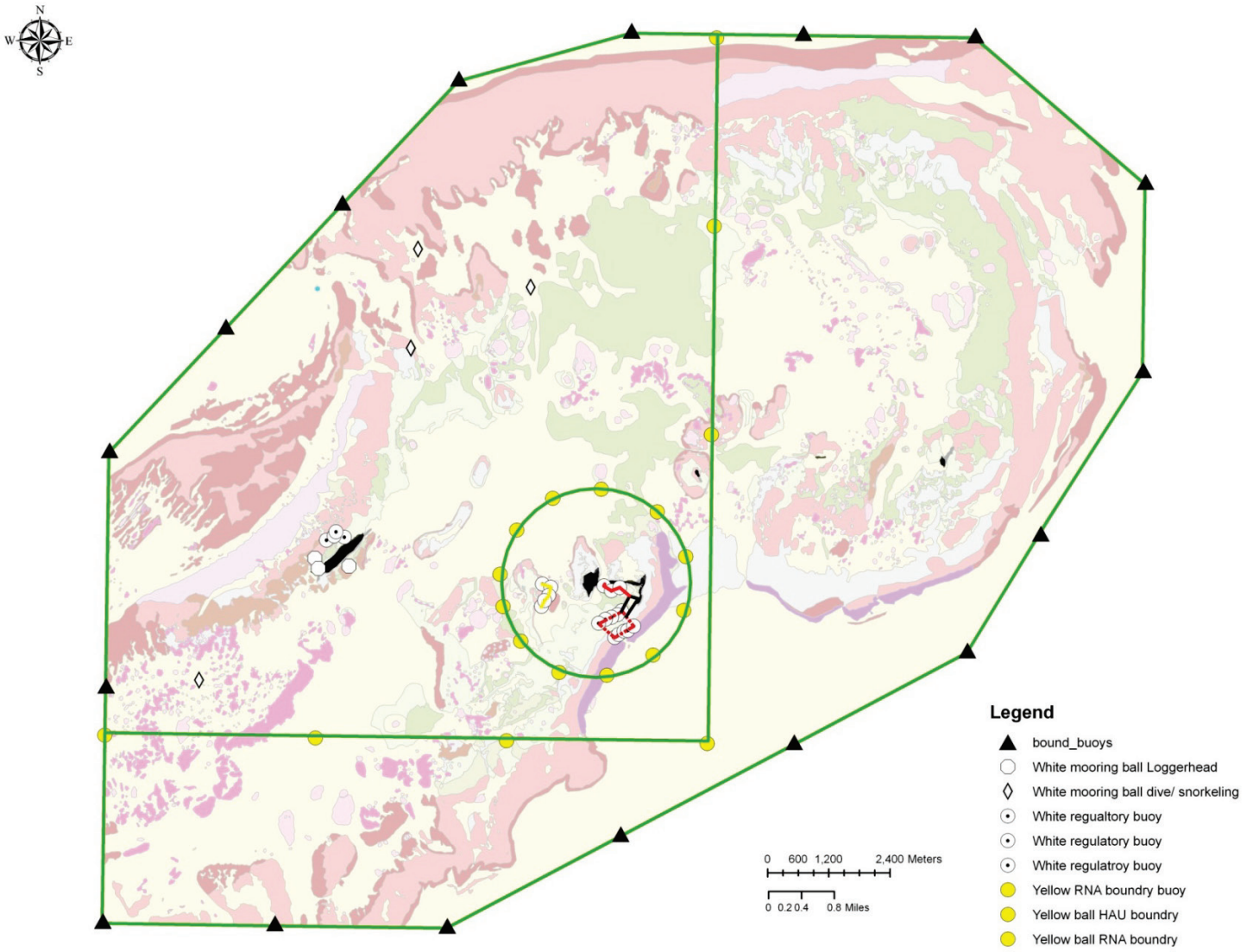


Figure 32. Full extent of the park and corresponding buoy placement.

Challenges and lessons learned

"*Mistakes are the portals of discovery.*" (James Joyce [1882 – 1941]). Some of the lessons learned from the development of this product include

- Accuracy Assessment:
  - The marine habitat classification is spatial-scale and landscape context dependent. Field data collection using this classification must take this into account. For example determining the difference between individual and aggregate patch reefs or between unconsolidated sediment and discontinuous seagrass can be difficult in the field without accompanying imagery. If the mapping product itself is not available, copies of imagery would help field crews better understand the context of what they are observing. The post-field evaluation of the AA is critical to resolve these issues.
  - Although a post-map final product AA is typical in vegetation mapping, a concurrent AA process is feasible and makes assessment of product quality occur in a timely fashion. However sufficient time must be provided for post-field evaluation of the data to resolve issues described above. In addition, rare categories such as Spur and Groove on the 2008 map may be under-represented by random point selection and more sampling than is necessary may occur in common habitat types such as Unconsolidated Sediment.
  - Although many scientists and/or staff may think they know what the various habitat categories mean, it is important to have formal training to standardize classification. In addition copies of the classification scheme with photos should be readily available to field crews. A standardized document such as the Dry Tortugas specific map class document that was recently developed (Appendix E) would have eliminated a lot of the confusion found in the field classification, e.g. confusion over the difference between Pavement and Remnant reef areas.
  - The photos and videos along with the development of the hyper-linking between these imagery sources to the AA points in the ArcGIS 9.3 map were shown to be invaluable for conducting the post processing of the AA data.
- The SCHEME habitat classification contained important reef sub-classes (Low vs. High Relief Spur and Groove; Reef Terrace vs. Reef Remnant) that were not available in the NOAA classification scheme, which were felt to be important because these areas have higher rugosity and potential for fish assemblages and coral growth. Thus, as the other classes were cross-walkable from the NOAA classification, the 2010 map uses the SCHEME classification.
- The acoustic data from side scan sonar gave details to areas of depths over 15m, which were previously not documented into such detail by previous technologies used in the area. This side scan sonar dataset, when merged with the corresponding LiDAR data, produced a detailed bathymetric dataset of over 90% of the park (Figure 33). The resulting 3D picture created from the LiDAR and side scan sonar/bathymetry gave a distinct picture of the geomorphic structure of the benthic habitat, which was extremely valuable for mapping and in determining the more rugose and higher potential areas for fish and benthic biodiversity
- Field data sets from outside sources varied in usefulness to the habitat mapping effort depending on the origin and training of the observers, but the corresponding photos

and video captures that were taken during data collection proved to be invaluable regardless of data source.

- The issue of the disconnect among researchers on not only what to monitor, but where, how often, and what methods has been resolved for the fish monitoring in the Dry Tortugas by the development of a standardized fish monitoring protocol. The Brandt et al 2009 document was established and agreed upon by those agencies involved in the monitoring of fish assemblages in the region as the fish monitoring protocol to be used throughout South Florida. This will set up cohesiveness in the datasets that are collected by the different agencies (Brandt et al., 2009). However in monitoring of the benthic communities, these issues still exist.

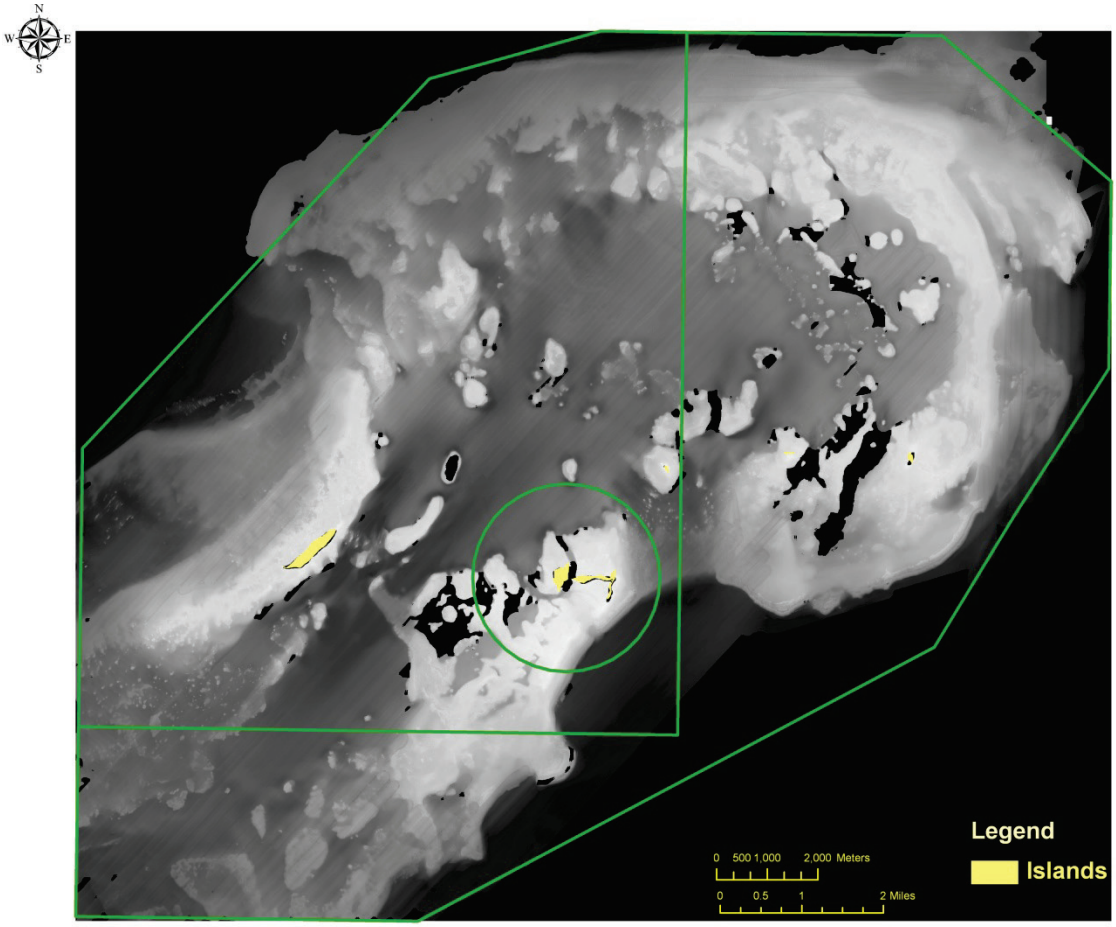


Figure 33. New merged LiDAR and side scan sonar/bathymetry layer.

Conclusion

The Dry Tortugas National Park (DRTO) selected management alternatives that established protection to park resources as well as providing for appropriate types and levels of visitor experiences. This was accomplished by establishing management zones and instituting a permit system for private as well as commercial boats. A research natural area (RNA) was established to protect a representative range of terrestrial and marine resources that ensures protection of spawning fish and fish diversity and protect near-pristine habitats and processes.

The establishment of the RNA has given a new level of protection for the marine environment of DRTO. The NPS establishing body has used all of the necessary mechanisms for establishment in this endeavor. The extensive involvement of user groups, stakeholders, NGOs, recreational and commercial fisherman, and government agencies from the very inception of the RNA's establishment has enhanced its popularity evidenced by its 99% acceptance by all user groups in the enabling legislation (Dry Tortugas National Park – Special Regulations, Final Rule. Federal Register 71(244):76154-76166). The hope is that with this continued support, the RNA will give the user groups a sense of ownership of this ecosystem, thereby increasing the likelihood of long-term success.

The current scientific monitoring programs are going through a collaborative change with hopes that in the near future there will be a scientifically rigorous and statistically powerful monitoring program established for both the benthic and fish components of the RNA and rest of the park. The 2010 benthic habitat map and its corresponding products along with the user map will be of great use to managers, state, federal and university researchers, along with various stakeholder groups and organizations. With this new information park management decisions can be made with more certainty based on data instead of assumptions.

These new products have been shown to have extreme value in accomplishing a multitude of tasks. Among them is the ability to track whether management interventions are successfully protecting the environment or whether changes are needed in the current regulations. The use of the products greatly depends upon the skill set of the user and their desired needs. The hope of the final product is to produce a multi-faceted DVD which will be accessible to the public to help in understanding the marine benthic community of DRTO and the RNA. The final product will make the DRTO benthic habitat available to users in the form of ArcGIS shapefiles or preconfigured JPEG/TIFF maps for non-ArcGIS users. It will also be produced so each user can use the ArcGIS files or will be able to print off the premade maps if this program is not available.

Summary of final products

The final 2010 benthic habitat mapping project contains 29 files. The filenames and descriptions are summarized below and are available on the South Florida / Caribbean Network's website, http://science.nature.nps.gov/im/units/sfcn/. In addition Appendix F contains printable versions of the maps.

Table 14. Summary of final products.

Category	Product or File Description	Filename
Raster Data	2006 IKONOS RGB Graphic	DRTO_2006_IKONOS_RGB_4m.pdf
	This imagery is “IKONOS is a commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. It offers multispectral (MS) and panchromatic (PAN) imagery,” which was taken for the Dry Tortugas National Park. NOTE: No Metadata was available for this data set.	DRTO_2006_IKONOS_RGB_4m.zip
	2006 IKONOS blue band Graphic	DRTO_2006_IKONOS_blue_band_4m.pdf
	This imagery is “IKONOS is a commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. It offers multispectral (MS) and panchromatic (PAN) imagery,” which was taken for the Dry Tortugas National Park. NOTE: No Metadata was available for this data set. This imagery is using the blue band which gives a better resolution for deeper water environments.	DRTO_2006_IKONOS_blue_band_4m.zip
	2007 NAIP RGB Graphic	DRTO_2007_NAIP_RGB_1m.pdf
	This imagery was developed by the National Agriculture Imagery Program with a resolution of 1meter, but due to the reflection off the water and the return of light due to the wave action and surface movements during the imaging process the imagery is not of high quality in all areas of the park. The metadata for this layer is located in the metadata file located in the product	DRTO_2007_NAIP_RGB_1m.zip
	Bathymetry data in a graphic format	DRTO_Raw_XYZ_bathymetry_data.pdf
	Raw bathymetry data in ASCII format	DRTO_Raw_XYZ_bathymetry_data.zip
	Side scan returns in a graphic format.	DRTO_Sidescan_Raw_30cm.pdf
	This is the raw imagery collected from the returns of the side scan sonar with a resolution of 30cm. The following are the layers that were sent to SFCN and were broken up into 7 different images because of their size.	DRTO_Sidescan_Raw_30cm.zip
	2010 LiDar Side scan sonar merged graphic	DRTO_2010_LIDAR_SS_merge_1m.pdf
	This data layer is a merged layer of 2004 LIDAR and 2010 Side Scan bathymetry into one filtered data set. The resolution for this layer is 1m	DRTO_2010_LIDAR_SS_merge_1m.zip

Category	Product or File Description	Filename
Project Report	Project report (contains full report about the benthic habitat map 2010 including funding source, background information {geology}, methods and results, final product specifications, brief description of products and files, NOAA marine benthic classification and key, photo-interpretation key with map class descriptions & photos (underwater, aerial, sonar), accuracy assessment), and example field data sheets (RHA, RVC, AA)	DRTO_benthic_rpt.pdf DRTO_benthic_rpt_pressquality.pdf
Field Data	Field Data (MDB) – contains field sites data RHA data RVC data (2004-2009) AA data (SFCN field + 2010 RVC) Graphic showing location of map field data sites Field site photos RHA photos AA photos & Video	 DRTO_benthic_RHA.mdb DRTO_benthic_RVC.mdb DRTO_benthic_AA.mdb DRTO_benthic_field_data.PDF DRTO_Field_photos_RHA.zip DRTO_Field_photos_aa.zip
Geospatial Marine Benthic Habitat Information	Zip folder containing geodatabase (DRTO_benthic.mdb) of spatial data (includes data for marine benthic habitat polygons, field data sets, accuracy assessment data, and park boundaries) ESRI ArcMap Project file – displays geodatabase (MDB) files Graphic of marine benthic communities (low resolution) Graphic of marine benthic communities (high resolution) Although use of the geodatabase and ArcMap Project File is recommended, individual shapefiles are also included as zip files: Marine benthic habitat polygons Park boundary Field data sites including RVC data, RHA data, AA data	DRTO_benthic.zip DRTO_benthic_2010_map_project.mxd DRTO_benthic_lowres.pdf DRTO_benthic_highres.pdf DRTO_2010_marine_benthic_polygons.zip DRTO_boundary.zip DRTO_benthic_RHA.zip DRTO_benthic_RVC.zip DRTO_benthic_AA.zip
Accuracy Assessment Information	Graphic showing locations of accuracy assessment points MS Excel format of 2008 AA data MS Excel format of 2011 AA data MS Excel format of 2011 AA summary	DRTO_aa.pdf DRTO_aa_2008.xls DRTO_aa_20011.xls DRTO_aa_2011_summary.xls
Project Metadata	Raster & imagery metadata Spatial marine benthic habitat metadata Park boundary metadata Field data sets metadata Accuracy Assessment data sets	meta_drto_2006_IKONOS_RGB_4m.txt meta_drto_2006_IKONOS_blue_band_4m.txt meta_drto_2007_NAIP_RGB_1m.txt meta_drto_Raw_XYZ_bathymetry_data.txt meta_drto_Sidescan_Raw_30cm.txt meta_drto_2010_LIDAR_SS_merge_1m.txt meta_drto_2010_marine_benthic_polygon.txt meta_drto_boundary.txt meta_drto_rvc_04_08.txt meta_drto_rvc_09_10.txt meta_drto_rha_sites.txt meta_drto_aa_2008.txt meta_drto_aa_rvc_supplements.txt meta_drto_aa_visited_2011.txt

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Appendix A. Reef Visual Census (RVC) Habitat Classification Key

Below is the RVC Habitat Classification Key from, "A cooperative multi-agency reef fish monitoring protocol for the Florida Keys coral reef ecosystem" (Brandt et al., 2009).

C.3.iv Habitat Data

Following the sample-specific data collection, habitat data are collected and recorded on the Fish/Habitat data sheet. The following variables are measured and recorded:

Habitat type: chosen from the following categories (circle one on the Fish/Habitat data sheet). At the surface, the diver should discuss with their buddy and other team members and try to come to a consensus. If a consensus is not achieved, divers should note that in the Field/Boat Log.

Target habitats:

- Isolated reef structure(s): E.g., patch reefs, rocky outcrops, pinnacle (Figure C.7-A)
- Contiguous reef structure with distinct spur and groove formation: E.g., low or high relief spur and groove (Figure C.7-B)
- Contiguous reef structure – Other: contiguous reef with no distinct formation; e.g., low relief hard bottom not spur and groove (Figure C.7-C)
- Reef Rubble (Figure C.7-D)

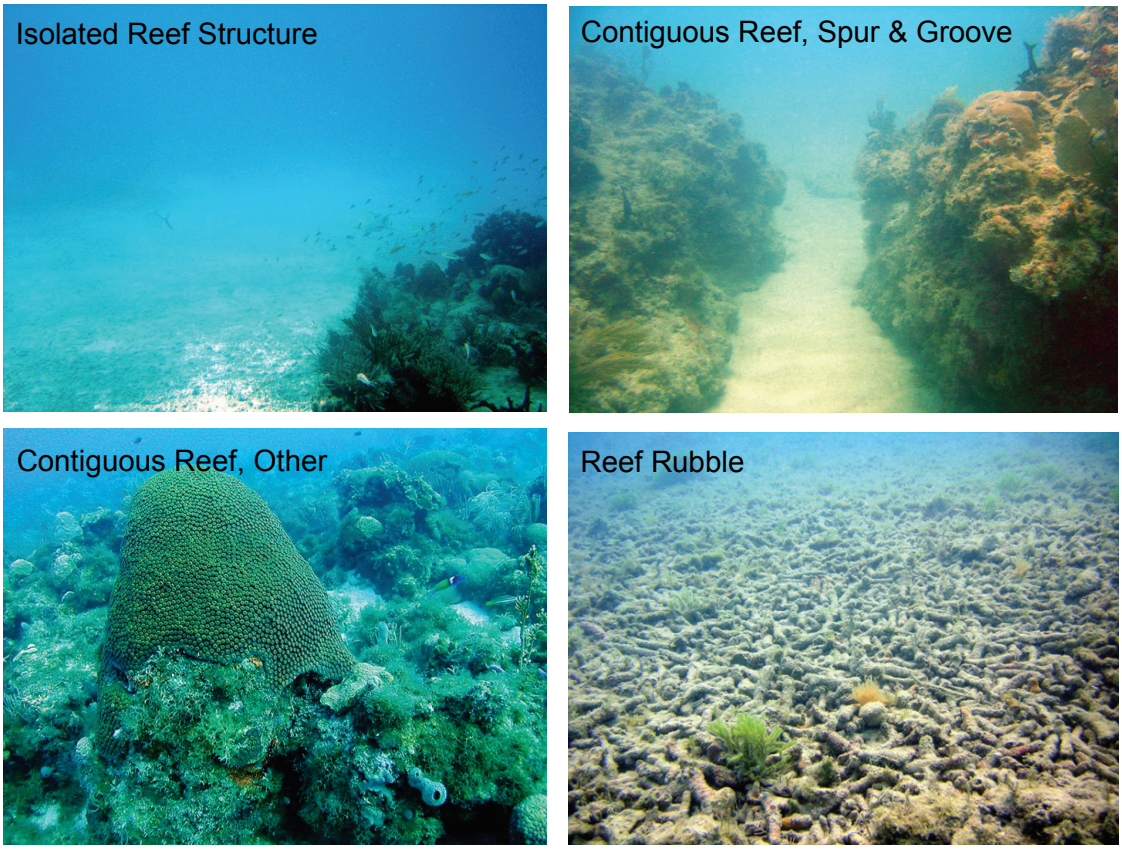


Figure C.7. Example photos of target habitats.

