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Coordinated Coral and Hardbottom Ecosystem Mapping, Monitoring and Management, Year 5

Florida Fish and Wildlife Conservation Commission
Fish and Wildlife Research Institute

Annual Project Report

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December 2016- Submitted by Richard O. Flamm – FWC FWRI

Final Project Report for CM619

Coordinated Coral and Hardbottom Ecosystem Mapping, Monitoring and Management

Executive Summary

This work addresses the need for a single coordinated perspective on the mapping, monitoring and management of the Florida Reef Tract. Prior to this project, mapping of the reef tract was conducted piecemeal with limited geographic scope using a wide range of mapping methods and classification schemes. The Unified Reef Map was developed as a solution for integrating existing map data into a single, seamless map of benthic habitats from Martin County to the Dry Tortugas. The Unified Reef Map consists of a geospatial framework which includes a single GIS database for mapping, monitoring, and management data associated with the Florida Reef Tract. Another component of the Unified Reef Map framework focused on making data available to the public via online map applications, web mapping services, and other web resources. These web-based map services provide current and historical *in situ* information about Florida reef habitats as well as other relevant spatial information such as management areas, field observations, marine infrastructure, and socio-economic data. Products generated during the final year of this 5-year project include version 2.0 of the Unified Florida Reef Map, updated ancillary data for the Unified Reef Map web mapping services, and the roll out of an updated webpage which provides access to project reports, GIS data, and online map applications. To date, the Unified Reef Map framework has contributed to several management efforts including the Florida Keys National Marine Sanctuary (FKNMS) Zoning and Regulatory Review by incorporating healthy coral reefs that were not captured in the 1995 zoning effort.

This study also contributed to the Our Florida Reefs (OFR) community planning process for southeast Florida's coral reefs. Community Working Group (CWG) meetings were held and were comprised of local reef users, scientists, and representatives from non-governmental organizations as well as local, state, and federal agencies. Topics of the meetings included updates on relevant current events, mooring buoy spatial planning, MPA framework, the Marine Planner decision support tool compiling a prioritized list of recommendations for the comprehensive management strategy, and preparation for the Southeast Florida Coral Reef Initiative (SEFCRI) review. Radio and Television public service announcements, print and electronic advertisements and press releases were produced and distributed to publicize the CWGs and encourage participation in the meetings. Outreach events were also conducted. The principle outcome of the OFR process was a prioritized list of Recommended Management Actions (RMAs). These were first drafted based on the work of the stakeholder-driven CWG and augmented with suggestions from the SEFCRI Team and Technical Advisory Committee. The draft RMAs were then presented to local stakeholders for discussion at a series of community meetings in January and February 2016. The public was encouraged to comment, write letters, and draft petitions in order to share their perspectives following the meetings. In all, almost 2000 comments were received and 12 letters and petitions. The CWG reviewed all feedback received and further edited RMAs based on suggestions and comments from the public. The final result was a prioritized list of 68 RMAs that will be contained in a final process summary report that will be rolled out in June 2017.

Methodology

Unified Reef Map – Years 1 & 2:

A technical team of source map authors and benthic mapping experts was formed to review and discuss the data integration process approach and to work out technical challenges for the Unified Reef Map. The best available benthic mapping layers were compiled into an ESRI ArcGIS Geodatabase. All Feature Class attribute tables were checked and corrected to ensure data integrity and additional fields were added to accommodate attributes of the original source data.

The Unified Class (UC) schema was developed to integrate different classification schemes throughout the region into a common framework while maintaining original source information. The UC system was adapted from several schemes throughout the area including; FWC's SCHEME (Madley, Sargent, & Sargent, 2002), NOAA Puerto Rico and US Virgin Islands Scheme (Kendall, et al., 2001), NOAA Florida Scheme (National Oceanic and Atmospheric Administration, 2008) and CMECS (Federal Geographic Data Committee, June 2012). Five hierarchical UC Level classes were added and attributed. Lower UC Levels represent more generalized classes. Higher UC Levels (Levels 3 and 4) provide more detailed information such as the type and extent of biological cover.

In order to spatially integrate data, individual source map Feature Classes were merged into a single Geodatabase Feature Class. The overlapping area of the layer with the most current information was kept. If overlapping areas were of a comparable time period (within approximately 5 years), priority was given to the layer which best matched the overall mapping area in terms of classification scheme and mapping resolution. Polygon geometry and classification were edited where features were incongruent along boundaries between maps using the best available imagery. Ancillary fields were added to document edits. Fields were also added and attributed to identify geographic region, reef map zone, and CMECS attributes including Geoform, Substrate and/or Biology.

The Unified Reef Map, *in situ* observation data, historic benthic maps, management areas, and other relevant ancillary layers are available through the map data service. An open source REST endpoint for this map data service allows for access by third party mapping applications. Updates to data services are maintained by FWC staff and automatically pushed to all clients and applications accessing the map data service. Additionally, URM map services are also available for viewing in a dedicated ArcGIS Online web map.

Management-focused meetings were held in South Florida and Key West to introduce the map product to local, state, and federal resource managers. The objective of the meetings was to demonstrate how resource managers can access and use the Unified Reef Map and associated spatial data to support decision making. These meetings and related correspondences between the technical team and managers resulted in a vetted Unified Reef Map product that provides a GIS-based framework for management, research, monitoring, and other uses.

Unified Reef Map – Year 3:

Data gaps in Boca Grande and Hawk Channel were mapped using photo-interpretation methods comparable to those used for surrounding areas in the Florida Keys. Photointerpretation was made using the best available satellite imagery, Lidar, side-scan sonar, ground verification information, and additional ancillary data where available. Edits to existing maps were made where there were differences in classification with neighboring maps. In addition to these data gap areas, the Unified Reef Map was updated with new data for Biscayne Bay Aquatic Preserve provided by the National Park Service.

The most recent updates of *in situ* data from the Coral Reef Evaluation and Monitoring Project (CREMP) were incorporated into the ancillary data sets and used to evaluate existing map classifications.. Documentation, metadata, GIS data/layer packages and CMECS crosswalk tables were updated in the web mapping applications and are available for download from the FWC website at http://ocean.floridamarine.org/IntegratedReefMap/.

ArcGIS server web map services were created for distribution of the Unified Reef Map, LiDAR, and other ancillary spatial data. These web map services were directly fed into the OFR Marine Planner web based mapping tool. Source GIS files and documentation were also made publicly available for download through the FWC website. Documentation made available on this web site includes accuracy assessment reports, final grant reports, related peer reviewed publications and links to source satellite imagery and in situ data.

Unified Reef Map – Year 4:

Data gaps in the northern Marquesas and Back Country areas were mapped using photo-interpretation methods comparable to those used for surrounding areas in the Florida Keys. More recent, higher resolution satellite imagery, LiDAR, and ground verification information were identified as data sources for mapping these historically unmapped areas. LiDAR reflectance and relative depth data provided information in deeper areas of the Marquesas where satellite imagery was inadequate. Additional ancillary data including field observations acquired by NOAA, FWC, and National Park Service (NPS) were referenced as necessary to assist with photo-interpretation. Existing maps of the surrounding area were considered during classification, and line-work was matched at map boundaries. Additional QA/QC of the Unified Reef Map was conducted to edit and correct topology errors throughout the entire study area. Approximately 820km^2 were mapped in the Marquesas and Back Country gap areas and integrated into the Unified Reef Map.

Additionally, a standalone patch reef data layer was also generated for the Unified Reef Map study area. The Unified Patch Reef Map provides a continuous and consistent spatial representation of individual and aggregated patch reefs in Southeast Florida and the Florida Keys. The Unified Patch Reef Map was created by extracting patch reef features from several maps throughout the Keys including NOAA, Nova Southeastern University (NSU), NPS, and FWC. Following compilation of datasets, patch reef features were extensively reviewed and edited using updated and higher resolution imagery, LiDAR, acoustic side-scan data, and ancillary patch reef mapping data to ensure map accuracy and consistency. The resulting GIS layer consists of 14,196 patch reefs identified using the best available imagery and a consistent minimum mapping unit and scale throughout the Unified Reef Map study area.

Unified Reef Map – Year 5:

Version 2.0 of the Unified Reef Map was released during Year 5 which included two major updates: 1) integration of the Unified Patch Reef Map into the Unified Reef Map, and 2) addition of new mapping data provided by NSU. Integration of the Unified Patch Reef dataset required extensive review and editing using updated high resolution imagery, LiDAR, acoustic side-scan, and ancillary patch reef mapping data. Intersected patch reef features from the Unified Reef Map were either merged or reclassified at a mapping scale comparable to the original source map. All edits were documented in the attribute table of the Unified Reef Map. Topology errors, including gaps and overlaps generated from the intersection, were reviewed and corrected. In addition to the Patch Reef features, updated map data of Southeast Florida benthic features were provided by NSU and integrated into the Unified Reef Map. Version 2.0 of the Unified Reef Map and additional layers depicting reef zones, regions, and map footprints were compiled into a geodatabase along with metadata and custom symbology for distribution. Online resources including the Unified Reef Map website and web mapping services (i.e. REST endpoints) were also updated during Year 5. Updates to the Unified Reef Map were made to improve consistency and accessibility to the most critical information and data. The primary Unified Reef Map web service was updated with Version 2.0 map data. Staff also coordinated with project partners to obtain the most current monitoring and management data to update the Ancillary Map Service.

Another deliverable for Year 5 included an accuracy assessment of the broader Unified Reef Map. A comprehensive accuracy assessment of the Unified Reef Map would require additional collection of in situ observations, particularly in recently mapped areas and in areas where maps are likely out of date (e.g. FKNMS hasn't been mapped since 2006). In the absence of funds to acquire additional in situ data, accuracy was assessed by compiling existing accuracy assessment results for individual maps and findings from FWC's review of integration issues which was a product of additional CMP special merit funding during Year 3. Findings suggest that most maps meet recommended accuracy standards with some exceptions for ephemeral habitats (e.g. seagrass) and certain hard bottom habitat classes (e.g. pavement v. reef, aggregated v. individual patch reef). Despite relatively high accuracy of individual maps, there were considerable differences between neighboring and/or overlapping maps and discrepancies revealed during the patch reef integration efforts. Most discrepancies were attributed to differences in mapping methods, map scale, resolution of source imagery, and conflicting interpretations of broadly defined classes. In effect, results suggest that one map is not necessarily more accurate than another, rather, both maps are often correct based on their respective mapping scale and methods. Detailed accuracy assessment results are summarized in Appendix I.

A final meeting was held with resource managers and mapping partners to acquire input on mapping issues and future monitoring needs. The meeting was held on April 14, 2016 at Nova Southeastern University in Dania Beach. Discussions with managers and map end users provided valuable feedback for addressing consistency in mapping scale, methods for new mapping efforts, classification issues, filling data needs (gaps), and acquiring future support for the Unified Reef Map. These discussions and lessons learned over the course of this 5-year project contributed to the creation of the Mapping Guide for Partners of the Florida Reef Tract (Appendix II). The Mapping Guide provides recommended best practices for resolving existing map issues and promoting consistent methods for future mapping efforts.