Water temperature, Secchi visibility and Current: temperature and visibility at the bottom; water current estimated by divers for each paired survey; categories as follows: None (none), Mod. (diver is able to stay in same position with a gentle kick), High (diver struggles to stay in same position).

Non-target habitats: if after diving for 5 minutes divers fail to find any of the target habitat types, divers should conduct a count in one of the non-target habitats noting the habitat type on the Field/Boat Log.

- Sand
- Sand-seagrass-hard-bottom matrix: mostly soft bottom, non-reef habitat
- Artificial reef (e.g., wrecks)

Substrate Slope: the maximum and minimum depths within the sample cylinder. These values refer to the maximum and minimum depths on the imaginary plane underlying the sample cylinder. If there is a slope these depths will be different (Figure C.8).

Max Vertical Relief: the maximum vertical relief within the sample cylinder of both hard (e.g., coral structure, coralline spur, rocky outcrop) and soft (e.g., octocorals, sponges and macroalgae) substrate (Figure C.8). These values should not be zero.

Surface Relief Coverage for Hard Vertical Relief (e.g., coral structure, coralline spur, rocky outcrop and sand): the estimated percentages of hard relief that fall into the following categories (all values in meters): < 0.2, 0.2-0.5, .05-1.0, 1.0-1.5, and >1.5. These values should sum to 100% (Figure C.8).

Surface Relief Coverage for Soft Vertical Relief (e.g., octocorals, sponges and algae): the category (< 0.2, 0.2-0.5, .05-1.0, 1.0-1.5, and >1.5m) representing the average vertical relief of all soft relief should be indicated by writing "100%" by that category (Figure C.8).

Abiotic Footprint: the percentage of the cylinder comprised of sand, hardbottom and rubble. These percentages should sum to 100%. Sand is defined as coarse biogenic or oolitic sand (grain sizes typically between 0.5-2 mm) and finer silt sized particles (< 0.2 mm). Sand is considered the substratum when sediment depth is usually 2-3 cm in depth or greater. It excludes a surface "dusting" of sediment particles overlying a consolidated substratum. Rubble ranges from coarse gravel (> 5 mm) to unconsolidated and moveable rocks (e.g. dislodged and moveable coral fragments). This category differs from consolidated hard-bottom because of its loose and moveable nature. Consolidated hard-bottom includes solid, consolidated lithogenic or biogenic substratum, including living and dead coral, and non-coral hard-bottom. Areas covered by seagrass should be coded as sand, since the biotic "grass" is growing in the abiotic sand substrate.

Biotic Cover - SAND: the percentage of the sand substrate that corresponds to the following categories: bare, under / supporting growth of macroalgae, under / supporting growth of seagrass, under / supporting growth of sponges, and other (e.g., Sargassum; see Appendix 2 for more examples). These values should sum to 100%. See preceding section for sand definition.

Biotic Cover – HARDBOTTOM: While looking at an aerial, canopy view of the cylinder, the percentage of the hardbottom substrate covered with algae < 1 cm height (e.g., turf algae, *Lobophora*), macroalgae > 1 cm height (e.g., *Halimeda, Dictyota*), live coral, octocoral, sponge, and other (e.g., *Palythoa*, *Cliona*; see Appendix 2 for more examples). These values should sum to 100%.

Comments: Under the "comments" section, divers should record information such as economically important species observed before or after the RVC survey (e.g., while descending or ascending), presence of *Acropora palmata* and/or *Acropora cervicornis* (if present circle), presence of black coral, number of Spiny Lobster, Conch and/or *Diadema antillarum*, and camera number used. If present, divers should also record the type and amount of fishing gear or debris (e.g., monofilament line, traps or trap debris including buoy line, etc.) within the cylinder in the "Fishing gear" section of the Fish/Habitat Data Sheet (Figure C.5). Additionally, any comments relative to the sampling or conditions encountered should be recorded in the "Comments" section of the data sheet.

Following fish and habitat data collection, sample end time is recorded and divers ensure that all sections on the Reef / Habitat data sheet are completed. Dive end time is recorded after all data have been collected and immediately prior to dive ascent.

Appendix B. A Classification Scheme for Mapping the Shallow-water Coral Ecosystems of Southern Florida



A Classification Scheme for Mapping the Shallow-water Coral Ecosystems of Southern Florida

Version 3.2
20 June 2008

"Systems of classification are not hatracks, objectively presented to us by nature. They are dynamic theories developed to express particular views about the history of organisms.

Gould, SJ 1987 In Hatracks and Theories, Natural History **96**(3).

Introduction

A hierarchical classification scheme is being developed to define and delineate the benthic habitats associated with southern Florida's shallow-water (generally, less than 30 m depth) coral ecosystems. The hierarchical scheme allows users to expand or collapse the thematic detail of the resulting map to suit their needs. This is an important aspect of the scheme as it provides a "common language" to compare and contrast digital maps derived from various remote sensing platforms. ***The ability to apply any component of this scheme is dependent on being able to identify and delineate a given feature in remotely sensed imagery and assess the accuracy of the resulting benthic habitat map.*** Furthermore, the hierarchical structure of the scheme enables users to add habitat categories to the resulting GIS-based maps.

A tropical coral ecosystem is composed of both habitats and structural zones. Benthic habitats found in a coral ecosystem include unconsolidated sediments (e.g., sand and mud); mangrove; submerged vegetation (e.g., seagrass and algae); hermatypic coral reefs and associated colonized hard bottom habitats (e.g., spur and groove, individual and aggregated patch reefs, and gorgonian-colonized pavement and bedrock); and uncolonized hard bottom (e.g., reef rubble and uncolonized bedrock). Typical structural zones include the Reef Crest, Forereef, Bank/Shelf, and Lagoon (Rohmann et al., 2005).

The development of the classification scheme is influenced by many factors including: the requirements of the Florida coral ecosystem conservation and management community; NOS's coral ecosystem mapping experience in the Florida Keys and U.S. Caribbean; existing classification schemes for the U.S. Caribbean, and Pacific and Hawaiian Islands (Holthus and Maragos 1995; Gulko 1998; Allee et al. 2000) and other coral reef systems (Kruer 1995; Reid and Kruer 1998; Lindeman et al. 1998; Sheppard et al. 1998; Vierros 1997; Chauvaud et al. 1998; Mumby et al. 1998; Kendall et al. 2001); the minimum mapping unit (MMU - 0.4 hectare or 4,046 sq m for visual imagery interpretation) previously used for mapping; and the spatial and spectral limitations of the imagery used to derive the maps.

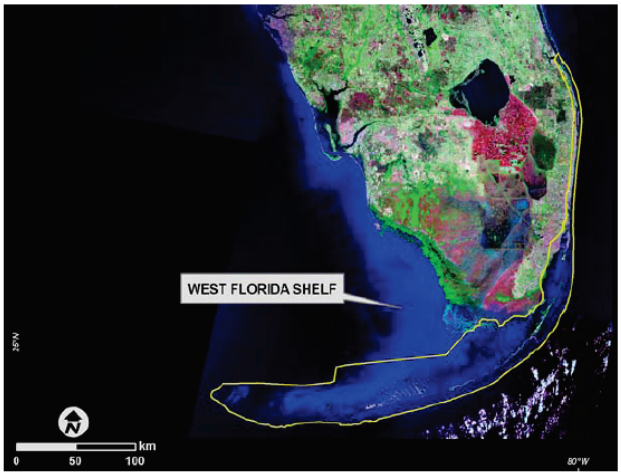


Figure 1. The yellow polygon delineates the approximately 13,000 sq km priority shallow-water benthic habitat mapping area of southern Florida.

The Florida Fish and Wildlife Research Institute, in partnership with the U.S. EPA's Gulf of Mexico Program, developed a benthic habitat scheme. That scheme, a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida was used to develop this scheme (Madley et al., 2002). The categories of habitats described in SCHEME have been linked to the habitat categories in this scheme and are shown in **Bold**.

This scheme was prepared using input from coral reef biologists, mapping experts, and resource managers familiar with southern Florida's coral ecosystems. The scheme will be modified based on feedback provided during its' application during actual mapping activities to ensure that each category describes the intended habitats and zones encountered in the field as accurately as possible.

Using the capabilities provided by the GIS, each polygon identified in the coral ecosystem landscape can be assigned three attributes. Each polygon can be assigned to a zone (e.g., fore reef), which denotes its' cross sectional location relative to emergent features (see Figure 2 on page 4). Each polygon can be assigned a geomorphological structure attribute, which denotes the physical structure (e.g., pavement) associated with its' underlying composition within the coral ecosystem. Finally, each polygon can be assigned a biological cover attribute, which denotes the type of biological cover (e.g., seagrass) found on the geomorphological structure of the location within the coral ecosystem.

The Coral Ecosystem Classification Scheme

Coral Ecosystem Geomorphological Structures

Structure Types - Fourteen distinct and non-overlapping geomorphological structure types have been described that can be mapped by visual interpretation of the IKONOS imagery. Habitats or features that cover areas smaller than the 0.4 ha MMU are not considered. For example, sand halos surrounding patch reefs are too small to be mapped independently. Structure refers only to predominate physical structural composition of the feature and does not address location (e.g., on the shelf or in the lagoon). The structure types are defined in a collapsible hierarchy ranging from four major classes (Unconsolidated Sediment; Coral Reef and Hardbottom; Other Delineations; and Unknown), to thirteen detailed classes (Sand; Mud; Spur and Groove; Individual or Aggregated Patch Reef; Aggregate Reef; Scattered Coral/Rock in Unconsolidated Sediment; Pavement; Rock/Boulder (volcanic and carbonate); Reef Rubble; Pavement with Sand Channels; Artificial; Land; and Unknown).

Unconsolidated Sediment

Sand: Coarse sediment typically found in areas exposed to currents or wave energy. Sand is associated with several zones including shoreline intertidal, bank/shelf, ridges and swales, and forereef. **(12 – Sand; 13 – Mixed Fine; 14 – Mixed Coarse; 15 – Granule)**

Mud: Fine sediment often associated with river discharge or the build-up of organic material in areas sheltered from high-energy waves and currents. Mud is associated with several zones including shoreline intertidal, and lagoon **(11 – Mud)**



Sand *Mud*

Coral Reef and Hardbottom: Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock or volcanic rock.

Spur and Groove: Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or reef crest. The coral formations (spurs) of this feature typically have a high vertical relief relative to pavement with sand channels (see below) and are separated from each other by 1-5 meters of sand or hard-bottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the forereef zone. **(31121 – High Relief Spur and Groove)**

Individual or Aggregated Patch Reef: Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that may or may not have organized structural axis relative to the contours of the shore, lagoon, bank/shelf, and ridges and swales zones.

Individual Patch Reef: Distinctive single patch reefs that are larger than or equal to 625 sq m (0.0625 ha). **(3121 – Individual Patch Reef; 3125 – Pinnacles)**

Aggregate Patch Reefs: Clustered patch reefs that individually are too small (less than the 0.4 ha MMU) or are too close together to map separately. **(3124 – Aggregated Patch Reefs (including Halo areas if present))**

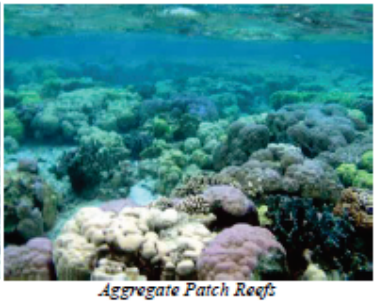
Aggregate Reef: High relief lacking sand channels of spur and groove. **(3111 – Linear Reef; 32 – Mollusk Reefs; 33 – Annelid Reefs (i.e., Sabellariid reefs))**



Spur and Groove



Individual Patch Reef



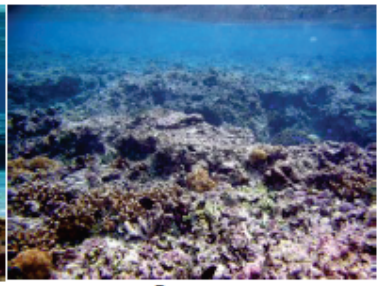
Aggregate Patch Reefs

Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e. smaller than individual patch reef). **(313 – Patchy Coral and/or Rock in Unconsolidated Bottom)**

Pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that are dense enough to begin to obscure the underlying surface. **(342 – Pavement (i.e., low relief hardbottom))**



Scattered coral/rock in unconsolidated sediment

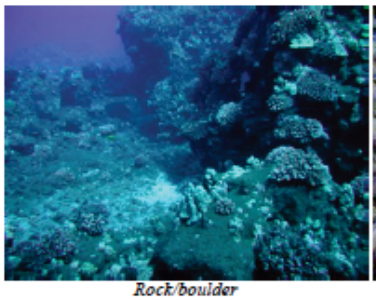


Pavement

Rock/Boulder: Solid carbonate blocks and/or boulders or volcanic rock. **(16 – Pebble; 17 – Cobble; 341 – Bedrock)**

Reef Rubble (volcanic and carbonate): Dead, unstable coral rubble often colonized with filamentous or other macroalgae. This habitat often occurs landward of well-developed reef formations in the reef crest, ridges and swales, or back reef zone. **(3113 – Reef Rubble)**

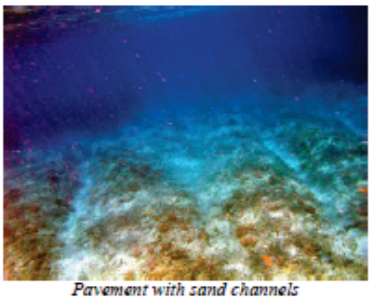
Pavement with Sand Channels: Habitats of pavement with alternating sand/surge channel formations that are oriented perpendicular to the reef crest or ridges and swales zone. The sand/surge channels of this feature have low vertical relief relative to spur and groove formations and are typically erosional in origin. This habitat type occurs in areas exposed to moderate wave surge such as the forereef zone. **(31122 – Low Relief Spur and Groove)**



Rock/boulder



Reef rubble



Pavement with sand channels

Other Delineations

Artificial: Man-made habitats such as submerged wrecks, large piers, submerged portions of rip-rap jetties, and the shoreline of islands created from dredge spoil. **(Modifier A – Artificial)**

Land: Terrestrial features above the spring high tide line. **(6 – Land)**

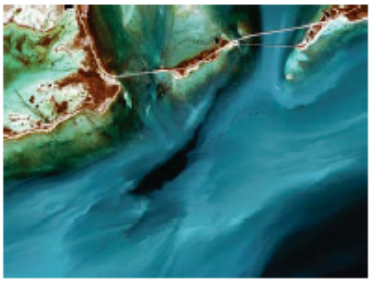
Unknown: Zone, Cover, and Structural feature that is not interpretable due to turbidity, cloud cover, water depth, or other interference. **(7 – Unknown)**



Artificial



Land



Unknown

Coral Ecosystem Zones

Zone Types - Twelve mutually exclusive zones can be identified from land to open water corresponding to typical insular shelf and coral reef geomorphology. Figure 2 (next page) is a cross-sectional diagram showing the generalized locations of most of these zones. The zones include: Shoreline Intertidal; Lagoon; Bank/Shelf; Back Reef; Ridges and Swales; Reef Crest; and Forereef.; Five zones not included in the diagram are Vertical Wall, Bank/ Shelf Escarpment, Channel, Dredged, and Unknown. Zone refers only to each benthic community's location and does not address substrate or cover types that are found within. A brief description of each zone is provided, starting on the next page.

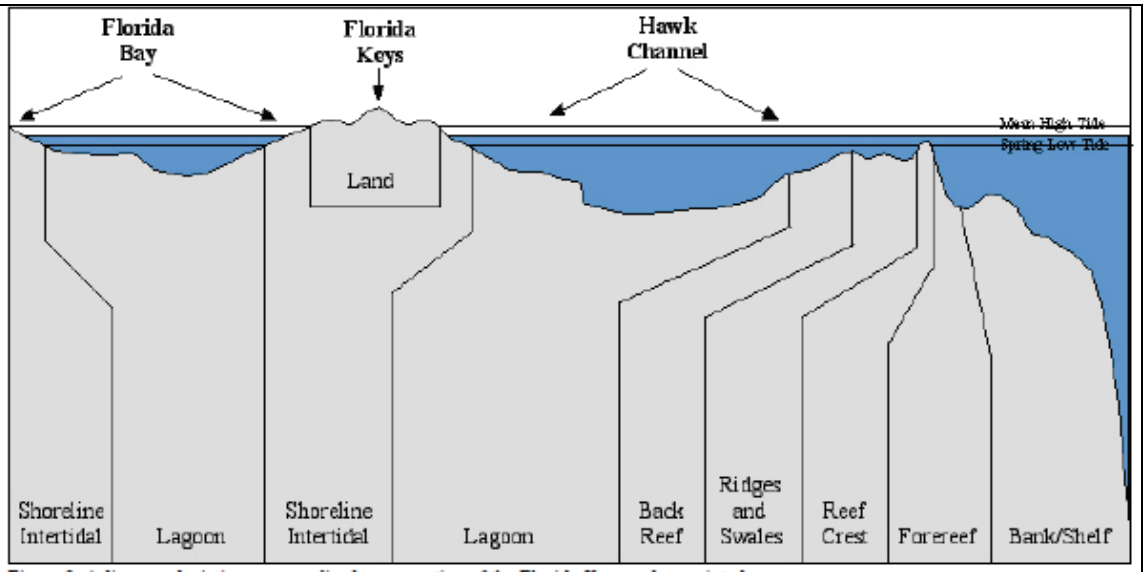


Figure 2. A diagram depicting a generalized cross-section of the Florida Keys and associated zones.