Our Florida Reefs Community Working Group

OFR CWG - Year 1: July 1, 2013 – December 31, 2014

Florida LLC (Carol Lippincott, Ph.D.) was contracted to provide professional facilitation services for the Our Florida Reefs (OFR) community working group meetings. The OFR-contracted facilitator worked with DEP's Coral Reef Conservation Program (CRCP) staff to coordinate community working groups. Facilitation of collaboration and information exchange between working groups was necessary to ensure the management options identified by the groups targeted the entire northern third of the Florida Reef Tract. Responsibilities included the development of meeting structure and agendas, creation of a working group charter with consensus approval by working group members, identification of background materials as needed, coordinating follow-up tasks from community working group meetings to ensure continued participation between meetings from working group members and, assisting working group members in coordinating additional informal efforts to further discuss and develop work as needed.

OFR CWG -Year 1: October 1, 2013 – 12/31/2014 Special Merit

The OFR Assistant activities included booking venues for OFR community working group meetings, ordering supplies, preparing meeting materials, and providing assistance to CRCP staff and the OFR facilitation contractor. Outreach included a total of 31 social media posts, 68 web updates, and 13 education/outreach events. Meeting minutes were recorded and compiled for 26 OFR community working group meetings. 6,031 total 30-second PSAs aired (11 total with 8 in English and 2 in Spanish) between December 1, 2014 and March 9, 2015. A total of 15 advertisements, including 6 newspaper and 9 magazine advertisements were produced and published.

OFR CWG - Year 2: July 1, 2014 – September 30, 2015

CWG meetings were held from July 2014 through June 2015. Working group meeting accomplishments included CWG member education about coral reef issues in southeast Florida often having guest speakers, development of shared interest and vision for southeast Florida coral reefs, introduction and use of the Marine Planner tool, compilation and prioritization of management actions for inclusion into the Marine Planner tool, and taking of public comment. Documentation of the OFR facilitation services was provided in the form meeting minutes, and progress reports.

Six outreach events run by the outreach coordinator were conducted during the contract period. During 2015, web postings, including blog updates, resource updates, and meeting announcements were produced continuously between January 5 and March 30, May 11 and July 16, and August 14 and September 15 of 2015. Twenty-five printed or electronic advertisements/meeting announcements were published regularly from January into September. Between July 1, 2015 and September 1, 2015 2,594 radio and television public service announcement were produced and distributed.

OFR CWG - Year 3: July 1, 2015 and September 30, 2016

Six outreach events were held between November 2015 and April 2016 and 4 presentations given between October 2015 and February 2016 to different stakeholder groups. Additional meetings included fish ID and coral ID classes in April 2016. There were 7 SEFCRI meetings, 5 of which spanned 2 days and one was the Bi-annual meeting on August 18, 2016. There were 4 Process Planning Team meetings held between October 2015 and January 2016. There were a total of 170 web postings including blog posts and website updates. There were 8 OFR ads distributed to print media and 1,192 OFR Rack Cards, SEFCRI pens, and/or ESRI App cards distributed at 22 additional outreach events. PSAs totaled 1,641 for TV with 290 in Spanish and 496 for radio with 86 in Spanish. The goal was to distribute 3,500 brochures, pamphlets, rack cards, pens, etc. That number was not reached and we believe for a few reasons. First, while these materials were made available at all outreach events, they were not necessarily picked up by many of the attendees. Second, expected attendance was lower than expected at some outreach events, which reduced the expected amount of materials distributed. The SEFCRI DEP program will continue to distribute the materials and they will also be available at their June 2016 roll-out of the RMAs.

OFR-CWG - Total project summary

There were over 14,000 PSAs aired on television and radio (including English and Spanish) throughout the OFR process that promoted the Community Working Group (CWG) meetings to the public. There were a total of 37 CWG meetings between March 2014 and June 2016, including a Decision Support Tool Workshop. Twelve Community Meetings held in 2016 were designed to acquire input on the Recommended Management Actions. During these 2016 meetings, there were a total of 517 attendees. At the close of the public comment period following 2016 Community Meetings, a total of 1,942 comments as well as 12 letters and petitions were received. Two CWG subcommittees were formed at the final June 2016 CWG meeting. A "Report Committee", which will be working with DEP staff to edit and augment the final report, and a "Fishing Liaison Committee", which will be engaging in outreach to their stakeholder group to disseminate information about OFR outcomes and other local efforts. The CWG achieved their goal of creating a prioritized list of RMAs, with some RMAs having already been implemented or on the verge of implementation.

Outcome

Unified Reef Map

Years 1 and 2 of this project produced and implemented a vetted methodology for integration and distribution of Florida Reef Tract spatial data. Extensive spatial edits and adjustments were completed around source map boundaries to create a seamless map. Presentations and discussions with marine resource managers provided valuable input which helped refine a distributable map product. General feedback from the management perspective confirmed that the tools and map products would be helpful in supporting decision making needs. During Years 3 and 4, significant data gaps in the Unified Reef Map were filled in Boca Grande Channel, Hawks Channel, northern Marquesas and the Back Country region west of Florida Bay. Also during Year 4 and in response to stakeholder requests, patch reefs were re-mapped at a consistent classification methodology and map scale. The standalone patch reef map was subsequently integrated with the Unified Reef Map during Year 5. Throughout the duration of the 5 year project, web mapping services and the Unified Reef Map website were kept current with updated data from map providers.

Stakeholders and other end users of the Unified Reef Map can access the updated map products and project information via several on-line sources:

- Unified Reef Map website (http://ocean.floridamarine.org/IntegratedReefMap/UnifiedReefTract.htm);
- Downloadable geodatabase available at FWC's new online data portal, http://geodata.myfwc.com/;
- Java-based web map viewer hosted by FWC (http://ocean.floridamarine.org/InDevelopment/IntegratedReefMap/#);
- ArcGIS Online web map (http://arcg.is/1L0NJUs); and

- Web mapping services for the Unified Reef Map and ancillary data which can be accessed directly by ArcGIS users and support FWC's online map viewers as well as other map applications including the Our Florida Reef's Marine Planner web map.

Differences in methods between map providers continues to be a factor influencing the accuracy, consistency, and comparability of mapped habitats. Collaborative meetings with map providers have been an effective tool for developing strategies to improve consistency between methods and identify mapping needs. Coordination among mapping partners has also helped to fill data gaps, ensure map information is current, and facilitate the use of new imagery and mapping technologies. These issues are discussed in the Accuracy Assessment Report (Appendix I) which summarizes existing accuracy assessment efforts and issues encountered during map integration efforts. While accuracy issues are inherent with any mapping process and may vary with habitat type, most discrepancies between individual source maps were not necessarily indicative of one map being more accurate than another. Rather, accuracy assessment results suggested that source maps are often correct according to their respective mapping scale and methods. For this reason, source information was maintained whenever possible and very few edits were made during the integration process. Instead, recommendations were proposed to improve consistency in mapping scale, classification methodology, and source imagery between map providers as maps are updated in the future.

Our Florida Reefs

The OFR communication strategy was supported by the production and distribution of products used to inform stakeholders and user groups on the stakeholder-driven OFR process. This communication strategy also improved the rates of participation by stakeholders in the northern four coastal counties along the reef tract through education and outreach efforts. Stakeholders were solicited for their input and participation in the OFR process. The OFR process provided stakeholders the opportunity to take part in coastal and marine spatial planning for the region's coral reefs in order to develop a management strategy that seeks to better balance the use and protection of southeast Florida's coastal and ocean resources. This communication strategy allowed CRCP to reach specific audiences that could not be targeted otherwise. Increased stakeholder participation provided support to management options identified and increased awareness at the state and federal level.

The principle outcome of the OFR process was a list of Recommended Management Actions (RMAs). These were first drafted based on the work of the stakeholder-driven Community Working Groups (CWG). The draft RMAs were then presented at community meetings for discussion with stakeholders during January and February 2016. The public was allowed to comment, write letters, and draft petitions. In all, almost 2000 comments were received and 12 letters and petitions. The CWG reviewed the comments and modified prioritized RMAs will be available in their final report to be released in 2017.

Further Recommendations

This project has successfully established a GIS framework for integrating information from throughout the Florida Reef Tract and a comprehensive set of tools for making data available to stakeholders and the broader public. Additionally, this project initiated and facilitated a cooperative network of managers and scientists to coordinate mapping and monitoring efforts. As the final year of this project ends, a major challenge is continued coordination to sustain these established resources. Based on previous coordination efforts, we recommend annual meetings attended by both management and technical staff, list-serve updates distributed to the Unified Reef Map user community, and more frequent correspondence between key GIS staff. Collaborative meetings with map providers and interested stakeholders during the initial and final phases of this project have been an effective tool for developing strategies to improve consistency and identify mapping needs. Maintaining coordination between mapping interests will help to address data gaps, ensure map information is current and as consistent as possible across the Florida Reef Tract. The Mapping Recommendations Guide (Appendix II) will also promote consistent methods and help to streamline the integration process for future map updates.

A major recommendation made during the mapping stakeholder meeting held in 2016 was to expand mapping efforts beyond the reef tract to include nearshore waters and contributing watersheds (Appendix III). This is an important consideration because the reef tract does not exist in isolation. The geospatial framework of the Unified Reef Map is uniquely suited to address these gaps and link watershed stressors with the condition and productivity of reef resources.

Similarly, we recommend integrating the reef tract and nearshore areas with those uplands whose drainages have influence over the health of the reef tract. These areas can be integrated through expansion of the mapping effort (nearshore bays and estuaries) and engaging uplands communities, organizations, and agencies need to be joined with the reef tract and treated as a single system.

We recommend that the reef tract, nearshore bays and estuaries, uplands, be operationalized as a social-ecological system (SES) (Berkes and Folke 1998; Ostrom 2009; Tabara and Chabay 2013). Most simply, a SES is the combined ecological and human components and their interactions in a complex managed landscape. By complex we are referring to the large number of components and the likelihood of unpredictable system behaviors. In an SES an ideal landscape-level management unit is a watershed because they bound the ecological and socioeconomic patterns and processes that shape the watershed and ultimately impact the Florida reef tract. For the Florida reef tract, the landscape extends from Martin County, Florida down through the Florida Keys and includes the nearshore as well as the upland areas that drain into the Atlantic and can influence the health of the reef. While managing the reef track without considerations of the other system components will likely be inefficient at best and futile at worst, it is a very difficult task because of its size, variety of ecosystems, and large number of political jurisdictions, social institutions, and beliefs and values of millions of residents and visitors.

Given that the southeast Florida reef tract SES would be large, with different habitats, with many socioeconomic and political regions, expertise and resources that span the region, and the simple fact that this research-management system is complex, an operations management (OM) approach to implement the SES is recommended (Krajewski and Ritzman 1999). By operations management we are referring to planning, organizing, and coordinating in the context of producing a desired outcome: a sustainable Florida reef tract. One of the strengths of OM is that it presents a structured platform from which to tackle complex problems, including organizational structure and function. Possible benefits include more highly structured problem solving; more efficient resource use; stronger and better defined partnerships; elimination of ineffectual legacy activities; removal of barriers between programs that hinder productivity and innovation; increasing creativity and staff morale by nurturing desired behaviors that emerge from employees in the lower half of the organizational hierarchy; and providing internal and external benefits through increased transparency and simplified reporting and accountability.

Success of the OFR process required effectiveness in two areas: stakeholder management and knowledge management. Stakeholder management involves recruiting and retaining, at a minimum, a core set of participants that represent a broad spectrum of the stakeholder community. Much of this stakeholder management was associated with the CWGs. Knowledge management, as it relates here, is a mechanism for managing both environmental data as well as input and information collected from stakeholders. Knowledge management also extends to developing strategies for communicating this information to the public. Knowledge management involved both the CWGs and the Marine Planner tool. Significant progress has been made in both these areas, in this regard, we recommend continued stakeholder engagement and the continued support of tools, like the marine planner, that help manage data and build knowledge. Finally, we suggest, that the OFR process be integrated into the SES described above and serve as a focal point for Florida reef tract collaborative decision making.

Citations

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Appendix I:

Accuracy Assessment of the Unified Reef Map

Introduction

Maps are thematic representations of reality and as a result are subject to varying degrees of error caused by uncertainty between thematic classifications and true ground, or in this case, seafloor conditions. Accuracy assessments provide a means for estimating classification error and are a useful tool for reporting the degree of uncertainty in the final map product. Map accuracy is a measure of agreement between classification results and reference or “ground-truth” observations. Accuracy assessments typically consist of field surveys to collect ground-truth data and comparing those observations to map results using various statistical tools. Map accuracy and precision are largely influenced by mapping methods including scale, source imagery, and classification scheme. This is important to note, as the reported accuracy of any map is a function of the spatial and thematic mapping scale as well as the feature mapping and classification methods.

The Unified Reef Map (URM) consists of individual regional maps that have been integrated to provide a seamless representation of benthic habitats across the Florida reef tract (Figure 1 and Table 1). Accuracy assessments have been conducted on several individual maps within the URM, however, the accuracy of the integrated URM product has yet to be evaluated. A single accuracy estimate for the entire URM is problematic due to differences in mapping methods which may influence accuracy estimates between individual maps. Furthermore, a comprehensive accuracy assessment would require additional in situ observations, particularly in recently mapped areas and in areas where maps are likely out of date. In the absence of additional in situ data, this report will provide a general accuracy summary of the URM by compiling results from individual map accuracy reports and findings from the Fish & Wildlife Research Institute (FWRI) 2015 report, *A Review of Issues Pertaining to the Integration of Florida Reef Tract Benthic Maps*.

Readers should also take note that accuracy assessment methods and metrics used to report results vary between maps and may limit direct comparisons of accuracy results between individual maps. Interpretation of accuracy assessment results must take into account the classification level and mapping scale at which results are reported. For example, accuracy will likely be higher for broad, broad level habitat classes (e.g. hard v. soft bottom) than for more detailed level classes (e.g. patch reefs, pavement, seagrass). Furthermore, there are varying ways for reporting map accuracy including overall accuracy and adjusted accuracy, which corrects for bias due to differences in proportional area between habitat classes (see Walker et al. 2013). Overall accuracy of broad level habitat classes is reported most consistently among individual maps throughout the Florida Reef Tract and will be the focus for this summary.

Overall Map Accuracy from Previous Assessments

Accuracy assessments have been performed for most individual maps within the URM study area. Accuracy assessment results for individual maps which have been incorporated in to the URM are summarized in Table 1. Overall or total map accuracy is generally high and ranges from 85.6% to 98.0% for broad habitat classes (sediment v. hardbottom/reef) among individual URM maps. Adjusting accuracy for differences in proportional area among classes (see Walker et al. 2013), in general, increased map accuracy by 5-10%. There were no obvious spatial patterns in accuracy among individual maps, although Walker et al. (2013) noted higher accuracy where habitat diversity was lower (e.g. Backcountry) compared to areas with higher habitat diversity (e.g. reef tract). Accuracy was also generally higher for more recent maps in the Southeast Florida region which were generated from higher resolution source imagery across multiple remote sensing platforms.

Overall accuracy for detailed habitat classes (i.e. types of hardbottom, sediment, seagrass) was slightly lower than for major classes, ranging from 84.6% to 96.0%. Map accuracy was generally lowest for certain types of reef and hardbottom. Accuracy of pavement ranked among the lowest classes in the Florida Keys map and Marquesas map. In Biscayne Bay, the National Park Service (NPS) reported low accuracy for spur and groove, pavement, reef terrace, and remnant reef. NPS reported similar results for the Dry Tortugas, indicating lowest accuracy certain types of aggregate reef (remnant v. reef terrace) and spur and groove (high v. low relief). Accuracy was also low for Seagrass particularly in the Marquesas and Florida Keys/Backcountry (80.4, 81.6%) maps.

All individual maps which are currently integrated into the URM meet accuracy standards recommended by the FGDC (85% attribute accuracy for wetlands) and by the NPS (80% for 1:24,000 vegetation maps). Maps are within the recommended range for thematic accuracy (85-95%) for the Florida Reef Tract published in the Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan (Rohmann and Monaco, 2005). Accuracy of most URM maps is also within the range reported by Zitello et al. (2009) of 96% for major classes and 86% for detailed classes in the Virgin Islands and Puerto Rico.

Table 1. Accuracy assessment results for maps throughout the Florida Reef Tract.

URM Map	Provider[1]	Overall Accuracy[2]	Citation
Palm Beach County	NSU	89.2%	Riegl, B. et al. 2005.
Broward County	NSU	89.6%	Walker, B.K. et al. 2008
Miami-Dade County	NSU	93.6%	Walker, B.K. 2009.
Martin County	NSU	85.6%	Walker, B.K. et al. 2012.
SE Florida (Key Biscayne to Hilsboro Inlet)	NSU	98.3%	Walker, B.K. et al. 2014.
Biscayne Bay	NPS	96.0% (v2011)	Estep, A.J. et al. 2014.
Florida Bay	FWRI	Unknown	
Florida Keys/Backcountry[2]	NOAA	90.4%	Walker, B.K. et al. 2013;
Marquesas	FWRI	91.2%	CP&E. 2011.
Dry Tortugas	NPS	98.0% (v2010)	Waara, R. J. 2011
Hawk Channel	FWRI	Not conducted.	
Boca Grande	FWRI	Not conducted.	
North Keys/Backcountry	FWRI	Not conducted.	

[1]Map provider or data owner, subcontractors not listed. NSU: Nova Southeastern University (NSU), FWRI: Florida Fish & Wildlife Commission, Fish & Wildlife Research Institute, NPS: National Park Service, South Florida/Caribbean Network (SFCN), NOAA: NOAA National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment (CCMA)
[2]Accuracy assessment did not include the entire mapped areas.
**Reported accuracy at the coarsest classification level (sediment v. hardbottom/reef) unadjusted for proportional area bias.*

Findings from the FWRI Report, "*Review of Issues Pertaining to the Integration of Florida Reef Tract Benthic Maps*"

The Unified Reef Map project seeks to integrate different benthic mapping efforts into a single continuous and seamless map. The data integration effort introduced the need to resolve discrepancies between maps in overlap areas and seams where maps meet. This work focused on integration issues in two areas within Biscayne National Park (BNP) where the National Park Service (NPS) mapping efforts overlap the mapping extents of both National Oceanic and Atmospheric Administration (NOAA) and the Nova Southeastern University (NSU). FWRI conducted ground truth surveys in 2014 to investigate areas where discrepancies between maps frequently occurred. In addition to comparison with ground truth data, discrepancies were evaluated by quantitatively comparing overlapping maps. As expected, there was lower agreement between the NPS and NOAA maps (65%) than between the NPS and NSU maps (80%). In general, higher resolution imagery enabled more detailed discrimination between habitats in the NPS and NSU maps compared to the NOAA map delineated from coarser Ikonos imagery. Discrepancies tended to be class specific, with frequent confusion between seagrass and pavement and also between certain hard bottom classes including pavement, aggregate reef, scattered coral rock and different types of patch reef habitat.

Low agreement between maps is not necessarily indicative of higher or lower map accuracy, rather, results suggest that maps are typically correct according to their respective mapping methods. Three primary factors which contributed to discrepancies and comparability between maps; 1) resolution of source imagery, 2) scale and minimum mapping unit (MMU), and 3) confusion between similar habitat types. Consistency in benthic mapping efforts would best be improved by adhering to an agreed upon methodology including consistent MMU, mapping scale and also consistent interpretation of classification schema between map sources.

Accuracy Issues and Sources of Map Error

Review of existing accuracy assessment results and findings from FWRI's 2014 verification efforts reveal the following sources of map error which are common among URM maps.

Issue 1) Time lag between collection of source imagery and ground truth observations

Several URM map sources attributed low map accuracy, in part, as a result of lag time between acquisition of source imagery and acquisition of ground verification information (Keys, Southeast FL, Marquesas). Seagrass cover can vary throughout the year in response to a variety of environmental factors which can cause shifts between continuous or discontinuous seagrass and sediment. Macroalgae which often co-occurs and can easily be confused with seagrass cover can also vary over short time periods contributing to lower accuracy (Marquesas). Sediment transport during large storm events may also influence the accuracy of low relief hardbottom habitats such as pavement and spur and groove (Walker et al. 2013; Walker 2009, Walker and Foster 2009). Ground truth observations collected months or years after acquisition of source imagery are unlikely to capture seasonal and storm-related habitat changes.

Issue 2) Scale and interpretation of field verification observations

Collection of in situ information is a critical component of guiding and verifying classification during the mapping process as well as assessing the accuracy of the resulting map product. Interpretation of field observations for accuracy assessments must consider how data were collected including distribution, extent, and spatial scale of individual observations. Disparity between mapping scale and observer scale was frequently cited as a major source for disagreement between map results and field observations (Tortugas, Biscayne, Keys, Marquesas, Southeast Florida). Field information is often collected at a scale far smaller ($<100m^2$) than most minimum mapping units ($>1,000m^2$). This scale disparity, may produce lower accuracy for classes which tend to include mixed bottom types or in polygons containing patches smaller than the minimum mapping unit. In these instances, field sites can be located within a particular bottom type that is either too small to map independently and/or is not representative of the dominant bottom type in the surrounding area. In the Backcountry/Keys map, for example, several sites identified as sand during field surveys were located in polygons mapped as aggregated patch reef. In some maps, such as Biscayne Bay and Dry Tortugas, these errors are considered acceptable given that certain habitats may include other bottom types, most often unconsolidated sediment. Throughout the URM, observer-mapping scale issues were most common for certain types of hardbottom (aggregated and individual patch reef, reef rubble, scattered coral rock, pavement, aggregate/remnant reef, spur and groove) and between discontinuous and continuous seagrass.