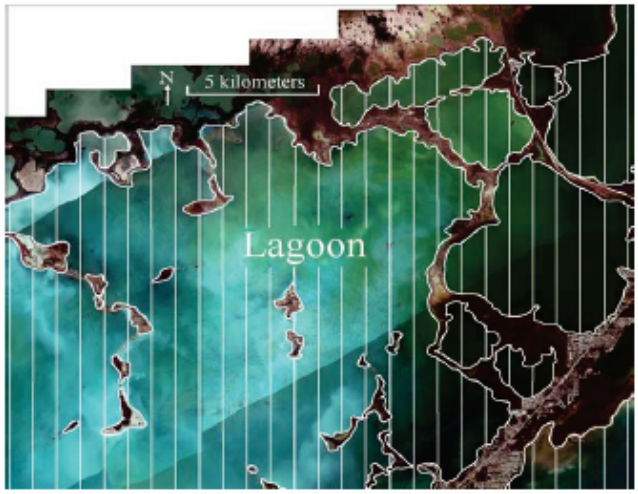
Shoreline Intertidal: Area between the mean high water line (or landward edge of emergent vegetation, such as Red Mangrove, when present) and lowest spring tide level (excluding emergent segments of barrier reefs). Typically, this zone is narrow due to the small tidal range in southern Florida. **(Modifier Z2 – Intertidal)** Typical biological cover types found in this zone:

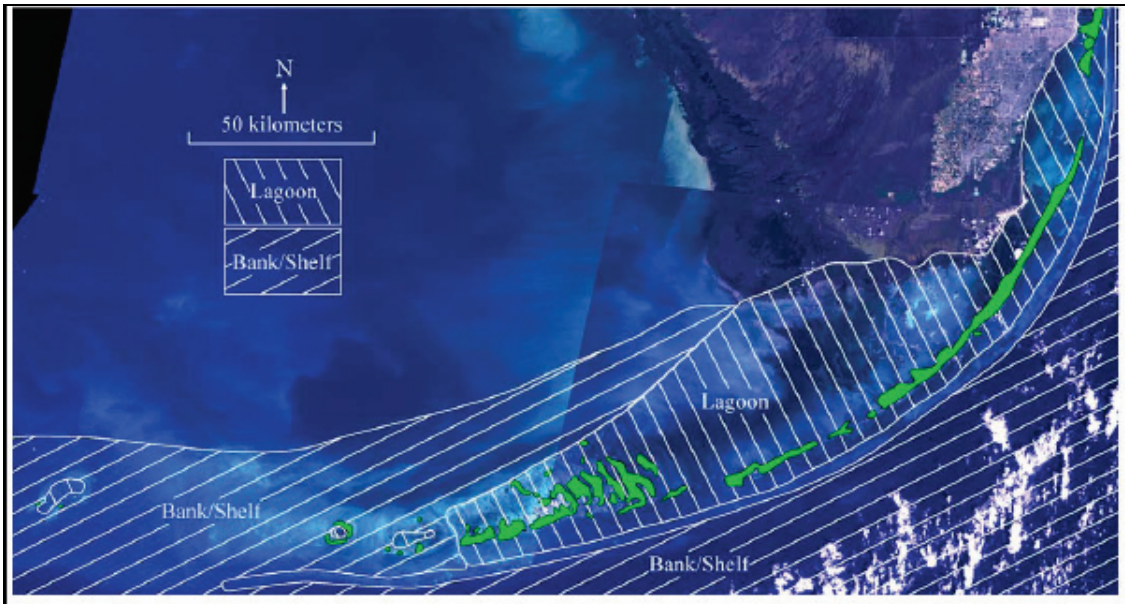
* Emergent Vegetation
* Uncolonized

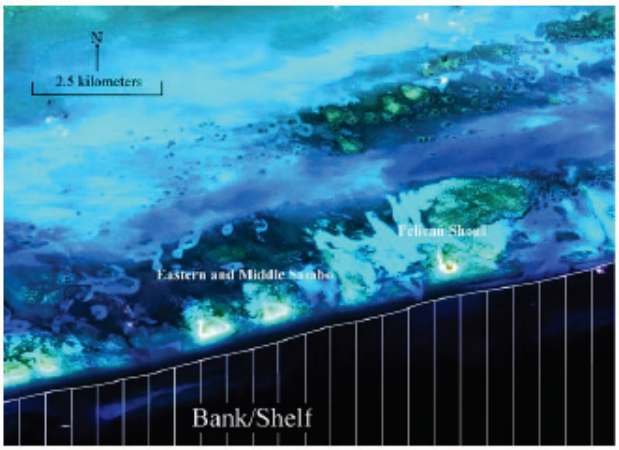


Lagoon: Shallow area (relative to the deeper water of the bank/shelf) between the shoreline intertidal zone and the back reef of a reef or a barrier island. This zone is typically protected from the high-energy waves found in the Bank/Shelf zone and can be interconnected by tidal exchange or riverbed channels and passes. See next figure showing Lagoon and Bank/Shelf locations. **(No equivalent)** Typical biological cover types found in this zone:

* Sand
* Seagrass
* Macroalgae
* Emergent Vegetation
* Patch Reef

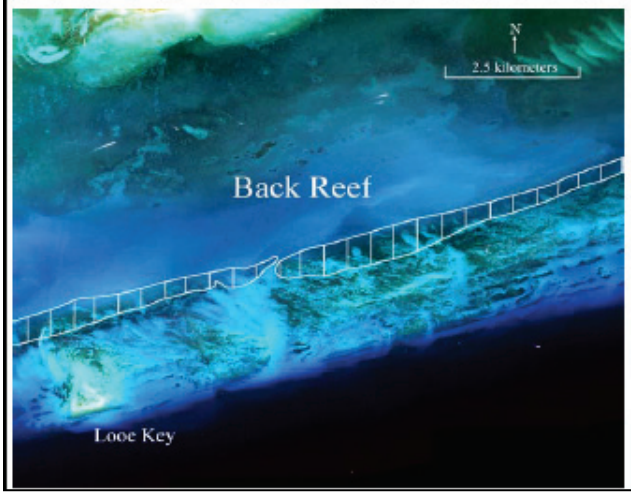






Bank/Shelf: A deep water (relative to the shallow water in a lagoon) area typically extending offshore from the seaward edge of the Forereef to the beginning of the escarpment where the shelf drops off into deep, oceanic water. The Bank/Shelf is generally the platform between the Forereef and deep ocean water or between the Shoreline Intertidal zone and open ocean if no Reef Crest is present. **(No equivalent)** Typical biological cover types found in this zone:

* Sand
* Live Coral
* Seagrass
* Macroalgae

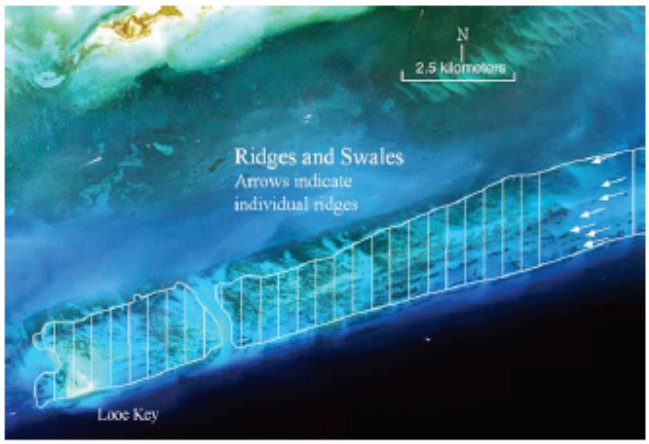


Back Reef: Area between the bank/shelf and the ridge and swale or reef crest zone. This zone is present when a bank/shelf, ridges and swales, or reef crest zone exist. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral
* Seagrass
* Macroalgae
* Encrusting/Coralline Algae
* Turf Algae

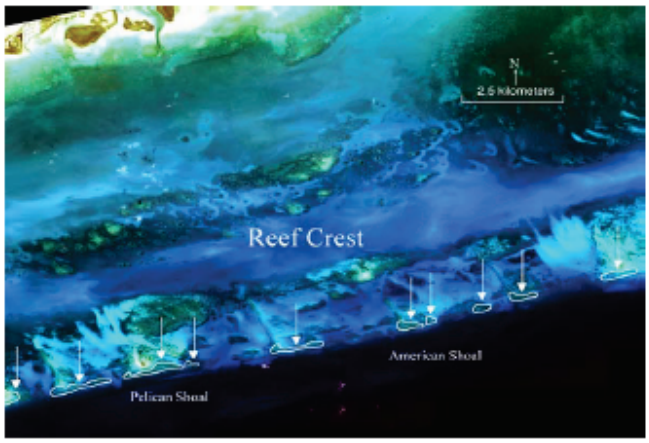
Ridges and Swales: An area of numerous thin, narrow, discontinuous bands of coral ridges and leeward sand and sediment-filled swales. Debris and reef-rubble fields behind many of the reefs may obscure these margin-parallel seabed features. This zone extends for an estimated 200 km along the shelf from the Key Largo to Halfmoon Shoal and is discontinuous due to topography, inconsistent responses of coral reefs to changing sea level, and from varying effects of the physical environment on reefs and sediments. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral



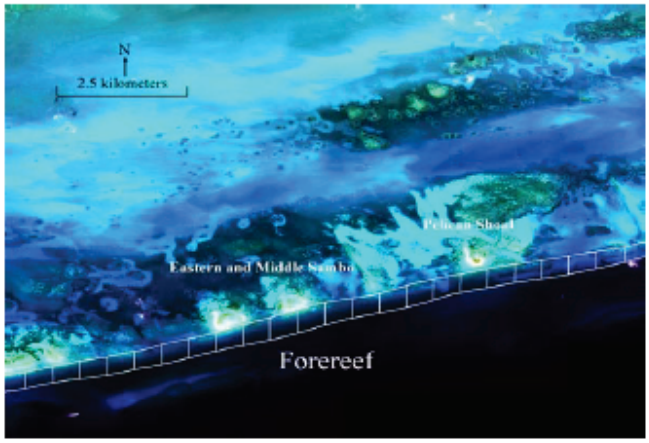
Reef Crest: The flattened, emergent (especially during low tides) or nearly emergent segment of a reef. This zone lies between the Ridge and Swale and Forereef zones. Breaking waves will often be visible in aerial images at the seaward edge of this zone. **(Modifier Z2 – Intertidal)** Typical biological cover types found in this zone:

* Live Coral
* Encrusting/Coralline Algae



Forereef: An area along the seaward edge of the Reef Crest that slopes into deeper water to the landward edge of the bank/shelf platform. Features not forming an emergent reef crest but still having a seaward-facing slope that is significantly greater than the slope of the bank/shelf are also designated as Forereef. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral
* Encrusting/Coralline Algae





Channel: Naturally occurring channels that often cut across several other zones. **(Modifier E – Submerged tidal canals)** Typical biological cover types found in this zone:

* Live Coral
* Seagrass
* Macroalgae
* Turf Algae
* Emergent Vegetation



Dredged: Area in which natural geomorphology is disrupted or altered by excavation or dredging. **(Modifier F – Dredged/Excavation)** Typical biological cover types found in this zone:

* Live Coral
* Seagrass
* Macroalgae
* Turf Algae
* Emergent Vegetation
* Unknown

Vertical Wall: Area with near-vertical slope from shore to shelf or shelf escarpment. This zone is typically narrow and may not be distinguishable in remotely sensed imagery, but is included because it is recognized as a biologically important feature. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral
* Encrusting/Coralline Algae

Bank/Shelf Escarpment: This zone begins on the oceanic edge of the Bank/Shelf ,where depth increases rapidly into deep, oceanic water and exceeds the depth limit of features visible in aerial images. This zone is designated to capture the transition from the shelf to deep waters of the open ocean. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral

Unknown: Zone, Cover, and Structural feature that is not interpretable due to turbidity, cloud cover, water depth, or other interference. **(7 – Unknown)**

Coral Ecosystem Biological Cover

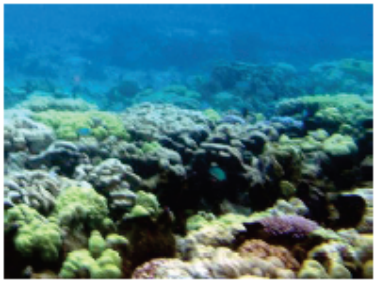
Biological Cover Types - Sixteen distinct and non-overlapping biological cover types can be identified that may be mapped through visual interpretation of the IKONOS imagery. Typically, habitats or features that cover areas

smaller than the 0.4 hectare MMU are not considered. The two exceptions are: 1) patch reefs in Hawk Channel with an area greater than 625 sq m (0.0625 ha); and 2) islands with an area greater that 1000 sq m (0.1 ha). Cover type refers only to predominate biological component colonizing the surface of the feature and does not address location (e.g., on the shelf or in the lagoon). The cover types are defined in a collapsible hierarchy ranging from six major classes (live coral, seagrass, macroalgae, encrusting coralline algae, turf algae, emergent vegetation, uncolonized, and unknown), combined with a density modifier representing the percentage of the predominate cover type (10%-<50%: sparse; 50%-<90%: patchy; 90%-100%: continuous).

The assignment of Habitat Cover and Cover Modifier categories to the map is a stepwise progression from Live Coral to Seagrass to Macroalgae, etc, until the Uncolonized category is reached. The Stepwise progression also proceeds from Live Coral-Continuous to Live Coral-Patchy to Live Coral-Sparse before jumping to the Seagrass category. The Stepwise progression would then proceed from Seagrass-Continuous to Seagrass-Patchy to Seagrass-Sparse before jumping to the Macroalgae category, etc. As a result, there will be cases where, for example, a habitat polygon may exhibit ~25% seagrass and ~75% macroalgae and will be classified as Seagrass-Sparse rather than Macroalgae-Patchy, even though the dominant seafloor cover is macroalgae.

Biological Cover categories that can be readily and accurately interpreted will be assigned, as feature attributes, to habitat polygons during the initial visual interpretation process. *In-situ* data from both the visual interpretation activity and local research and monitoring will be used to determine Biological Cover attributes of feature polygons during the map production process. During this process, the *Live Coral*, *Macroalgae*, *Encrusting/Coralline Algae*, and *Turf Algae* cover categories will be assigned as preliminary feature attributes. Draft map products showing coral ecosystem zone, structure, and the *Seagrass* biological cover will be reviewed for overall accuracy using standard map accuracy techniques. A peer review process will be used to determine accuracy of the *Live Coral*, *Macroalgae*, *Encrusting/Coralline Algae*, and *Turf Algae* biological cover features shown on draft maps and whether or not they should be included in the final map product.

Live Coral: Substrates colonized by sponges, octocorals, and hexacorals and have at least 10% live coral cover.



Hexacorals



Octocorals

Continuous Coral: Live coral covering 90% or greater of the substrate. May include areas of less than 90% coral cover on 10% or less of the total area that are too small to be mapped independently (generally less than 0.4 ha). **(No equivalent)**

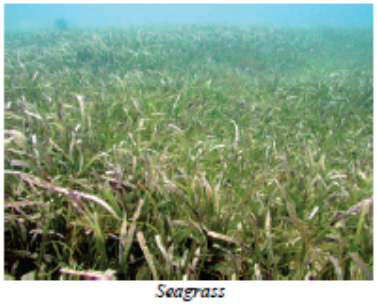
Patchy Coral: Discontinuous live coral with breaks in coverage that is too diffuse, irregular, or result in isolated patches that are too small (generally smaller than the 0.4 ha MMU) to be mapped as continuous coral. Overall live coral cover is estimated at 50%-<90% of the bottom. **(No equivalent)**

Sparse Coral: Discontinuous live coral with breaks in coverage that is too diffuse, irregular, or result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as patchy coral. Overall live coral cover is estimated at 10%-<50% of the bottom. **(No equivalent)**

Representative Hexacoral Species:	Representative Octocoral Species
Acropora cervicornis	*Briareum asbestinum*
Acropora palmate	*Eunicea succinea*

Acropora spp.	*Gorgonia ventalina*
Agaricia spp.	*Leptogorgia virgulata*
Montastrea annularis	*Plexaura flexuosa*
Lophelia prolifera	*Plexaura homomalla*
Oculina varicose	*Plexaurella spp.*
Porites porites	*Pseudoplexaura spp.*
Porites spp.	*Pseudopterogorgia spp.*

Seagrass: Habitat with 10 percent of more of seagrass (e.g., Halophila sp.).



Seagrass



Macroalgae

Continuous Seagrass: Seagrass community covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the MMU). **(211 – Continuous Submerged Rooted Vegetation SRV)**

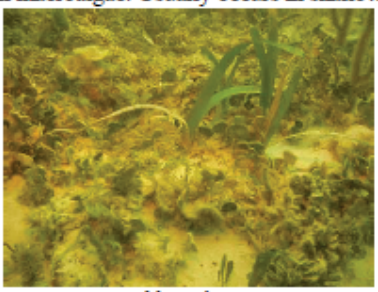
Patchy Seagrass: Discontinuous seagrass community with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as continuous seagrass. Overall cover is estimated at 50%-<90% of the bottom. **(2111 - Dense patches of SRV in a matrix of continuous, sparse SRV)**

Sparse Seagrass: Discontinuous seagrass community with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as patchy seagrass. Overall cover is estimated at 10%-<50% of the bottom. **(212 – Discontinuous SRV)**

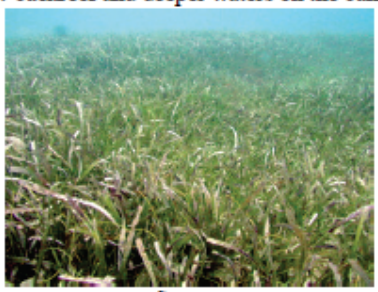
Representative Seagrass Species:

Thalassia testudinum	*Halophila decipiens*	*Syringodium filiforme*
Halodule wrightii	*Halophila johnsonii*	*Halophila engelmanni*

Macroalgae: Substrates with 10 percent or greater coverage of any combination of numerous species of red, green, or brown macroalgae. Usually occurs in shallow backreef and deeper waters on the bank/shelf zone.



Macroalgae



Seagrass

Continuous Macroalgae: Macroalgae covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the 0.4 ha MMU). **(2211 - Continuous attached macroalgae)**

Patchy Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse, irregular or

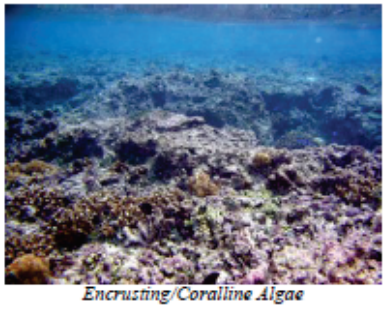
result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as continuous macroalgae. Overall cover is estimated at 50%-<90% of the bottom. **(22111 - Dense patches of attached macroalgae in a matrix of continuous, sparse macroalgae)**

Sparse Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small (smaller than the MMU) to be mapped as patchy macroalgae. Overall cover is estimated at 10%-<50% of the bottom. **(2212 - Discontinuous attached macroalgae)**

Representative Species:

Caulerpa spp.	*Laurencia spp.*	*Halimeda spp.*
Dictyota spp.	*Lobophora variegata*	

Encrusting/Coralline Algae: An area with 10 percent or greater coverage of any combination of numerous species of encrusting or coralline algae. May occur along reef crest, in shallow back reef, relatively shallow waters on the bank/shelf zone, and at depth.



Encrusting/Coralline Algae

Continuous Coralline Algae: Coralline algae covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the 0.4 ha MMU). **(No equivalent)**

Patchy Coralline Algae: Discontinuous coralline algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as continuous coralline algae. Overall cover is estimated at 50%-<90% of the bottom. **(No equivalent)**

Sparse Coralline Algae: Discontinuous coralline algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as patchy coralline algae. Overall cover is estimated at 10%-<50% of the bottom. **(No equivalent)**

Representative Species:
Porolithon gardineri

Turf Algae: A community of low lying species of marine algae composed of any or a combination of algal divisions dominated by filamentous species lacking upright fleshy macroalgal thali.



Turf Algae

Continuous Turf Algae: Turf algae covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the 0.4 ha MMU). **(No equivalent)**

Patchy Turf Algae: Discontinuous Turf algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as continuous Turf algae. Overall cover is estimated at 50%-<90% of the bottom. **(No equivalent)**

Sparse Turf Algae: Discontinuous Turf algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as patchy Turf algae. Overall cover is estimated at 10%-<50% of the bottom. **(No equivalent)**

Representative species:

Sargassum spp.	*Dictyota spp.*	*Avrainvellea spp.*
Rhipocephalus spp.	*Cladophora spp.*	*Batophora spp.*

Digenia spp.	*Chondria spp.*	*Laurencia spp.*
Gracilaria spp.	*Caulerpa spp.*	*Halimeda spp.*

Emergent Vegetation: Emergent habitat composed primarily of *Rhizophora mangle* (red mangrove) and other species. Generally found in areas sheltered from high-energy waves. This habitat type is usually found in the shoreline/intertidal or reef flat zone. **(4 – Tidal Marsh; Modifier M – Mat algae; N – Attached macroalgae)**



Emergent Vegetation

Marsh: Habitat dominated by marsh species such as *Spartina spps.* or *Saliconia spps.*

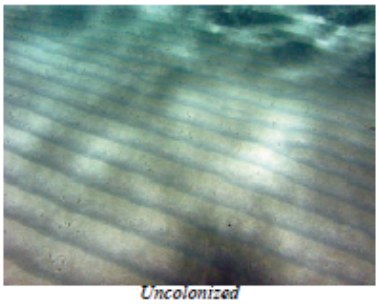
Mangrove: Habitat dominated by mangrove species *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove), and *Conocarpus erectus* (buttonwood).