3) Availability and resolution of source data

Map accuracy and precision are highly influenced by the availability and quality of source imagery and ancillary information used to inform benthic classification. Spatial resolution was cited as a contributor to low accuracy in nearly all accuracy assessments conducted in the URM. Higher resolution imagery improved discrimination between certain hard bottom classes with visually similar signatures and often lack visually distinct boundaries. Furthermore, accuracy generally increased when maps were updated with higher resolution source imagery in the Dry Tortugas, Biscayne Bay, and Southeast Florida. Ancillary data including LiDAR, sidescan/multibeam sonar, and intensive ground surveys also improved accuracy of linear reef subclasses, spur and groove, and pavement.

4) Confusion between similar habitats

Accuracy of certain habitat classes remained low in several maps, despite additional field verification and higher and more robust source imagery. Often confusion between these similar classes occurred at the user-level either during photo-interpretation or classification of field observations. These errors were common for aggregate reef and pavement classes which share similar aerial signatures and also classes which may consist of more than one bottom type including reef rubble, scattered coral rock, spur and groove, and subclasses of linear reef (e.g. remnant, reef terrace) Several maps also reported difficulty visually distinguishing sediment colonized by macroalgae with seagrass particularly in areas where both macroalgae and seagrass co-exist. Lack of clear classification thresholds between certain classes may have also contributed to low accuracy. For example, Walker et al. cited the need for a size threshold distinguishing larger patch reefs from structurally and visually similar aggregate reefs. Walker et al. also attributed map error to lack of a clear vertical relief threshold between low relief pavement and other higher relief reef classes (2014).

Recommendations for Assessing and Improving Map Accuracy

<u>Classification Scheme Refinements</u>

Classification scheme modifications which reduce confusion between visually and spatial similar bottom types will contribute to higher map accuracy as well as consistency between maps throughout the URM study area. Specific recommendations for the URM include;

- Vertical relief threshold between low relief pavement and higher relief reef classes
- Inclusion of sand grazing halo should be clearly specified for individual and aggregated patch reefs,
- Designate a size threshold differentiating individual patch reefs from larger reef classes (Walker et al. 2014)
- Creation of a mixed hardbottom-seagrass class or, similar to CMECs, classification of geological structure independent of biological cover which retains both hardbottom and seagrass information, compared to other classification schemes which document the dominant cover type,
- Clear decision rules and subclasses or modifiers which retain information of less dominant classes for mixed bottom types,

Classification modifications should consider whether application of thresholds and decisions rules is feasible given the typical spatial and vertical resolution of source imagery, particularly current LiDAR and side scan/multibeam sonar (Estep et al. 2014). Ideal thresholds will also be derived from observed differences between classes from field surveys and existing research (Brock et al. 2008) and whether differentiation between classes is ecologically relevant.

<u>Improved Field Verification Methods</u>

Accuracy of map results may be increased with modifications and refinement of field verification methods. Adherence to a standardized field monitoring protocol by mapping partners would encourage consistency and maximize observer information for accuracy assessments (Waara et al. 2011). Standardized monitoring methods should consider the following;

- Several URM accuracy assessments suggested collection of field verification and accuracy assessment data at a spatial scale more comparable to the mapping scale and minimum mapping unit (Waara et al. 2011, Estep et al. 2014, Walker et al. 2014). Observations over a larger area may be achieved via drifting observations (Walker et al. 2014) or video transects (Walker et al. 2013, FWRI 2015).
- Clearer guidance for omission of observations which are not likely representative of the dominant habitat (e.g. patch of sand located in a polygon classified as aggregated patch reef). Rohmann and Monaco (2005) recommend acceptable disagreement between map and field observations where "a seven-meter radius field assessment falls on a habitat feature in the field that is smaller than the MMU. For example, if a field assessment falls on a small patch reef surrounded by sand that is less than the MMU and thus is not mapped, the point is excluded from the accuracy assessment report". Field methods should also indicate whether to include errors located near polygon edges in accuracy assessment results (Estep et al. 2014, Rohmann ad Monaco 2005, Walker et al. 2014),

- Intensive observer training prior to field surveys and provide observers with classification criteria, photos, and aerial imagery during field surveys (Waara et al. 2011, Estep et al. 2014).
- Increased sampling for classes with lower accuracy, particularly between similar types of hardbottom (pavement, spur and groove, remnant reef), where seagrass and macroalgae co-occur, and in areas where bottom type is mixed (aggregated patch reef, scattered coral rock, spur and groove) (Madden and Goodin, 2007). Increased sampling is also recommended for species-level mapping (Walker et al. 2014)
- Shorter lag between acquisition of source imagery and field surveys. Waara et al. (2011) recommended concurrent collection of field verification and accuracy assessment data may improve timeliness and efficiency of field survey efforts.

Improved Imagery and Ancillary Source Data

Accuracy improvements are likely to result from source data that is 1) higher spatial and spectral resolution, 2) collected more frequently, and 3) combined with data across multiple remote sensing platforms (e.g LiDAR, side scan/multibeam). The subtle or finer scale feature detail available with higher resolution imagery helped to improve accuracy of several classes including; aggregate reef, spur and groove and pavement. Source data providing vertical elevation/relief information such as LiDAR or sidescan/multibeam sonar also improved accuracy of spur and groove, scattered coral rock, pavement, linear reef subclasses, and detection of Acropora and larger coral colonies (Walker et al. 2014). Combination of imagery across multiple remote sensing platforms can improve differentiation between classes which tend to have lower accuracy such as pavement, aggregate reef, and different types of biological cover (e.g. algae v. seagrass).

Conclusions

Map accuracy is influenced by a variety of factors including photointerpretation preferences, spatial and thematic mapping scale and methods, field verification methods, resolution of source imagery and availability of ancillary data. Differences in accuracy between maps can be addressed to some extent by development and adherence to accuracy standards such as the accuracy standard recommended in the Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan (Rohmann and Monaco 2005) and standardized field monitoring protocols (Waara et al. 2011). Implementation of these standards relies on the continued collaboration between URM map partners. Benefits of improved map accuracy and precision include; more detailed bottom type information that are better predictors of habitat suitability for reef fish and other fauna (Waara et al. 2011), improve site selection for biological monitoring and restoration efforts (Estep et al. 2014), and inform re-zoning protection efforts (Estep et al. 2014).

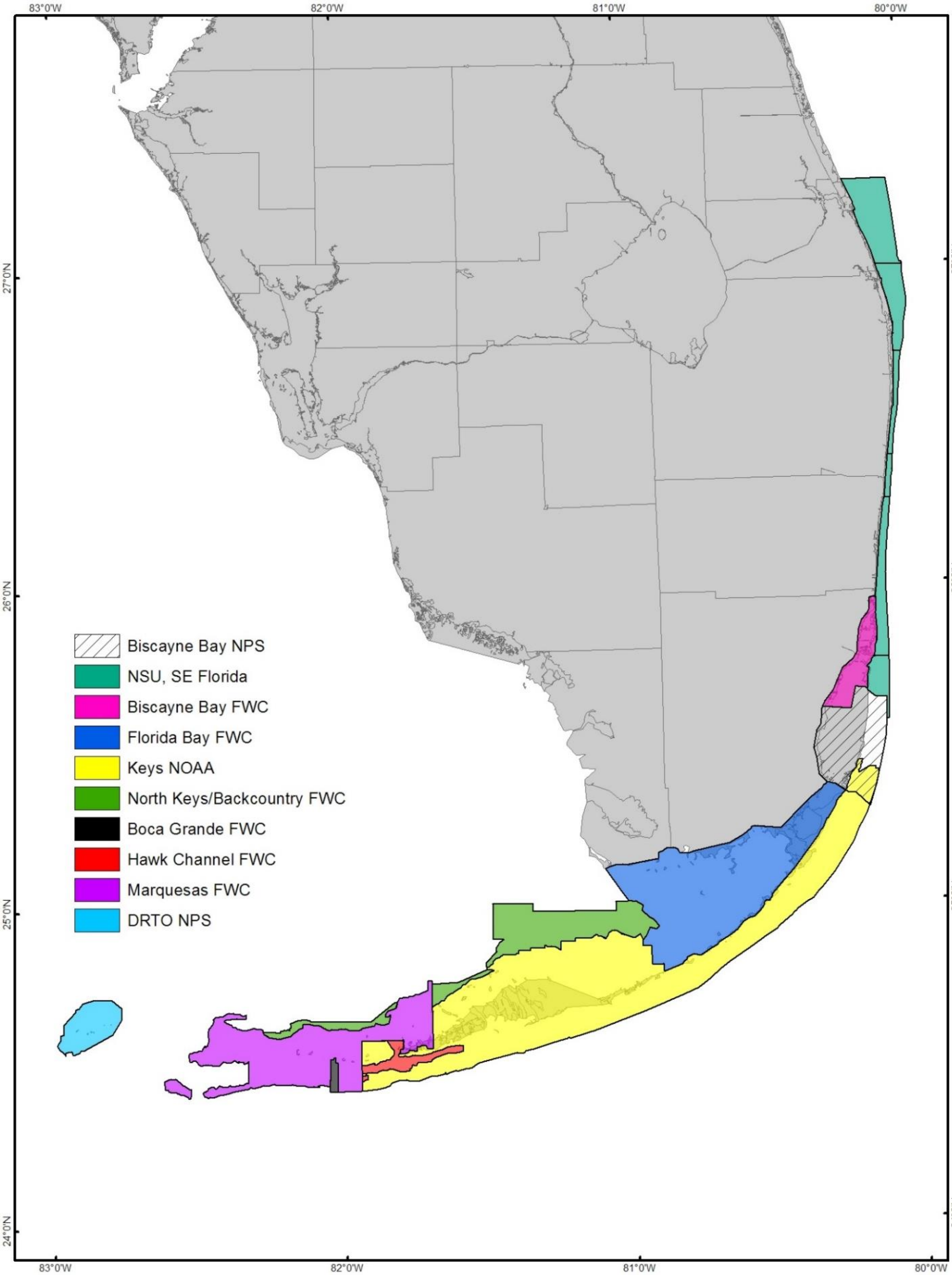

Figure 1. URM study area and map providers

Table 2. Metadata summary and accuracy assessment results for individual maps within the Unified Reef Map v2.0.

URM Name	Data Provider[1]	Minimum Mapping Unit	Mapping Scale	Source Imagery	Overall Map Accuracy[2]	Citation
Martin County	NSU	1 acre and smaller for patch reefs	1:6,000	LiDAR, 2008-2009 (4m)	Major = 85.6% (94.9% adjusted) Detailed habitat = 85.0% (91.5% adjusted)	Walker, B.K. et al. 2012.
Palm Beach County	NSU	1 acre and smaller for patch reefs	1:6,000	LiDAR, 2002 QTC Acoustic, 2006	Major = 89.2%	Riegl, B. et al. 2007.
Broward County	NSU	1 acre and smaller for patch reefs	1:6,000	LiDAR, 2002 QTC Acoustic, 2003-04	Major = 89.6% Generalized 3 classes = 88.1% (linear reef, pavement, sediment)	Riegl, B. et al. 2004.
Miami-Dade County	NSU	1 acre and smaller for patch reefs	1:6,000	Aerial image, 2005 (1ft) LiDAR, 2002 (4m)	Major* = 93.6% Detailed habitat = 90.5%	Walker, B.K. 2009.
Southeast Florida (Key Biscayne to Hillsboro Inlet)	NSU	0.1 ha (~0.2 acre)	1:1,000	Aerial image, 2013 (1ft) LiDAR, 2008-2009 (4m)	Major* = 98.3% Detailed habitat = 96.0% (95.9% adjusted)	Walker, B.K. et al. 2014.
Biscayne Bay (v2011)	NPS	~1 acre, all discernible patch reefs	ns	Aerial image, 2005 (30cm) LiDAR, 2008 (3m)	Major* = 96% (exact) Detailed habitat = 94.4% (acceptable)	Estep, A.J. et al. 2014.
Florida Bay	FWRI	0.5 acre	1:24,000	Aerial image, 2004	Not specified/Unknown	FWRI, 2004.
Florida Keys & Backcountry	NOAA	~1 acre	1:6,000	IKONOS, 2006 (4m)	Major = 90.4% (92.6% adjusted) Detailed structure = 84.6% (85.9% adjusted) Seagrass = 81.6-86.6% (88.7-86.6% adjusted)	Walker, B.K. et al. 2013; Rohmann, S.O. & M.E. Monaco. 2005.
Marquesas	FWRI	~1 acre and 0.154 acre for patch reefs	ns	IKONOS, 2006 (1-4m)	Major = 91.2% (90.8% adjusted) Detailed structure = 87.0% (88.6% adjusted) Seagrass = 80.4-86.5% (80.4-88.2% adjusted)	Coastal Planning and Engineering (CP&E). 2011.
Dry Tortugas (v2010)	NPS	~1 acre and all discernible patch reefs	ns	NAIP, 2007 (1m) IKONOS, 2006 (4m) LiDAR, 2004 (1m) Side scan, 2008 (30cm)	Major* = 98% (acceptable) Detailed habitat = 89.7% (acceptable)	Waara, R. J. 2011
Hawk Channel	FWRI	1 acre & patch reefs 0.154 acre	ns	WV2, 2010-2013 (0.5m) Side scan, 2012-13 (30cm)	Accuracy assessment not conducted.	FWRI, 2014.
Boca Grande	FWRI	1 acre and 0.154 acre for patch reefs	1:3,000	WV2, 2013 (0.5m) GE1, 2011 (1.8m) LiDAR, 2012 (3m) Side scan, 2012-13 (30cm)	Accuracy assessment not conducted.	FWRI, 2014.
North Keys/ Backcountry	FWRI	1 acre	1:3,000	Aerial 2012-13 (0.5ft), WV2, 2010, 2013 (0.5m), GE1, 2011-2012 (1.8m), LiDAR, 2012 (3m)	Accuracy assessment not conducted.	FWRI, 2014.

[1]*Subcontractors not listed.* ***NSU:*** *Nova Southeastern University (NSU),* ***FWRI:*** *Florida Fish & Wildlife Commission, Fish & Wildlife Research Institute,* ***NPS:*** *National Park Service, South Florida/Caribbean Network (SFCN),* ***NOAA:*** *NOAA National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment (CCMA)*

[2]***Major*** *= Unconsolidated Sediment v. Hardbottom/Reef,* ***Major**** *= calculated, not directly reported by data source.* **Detailed (geomorphological) structure** *= Sand, Mud, Pavement, Patch Reef, Aggregate Reef, Spur and Groove, Rubble, Pavement with Sand Channels,* **Detailed habitat =** *Aggregated & Individual Patch Reefs, Continuous SRV, Discontinuous SRV, Spur and Groove, Patchy Coral and/or Rock in Unconsolidated Bottom, Pavement, Reef Rubble, Reef Terrace, Remnant,, Unconsolidated Sediment*

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Appendix II:

Mapping Guide for Partners of the Florida Reef Tract

Coordinated Coral and Hardbottom Ecosystem Mapping, Monitoring and Management

The *Mapping Guide for Partners of the Florida Reef Tract* was designed to serve as a "best practices guide" for mapping the Florida Reef Tract. The goals of this document are to promote consistent methods among partners and ensure mapping efforts meet management needs. Mapping partners and managers can use this guide as a reference for optimizing current methods, and as a standards of practice for mapping projects. These recommendations will benefit long term maintenance of the Unified Reef Map (URM) by resolving inconsistencies among maps and increasing efficiency of map integration. These recommendations also support cooperative research efforts and coordinated monitoring of the Florida Reef Tract.

This Guide is organized based on four primary mapping needs for the Florida Reef Tract. Recommendations were based on 1) guidance from mapping partners, 2) participant feedback during mapping coordination meetings, and 3) lessons learned throughout the Unified Reef Map integration process. This effort is supported by the invaluable contributions of our mapping partners and funding from the Florida Department of Environmental Protection's Coastal Management Program under NOAA's Coastal Zone Management (CZM) program. A list of partners and the URM study area is shown in Table 1 and Figure 1.

1) **Improve consistency in mapping scale and minimum mapping unit (MMU)**

<u>Issue:</u> Reported map scale and MMU does not correspond to true mapping scale. The resolution of source imagery is a more reliable indicator of true mapping scale.

<u>Issue:</u> Map scale and MMU vary considerably among maps throughout the URM (**Error! Reference source not found.**). Differences in mapping scale limit spatial comparisons across the Reef Tract and create inconsistent linework and classification along seams between neighboring maps.

<u>Recommendations:</u>

- Mapping partners will adhere to a clearly defined mapping scale and MMU.
- At a minimum, metadata should include mapping scale, MMU, detailed image information (resolution, acquisition dates, sensor type) and any additional information used during the classification process (i.e. bathymetry, historic maps, field data, etc.)
- Adopt the following mapping scale guidelines for all new mapping efforts in the Florida Reef Tract
    - **Recommended digitizing scale = 1:4,000, no more than 1:3,000**
        - Average resolution of newer imagery and source data = 0.5m to 1.0m
        - # pixels/cells to distinguish between spatial features = 4 pixels *(Rohmann and Monaco, 2005)*
        - Digitizing scale is a function of resolution and size of smallest detectable feature = 1000* resolution * smallest detectable feature *(Tobler, 1987)*
    - **Recommended MMU for all features = 0.1ha**
        - Based on NOVA Southeast university's SEFL 2013 updated maps
        - Likely approximates National Park Service's true mapping scale and MMU
        - Is reasonable in most areas considering coverage of higher resolution imagery

- Will likely improve discrimination between problematic classes
- **Recommended MMU for patch reefs = 150sqm**
  - Based on Unified Patch Reef v1.3

2) **Resolve classification issues**

Issue: Classification of seagrass mixed with hardbottom differs among maps using NOAA's GeoForm/BioCover scheme (Zitello et al 2009) and maps classifying habitats based on the SCHEME system (e.g. NPS, NSU, Florida Bay). When GeoForm and BioCover are not classified as separate attributes often only BioCover information (i.e. seagrass) is retained while presence of hard bottom is not documented.

Issue: Classification of certain habitats such as patch reefs and seagrass is sensitive to MMU size and mapping scale. For example, identifying a patch reef as either an individual or aggregated patch reef, will vary among maps with different MMUs. A group of small patch reefs would be delineated separately and classified as individual patch reefs at a smaller MMU, whereas, the same group of patch reefs at a larger MMU would be grouped together and classified as aggregated patch reefs. Delineation between sediment and seagrass is also influenced by map scale and MMU. For example, at a coarser scale an area may be classified as discontinuous seagrass, whereas, at a finer scale that same area would be subdivided into patches of continuous seagrass and sediment.

Issue: Hardbottom classes such as pavement, aggregate and patch reef are often not mapped consistently throughout the URM. Differences among hardbottom classes are often subtle both in situ and from aerial imagery. Because of these similarities it is often difficult to consistently apply current classification schemes, especially because current schemes lack clear thresholds among classes. Additionally, information necessary for discriminating among types of hardbottom is either not available or not mapped at a scale fine enough to inform classification. For example, high resolution bathymetry would likely improve consistent classification between low relief pavement and higher relief reef habitat, which often appear very similar in aerial imagery when pavement is heavily colonized.

Issue: Difficultly distinguishing sediment from seagrass when seagrass cover is sparse and near the 10% cover classification threshold. This is particularly challenging in the presence of algae which is easily confused with seagrass.

Recommendations

- Modify existing classification schemes and encourage mapping partners to implement proposed changes for new mapping efforts. Proposed classification criteria are listed in Tables 3 and Figure 3 and include;
  - Addition of *Pavement with Seagrass* at UC Level 0 and modified decision rules which identifies both GeoForm and BioCover in the initial phases of classification (Figure 2). This modification will ensure that both seagrass and pavement are represented at the coarsest level of the Unified Reef map, which is the default display for online map viewers and the most practical scale for conducting reef-tract wide assessments. For maps using the GeoForm and BioCover classification method, this modification will be largely superficial, only changing the way data are symbolized at the Unified Reef Maps coarsest UC Levels. In the remaining areas of the URM where hardbottom has not been traditionally mapped if seagrass was present, maps should be updated or reclassified to include hardbottom using the new *Pavement with Seagrass* class (i.e. Florida Bay, NSU, NPS).

  - Clear decision thresholds for hardbottom classes based on unique characteristics such as relief, feature size, presence of grazing halo, and extent of coral cover (Table 3 and Figures 2 and 3).
  - Classification rules which are independent of map scale or MMU for patch reefs and seagrass (i.e. presence of shared halo for patch reefs).
- Expand collection of ancillary data which can improve discrimination between similar habitats including high resolution bathymetric data and increased field verification observations, particularly for classes which cannot easily be delineated from aerial imagery alone (e.g. hardbottom classes and seagrass v. algae)

3) **Assess and improve map accuracy**

Issue: Currently, there is no estimate for the overall accuracy of the entire URM map. Accuracy assessments have been conducted in portions of the Florida Reef Tract, however, gaps among studies and differences in accuracy assessment methods limit comparisons among maps. Maps requiring accuracy assessments include; Boca Grande, Hawk's Channel, North Keys/Backcountry, and the Unified Patch Reef dataset.