Representative species:

Avicennia germinans	*Salsola kali*	*Spartina alterniflora*
Laguncularia racemosa	*Distichlis spicata*	*Juncus roemerianus*
Rhizophora mangle	*Batis maritima*	*Spartina patens*
Conocarpus erectus	*Cladium mariscoides*	*Vallisneria americana*
Ruppia maritime	*Salicornia virginica*	

Uncolonized: Substrates not covered with a minimum of 10% of any of the above biological cover types. This habitat is usually on sand or mud structures. Overall uncolonized cover is estimated at 90%-100% of the bottom. **(18 – Detrital floor)**

Unknown: Zone, Cover, and Structural feature that is not interpretable due to turbidity, cloud cover, water depth, or other interference. **(7 – Unknown)**



Uncolonized

For more information about this classification scheme or the southern Florida shallow-water coral ecosystem mapping project, please contact:

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Appendix C. Development of a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida

Version 02/20/04

Development of a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida

Report to U.S. EPA – Gulf of Mexico Program

From

Florida Fish and Wildlife Conservation Commission
Florida Marine Research Institute

As part of grant assistance agreement MX-97408100, "EPA Florida Blueways"

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Preface

The Gulf of Mexico Program (GOMP) and the Florida Marine Research Institute (FMRI) have been involved with research of marine and estuarine habitats throughout Florida and the entire Gulf of Mexico for many years. This experience has made apparent a need for a standardized method for classifying landscape scale marine and estuarine habitats. More than 15 benthic habitat classification systems have been used in Florida within the past 25 years and various other systems are in use throughout the other Gulf of Mexico states. Such a variety in classification systems makes comparison of mapping results and compilation of regional maps for statewide or Gulf wide reporting problematic. Evidence of the desire for a standardized, hierarchical classification system was gained from results of a 1998 workshop in which researchers and marine resource managers ranked creation of standard mapping protocols and a hierarchical classification system as the top two priorities (FMRI, Seagrass and Aquatic Habitat Workshop Summary 1998).

With GOMP funding support, FMRI has worked on reviewing classification systems used within Florida as well as throughout the world in attempt to recommend one system or create a hybrid system as a state of Florida standard. A draft hybrid system was formed and mailed to marine resource professionals for review in early June 2002. Background materials relaying the intent of the project were included with mailed invitations to attend a workshop in July 2002. Copies of the workshop materials have been included in the final report to the Gulf of Mexico Program.

Comments and recommendations provided during and after the July workshop were reviewed and researched. The System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) has been improved as a result of the workshop and exists now as a more focused product. We consider SCHEME to be complete enough to be useable for the intended classification of marine and estuarine habitats of Florida, although this revised version of SCHEME will now be provided to the previous workshop participants as well as additional resource managers and mapping experts for a second review. In addition, as is the case with all classification systems, application of this system will certainly result in modifications and enhancements. As SCHEME is applied we should all, "… continuously question the classification system [we] are using. Look for flaws and weaknesses, and strengths, in the classification. Seek out [items] which do not easily fit into it, and ask, 'Why?', and, 'How could the classification be improved?' A classification is not only an end that we work for, it is also a beginning - a beginning of testing to find out if the classification in fact works in the real world (From http://csmres.jmu.edu/geollab/Fichter/SedRx/Classtheory.html). "

Introduction

Florida's expanding population, especially along the coastline, has increased the threats of water quality degradation, habitat loss, and direct harmful encounters with marine and estuarine plants and animals. An ecosystem approach to conservation has often been used in terrestrial systems, however, this has been less true for marine and estuarine ecosystems (Allee et al.2000). As the

ecosystem evaluation of Florida coastal waters has gained interest and necessity, the need for a common language for inventorying marine and estuarine habitats has become evident.

In Florida, habitat mapping and inventorying is performed through a variety of government agencies at state, federal, and local levels as well as private industry. The methods employed are varied and at times used in conjunction. Interpretation of aerial photography is the most common method of regional scale habitat inventorying in near shore waters, although underwater videography, snorkel/SCUBA dive observations, and single beam acoustic sensors are also common methods. More recently hyperspectral imaging and LIDAR (Light Detection and Ranging) have gained more research attention and seem to be promising tools in benthic habitat interpretation. With thought toward the array of mapping agencies and variety of research tools the following objective and guiding principles were deemed appropriate. These were created or gathered from the variety of classifications systems discussed throughout this report.

Objective

Form a standardized system for classification of marine and estuarine benthic habitats of Florida. The intent is to create a system that will provide common language for description and consistent inventory and reporting of Florida's estuarine and marine benthic habitats.

Guiding Principles (in no certain order):

- The classification should be applicable for all marine and estuarine waters surrounding Florida. The intended geographic scope of this draft stretches from the extreme high tide line of influence out through the seaward edge of the continental shelf.
- Intent will be to create objective definitions of all habitat categories.
- Application of the classification should be repeatable and consistent.
- The classification scheme will be hierarchical in design so that habitat classifications can be performed at a variety of scales and levels of detail, yet still be comparable to all other classifications determined with this scheme.
- The hierarchical design of the classification will make the system dynamic, thus capable of future category additions.
- The classification system will be intended for use with classical mapping techniques as well as techniques in development. Newer technologies will be considered while forming this system in attempt to accommodate data produced from these technologies and proposed technologies of the near future.
- The classification categories should be mutually exclusive and encompassing of all landscape level benthic habitats of Florida.

- The classification is intended to describe habitats existing at the time of examination; no consideration of potential future or past habitat types is accommodated by this scheme.

- Development of the classification scheme will include consideration of previous and current classification schemes used throughout Florida. Attempts should be made to crosswalk with all other classification schemes used for habitats of Florida's coastal waters.

- Attempts should be made to compare and contrast similar terminology of previous classifications to aid users with classification crosswalks.

- The classification scheme should be created with intent to fit within the national effort to form a national marine and estuarine classification system.

- The classification will be cooperatively developed through invitation of the widest range of individuals and institutions known to have stake and expertise in Florida habitat classifications.

Review of Classification Systems

The initial stage of this project involved gathering existing classification systems for review. More than forty classification systems were reviewed with the intent to find one that would meet the aforementioned project goals or provide components from several that would be used for forming a hybrid system. No systems were found that provided means to classify all of Florida's benthic habitats while also allowing for the level of detail needed for managing these resources. Brief reviews of relevant classification systems used throughout the United States or Florida are presented here.

Anderson et al. (1976), US Geological Survey -- Land use and land cover classification system that has been widely used within the United States, however, the system was not designed for, nor capable of mapping benthic habitats. Estuarine areas are mapped at the general level of "Bays and Estuaries" only to the extent of "inlets or arms of the sea that extend inland". Categories for marine waters do not exist.

Cowardin et al. (1979), US Fish and Wildlife Service -- The first national classification system to incorporate major marine habitats (Allee et al. 2000). While this system does not provide for mapping all the habitat components necessary for resource management in Florida it is a good framework for hierarchical levels and classification organization. SCHEME Classes are roughly similar to the Cowardin et al. Classes; however, the Subclass level and Modifier lists have been expanded significantly more in SCHEME.

Dobson et al. (1995), National Oceanic and Atmospheric Administration Coastal Change Analysis Program (C-CAP) -- The C-CAP classification does not provided for mapping at levels of detail past broad reef and submersed aquatic vegetation levels. SCHEME has expanded the levels beyond those available with the C-CAP system, yet has provided for categories of the two systems to crosswalk.

Allee et al. (2000), National Oceanic and Atmospheric Administration -- The thirteen level structure (Table 1) provided in Allee et al. (2000) report seems to be the framework supporting the ongoing effort to develop a national standard for marine and estuarine ecosystem classification. The Allee et al. system allows for mapping at geographic extents greater than the whole of Florida, such as temperate or polar zones. SCHEME was developed to fit into Levels 11-13 of the thirteen level Allee et al. system. The intention is to be able to easily crosswalk SCHEME categories with those provided in the final national marine and estuarine ecosystem classification system. Creating SCHEME to nest inside the thirteen level structure of Allee et al. (2000) allows the system to be used on regional/local levels for landscape scale mapping while providing the pathway to easily incorporate their data into the national inventory framework.

Florida Department of Transportation (1985) -- The Florida Land Use, Cover and Forms Classification System (FLUCCS) is widely used in Florida. Many of the aquatic vegetation mapping programs use the FLUCCS system to classify seagrasses. The system does not include all the benthic habitats of Florida or expand to levels of detail desired even for the few included categories such as submersed aquatic vegetation.

Florida Natural Areas Inventory (FNAI) (1990) -- The community descriptions are well described and the document serves as a good source of information regarding common plant and animal associations in each habitat. Categories are slightly rearranged for SCHEME and additional Subclasses have been added to make it a more robust classification. Rearrangement of the categories structure resulted in 7 Classes and 18 Subclass 1 categories as opposed to the analogous 12 Natural Communities and 12 unnamed category divisions within the Natural Communities of the FNAI system.

Classification Development and Design

General Overview

The levels assigned to SCHEME are as follows:

X Class
  XX Subclass 1
    XXX Subclass 2
      XXXX Subclass 3
        XXXXX Subclass 4

The Class categories are similar to the Cowardin et al. (1979) Classes by design to allow for crosswalk and comparisons between the two systems. As in the Cowardin et al. system the Classes describe the general dominant life forms or the physiography and composition of the substrate. The Classes are capable of being applied without detailed field measurements. Subclasses define habitats with finer resolution descriptions or with geographic extents that require field measurements for verification.

Some Subclasses are of interest to researchers and managers but are not feasible to map at the landscape scale. For instance, SCHEME includes the ability to map grain size characteristics that are not determined at the landscape scale. This is an example of our attempt to expand the usefulness of SCHEME to address needs of various resource managers and researchers. Although a few of these finer resolution habitat mapping units are accounted for in this early version of SCHEME, it is expected that most additions and alterations will be needed at the fine resolution units (i.e. Subclasses and Modifiers), not at the Class level. Further review and use will promote possible addition of other habitat characteristics.

Tides and Salinity

Many marine/estuarine classification schemas use tidal characteristics and salinity values to define categories. For example, the Cowardin et al. schema has Subsystem categories of Subtidal and Intertidal. This has the disadvantage of forcing users to describe the tidal characteristics of all habitats delineated even though the scope of the research project may only encompass a short time period (i.e. month or less) and is absent of salinity measurements. Building tidal characteristics and salinity values into Class or Subclass definitions would exclude some projects from classifying data with SCHEME or force data collection of these variables into research projects. SCHEME has avenues to include salinity and tidal information through General Modifiers.

Scale Issues

For landscape level benthic mapping, photographic scale normally ranges from 1:12,000 to 1:48,000 (Finkbeiner et al. 2001). A 1:12,000 scale may be necessary in areas of low water clarity. It is possible that chronic turbidity or water color issues may prevent acquisition of useful aerial photographs in some regions regardless of scale. Conversely, 1:48,000 scale photography is a viable alternative for relatively clear water areas such as the Florida Keys.

For coral habitat mapping of high-priority areas, 1:12,000 to 1:48,000 scale aerial photography is recommended for high resolution maps required by state agencies. These scales will allow delineation of features less than or equal to 5 meters in size (U.S. Coral Reef Task Force, Mapping and Information Synthesis Working Group 1999).

Most programs currently conducting routine SAV mapping in Florida are using 1:24,000 scale photography. The appropriate scale for a particular project will be a compromise between issues of the water quality conditions, geographic extent of the study area, the level of habitat delineation desired, and the budget available to support project completion.

A 0.03 ha (0.5 acre) minimum mapping unit is recommended for 1:24,000 scale photography (Finkbeiner et al. 2001). It should be noted that data collected by techniques other than aerial photography are not constrained to the same minimum mapping units. For instance, sediment grain size data collected from discreet point locations much smaller in size than 0.5 acres may still be classified with SCHEME. Also, some of the Subclass categories and most of the Modifiers can't be classified with the use of aerial photography alone. Observer measurements or observations in the field will be necessary to justify use of many of the Subclasses and Modifiers. In addition to in situ observations, pre-existing data, such as artificial reef locations

or habitat restoration locations could be classified with SCHEME and utilized as ancillary data or added to a map of newly acquired data with a GIS.

Classification System

A hierarchical structure with five levels and two lists of modifiers were developed. The hierarchical nature allows the classification to be applied at appropriate levels depending on the level of detail of the data (Vegetation Classification Panel of the Ecological Society of America 2000). The modifiers allow detailed information to be included at all levels of the structure.

The flow chart shown in Figure 1 illustrates the SCHEME protocol for classifying Unconsolidated Sediments, Submersed Aquatic Vegetation, and Coral/Hardbottom habitats when more than one type may be present. Examples of SCHEME application are provided in the following sections along with information specific to each Class listed.

Unconsolidated Sediments

The categories for Unconsolidated Sediments were modeled after the commonly used Wentworth size classes (Locker 1999). Particle size fractionation classification is desirable for research related to benthic infauna, sediment movement, and artificial reef placement. These category distinctions are most accurately made with sieve tests although Subclasses (i.e. mud versus sand versus pebble) distinctions are commonly estimated with observer sight and touch during field visits.

Example 1: A code of 1 would indicate an area of unconsolidated sediments of unknown composition or origin.

Example 2: A code of 122-Z2 would be used to represent an intertidal bank of fine sand with 50% or more of the particulates sieving out to 0.125-.25mm.

Example 3: A code of 122-X(3-5) would be used to indicate an area of fine sand with 50% or more of the particulates sieving out to 0.125-.25mm and a sediment depth range of 3-5m.

Submersed Aquatic Vegetation (SAV)

SAV is monitored as a biological indicator for Florida coastal waters as well as elsewhere in the world. Seagrass biomass often decreases as a result of decreases in water quality. Alternatively, abundance of certain macroalgal species increase in response to increased nutrient pollution. Thus, being able to detect changes in SAV biomass or abundance is important to coastal managers. Continuous seagrass beds that are changing to discontinuous beds through time may indicate a detioration of water quality. On the other hand, occurrences of discontinuous seagrass in areas where it was absent could indicate an increase in water quality allowing for seagrass colonization (Finkbeiner et al. 2001).

As seen in Table 1, a variety of mapping programs classify SAV according to percent cover categories. The percent cover categories vary widely between these programs, with the range from two to six SAV categories. The category ranges are not based on ecological function or value but assigned arbitrarily with the goal of attaining finer resolution in the data to interpret the increase or decrease of SAV percent cover. In some cases the ranges are set after accuracy assessments involving randomized field verification checkpoints indicate ranges that are delineated with high accuracy and ranges that produce errors in percentages too high for reliable reporting. The legitimacy, repeatability, and accuracy of photographic interpretation associated with all percent cover ranges will vary with water quality conditions, species compositions, epiphyte cover, tidal stage, aspect of the seagrass blades, and brightness of substrate. The South Florida Water Management District's Surface Water Improvement and Management Program and the United States Geological Survey's Biological Resources Division each tested SAV classification systems with five categories of percent cover. After separate analyses they reported that the five categories were not interpreted with acceptable accuracy and reducing the number of categories to two or three increased the accuracy (D. Tomasko and L. Handley, personal communications). While interpretation of seagrass densities has been performed with inconsistent results, morphological classification (i.e. continuous versus patchy) of seagrass habitats has been possible (Handley 1992).

Figure 1. SCHEME Decision Support Key for SAV, Reef/Hardbottoms, and Unconsolidated Sediments Classes.

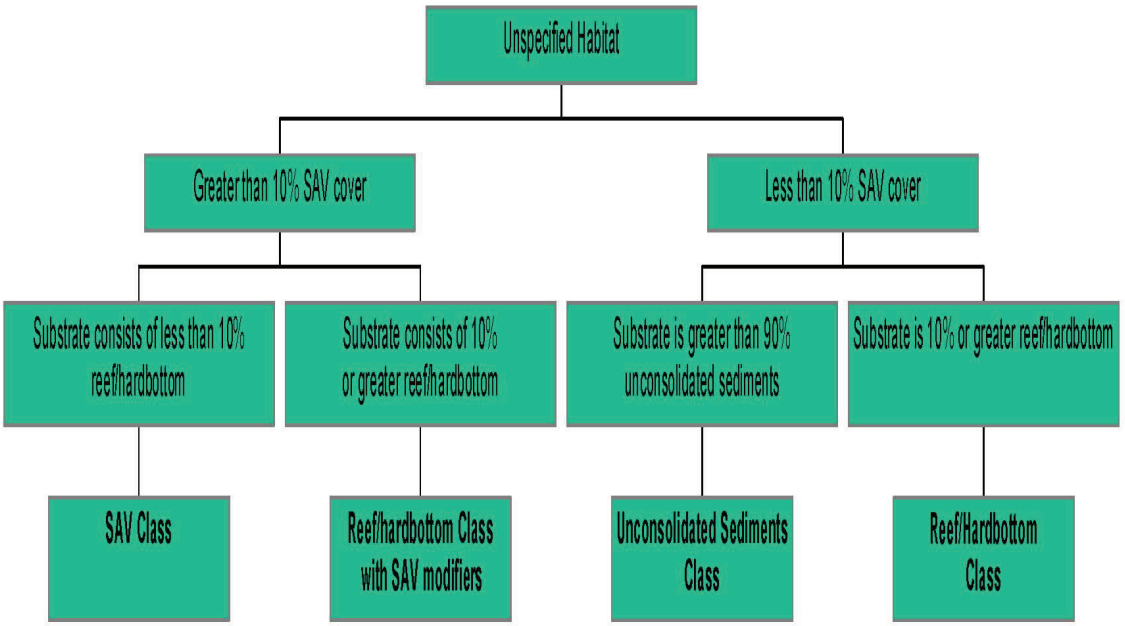


Table 1. This is a partial presentation of seagrass classification systems to illustrate the variation of categories. Some of the agencies listed have previously employed more than one classification. *Note that the percent cover value listed in the SWFWMD column are not actually a part of the formal category descriptions but are commonly used by the District and contractors to assess seagrass.

	1	2	3	4	5	6	7	8	9
	SJRWMD	**SWFWMD**	**SFWMD**	**FMRI/NOAA Florida Keys**	**USGS-BRD**	**CSA, Inc. and MMS**	**Palm Beach Co.**	**Chesapeake Bay**	**NOAA Puerto Rico and USVI**
	>10 - 50%		>10 - 85%	> 50% - 90% in sand/mud	1-10%	0-10%	less than 10%	Very sparse <10% coverage	>10 - < 30%
				> 50% in hardbottom	15-40%	10-70%	11-40%	sparse 10-40%	>30 - < 50%
				< 50% in sand/mud	45-70%		41-70%	moderate 40-70%	>50 - < 70%
				< 50% in hardbottom	75-85%				>70 - < 90%
Contin-uous seagrass	>50%	> 75%*	> 85%	> 90% Moderate-Dense	> 90%	>70%	greater than 70%	dense 70-100%	>90%
				>90% Sparse (Dense patches in continuous sparse seagrass)					
PHOTO SCALE	1:24,000	1:24,000	1:24,000	1:48,000	1:24,000			1:24,000 (B and W)	1:20,1:28 and 1:48k
MIN. MAP UNIT(acres)	0.25	0.5	0.25	1	1		0.25	?	1

In order for the statewide classification system to crosswalk with each of the pre-existing programs, SCHEME has been simplified to two SAV categories absent of any density interpretation limitations. In this fashion, data created with the variety of classification systems previously in use will be capable of classification with SCHEME, thus enabling comparison between programs and regions. However it must be realized that direct comparisons of SAV trends between data from mapping programs will contain error because of the variations in definitions of continuous and patchy categories employed by the various mapping entities. New mapping programs will be able to use SCHEME SAV classifications resulting in estimates of continuous and discontinuous seagrass areas. Leaders of new mapping project should consult Finkbeiner et al. 2001, Handley 1992, and Dobson et al. 1995 for guidelines in SAV mapping.

In order to classify Unconsolidated Sediments and SAV with one classification system a lower limit for SAV classification had to be set. Dobson et al. (1995) stated,

> "If vegetation (except pioneer species) covers 30% of the substrate, classes are distinguished on the basis of the life form of the plants that constitute the uppermost layer of vegetation and that occupy an area coverage 50% of vegetative cover."

For SCHEME the following version has been adopted,

> "If vegetation covers 10% of the substrate, Subclasses are distinguished on the basis of the life form of the plants that constitute the uppermost layer of vegetation and that occupy an areal coverage 50% of vegetative cover. Taxonomic modifiers will be listed in order of decreasing percent cover."

The lower limit of 10% cover of the substrate has been chosen for SCHEME because, 1) the majority of mapping programs in Florida already employ that minimum limit (Table 1), and 2) it minimizes the instances when sparse SAV would be classified as Unconsolidated Sediments, thus creating underestimates of SAV habitat.

SCHEME provides mechanisms for labeling SAV from the very broad Class level "Submersed Aquatic Vegetation" through the level of species identification. Species identification is not possible from 1:24,000 scale aerial photography except in rare instances when monospecific stands of turtle grass can be interpreted because of a darker signature (Handley 1992). FMRI and other groups are currently researching the possibility to detect SAV species and hardbottom community types with hyperspectral imagery. Species information will be designated with taxonomic modifiers as described in this document only when field verification has taken place. Following the SCHEME Decision Support Key (Figure 1), SAV noted in coral or hardbottom habitats should be noted with a seagrass modifier (i.e. H in the General Modifier list). Using the codes on the Classification Key, a few examples are provided below for clarification.

Example 1: A code of 2 would be used to represent an SAV habitat when more detailed knowledge is unknown. This code would indicate that SAV was present but no information as to the mix of macroalgae and seagrass is present and species are unresolved.

Example 2: A code of 212-Hwri,Sfil would be used to indicate a polygon of discontinuous (i.e. patchy) seagrass containing a known greater percentage of shoal grass, Halodule wrightii, and a lesser percentage of manatee grass, Syringodium filiforme.

Example 3: A code of 341-I would be used to indicate an area of bedrock habitat with a percent cover of greater than 10% seagrass.

Although, providing a method for indicating seagrass at the Subclass levels along with General and Taxonomic modifiers adds complexity to the classification system this seems necessary to create opportunities to classify complex habitats with mixed geological and biological components. The Decision Support Key (Figure 1) is provided to aid users in consistently classifying the SAV and Coral/Hardbottom Classes.

Corals and Hardbottom

The corals and hardbottom categories were developed to crosswalk with the classification system used for the Benthic Habitats of the Florida Keys (1998) product created by NOAA and FMRI. This has been the only regional landscape classification in Florida to include coral and hardbottom dominated habitats and has been recommended to serve as a prototype for desired research and management of coral reef ecosystems (U.S. Coral Reef Task Force, Mapping and Information Synthesis Working Group 1999). In addition, various classifications (Coyne et al. 2001, Holthus and Maragos 1995, Kendall et al. 2002, Mumby et al. 1998, Mumby and Harborne 1999) and characterizations (Ault et al. 2002, FNAI 1990, Jaap 1984, Jaap and Hallock 1991) of tropical and subtropical coral habitats were reviewed and influenced SCHEME design.

Using the codes on the SCHEME Classification Key, a few examples are provided below for clarification.

Example 1: A code of 31 would represent a coral reef without further definition of structure or species presence.

Example 2: A code of 311-Ovar would be used to indicate a platform reef feature with *Oculina varicosa* as the dominant coral species.

Example 3: A code of 31122-Acer,AGAR would represent a low relief spur and groove area dominated by Acropora cervicornis also containing noticeable fire coral, Agaricia spp. Because the species is not identified, the first four letters of the Genus are listed in all capitals to distinguish the code from a Genus species abbreviation, such as used for the Acropora cervicornis in this example.

Tidal Marsh and Tidal Swamp

These Classes will likely be used in conjunction with Taxonomic Modifiers. Florida marshes are often delineated according to the dominant indicator species, either black needlerush or smooth cordgrass.

Example 1: A code of 4-Salt would represent a tidal marsh dominated by *Spartina alterniflora.*

Discussion

"Systems of classification are not hatracks, objectively presented to us by nature. They are dynamic theories developed to express particular views..." Stephen Jay Gould (From http://csmres.jmu.edu/geollab/Fichter/SedRx/Classtheory.html)

In the current format SCHEME is complete enough to be employed with habitat classification projects. As SCHEME is used weaknesses will be exposed and modifications can be devised. SCHEME has already been tested by NOAA Coastal Services Staff in the Dry Tortugas, Florida and they are intending to use a form of it for a mapping project in Long Island, New York. The Florida Marine Research Institute has initiated efforts to engage SCHEME for two habitat delineation projects in Broward County, Florida and the Florida Keys. Results of these uses will need to be assessed and modifications to SCHEME may result.

Although thought toward cartography and database design elements have been considered, issues such as how the coding system, which can be bulky if the level of mapping is detailed, will aid or hinder habitat maps will best be examined through utilization. Database design and GIS issues regarding the category coding (i.e. numbering systems and modifier codes) of SCHEME will become evident with application. Creation of a database and digital forms and spreadsheets will be prepared and tested through project application. The resulting forms could then be shared with interested agencies to aid standardization.

Because many agencies are actively mapping benthic habitats for various reasons, habitat data will continue to be collected with differing specifications and protocols. Metadata records need to be consistently recorded and made accessible for purposes of comparing reports, products and raw data. Further evolution of SCHEME should include development of standards and protocols for the common techniques of data collection. Complete specifications of aerial photography collection, processing, and analysis should be recommended, such as in the previously mentioned Dobson et al. (1995) and Finkbeiner et al. (2001) documents. The specifications explained in these documents could be enhanced with description of regional recommendations for Florida. We are monitoring activities of the U.S. Coral Reef Task Force as they synthesize coral habitat mapping plans and recommend protocols and procedures for data collection with newer technologies leading to coral habitat maps of the United States.

SCHEME will be shared with interested agencies for purposes of review, use and enhancement. Comments or inquiries should be addressed to Kevin Madley, (727) 896-8626, kevin.madley@fwc.state.fl.us.

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Appendix 1. Proposed national marine and estuarine ecosystem classification system as outlined in Allee et al. (2000).

1. Life Zone –
    1a. Temperate
    1b. Tropical
    1c. Polar

2. Water/Land
    2a. Terrestrial
    2b. Water

3. Marine/Freshwater
    3a. Marine/Estuarine
    3b. Freshwater

4. Continental/Non-Continental
    4a. Continental
    4b. Non-Continental

5. Bottom/Water Column
    5a. Bottom (Benthic)
    5b. Water Column

6. Shelf, Slope, Abyssal
    6a. Shallow – on or over the continental shelf, <200m
    6b. Medium – on or over the continental slope; 200 - 1000m
    6c. Deep – on or over the rise and deeper features; >1000m

7. Regional Wave/Wind Energy
    7a. Exposed/Open – open to full oceanic wave or wind energies
    7b. Protected/Bounded – protected from full wave or wind energies

8. Hydrogeomorphic or Earthform Features
    8a. Continental - Nearshore (surfzone); Inshore (rest of shelf); Straight or partially enclosed shorelines; Lagoons, Fjords; Embayments; Estuaries - Shore zone; Off shore zone; Delta; Carbonate settings; Outer continental shelf; Upper continental slope; Upper submarine canyon
    8b. Non-Continental - Island (Volcanic; Low); Atoll; Submerged reef types

9. Hydrodynamic Features
    9a. Supratidal – above high tides
    9b. Intertidal – extreme high to extreme low water
    9c. Subtidal – below extreme low water

Appendix 1 (continued). Proposed national marine and estuarine ecosystem classification system as outlined in Allee et al. (2000).

9. Hydrodynamic Features (Continued)
   9d. Circulation features -- e.g., eddies

10. Photic/Aphotic
   10a. Photic
   10b. Aphotic

11. Geomorphic Types or Topography - Cliff; Bench; Flat; Reef flat; Spur-and-Groove; Sand bar; Crevice; Slump; Rockfall; Terrace; Ledge; Overhang; Steeply sloping; Riverine; Fringe; Inland; Beach face; Dunes

12. Substratum and Eco-type
   12a. Substratum (Not limited to this list) - Cobble; Pebble; Sand; Silt; Mud; Bedrock; Peat; Carbonate; Boulder; Biogenic; Organic; Anthropogenic
   12b. Eco-type (Not limited to this list) - Coastal; Soft bottom; Hard bottom; Water column; Beach; Mangrove; Wetland; Seagrass bed; Coral reef; Kelp bed; Mud flat

13. Local Modifiers and Eco-unit
   13a. Modifiers (Not limited to this list) - Temperature; Local energy regimes – waves, tides, current; Salinity; Nutrients; Alkalinity; Roughness/relief; Dynamism; Edge effects – from adjacent areas; Anthropogenic disturbances; Biological interactions; Extreme events – history
   13b. Eco-units - Unlimited representation of species resulting from modifiers applied at the above hierarchical levels

Appendix 2. Florida System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) key.

Classification categories are structured as follows:

X Class
  XX Subclass 1
    XXX Subclass 2
      XXXX Subclass 3
        XXXXX Subclass 4

Habitats:

1. **Unconsolidated Sediments (zero to less than 10 percent colonization)**
   Unconsolidated sediments with less than 10 percent colonization by SAV or corals.

   11. **Mud (i.e. silts and clays) [<0.0625mm grain sizes comprise greater than 50% of sediment]**
   Sediments most often found in depositional environments that are protected from wind and wave energy.

   12. Sand [0.0625-2mm grain sizes comprise greater than 50% of sediment]
   Sediments usually found in areas exposed to wind and wave energy that causes silts and clays to be removed.

   121. Very fine sand [0.0625-0.125mm grain sizes comprise greater than 50% of sediment]

   122. Fine sand [0.125-.25mm grain sizes comprise greater than 50% of sediment]

   123. Medium sand [0.25-.5mm grain sizes comprise greater than 50% of sediment]

   124. Coarse sand [0.5-1mm grain sizes comprise greater than 50% of sediment]

   125. Very coarse sand [1-2mm grain sizes comprise greater than 50% of sediment]

   13. Mixed Fine
   Mixture of sand and mud, possibly with sparse grains of larger size categories such as granules or pebbles (no one substrate type presence is greater than 50%)

   14. Mixed Coarse
   Granules, pebbles, cobbles are the possible components that comprise over 50% of the sediment (no one substrate type presence is greater than 50%)

141. Shell hash – substrate covered with a mixture of shell material from granules (2-4mm grain sizes) to whole shells.

15. Granule [2-4mm grain sizes comprise greater than 50% of sediment]

16. Pebble [4-64mm grain sizes comprise greater than 50% of sediment]

17. Cobble [64-256mm grain sizes comprise greater than 50% of sediment]
Note: Rocks larger than 256mm (=10 in) in diameter are classified as bedrock in the consolidated bottom category.

18. Detrital floor
Detrital material (e.g. seagrass, algae, leaf litter, etc.) that builds up in intertidal and shallow waters, often along windward shorelines. This semi-permanent feature creates an organic mud buildup under the newly deposited detrital material. More permanent feature than the Drift Wrack general modifier.

2. Submersed Aquatic Vegetation (SAV)
Any combination of SAV (i.e. seagrasses, oligohaline grasses, attached macroalgae and drift macroalgae) that covers 10 to 100 percent of a substrate. If reef or hardbottom is more abundant than the SRV the polygon should be recorded as Reef/Hardbottom Class and SRV should be noted with Modifiers.

21. Submersed Rooted Vascular Plants (SRV) (i.e. seagrasses and oligohaline grasses)
Habitat with 10 percent or more cover of SRV.

211. Continuous SRV
This includes continuous beds of any shoot density (i.e. sparse continuous, dense continuous or any combination). These areas appear as continuous seagrass signatures; however, small (less than 0.5 acres) bare sediment areas may be observed as infrequent features within the area.

2111. Dense patches of SRV in a matrix of continuous, sparse SRV
Continuous coverage of sparse SRV in which dense patches of SRV are clearly observed interspersed within the area. This pattern is often the result of effects from the sediment or underlying bedrock characteristics.

212. Discontinuous SRV
Areas of SRV with breaks in coverage that result in isolated patches of SRV, usually in unconsolidated bottom but also exist in hard bottom areas. If the hardbottom is more abundant than the SRV the polygon should be recorded as Reef/Hardbottom Class and SRV can be noted with Modifiers. Generally, these grass features appear as semi-round patches or elongated strands separated by bare sediment.

22. Macroalgae

221. Attached Macroalgae
Habitat with 10 percent or more cover of mixed or monospecific macroalgae attached to the substrate with holdfasts, rhizomes, or other morphological feature.

2211. Continuous attached macroalgae
This includes continuous beds of any density (i.e. sparse continuous, dense continuous or any combination). These areas appear as continuous attached macroalgae or SRV signatures. Often macroalgae can't be interpreted from the imagery without field verification to detect the difference from SRV. Small (less than 0.5 acres) bare sediment areas may be observed as infrequent features within the area.

22111. **Dense patches of attached macroalgae in a matrix of continuous, sparse macroalgae**
Continuous coverage of sparse attached macroalgae in which dense patches of attached macroalgae are clearly observed interspersed within the area. This pattern is often the result of effects from the sediment or underlying bedrock characteristics.

2212. Discontinuous attached macroalgae
Areas of attached macroalgae with breaks in coverage that result in isolated patches, usually in unconsolidated bottom but also exist in hard bottom areas.

222. Drift Macroalgae
Habitat with 10 percent or more cover of mixed or monospecific macroalgae that is not attached to the substrate. Drift algae may move constantly with wind or wave forces or may be observed in one location for long periods of times (possibly months) because of lack of energy forces or due to becoming entangled on substrate features.

2221. Continuous drift macroalgae
This includes continuous beds of any density (i.e. sparse continuous, dense continuous or any combination). These areas appear as continuous attached macroalgae or SRV signatures. Often macroalgae can't be interpreted from the imagery without field verification to detect the difference from SRV. Small (less than 0.5 acres) bare sediment areas may be observed as infrequent features within the area.

2222. Discontinuous drift macroalgae
Areas of attached macroalgae with breaks in coverage that result in isolated patches, usually in unconsolidated bottom but also exist in hard bottom areas.

3. Reef/Hardbottom
Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms or exposed bedrock, possibly with various degrees of concealment from attached plant and animal colonization. Unconsolidated

bottom and SAV may occur within these habitats, although in less abundance than the reef/hardbottom.

31. Coral Reef

Hardened substrate formed by reef building corals. May be live coral or relict reefs. Often bedrock is the base for these reefs but the presence of coral or remnant coral on the surface is reason to categorize the dominant habitat as coral reef.

311. Platform Reef (also bank reef)

Hardened substrate formed by reef building corals that exist in a quasi-continuous structure along a shelf edge or similar dropoff removed from any coastline. These are typically elongate structures and may be referred to as bank reefs. The following Subclass categories may be present in various combinations within a platform reef.

3111. Linear Reef

Linear, contiguous coral formations. Reef crest, fore reef, and back reef zones could be mapped as Linear Reef. Most often has associated spur and groove and reef rubble habitats.

31111. Reef Terrace (high profile)

Contiguous reef with high complexity and high relief (>2m).

31112. Remnant (low profile)

Reefs of relief less than 2m that lack distinctive spur and groove characteristics. These reefs consist of coral and hard bottom features; often support soft corals, sponges, seagrass; and are usually found growing parallel to the reef tract, though they may form transverse features that grow perpendicular to the reef tract.

3112. Spur and Groove

Distinct coral bands separated by sand or uncolonized hardbottom grooves. This habitat type usually occurs in the fore reef zone.

31121. High Relief Spur and Groove

Distinct coral bands separated by sand or uncolonized hardbottom grooves. The coral bands have 1.5- 4m relief.

31122. Low Relief Spur and Groove

Distinct coral bands oriented perpendicular to the shore or bank and separated by sand or uncolonized hardbottom grooves. The coral bands have <1.5m relief.

3113. Reef Rubble

Dead, unstable coral rubble that often occurs landward of platform reefs.

312. Patch Reefs

Irregularly shaped reef communities. They may range in size from tens to thousands of square meters. Patches are separated from each other by uncolonized hardbottom, sand, or colonized substrate with submersed aquatic vegetation (SAV), macroalgae, gorgonians or sponges. Most often the patches are surrounded by a halo of bare substrate created by foraging, obligate reef inhabitants.

3121. Individual Patch Reef

Isolated, single reef (larger than the minimum mapping unit of the project) without associated halo area. These individual reefs may have an associated halo, however if large enough (i.e. greater than the minimum mapping unit) to be delineated the halo will be mapped as its own subclass.

3124. Aggregated Patch Reefs (includes Halo areas if present)

Clustered patch reefs, usually too small (less than the minimum mapping unit) or too close together to map individually or where halos coalesce.

3125. Pinnacles

High complexity patch reefs that have high relief (up to 15m) from the sea floor. These structures may occur in clusters and are typically surrounded by large sand plains.

313. Patchy Coral and/or Rock in Unconsolidated Bottom

Areas of primarily sand, submerged aquatic vegetation (SAV), or low relief rock covered with a sand veneer. Often adjacent to spur and groove habitats, these areas contain small, individual corals or rocks that are distinctive yet a very low percentage of the total cover (and certainly smaller than the minimum mapping unit).

32. Mollusk Reefs

Concentrations of sessile mollusks that attach to hard substrate and with the correct conditions will proliferate allowing the reef to grow. In Florida, these areas are most common in estuarine areas and are not known to occur in water deeper than 40 feet.

321. Bivalve Reefs (i.e. oyster reefs)

Mollusk reefs dominated by oysters; at times partially exposed during low tide.

322. Gastropod Reefs (i.e. Vermetid reefs)

Mollusk reefs created by a worm-like mollusk of the genus *Petaloconchus.* In Florida, these reefs are only known to be found in shallow waters seaward of the outer islands in the Ten Thousand Islands area of southwest Florida.

33. Annelid Reefs (i.e. Sabellariid reefs)

Structures formed from colonies of Sabellariid worm tubes. Commonly found in the tidal zone on the east coast of Florida, these structures are mostly formed on hard substrates and may be exposed at low tide. Storm events can break the sand structures thus changing the extent of the colony at the time of mapping. The reefs also expand as worm larvae settle on the mounds and build additional tubes.

34. Hardbottom

Hard substrate composed of exposed bedrock or created through syndepositional cementation of sediment.

341. Bedrock

Exposed bedrock and/or rocky outcrops with low to high relief and high complexity.

342. Pavement (i.e. low relief hardbottom)

Flat, low relief, mostly solid rock substrate.

4. Tidal Marsh (i.e. salt marsh, coastal marsh)

Communities of emerged halophytic vegetation along low-wave energy intertidal areas and river mouths. These areas are dominated by grasses, rushes and sedges (i.e cordgrass, needlerush, and sawgrass).

41. Salt pan

Exposed or water-filled depressions in a tidal marsh area. Often covered by layers of blue-green algae but possibly bare sediment only. Glassworts or saltworts may be present. Sand barrens most often exist in high marsh areas; conversely mud barrens may occur in the intertidal zone as water retention pools during low tide.

42. Salt marsh algae

Mud flats dominated by a mixture of benthic microalgae, phytoplankton, and macroalgae.

5. Tidal Swamp (i.e. mangrove, mangrove forest)

Dense, low forests primarily located along coastal areas. Various tidal marsh grasses and shrubs may be associated but these communities are dominated by a mix of red, black and white mangroves.

6. Land

Mainland, islands, causeways and other land normally above the high tide line. Depending on the mapping project the line delineating the water/land interface may be formed anywhere between the extreme low and extreme high tide marks.

7. Unknown benthic habitat (i.e. not lending to interpretation because of water quality, depth, or lack of field investigation)

71. Turbid plume

Area of dark colored water often associated with river mouths, bays and coastlines. The often brown water results from vegetation tannins leached into the rivers and/or organic particles carried seaward from the river water. Plumes varying in color from white to emerald green are also observed in areas with fine carbonate sediments (e.g. Florida keys). These plumes will often prevent mapping of benthic habitats from photography.

72. Phytoplankton bloom

Area of water that contains abnormally high concentrations of phytoplankton. These blooms can often be seen in aerial photography and will prevent mapping of benthic habitats by decreasing water clarity. The classes listed below should be used only if a distinct color is associated with the bloom when mapped.