Issue: Disagreement between field and map results due to disparity between the resolution of *in situ* observations and mapping scale (Walker et al 2013; Estep et al 2014; Waara et al 2011). Additionally, disagreement is more likely to occur due to time lags between field observations and image acquisition. Collectively these issues can limit usefulness of survey data and the reliability of accuracy assessment results.

Recommendations:

- Conduct accuracy assessments in recently mapped areas including Hawk's Channel, Boca Grande, North Keys/Backcountry, and the Unified Patch Reef dataset.
- Conduct a comprehensive accuracy assessment of the URM.
- Develop field verification methods and accuracy assessment standards for mapping partners. These standards should include the following;
  - Encourage collection of groundtruth and/or accuracy assessment data as close to collection of source imagery as possible to reduce errors due to temporal changes in benthic communities (see Walker et al 2014).
  - Reference data should be collected at a scale as close to the MMU as possible (Walker et al 2014; Waara et al 2011). The scale of field observations should also take into account the type of benthic class being evaluated and variability of benthic features within that class.

4) **Continued support for the Unified Reef Map and future mapping efforts**

- The URM is a dynamic map which requires continued maintenance to ensure data are current and publicly accessible. GIS editing will be necessary as maps are updated and provided by URM partners. The URM website and web mapping services will require maintenance as needed and web server support.
- There are various gaps throughout the Florida Reef Tract, these areas are represented as voids in the URM or features which were delineated but have not been classified. Gaps in map coverage typically occur where there are gaps in source imagery or where imagery cannot be interpreted due to cloud cover, high turbidity, sun glint or glare, or other atmospheric conditions. There are also gaps between the benthic coverage of the URM and intertidal and terrestrial maps.

- Advances in remote sensing technology have created opportunities to expand the URM to include areas and features which have historically been unmapped such as deep water corals, turbid channels, and fine scale hardbottom features. Reduced acquisition costs enable more frequent and current source imagery which may improve map accuracy for ephemeral habitats such as seagrass and low relief hardbottom. Collection of high resolution bathymetric data (LiDAR and side scan/multibeam) can improve accuracy of smaller habitat features, enable discrimination between low relief and high relief hardbottom, help resolve visually similar classes, and allow species-level identification (Walker et al 2014).

<u>Recommendations:</u>

- Updates are recommended for the following areas/habitats; Florida Bay, NOAA Keys and Marquesas.
- Expand the URM to include the following;
    - Dry Tortugas Eco Reserves
    - Offshore deeper water reefs using new acoustic technologies such as multi-beam or side-scan sonar (60 – 100ft deep)
    - Bays and estuaries north of Biscayne Bay, shoreward of the reef tract
    - Gaps between the URM coverage and intertidal or terrestrial maps. Filling these gaps will enable integration of the benthic URM with terrestrial maps to create a continuous "land-to-sea" map.
- Expand collection of high resolution bathymetric data (LiDAR and acoustic) throughout URM.
- Expand mapping of *Acropora* and other coral species of concern
- Additional field monitoring of areas where *Acropora* and other species of concern are expected. These habitats are difficult to map from aerial imagery and require additional field verification. Survey methods developed by Walker and others (2014) provide an ideal framework for mapping and monitoring these communities over time. Implementing a citizen science-based program may provide a cost effective solution to increasing collection of ground truth and accuracy assessment data.
- Improve integration of field data with benthic maps by cross-walking observations to the URM Unified Class scheme where possible.

Table 1. List of Florida Reef Tract mapping partners, v2016

Partner[1]	Points of Contact	Areas mapped in the URM
Biscayne Bay National Park	Andy Davis, andy_davis@nps.gov Amanda Bourque, Amanda_bourque@nps.gov Caryl Alarcon, caryl_alarcon@nps.gov	Biscayne Bay
Dry Tortugas National Park	Rob Warra, Rob_Waara@nps.gov	Dry Tortugas National Park
Everglades National Park	Matt Patterson, matt_patterson@nps.gov	Florida Bay (2016)
FWC Fish and Wildlife Research Institute (FWRI)	Renee Duffey (primary) Renee.Duffey@myfwc.com Richard Flamm, Richard.Flamm@myfwc.com Paul Carlson (seagrass mapping) Paul.Carlson@myfwc.com	Florida Bay (2004) Biscayne Bay (portions) Marquesas, Boca Grande Channel, Hawk's Channel Northern Keys/ Backcountry
NOAA-NCCOS Center for Coastal Monitoring and Assessment (CCMA)	Steve Rohmann, Steve.Rohman@noaa.gov Mark Monaco, mark.monaco@noaa.gov	Florida Keys National Marine Sanctuary (FKNMS)
Nova Southeastern University (NSU)	Brian Walker, walkerb@nova.edu	Martin County Palm Beach County Broward County Miami-Dade County
Martin County	Kathy Fitzpatrick, kfitzpat@martin.fl.us Jessica Garland, jmeinard@martin.fl.us	
Palm Beach County	Janet Phipps, jphipps@pbcgov.org	
Broward County	Ken Banks, kbanks@broward.org	
Miami-Dade County	Jamie Monty, montyj@miamidade.gov Josh Mahoney, mahonj@miamidade.gov Sara Thanner, ThannS@miamidade.gov	
FDEP Coastal Management Program (CMP)	Lauren Waters, lauren.waters@dep.state.fl.us Francisco Pagan, francisco.pagan@dep.state.fl.us	
Florida Keys National Marine Sanctuary (FKNMS)	No contact person designated	
South Florida Water Management District (SFWMD)	No contact person designated	

[1]Includes primary points of contact responsible for mapping or subcontracting map efforts, does not include managers or other map end users.

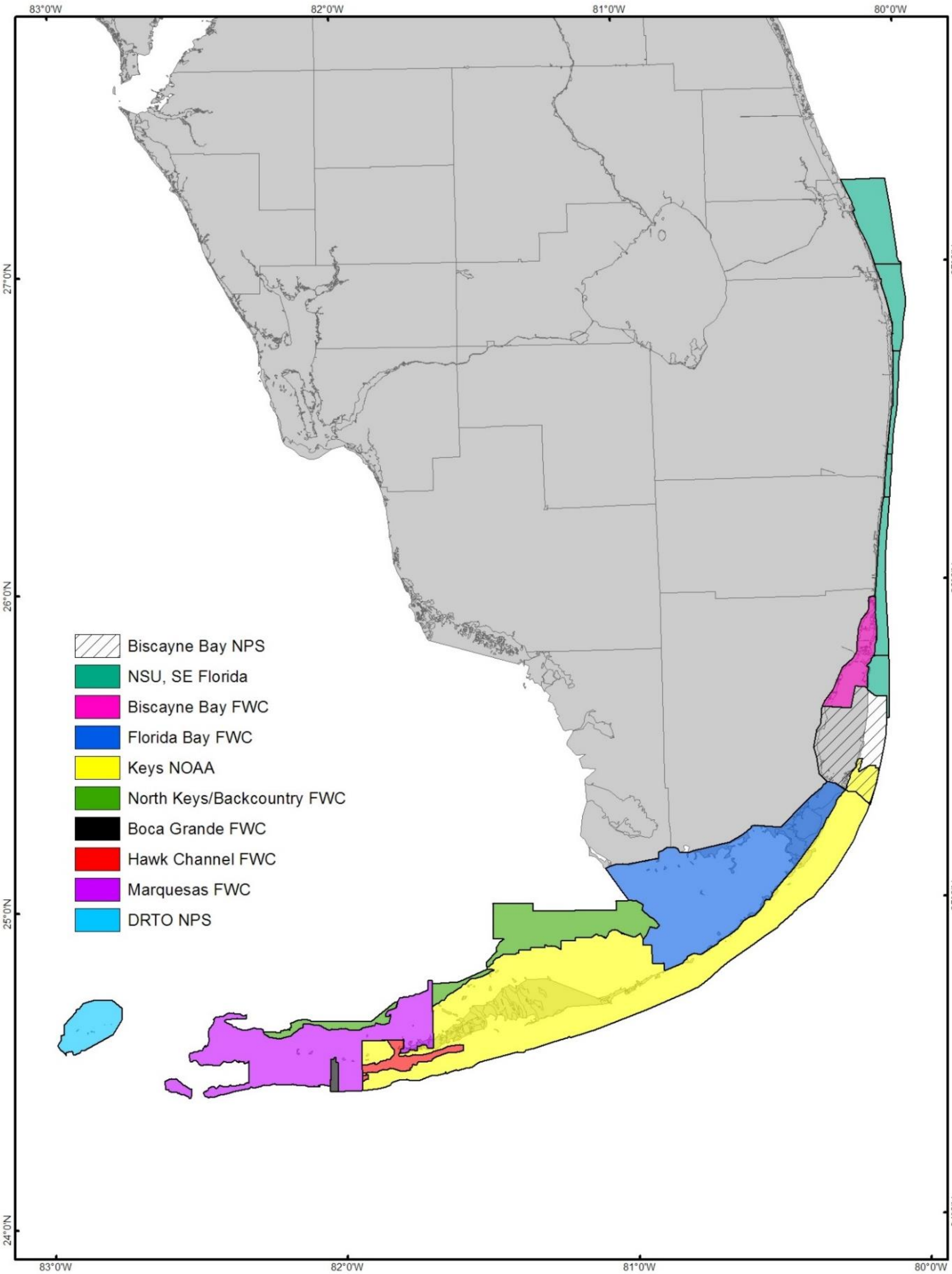

Figure 1. Unified Reef Map data sources and mapping partners.

Table 2. Metadata summary of Unified Reef Map (URM) mapping partners, v2016.

URM Name	Data Provider[1]	Minimum Mapping Unit	Mapping Scale	Source Imagery
Martin County	NSU	1 acre and smaller for patch reefs	1:6,000	LiDAR, 2008-2009 (4m)
Palm Beach County	NSU	1 acre and smaller for patch reefs	1:6,000	LiDAR, 2002 QTC Acoustic, 2006
Broward County	NSU	1 acre and smaller for patch reefs	1:6,000	LiDAR, 2002 QTC Acoustic, 2003-04
Miami-Dade County	NSU	1 acre and smaller for patch reefs	1:6,000	Aerial image, 2005 (1ft) LiDAR, 2002 (4m)
Southeast Florida (Key Biscayne to Hillsboro Inlet)	NSU	0.1 ha (~0.2 acre)	1:1,000	Aerial image, 2013 (1ft) LiDAR, 2008-2009 (4m)
Biscayne Bay (v2011)	NPS	~1 acre, all discernible patch reefs	ns	Aerial image, 2005 (30cm) LiDAR, 2008 (3m)
Florida Bay	FWRI	0.5 acre	1:24,000	Aerial image, 2004
Florida Keys & Backcountry	NOAA	~1 acre	1:6,000	IKONOS, 2006 (4m)
Marquesas	FWC	~1 acre and 0.154 acre for patch reefs	ns	IKONOS, 2006 (1-4m)
Dry Tortugas (v2010)	NPS	~1 acre and all discernible patch reefs	ns	NAIP, 2007 (1m) IKONOS, 2006 (4m) LiDAR, 2004 (1m) Side scan, 2008 (30cm)
Hawk Channel	FWC	1 acre & patch reefs 0.154 acre	ns	WV2, 2010-2013 (0.5m) Side scan, 2012-13 (30cm)
Boca Grande	FWC	1 acre and 0.154 acre for patch reefs	1:3,000	WV2, 2013 (0.5m) GE1, 2011 (1.8m) LiDAR, 2012 (3m) Side scan, 2012-13 (30cm)
North Keys/ Backcountry	FWC	1 acre	1:3,000	Aerial 2012-13 (0.5ft), WV2, 2010, 2013 (0.5m), GE1, 2011-2012 (1.8m), LiDAR, 2012 (3m)

[1]Subcontractors not listed.
***NSU:** Nova Southeastern University (NSU)*
***FWC:** Florida Fish & Wildlife Commission, Fish & Wildlife Research Institute*
***NPS:** National Park Service, South Florida/Caribbean Network (SFCN)*
***NOAA:** NOAA National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment (CCMA)*
***WV2** = WorldView-2 Satellite*
***GE1** = GeoEye-1 Satellite*
***ns** = not specified by data provider*

Table 3. Proposed changes to URM classification methods to be adopted in the Mapping Guide for Partners of the Florida Reef Tract.