721. Green bloom
722. Red bloom
723. Black bloom

General Modifiers–Modifier labels (e.g. A, B, C…) will be used to indicate more specific information about map categories. For instance, 123-E would represent a natural, submersed tidal channel with medium sand sediment type. Also, an area of flat, low relief hardbottom with dominant cover types of octocorals and sponges would be labeled 342-QR. Another example, 34-A22 would represent an artificial reef consisting of concrete culverts.

A. Artificial
- **1. Tires**
- **2. Concrete materials of opportunity**
  - **21. Concrete blocks**
  - **22. Culverts**
  - **23. Riprap**
- **3. Designed materials**
  - **31. Reef balls**
  - **32. PVC structures**
- **4. Vessels, automobiles, planes, military ordnance (whole or portions)**
- **5. Steel structures (i.e. oil rigs, lighthouses, etc.)**
- **6. Cables**
- **7. Pipelines**

B. Venetian canals-- anthropogenic canals landward of shoreline
C. Streams-- natural canals landward of shoreline
D. Island moats— deepwater canals wholly or partially surrounding islands
E. Submersed tidal canals— natural canals seaward of shoreline
F. Dredged/Excavation— anthropogenic canals seaward of shoreline or sediment borrow pits
G. Spoil/Fill – area of positive vertical relief created by placement of dredged sediments
H. Restoration-- area of restoration activity (e.g. previous salt marsh planting area)
I. Seagrass – this modifier can be used when seagrass is present in areas of 10% or greater cover of coral or hardbottom
J. Drift seagrass— accumulation of seagrass that may be drifting in water column or lying on the bottom

K. **Drift wrack**— mix of various materials (e.g. seagrass, macroalgae, mangrove litter, etc.) that may be drifting in water column or lying on the bottom

L. **Drift macroalgae**-- accumulation of macroalgae that may be drifting in water column or lying on the bottom

M. **Mat algae**— thin veneer of algae on substrate

N. **Attached Macroalgae**
   1. **mixed browns**
   2. **mixed reds**
   3. **mixed greens and calcareous**

O. **Urchin Front**— congregation of urchins often dense enough to obscure the substrate in photography

P. **Boat propeller scars**
   1. **Light scarring**
      Scarring in less than 5% of an SAV polygon
   2. **Moderate scarring**
      Scarring in 5-20% of an SAV polygon
   3. **Heavy scarring**
      Scarring in more than 20% of an SAV polygon

Q. **Octocoral bed**—soft coral species attached to substrate

R. **Sponge bed**—sponge species attached to substrate

S. **Hard corals**—hard coral species attached to substrate

T. **Dead coral**

U. **Substrate ripples** – area containing troughs and ridges of substrate as opposed to flat substrate. Height range listed in meters e.g. (0.5-1.0m).

V. **Carbonate substrate**

W. **Siliciclastic substrate**-- Pertaining to clastic noncarbonate rocks or sediments which are almost exclusively silicon-bearing, either as forms of quartz or as silicates

X. **Sediment depth** – depth of the surface substrate material. Range listed in meters e.g. (0-2m)

Y. **Salinity (e.g. 32ppt)**

Z. **Tidal Status**
   1. **Subtidal** – Never exposed to the air.
   2. **Intertidal** – Exposed to the air even if only during the lowest spring tides.
   3. **Supratidal** – Normally exposed to the air, only submersed during flood or storm events.

AA. **Biological habitat modifications**
   1. **Fish excavations** (e.g. tilefish, grouper, stingrays)
   2. **Invertebrate bioturbation zones** (e.g. polychaetes, crabs, shrimps, etc.)

BB. **SAV epiphytes – presence of algal or animal epiphytes are visible on the surface of SAV. A relative abundance can be characterized with the sub-modifiers listed:**
   1. **Light**
   2. **Medium**
   3. **Heavy**

Taxonomic Modifiers– This is a partial list. The intent is to build this list from expert input or compilation of published Florida species lists. These taxonomic modifiers would be used similar to the General Modifiers list except labels would be composed of the genus and species

abbreviations composed of the first letter of the genus and the first three letters of the species. This coding mechanism allows for inclusion of new species and manageable changes as taxonomic name changes occur through peer-reviewed literature.

Examples: 211-Ttes would represent an area of dense, continuous turtle grass (*Thalassia testudinum*) whereas 211 would represent an area of dense, continuous SRV of unknown species types. Likewise, an area of coastal needlerush marsh would be labeled 4-Jroe. These modifiers would be used in order of decreasing percent cover. For instance, 4-Jroe/Salt would indicate a polygon of tidal marsh with a mixture of needlerush (*Juncus roemerianus)* and smooth cordgrass (*Spartina alterniflora*); needlerush is more prevalent in this polygon because the Jroe modifier occurs first in the sequence.

Seagrasses
Thalassia testudinum
Halodule wrightii
Syringodium filiforme
Halophila engelmanni
Halophila johnsonii
Halophila decipiens

Tidal Marsh Plants
Ruppia maritima
Vallisneria americana
Juncus roemerianus
Spartina alterniflora
Spartina patens
Salicornia virginica
Cladium mariscoides
Batis maritima
Distichlis spicata
Salsola kali

Tidal Swamp Plants
Avicennia germinans
Laguncularia racemosa
Rhizophora mangle
Conocarpus erecta

Macroalgae
Argardhiella spp.
Avrainvellea spp.
Batophora spp.
Bryopsis spp.
Calothrix spp.
Caulerpa spp.
Chondria spp.
Cladophora spp.
Dictyota spp.
Digenia spp.
Gracilaria spp.
Halimeda spp.
Laurencia spp.
Oscillatoria spp.
Penicillus spp.
Rhipocephalus spp.
Sargassum spp.

Corals
Acropora cervicornis
Acropora palmata
Acropora spp.
Agaricia spp.
Montastrea annularis
Oculina varicosa
Porites porites
Porites spp.
Lophelia prolifera
Enallopsammia profunda
Siderastrea spp.

Appendix 3. Complete list of literature reviewed.

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Appendix D. Datasheets

1. Accuracy assessment data sheet. (1 page).
2. Rapid Habitat Assessment data sheet. (1 page).
3. Reef fish Visual Census data sheet (1 page).

SFCN Benthic Accuracy Assessment Sheet

Site:	

Observer Names:	
Date:	
Time:	
Depth:	
Circle one:	Video Photo

Habitat Structure	(check one)
Aggregated Patch Reefs	
Artificial	
Continuous SRV	
Discontinuous SRV	
High Relief Spur and Groove	
Individual Patch Reef	
Land	
Low relief Spur and Groove	
Patchy Coral/Rock in Unconsol. Bottom	
Pavement	
Reef Rubble	
Reef Terrace (high profile)	
Remnant (low profile)	
Unconsolidated Sediment	

NOTES:

Site:	

Observer Names:	
Date:	
Time:	
Depth:	
Circle one:	Video Photo

Habitat Structure	(check one)
Aggregated Patch Reefs	
Artificial	
Continuous SRV	
Discontinuous SRV	
High Relief Spur and Groove	
Individual Patch Reef	
Land	
Low relief Spur and Groove	
Patchy Coral/Rock in Unconsol. Bottom	
Pavement	
Reef Rubble	
Reef Terrace (high profile)	
Remnant (low profile)	
Unconsolidated Sediment	

NOTES:

SFCN Rapid Habitat Assessment Sheet

Observer Name:

1	Station/GPS position	
	Date	
	Time	

2	Depth (feet - use depth gauge)	
	Min *	Max *

* Max = depth to lowest point of sea floor

* Min = depth to highest point of sea floor

3	Rugosity	
	Low (tallest hard structure <0.5m)	
	Medium (tallest hard structure is 0.5 - 1.5m)	
	High (tallest hard structure >1.5m)	

4	Habitat Structure (select one)	
	Colonized hardbottom	*Uncolonized Hardbottom*
	Linear Reef	Reef Rubble
	Spur & Groove	Uncolonized Pavement
	Patch Reef	Uncolonized Bedrock
	Aggregated Patch Reef	Uncolonized Pavement & Sand Channel
	Scattered Coral & Rock in sand	
	Colonized Pavement	
	Colonized Bedrock	
	Colonized Pavement & Sand Channel	

5	Abiotic Footprint	% cover
	Subtrate	
	Hardbottom	
	Sand	
	Rubble	

6	Biotic Footprint	% cover
	Live coral (A)	
	Gorgonians (B)	
	Sponges (C)	
	Macroalgae (D)	
	Bare/turf/uncolonized by A-D	

7	Presence/Absence	
	Macro-inverts.	P/A
	Diadema	
	Conch	
	Lobster	

8	High/Medium/Low	
	Fish Groups	H/M/L
	Planktivores	
	Herbivores	
	Mobile Inverts.	
	Piscivores	

NOTES

Diver: _____ Date: _____ Field Number:

Buddy: _____ Sample Start Time: _____

Dive Start Time: _____ Sample End Time: _____

Dive End Time: Max Dive Depth: _____ ft

Station Depth: _____ ft

Fishing Gear:

Habitat type:	
1. Contiguous S&G	4. Rubble
2. Cont. Not S&G	5. (Matrix)
3. Isolated	0. (Sand)

Underwater visibility: _____ ft m

Water temperature: _____ F

Radius of cylinder: 7.5m 5.0m

Current: None Mod. High

Substrate Slope	
Max depth _____ ft	
Min depth _____ ft	
Max vertical Relief	
Hard Relief _____ m	
Soft Relief _____ m	

Surface Relief Coverage %		
	Hard	Avg. of Soft
< 0.2 m	%	%
0.2-0.5 m	%	%
0.5-1.0 m	%	%
1.0-1.5 m	%	%
> 1.5 m	%	%
TOTAL	100%	100%

Abiotic Footprint	
SAND	%
HARD-B	%
RUBBLE	%
Total	100%

Biotic Cover - Dominant Biological Cover %			
SAND		HARDBOTTOM	
"Bare"		~~Crustose Algae~~	
~~Algal Turf (<1cm)~~		Algae (<1cm)	
Macro Algae		Algae (>1cm)	
Sea grass		Live Stony Coral	
Sponge		Octocoral	
_____ Other 1		Sponge	
_____ Other 2		_____ Other 1	
		_____ Other 2	
TOTAL	100%		100%

Species	N	Avg	Min	Max

Species	N	Avg	Min	Max

Comments:

Presence of: *A. palmata* *A. cervicornis* Black Coral

Spiny Lobster # Conch # Diadema #

Appendix E. Map Class Photo-Interpretation Key and Photos.

1. **Unconsolidated Sediments (zero to less than 10 percent colonization)**
   Unconsolidated sediments with less than 10 percent colonization by SAV or corals.





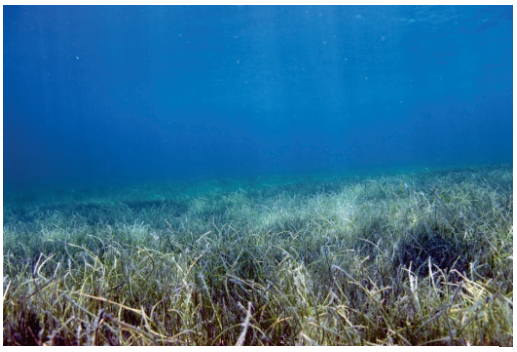


2. Submersed Rooted Vascular Plants (SRV) (i.e. seagrasses and oligohaline grasses)

Habitat with 10 percent or more cover of SRV.

a. Continuous SRV

This includes continuous beds of any shoot density (i.e. sparse continuous, dense continuous or any combination). These areas appear as continuous seagrass signatures; however, small (less than 0.5 acres) bare sediment areas may be observed as infrequent features within the area.





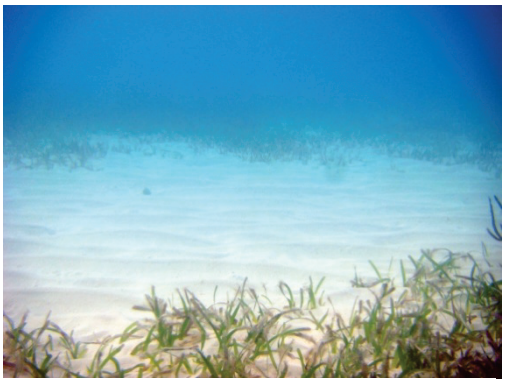


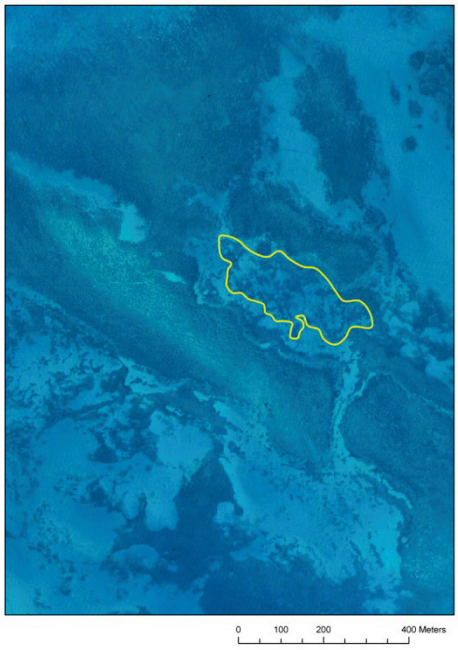


b. Discontinuous SRV

Areas of SRV with breaks in coverage that result in isolated patches of SRV, usually in unconsolidated bottom but also exist in hard bottom areas. If the hardbottom is more abundant than the SRV the polygon should be recorded as Reef/Hardbottom Class and SRV can be noted with Modifiers. Generally, these grass features appear as semi-round patches or elongated strands separated by bare sediment.









3. Reef/Hardbottom

Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms or exposed bedrock, possibly with various degrees of concealment from attached plant and animal colonization. Unconsolidated bottom and SAV may occur within these habitats, although in less abundance than the reef/hardbottom.

a. Coral Reef

Hardened substrate formed by reef building corals. May be live coral or relict reefs. Often bedrock is the base for these reefs but the presence of coral or remnant coral on the surface is reason to categorize the dominant habitat as coral reef.

i. Platform Reef (also bank reef)

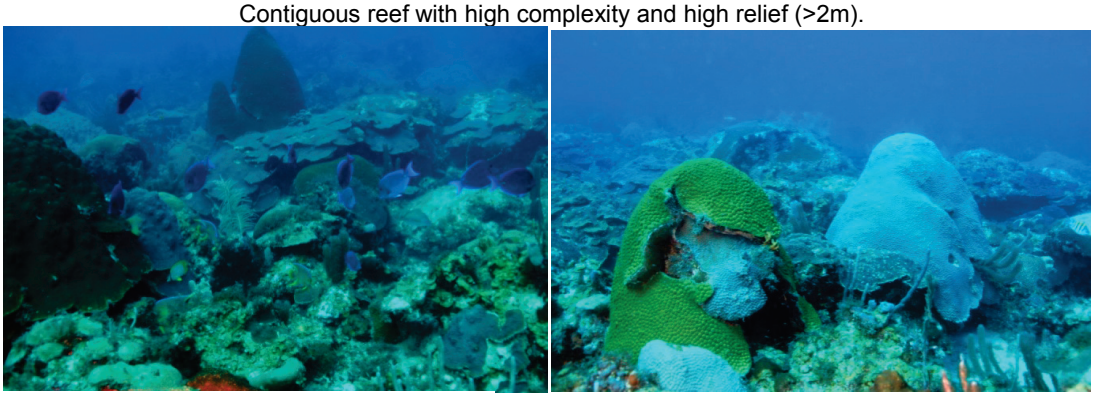
Hardened substrate formed by reef building corals that exist in a quasi-continuous structure along a shelf edge or similar dropoff removed from any coastline. These are typically elongate structures and may be referred to as bank reefs. The following Subclass categories may be present in various combinations within a platform reef.

1. Linear Reef

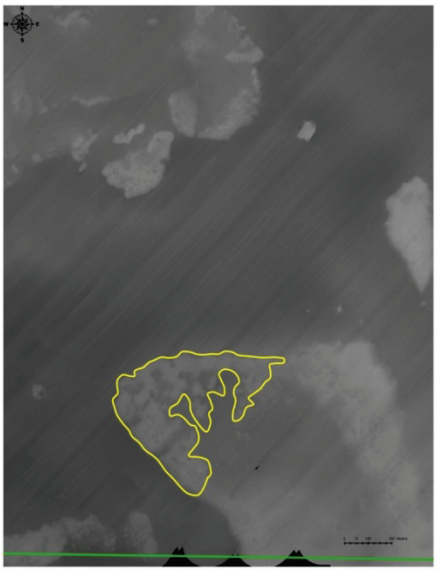
Linear, contiguous coral formations. Reef crest, fore reef, and back reef zones could be mapped as Linear Reef. Most often has associated spur and groove and reef rubble habitats.

a. Reef Terrace (high profile)

Contiguous reef with high complexity and high relief (>2m).



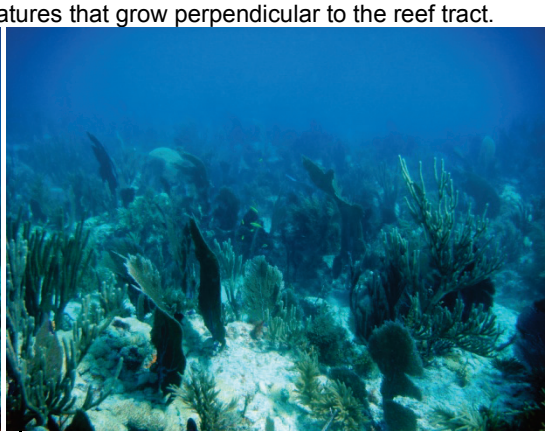




b. Remnant (low profile)

Reefs of relief less than 2m that lack distinctive spur and groove characteristics. These reefs consist of coral and hard bottom features; often support soft corals, sponges, seagrass; and are usually found growing parallel to the reef tract, though they may form transverse features that grow perpendicular to the reef tract.







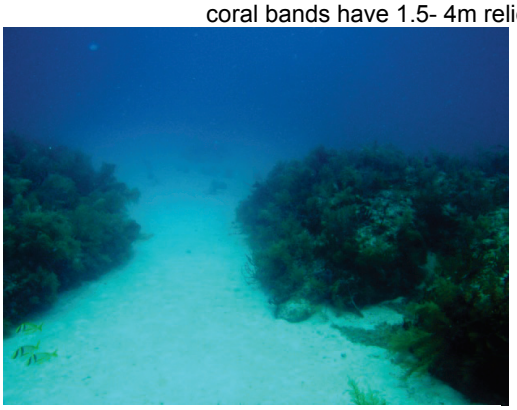


c. Spur and Groove

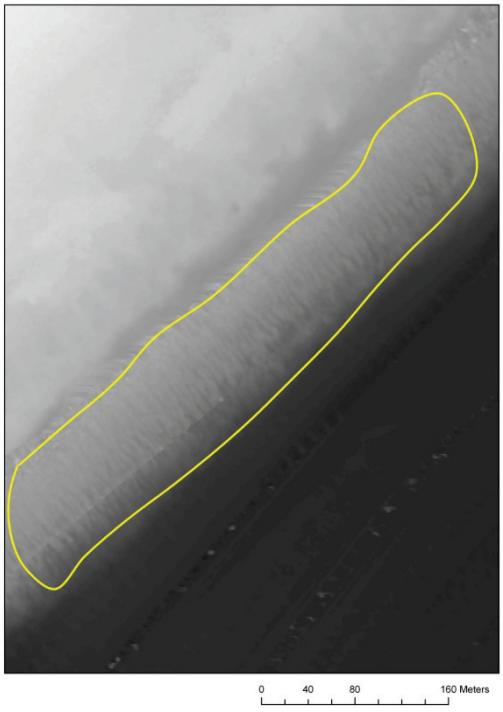
Distinct coral bands separated by sand or uncolonized hardbottom grooves. This habitat type usually occurs in the fore reef zone.