Unified Class (UC)	**NOAA**[1]	**SCHEME**[2]**/ NSU**[3]	**Proposed**
Individual or Aggregated Patch Reef *UC Level 1*	Coral formations that are isolated from other coral reef formations by bare sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. They are characterized by a roughly circular or oblong shape with a vertical relief of one meter or more in relation to the surrounding seafloor	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 SAV, macroalgae, gorgonians or sponges. Most often the patches are surrounded by a halo of bare substrate created by foraging, obligate reef inhabitants.	***Individual or Aggregated Patch Reef* class will be replaced by subclasses *Individual Patch Reef* and *Aggregated Patch Reef*.**
Individual Patch Reef **New class at UC Level 1, previously at UC Level 4*	Distinctive single patch reefs that are **larger than or equal to the MMU**	Isolated, **single reef (larger than the MMU)** without associated halo area. These individual reefs may have an associated halo, however **if large enough (>MMU)** to be delineated the halo will be mapped as its own subclass.	**Smaller (<1ha)** distinctive single coral formation that is isolated from other coral reef formations with a vertical relief of one meter or more. Most patches are often surrounded by a halo of bare substrate created by foraging, obligate reef inhabitants. **Larger, neighboring patch reefs close enough that halos coalesce should be classified as *Aggregated Patch Reefs*.**
Aggregated Patch Reef **New UC Level 1*	Clustered patch reefs that individually are **too small (<MMU) or are too close together to map separately**	Clustered patch reefs that individually are **too small (<MMU) or are too close together to map separately or where halos coalesce**	Clustered coral formations that are **too small or are too close together to map separately as *Individual Patch Reefs*.** Clustered patches are often surrounded by a halo of bare substrate created by foraging, obligate reef inhabitants. **Includes larger, individual patch reefs sharing a halo with 1 or more patch reefs.**
Aggregate Reef UC Level 1	Continuous, high-relief coral formation of variable shapes lacking sand channels of Spur and Groove. Includes linear reef formations that are oriented parallel to shore or the shelf edge. This class is used for such commonly referred to terms as linear reef, fore reef or fringing reef	Linear Reef (under Platform 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.	Contiguous, high-relief **(>1m)** coral formation of variable shapes lacking sand channels of *Spur and Groove*. Includes linear reef formations that are oriented parallel to shore or the shelf edge. Reef crest, fore reef, and back reef zones could be mapped as Aggregate Reef. Also referred to as fringing **or bank** reef formations. **Reefs smaller than 1ha should be classified as patch reefs.**
Reef Rubble UC Level 1	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.	*Rare occurrences of reef rubble in the SEFL mapping area are classified as Colonized Pavement.	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.
Scattered Coral/Rock in Unconsolidated Sediment UC Level 1	Primarily sand bottom with scattered rocks or small, isolated coral heads that are too **small to be delineated individually (i.e., smaller than individual patch reef)**. If the density of small coral heads is greater than 10% of the entire polygon, this structure type is described as Aggregated Patch Reefs.	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 <MMU**).	Primarily sand bottom with **<10% of the area** consisting of scattered colonized rocks or small, live coral heads that are too small to be delineated individually.

Table 3, continued.

Unified Class (UC)	**NOAA**[1]	**SCHEME**[2]/ **NSU**[3]	**Proposed**
Pavement UC Level 1	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. On less colonized Pavement features, rock may be covered by a thin sand veneer or turf algae.	Flat, low-relief, solid carbonate rock	Flat, low relief (**<1m**), solid carbonate rock often colonized by macroalgae, hard coral, zoanthids, and other sessile invertebrates. Contiguous underlying rock **can often be obscured by a sediment veneer supporting turf algae and seagrass. Pavement with greater than 10% seagrass cover should be mapped as *Pavement with Seagrass*.**
Pavement with Seagrass (Proposed)	GeoForm = Pavement BioCover = Seagrass % BioCover = >10% *UC Level 1 = Pavement*	Hardbottom & seagrass both present (>10%) AND: **Hardbottom is dominant = Pavement with SRV Modifier** Or, **Seagrass is dominant = Discontinuous Seagrass, Pavement may be noted depending on data provider**	Flat, solid carbonate rock with **greater than 10% seagrass** cover. Typically consists of intermittent seagrass patches occurring in areas where underlying pavement rock is covered by sediment. Exposed or semi-exposed hard-bottom is often colonized by sessile invertebrates including hard coral, zoanthids, and sponges.
Continuous Seagrass UC Level 1	GeoForm = Unconsolidated Sediment BioCover = Seagrass % BioCover = >90% *UC Level 1 = Continuous Seagrass*	**SCHEME:** 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 (< 0.5 acres)** bare sediment areas may be observed as infrequent features within the area. **NSU:** Seagrass community covering 90% or greater of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (less than the MMU).	**Unconsolidated sediment colonized by** continuous seagrass covering 90% or greater of the substrate. May include patches of bare substrate covering less than 10% of the total area that are too small to be mapped independently.
Discontinuous Seagrass UC Level 1	GeoForm = Unconsolidated Sediment BioCover = Seagrass % BioCover = 10-90% *UC Level 1 = Discontinuous Seagrass*	**SCHEME:** 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. **NSU:** Seagrass community 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 continuous seagrass.	**Unconsolidated sediment** colonized by intermittent seagrass **covering 10-90%** of the total area. Seagrass community 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 continuous seagrass.

[1]Zitello et. Al 2009, [2]Madley et. al. 2002, [3]Walker et al 2014

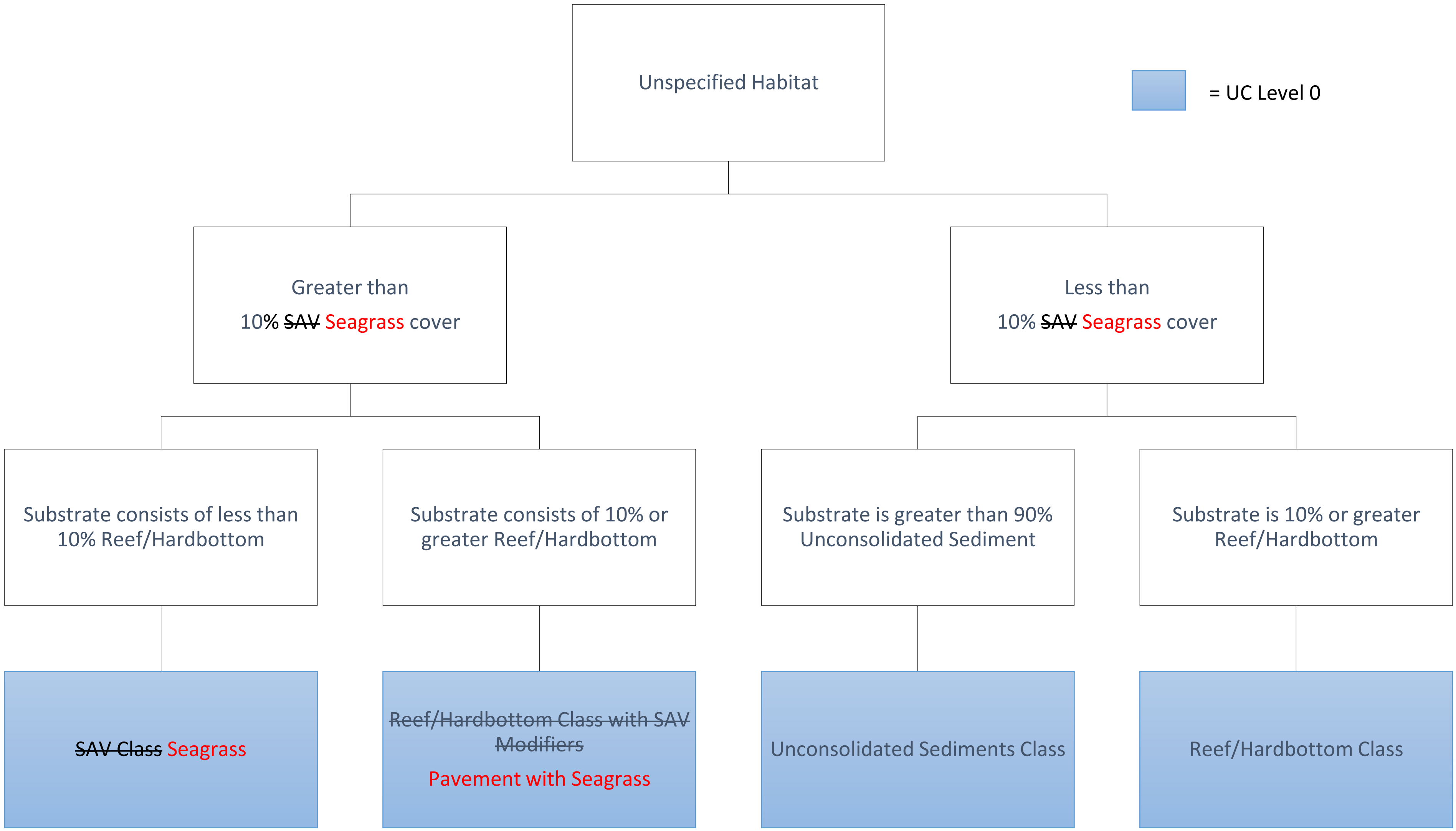

Figure 2. SCHEME classification decision tree (Madley et al. 2002) with proposed modifications for UC Level 0 classes (in red text)) to be adopted in the Mapping Guide for Partners of the Florida Reef Tract.