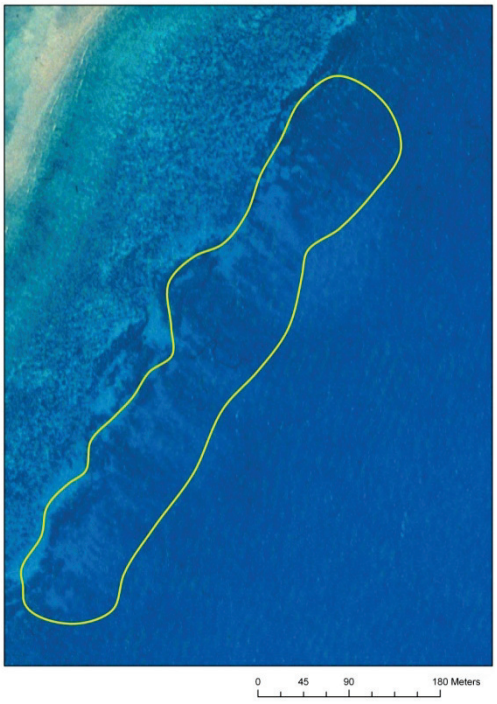
d. High Relief Spur and Groove

Distinct coral bands separated by sand or uncolonized hardbottom grooves. The coral bands have 1.5- 4m relief.





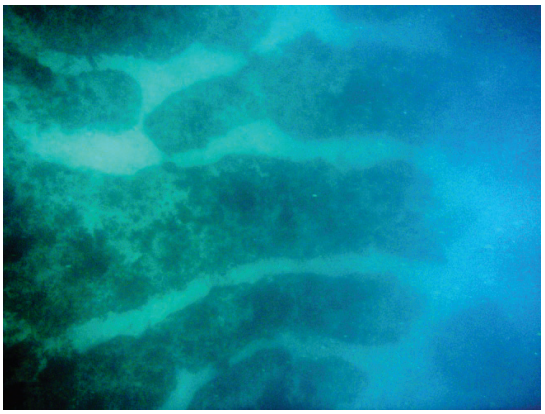




e. Low Relief Spur and Groove

Distinct coral bands oriented perpendicular to the shore or bank and separated by sand or uncolonized hardbottom grooves. The coral bands have <1.5m relief



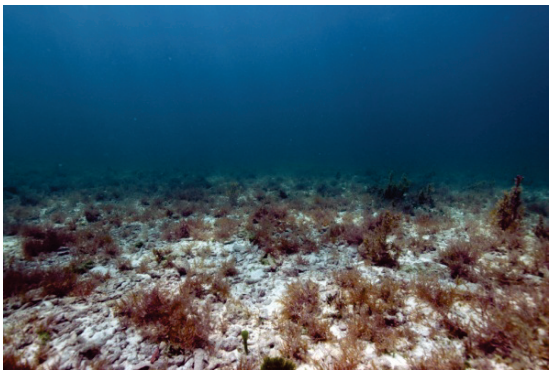


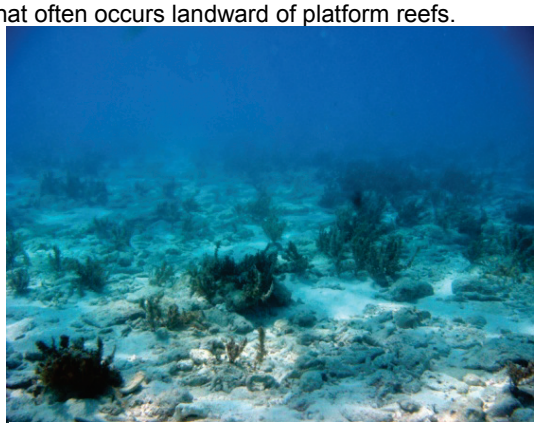




f. Reef Rubble

Dead, unstable coral rubble that often occurs landward of platform reefs.







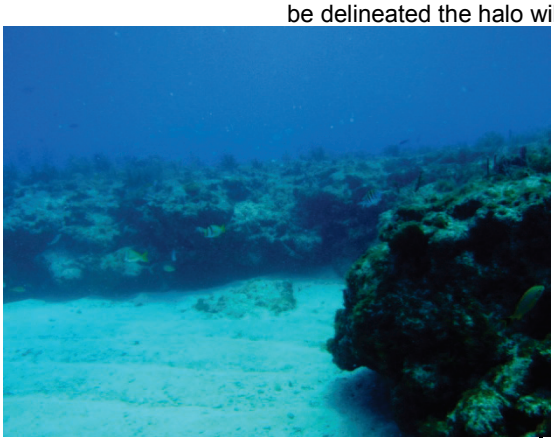


g. Patch Reefs

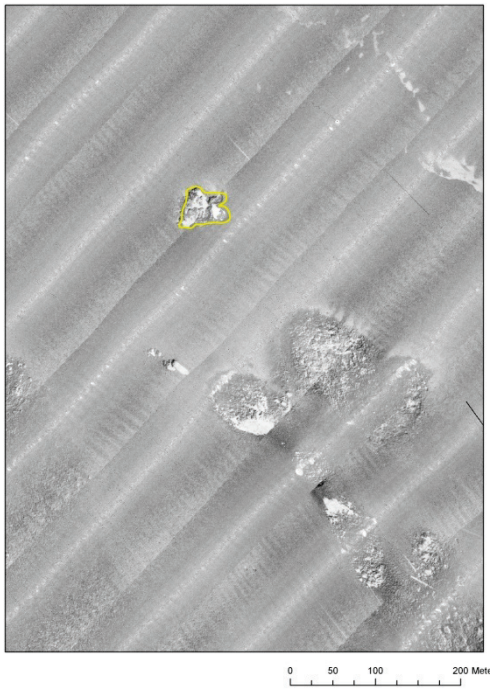
Irregularly shaped reef communities. They may range in size from tens to thousands of square meters. Patches are separated from each other by uncolonized hardbottom, sand, or colonized substrate with submersed aquatic vegetation (SAV), macroalgae, gorgonians or sponges. Most often the patches are surrounded by a halo of bare substrate created by foraging, obligate reef inhabitants.

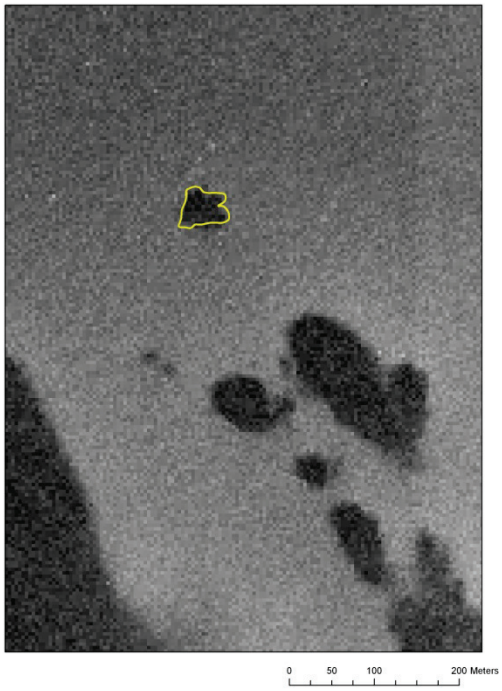
i. Individual Patch Reef

Isolated, single reef (larger than the minimum mapping unit of the project) without associated halo area. These individual reefs may have an associated halo, however if large enough (i.e. greater than the minimum mapping unit) to be delineated the halo will be mapped as its own subclass.



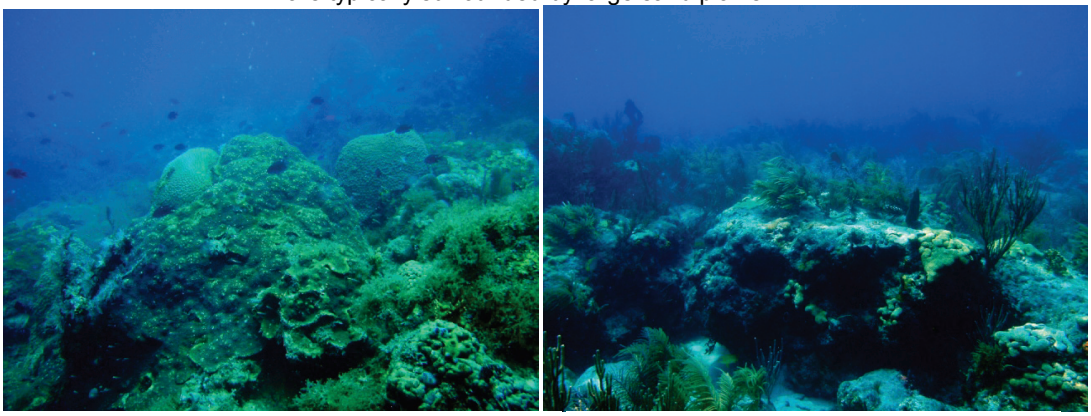


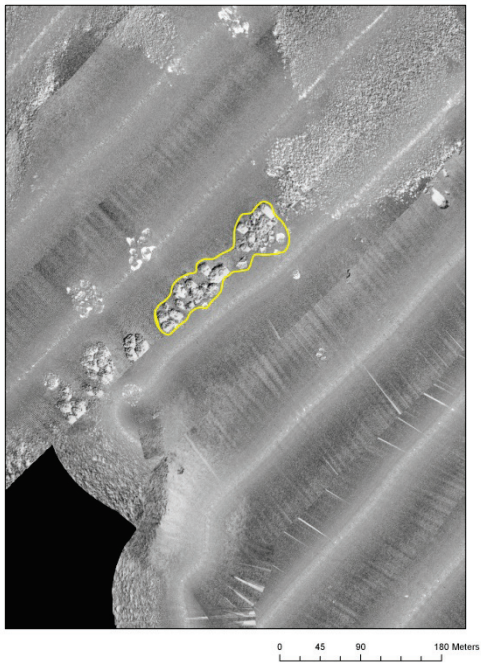




ii. Aggregated Patch Reefs (includes Halo areas if present)

High complexity patch reefs that have high relief (up to 15m) from the sea floor. These structures may occur in clusters and
are typically surrounded by large sand plains.

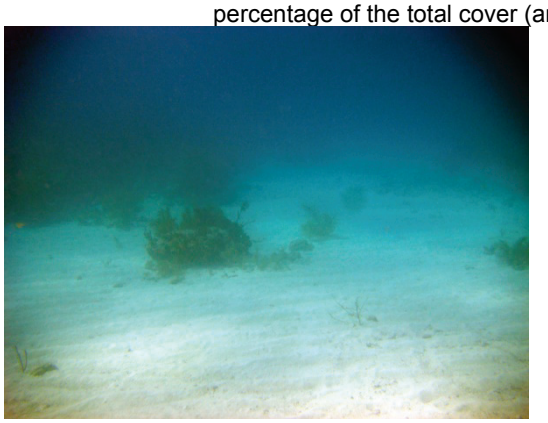


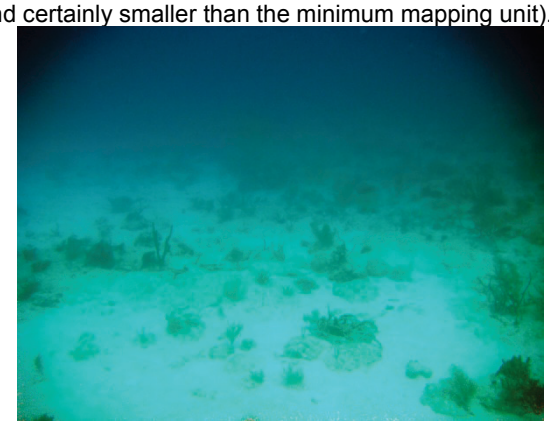




h. Patchy Coral and/or Rock in Unconsolidated Bottom

Areas of primarily sand, submerged aquatic vegetation (SAV), or low relief rock covered with a sand veneer. Often adjacent to spur and groove habitats, these areas contain small, individual corals or rocks that are distinctive yet a very low percentage of the total cover (and certainly smaller than the minimum mapping unit).









b. Hardbottom

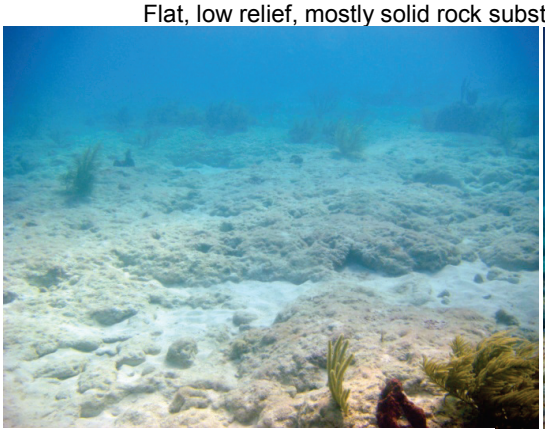
Hard substrate composed of exposed bedrock or created through syndepositional cementation of sediment.

i. Bedrock

Exposed bedrock and/or rocky outcrops with low to high relief and high complexity.

ii. Pavement (i.e. low relief hardbottom)

Flat, low relief, mostly solid rock substrate.

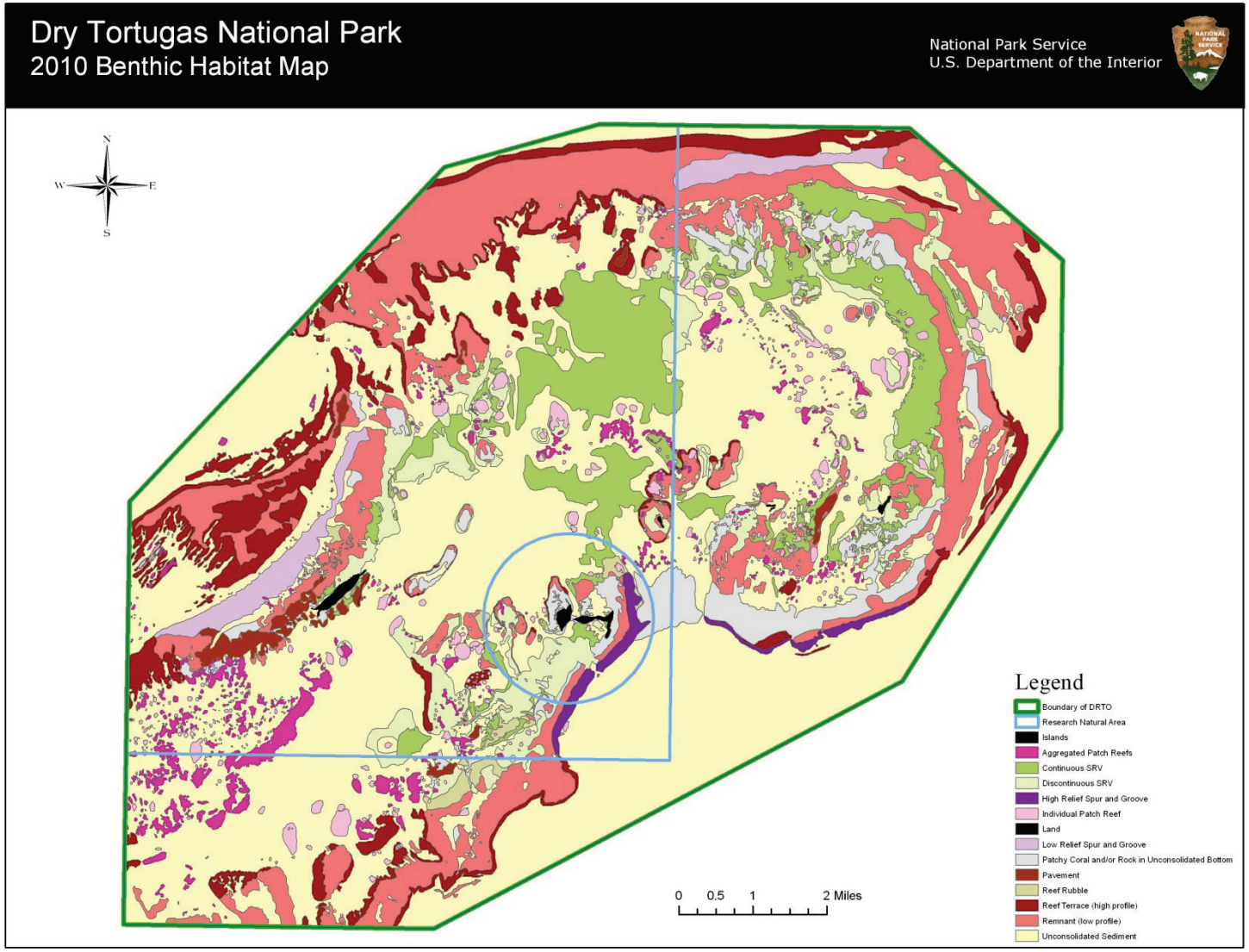


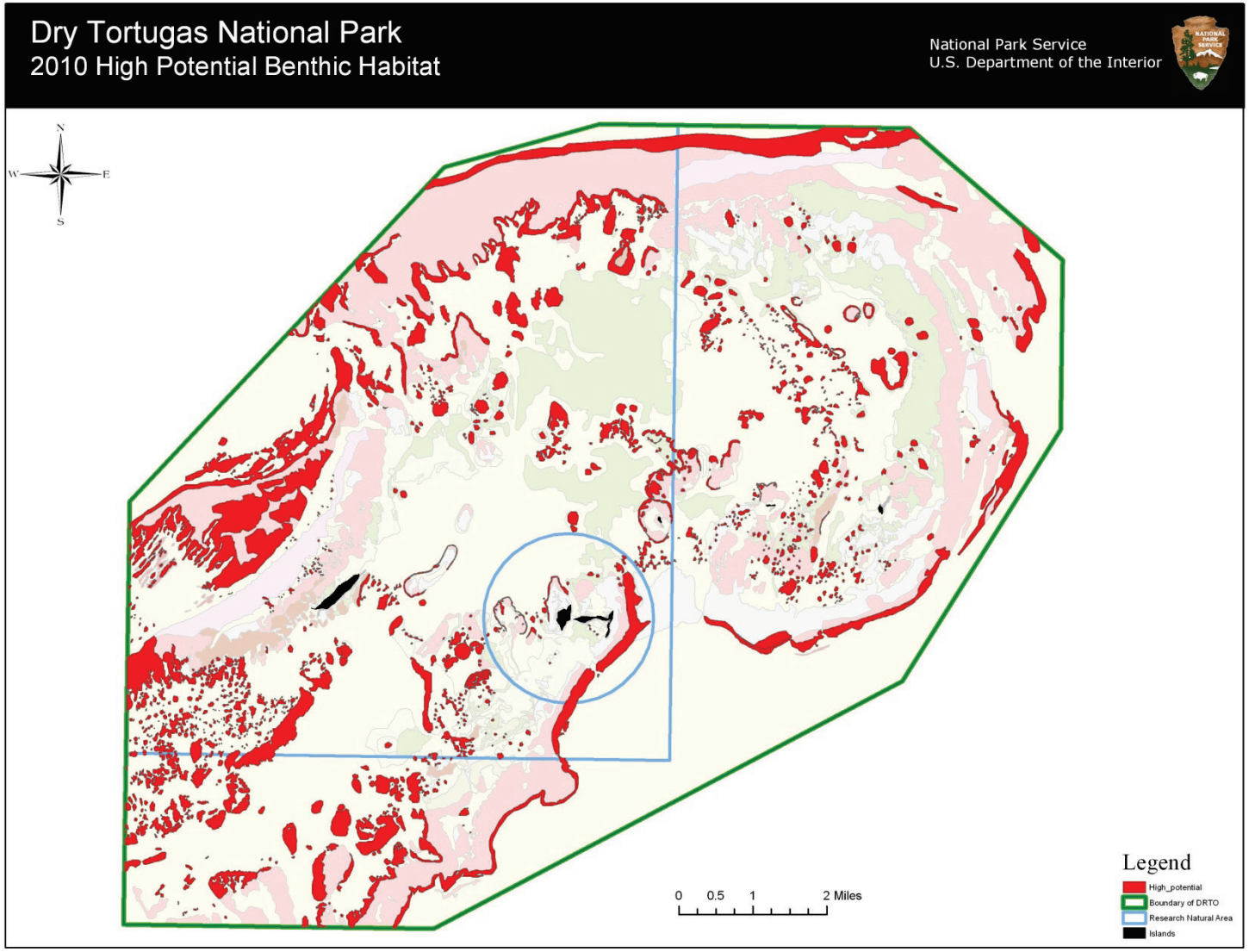


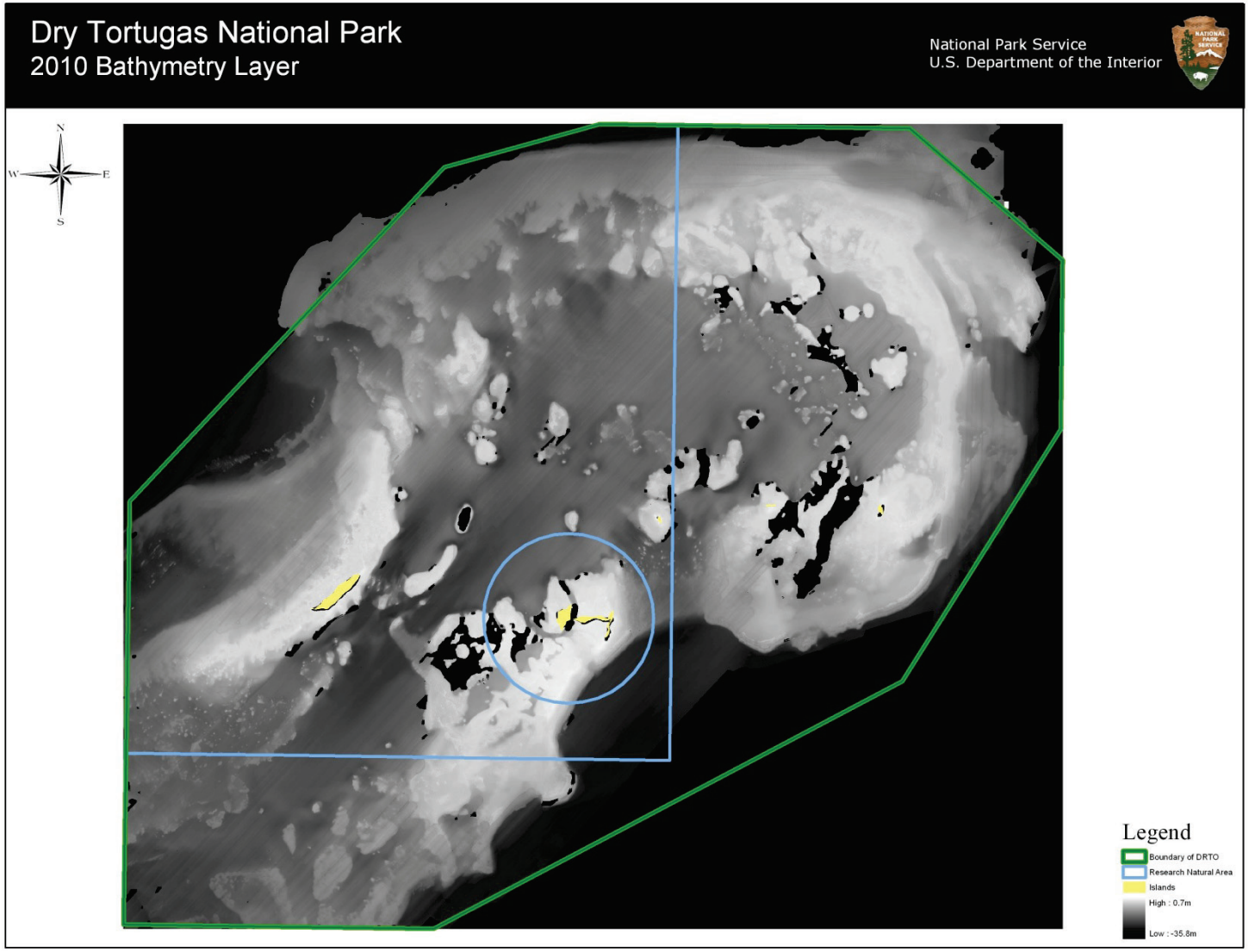


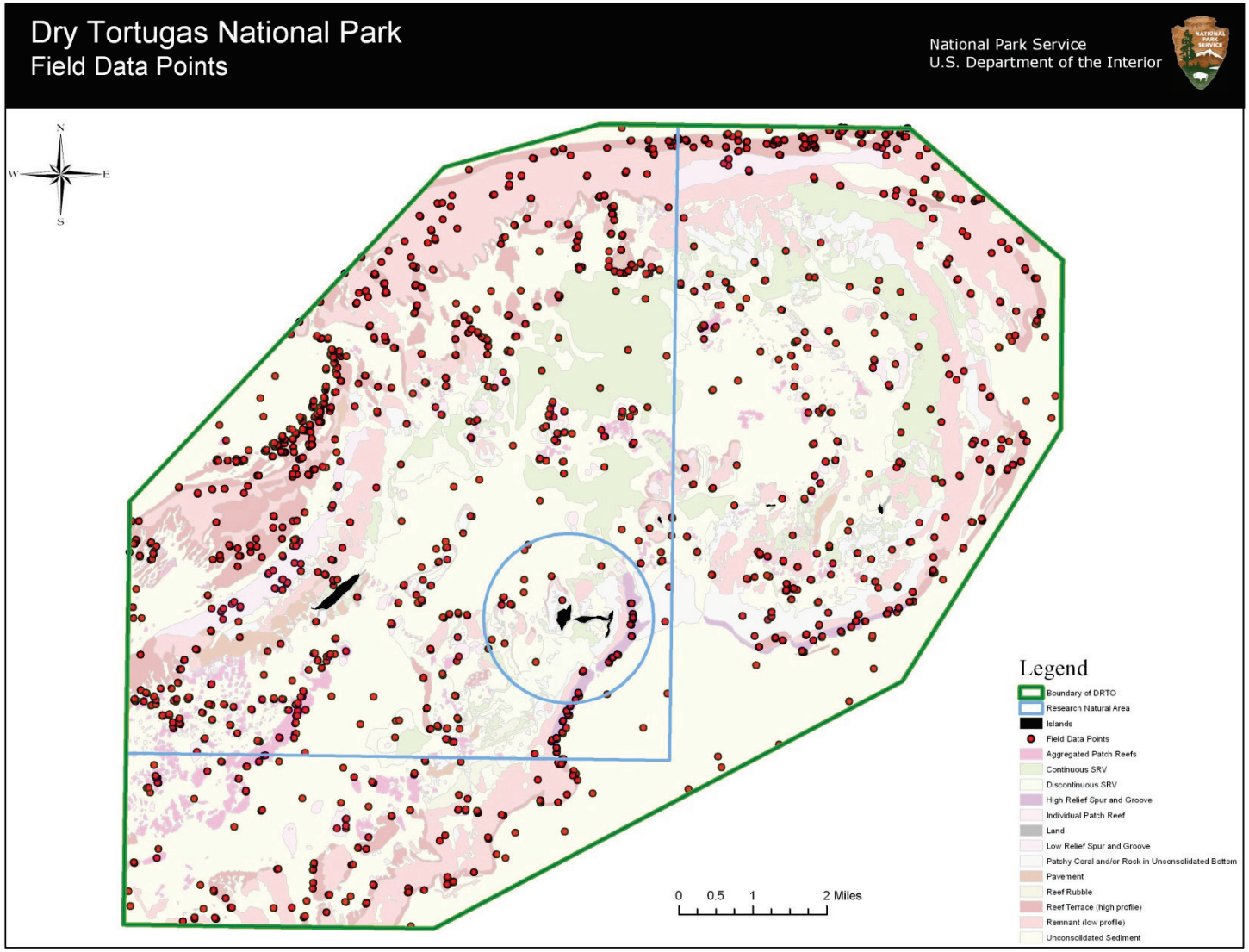


Appendix F. Maps


Dry Tortugas National Park
2010 Benthic Habitat Map
National Park Service
U.S. Department of the Interior
N
W
E
S
0 0.5 1 2 Miles
Legend
Boundary of DRTO
Research Natural Area
Islands
Aggregated Patch Reefs
Continuous SRV
Discontinuous SRV
High Relief Spur and Groove
Individual Patch Reef
Land
Low Relief Spur and Groove
Patchy Coral and/or Rock in Unconsolidated Bottom
Pavement
Reef Rubble
Reef Terrace (high profile)
Remnant (low profile)
Unconsolidated Sediment


Dry Tortugas National Park
2010 High Potential Benthic Habitat
National Park Service
U.S. Department of the Interior
N
W
E
S
0 0.5 1 2 Miles
Legend
High_potential
Boundary of DRTO
Research Natural Area
Islands


Dry Tortugas National Park
2010 Bathymetry Layer
National Park Service
U.S. Department of the Interior
N
W
E
S
Legend
Boundary of DRTO
Research Natural Area
Islands
High : 0.7m
Low : -35.8m


Dry Tortugas National Park
Field Data Points
National Park Service
U.S. Department of the Interior
N
W
E
S
0 0.5 1 2 Miles
Legend
Boundary of DRTO
Research Natural Area
Islands
Field Data Points
Aggregated Patch Reefs
Continuous SRV
Discontinuous SRV
High Relief Spur and Groove
Individual Patch Reef
Land
Low Relief Spur and Groove
Patchy Coral and/or Rock in Unconsolidated Bottom
Pavement
Reef Rubble
Reef Terrace (high profile)
Remnant (low profile)
Unconsolidated Sediment

Appendix G. Accuracy Assessment (AA) of the 2010 Benthic Habitat Map

Introduction

In June 2011 SFCN conducted an accuracy assessment (AA) of the 2010 benthic habitat map for DRTO.

Methods

The AA was accomplished by using the 2010 Reef Visual Census (RVC) fish monitoring data and corresponding photos, combined with collecting additional AA field data points where needed to complete the AA of all the benthic habitat classes. The target for the AA was to sample 20 field AA points per map class.

First the 2010 RVC benthic habitat data and corresponding photos were used to help in determining the accuracy of the polygons. NOTE: To see the protocol for the RVC monitoring go to: http://science.nature.nps.gov/im/units/sfcn/vital_signs/marine_fish_communities/FLKeys_Reef_Fish_monitoring_protocol_1Oct2009.pdf. RVC points were randomly selected within hardbottom habitats and where photos could be used to classify the habitat and thus reduce the amount of additional field data collection required. The RVC data was used by taking the existing benthic data and corresponding photos and looking at the map polygons that these points fell upon to make an assessment of what habitat type was located in that area. Points were not included where photos were blurred or otherwise indistinguishable, or in cases where a point fell on the Unconsolidated Sediment map class within a few meters of a edge of a reef map class and the photos only show the divers over the reef. The RVC method instructs divers to swim to the reef and it is possible the GPS on the buoy had drifted over into the neighboring polygon.

In cases where there were insufficient RVC points to satisfy the 20 points needed per map class, additional field AA points were collected. AA points were randomly selected within each map class, with the constraints of being >5m from an edge and >50m from another point. A description of this method is located in the methods section of this report describing the AA of the 2008 map. Three additional field AA points were added to assess the Remnant Reef (low profile) category as there was a large portion of eastern DRTO that was not sampled by the RVC monitoring because it is too shallow. These additional points coupled with RVC field points made sure this area was covered spatially for accuracy assessment. Twenty AA field points were sampled in the Unconsolidated Sediment map class even though nine of the RVC points were considered valid for AA. This was done to help complete the coverage of the park and because those nine fell on polygon edges. Two additional RVC points were evaluated for the Reef Terrace map class because the data were available. Field AA points were based upon *in situ* classifications and corresponding field photos, whereas RVC point classifications were made based upon field photos and data. Similar to the AA for the DRTO 2008 benthic habitat map , a post-field evaluation of the AA points was needed in order to determine if a point whose field classification was not an exact match to the map classification was still acceptable as a correctly identified polygon on the map.

The RVC and corresponding field AA results were recorded in a MS Excel Spreadsheet. Reasons for classifying points as acceptable that were not an exact match are as follows:

- ***Classification Scale***- The habitat classification is spatial-scale and landscape context dependent. This creates a difficulty for *in situ* field classification in the absence of either a map context or imagery, as the area a diver can efficiently evaluate is much smaller than the actual minimum mapping unit . For example, determining the difference between individual and aggregate patch reefs or between unconsolidated sediment and discontinuous submerged rooted vegetation can be difficult in the field without accompanying imagery. A specific example is shown in the main report (Figure 7) where a small area within a larger polygon may be classified differently than the rest of the polygon. If the size of this small area is smaller than the minimum mapping unit, the mapped polygon annotation may be acceptable. This can only be found in the post-field review.
- ***Polygon edge***- The polygon was determined acceptable when the AA point landed within 3 m of the edge between two different polygon habitats and one of the polygons matched the AA point.
- ***On edge between classification definitions***- If the field data and video/photos showed the habitat was in between classification definitions and the map annotation was felt to be reasonable, the point was declared acceptable. For example, a field AA point landed on an area of very sparse reef rubble overlying unconsolidated sediment. The field classification was reef rubble but the map annotation of unconsolidated sediment was determined acceptable.

Results

116 RVC points and 136 field AA points were used in this AA for a total of 252 accuracy assessment points. There were 179 points initially found to be an exact match between the map classification and the field classification. Upon post-field evaluation, 47 points were still found to have an acceptable map classification. Table A provides a summary of the reasons a point that was not an exact match was still declared acceptable.

Tables B and C summarize the AA results. The overall raw accuracy was 90% with a lower 90% confidence interval of 86.0% (Table A). The misclassifications are broken down by Map Class in Table B.

Table A. Summary of reasons an AA point was considered acceptable when it was not a 100% match to the field classification.

Acceptance Rationale	# AA Points
On edge between classification definitions	7
Polygon edge	6
Classification scale	30
Classification scale; on edge between classification definitions	3
Classification scale; polygon edge	1
Grand Total	47

Table B. Summary of AA results. The table provides the total number RVC points, field AA points, number of points with an exact match to the field classification, the number deemed acceptable, and finally the acceptable accuracy. Lower 90% confidence intervals are provided for the overall map, within hardbottom, and within softbottom.

Map_Class	# RVC points	# Field points	Total RVC + Field points	# Points 100% match to field classification	# Points acceptable classification		Acceptable accuracy	Std Err	Lower 90% CI
					N	Y			
Aggregated Patch Reefs	20		20	20	0	20	100.0%	--	
High Relief Spur and Groove	13	7	20	12	8	12	60.0%	11.2%	
Individual Patch Reef	20		20	20	0	20	100.0%	--	
Low Relief Spur and Groove	4	15	19	14	0	19	100.0%	--	
Patchy Coral and/or Rock in Unconsolidated Bottom	5	15	20	13	1	19	95.0%	5.0%	
Pavement		20	20	10	4	16	80.0%	9.2%	
Reef Rubble	1	19	20	7	8	12	60.0%	11.2%	
Reef Terrace (high profile)	22		22	18	0	22	100.0%	--	
Remnant (low profile)	20	3	23	21	1	22	95.7%	4.3%	
Total Hardbottom	105	79	184	135	22	162	88.0%	2.4%	83.4%
Continuous SRV	2	18	20	10	0	20	100.0%	--	
Discontinuous SRV		19	19	9	4	15	78.9%	9.6%	
Unconsolidated Sediment	9	20	29	25	0	29	100.0%	--	
Total Unconsolidated Sediment	11	57	68	44	4	64	94.1%	2.9%	87.0%
Grand Total	116	136	252	179	26	226	89.7%	1.9%	86.0%

Table C. Accuracy assessment data broken down by category.

Map Classification	Field/Photo Classification	Acceptable		Total Points
		N	Y	
Aggregated Patch Reefs	Aggregated Patch Reefs		20	20
Continuous SRV	Continuous SRV		10	10
	Discontinuous SRV		5	5
	Individual Patch Reef		1	1
	Individual Patch Reefs		1	1
	Remnant (low profile)		2	2
	Unconsolidated Sediment		1	1
	Total		*20*	*20*
Discontinuous SRV	Continuous SRV	3	4	7
	Discontinuous SRV		9	9
	Patchy Coral and/or Rock in Unconsolidated Bottom		1	1
	Reef Rubble	1		1
	Unconsolidated Sediment		1	1
	Total	*4*	*15*	*19*
High Relief Spur and Groove	High Relief Spur and Groove		12	12
	Low relief Spur and Groove	2		2
	Patchy Coral and/or Rock in Unconsolidated Bottom	1		1
	Reef Rubble	1		1
	Remnant (low profile)	4		4
	Total	*8*	*12*	*20*
Individual Patch Reef	Individual Patch Reef		20	20
Low Relief Spur and Groove	High Relief Spur and Groove		1	1
	Individual Patch Reef		1	1
	Low relief Spur and Groove		14	14
	Reef Rubble		1	1
	Reef Terrace (High Profile)		2	2
	Total		*19*	*19*
Patchy Coral and/or Rock in Unconsolidated Bottom	Aggregated Patch Reefs		1	1
	Continuous SRV		1	1
	Individual Patch Reefs		1	1
	Patchy Coral and/or Rock in Unconsolidated Bottom		13	13
	Reef Rubble		1	1
	Reef Terrace (High Profile)		1	1
	Remnant (low profile)		1	1
	Unconsolidated Sediment	1		1
	Total	*1*	*19*	*20*

Map Classification	Field/Photo Classification	Acceptable		Total Points
		N	Y	
Pavement	Discontinuous SRV		1	1
	Low relief Spur and Groove		1	1
	Pavement		10	10
	Reef Rubble		2	2
	Remnant	2		2
	Remnant (low profile)		2	2
	Unconsolidated Sediment	2		2
	Total	*4*	*16*	*20*
Reef Rubble	Aggregated Patch Reefs	1		1
	Continuous SRV	1		1
	Discontinuous SRV		1	1
	Individual Patch Reefs	1		1
	Low relief Spur and Groove		1	1
	Patchy Coral and/or Rock in Unconsolidated Bottom		2	2
	Reef Rubble		7	7
	Remnant (low profile)	5		5
	Unconsolidated Sediment		1	1
	Total	*8*	*12*	*20*
Reef Terrace (high profile)	Reef Terrace (High Profile)		18	18
	Remnant (low profile)		3	3
	Unconsolidated Sediment		1	1
	Total		*22*	*22*
Remnant (low profile)	Continuous SRV		1	1
	Discontinuous SRV	1		1
	Remnant (low profile)		21	21
	Total	*1*	*22*	*23*
Unconsolidated Sediment	Discontinuous SRV		2	2
	Individual Patch Reef		1	1
	Patchy Coral and/or Rock in Unconsolidated Bottom		1	1
	Unconsolidated Sediment		25	25
	Total		*29*	*29*
Grand Total		26	226	252

Discussion

The overall classification accuracy of the 2010 benthic habitat map was at least 89.7% (lower 90% CL= 86.0%), which met the accuracy standards of the NPS Vegetation Mapping Inventory Program of 80% with a 90% confidence interval and improved upon the 2008 map accuracy of 83.2% (lower 90% CL =79.8%). NOTE: this standard was used as there is currently no set accuracy standard for marine benthic mapping. After dividing up the map areas into softbottom and hardbottom categories, the overall accuracy of the 2008 benthic habitat map for the softbottom habitats was 89.4% (lower 90% CL=85.2%), which was improved slightly in the new 2010 map to 94.1% (lower 90% CL=87.0%). However for the hardbottom habitats the 2008 map had an overall accuracy of 75.2% (lower 90% CL=69.1%) as compared to the new 2010 map's 88.0% (lower 90% CL=83.4%). This was a substantial improvement to the accuracy of the benthic map in areas that will greatly assist both fish and coral reef monitoring. In addition, the 2010 map sub-divided two of the hardbottom categories, thereby adding a more complex identification scheme to those important reef structure habitats.

Upon analysis of the results, the map classes that had the greatest errors were: 1) High Relief Spur and Groove, and 2) Reef Rubble. One reason for this was that in the High Relief Spur and Groove category, the AA showed that the inside edges of the largest polygons were actually Low Relief Spur and Groove. With minor redrawing of the line work, the accuracy greatly improved in this category. The second reason was that the Reef Rubble category is difficult to determine with remote sensing data as it is commonly found interspersed among other benthic habitats. Additionally, the imagery displays similarities to the Reef Remnant map class, which created difficulties during photo-interpretation.

The 2010 benthic habitat map was designed to be a non-static map, so as new data becomes available, improvements will be made to produce the most accurate map possible for the park. The newly acquired data from the AA and 2010 and 2011 RVC benthic data could easily be used correct these minor errors in a future version of this benthic map product.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 364/108878, July 2011

National Park Service
U.S. Department of the Interior

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