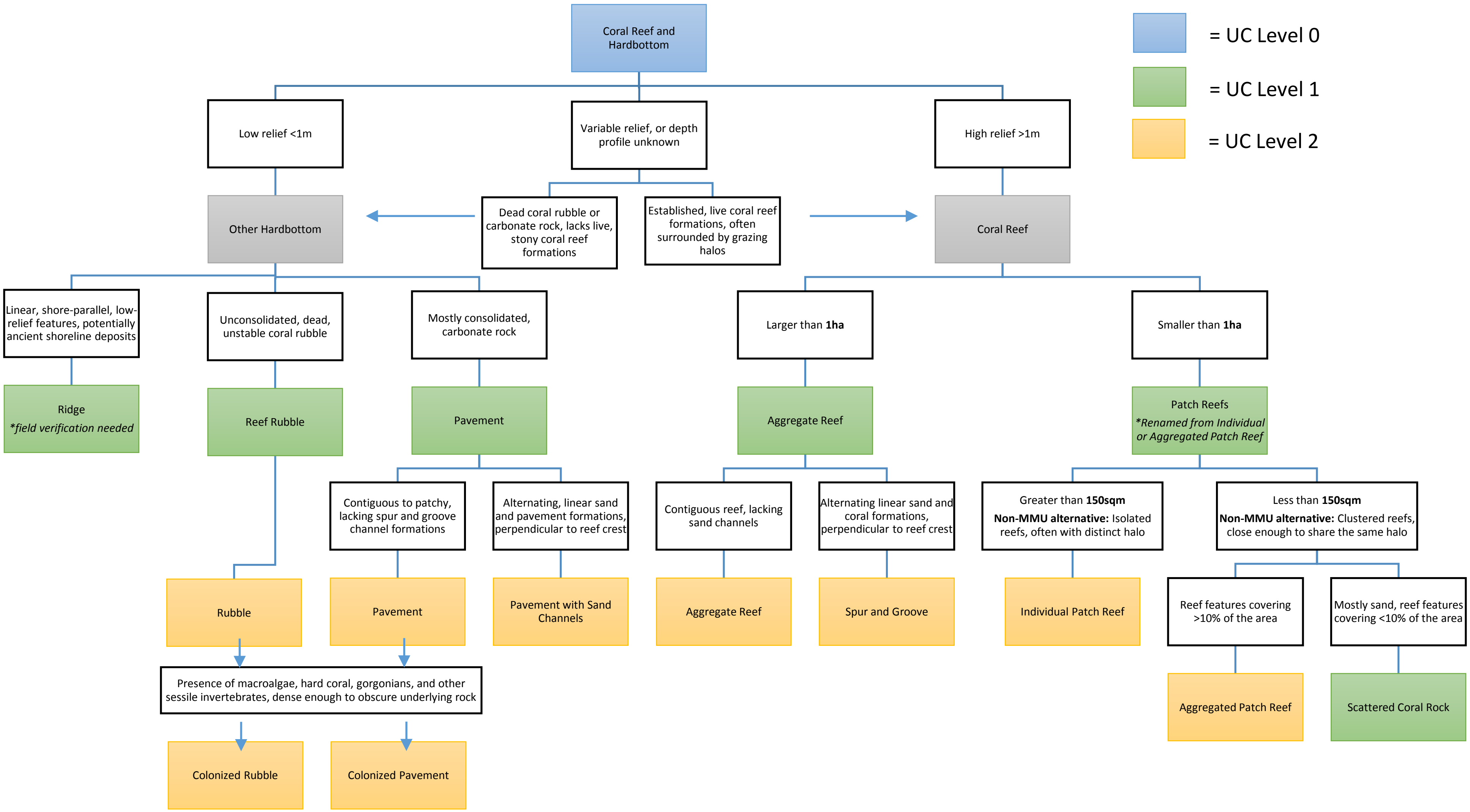
Coral Reef and Hardbottom
Low relief <1m
Variable relief, or depth profile unknown
High relief >1m
= UC Level 0
= UC Level 1
= UC Level 2
Other Hardbottom
Dead coral rubble or carbonate rock, lacks live, stony coral reef formations
Established, live coral reef formations, often surrounded by grazing halos
Coral Reef
Linear, shore-parallel, low-relief features, potentially ancient shoreline deposits
Unconsolidated, dead, unstable coral rubble
Mostly consolidated, carbonate rock
Larger than 1ha
Smaller than 1ha
Ridge
*field verification needed
Reef Rubble
Pavement
Aggregate Reef
Patch Reefs
*Renamed from Individual or Aggregated Patch Reef
Contiguous to patchy, lacking spur and groove channel formations
Alternating, linear sand and pavement formations, perpendicular to reef crest
Contiguous reef, lacking sand channels
Alternating linear sand and coral formations, perpendicular to reef crest
Greater than 150sqm
Non-MMU alternative: Isolated reefs, often with distinct halo
Less than 150sqm
Non-MMU alternative: Clustered reefs, close enough to share the same halo
Rubble
Pavement
Pavement with Sand Channels
Aggregate Reef
Spur and Groove
Individual Patch Reef
Reef features covering >10% of the area
Mostly sand, reef features covering <10% of the area
Presence of macroalgae, hard coral, gorgonians, and other sessile invertebrates, dense enough to obscure underlying rock
Aggregated Patch Reef
Scattered Coral Rock
Colonized Rubble
Colonized Pavement

Figure 3. Recommended hardbottom/reef classification decision tree

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Appendix III:

Management Needs for Mapping, Monitoring, and Citizen Engagement along the Florida Reef Tract

The management needs below were identified by participants in the unified reef track meeting held April 14, 2016.

1) Mapping, monitoring and research needs

Need: Mapping gaps

- Nearshore bays and estuaries landward of the reef tract in SEFL
- Integrate the benthic URM with intertidal and upland habitats to create a seamless land-to-sea map
- Expand the OFR Marine Planner beyond the SE reef tract to include Biscayne Bay and the Florida Keys.

Need: Monitoring gaps

- Consistent methods for reef monitoring including survey design, sampling frequency, and measured variables
- Coordinated disease-response monitoring throughout the Reef Tract
- Expanded genetic monitoring and consistent reporting of genetic results
- Long term post-restoration monitoring of coral out plants, beach renourishment efforts, artificial reef construction, etc.
- Monitoring of environmental variables which may impact reef communities both at the reef tract as well as associated nearshore waters and contributing watersheds (e.g. temperature, water clarity, CO_2

Need: Additional research

- Assessing upland impacts to the Florida Reef Tract
- Evaluating changes in hardbottom over time
    - Example: Changes in hardbottom and sediment shifts in nearshore Palm Beach County
- Associate reef structure and function with reef-fish distribution and abundance
- Determine coral restoration success and continue to evaluate out plant establishment and recruitment
- Improve understanding of climate change effects on the Florida Reef Tract

Recommendations

- The reef tract, nearshore bays and estuaries, uplands, and human influences make up a social-ecological system (SES). Most simply a SES is the ecological and human components and their interactions of a complex landscape. By complex we are referring to the large number of components and the likelihood of unpredictable system behaviors. In conservation, the landscape can be considered an ideal management unit because they are "easily" encapsulated by often well-defined boundaries, like a watershed for example. For the Florida reef tract, the landscape extends from Stuart, Florida down through the Florida Keys and includes the nearshore as well as the upland areas that drain into the Atlantic and can influence the health of the reef. While managing the reef track without considerations of the other system components will likely be inefficient at best and futile at worst, it is a very difficult task because of its size, variety of ecosystems, and large number of political jurisdictions, social institutions, and beliefs and values of millions of residents and visitors. With these considerations in mind we recommend the following:
    1. Re-conceive the Florida reef tract as a social-ecological system.
        a. Include collaborative management as a major organizing philosophy
        b. Introduce operations management concepts and consider identifying an operations manager to begin organizing the SES for long-term research, management, and collaboration.
            i. Develop operations models and use these as road maps for collaboration and funding.

2. Maintain the Our Florida Reefs initiative and expand it to include nearshore and uplands areas in its sphere. The OFR should serve as a foundation for expanding collaborations across the Florida reef tract SES.
3. Work with state and local government agencies to secure commitments of staff and resources for stabilizing and strengthening the SES to protect the reef tract.
4. Explore new remote sensing technologies and opportunities for leveraging alternative sources for imagery and bathymetric data

- There is a need to understand and articulate how healthy reefs are associated with healthy reef-fish populations and then to apply this knowledge to improve management decision making and stakeholder collaboration. We need to understand how reef fish use different parts of the reef and interact with the reef at various spatial scales, how the spatial arrangement of physical attributes of the reef affect distribution and abundance of reef fish life stages, how reef-fish life stages respond to changes to the reef tract and stressors originating from human uses in and around the reef tract. Addressing this issue is expected to include species-habitat modeling, spatial modeling, and scenario-based simulations. Regulations, the Magnuson-Stevens and National Environmental Policy Acts, have requirements that support this need. Identifying essential fish habitat--mapping and censusing the organisms that use them—and cumulative effects analysis to assess impacts and cause and effect are two relevant examples.
- Work with NOVA Southeastern University to expand the OFR Marine Planner to cover all the reefs in Florida waters.
- Continue to support and expand monitoring efforts through coordination with partners, securing funds for long term monitoring, and exploring unique solutions for multi-agency collaboration. High priority monitoring and research include; genetic research, larval dispersal and population connectivity for species of special concern, post-restoration monitoring, water quality, CO_2 and ocean acidification.
- Work with partners to develop standards for measuring and reporting genetic information.
- Expand coral nursery efforts and post-restoration monitoring.

  Continue support and encourage collaboration between the numerous initiatives and agencies with similar objectives including; FWRI, Nova Southeastern University, Rosenstiel School of Marine and Atmospheric Science of the University of Miami, DEP's Coral Reef Conservation Program (CRCP), FKNMS, Marine Biodiversity Observing Network (MBON), NOAA Office for Coastal Management, etc.

2) Agency coordination needs

Need: Ensure compatibility of maps, minimize negative effects of scale

Recommendations

- Initiate the *Florida Reef Tract Mapping Committee*
  1. Identify 1-2 contacts from the primary mapping partners and agencies throughout the reef tract
  2. Revise and adopt the "Mapping Guide for Partners of the Florida Reef Tract" doc

3) Engaging public participation in reef management

Need: Keeping the public involved

Recommendations

- Maintain, support, and strength the Our Florida Reefs initiative.
- Expand the Our Florida Reefs initiative to include uplands land uses that effect the reef.
- Rethink meeting frequencies, times, and places to increase effectiveness of the meetings if needed.

4) Distributing scientific information to the public

Need: Ensure that the public has access to information concerning the reef tract

Recommendations

- Develop a single web application for distributing mapping, monitoring, and management information throughout the entire Florida Reef Tract
    1. Expand the OFR Marine Planner web viewer and Decision Support tool to include the entire Reef Tract.
- Develop mobile mapping and reporting applications
- Use Our Florida Reefs to keep citizens informed in additional to their other responsibilities.