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A Comparison of Qualitative and Quantitative Data Collection Techniques to Assess Mapping Accuracy in the Florida Keys

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HALMOS COLLEGE OF NATURAL SCIENCES AND
OCEANOGRAPHY

A comparison of qualitative and quantitative data collection techniques to assess mapping accuracy in the Florida Keys

By

Ian K. Rodericks

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the degree of Master of Science with a specialty in:

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Ian K. Rodericks

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Halmos College of Natural Sciences and Oceanography

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Abstract

Benthic habitat maps provide the spatial framework for many research science and management activities in coastal areas such as coral-reefs. Accuracy, the degree to which information on a map matches true or accepted values, of benthic habitat maps is important because often times the map will be used in decision-making processes about how we manage our marine resources. It is critical that some measure, such as the accuracy, of the map be known in order to give a sense of how the overall map portrays the seascape. This study compared the accuracy in the following map classes; major structure, major and detailed biological cover, and detailed coral cover, of the 2014 NOAA Florida Keys Coral Reef Ecosystem Habitat map using two separate quantitative, *in situ*, and qualitative, drop camera, data sets in order to assess how the data sets compare to one another. Benthic habitat map classes of the NOAA Florida Keys map were based on a NOAA peer-reviewed hierarchical coral reef habitat classification scheme. Accuracy assessment tests to see how often the NOAA Florida Keys map producer correctly classified the different habitats, included error matrix analyses (overall, user's and producer's accuracy), and the tau coefficient. Study areas in the Florida Keys reef tract included hard-bottom reef habitat from Key West to the northern end of Key Largo, and focuses on three regions of interest that encompass the eastern and western Lower Keys and Key Largo. The Qualitative, drop-camera, accuracy assessment (AA) analyses for all three regions of interest gave overall accuracies of 84.2%, ±16.9, at the major level of geomorphological structure, 85.4%,

±16.4, and 73.8%, ±18.7, at the major and detailed levels of biological cover and 70.4%, ±20.6, for detailed coral cover. The Quantitative, *in situ*, AA analyses for all three regions of interest gave overall accuracies of 86.1%, ±0, at the major level of geomorphological structure, 85.2%, ±1.9, and 50.7%, ±13.4, at the major and detailed levels of biological cover and 47.5%, ±13.4, for coral cover. Qualitative and quantitative accuracies were similar at the major geologic structure (hard vs. soft bottom) and major biological cover (i.e. seagrass, algae) however qualitative AA's for detailed biological cover (i.e. percent of seagrass, algae) and detailed coral cover (percent of coral) were 23.1% and 22.9% higher than the quantitative AA's. This trend was also found when analyzing the accuracies for the individual regions of interest. The results suggest that for performing an AA of broad map categories, a Qualitative AA compares well with an *in situ* Quantitative AA, but for more detailed map categories the *in situ* quantitative AA is more accurate. Marine resource managers should consider these accuracies when making decisions based on the 2014 NOAA Florida Keys Coral Reef Ecosystem Habitat map.

Keywords: Florida Keys, Mapping, GIS, Accuracy Assessment, Coral Reef Mapping

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This has been an amazing experience and without the following people and agencies, my thesis would not have been possible. I first thank my advisor Dr. Brian Walker for the guidance and support throughout this project. I also thank Dr. Steven Miller and his team (Mark Chiappone and LeAnne Rutten) for allowing me to use their data as well as being on my committee. Thank you Dr. Richard Spieler for being on my committee. Thanks to the Brian Keller Memorial Fellowship, Dr. Steve Rohmann, National Oceanic and Atmospheric Administration, and the National Fish and Wildlife Foundation for providing me with the funding to do my thesis. Acknowledgement also goes out to lab mates, Amanda Costaregni, Katelyn Klug, Charlotte Berry, and Kristin Cumming for helping me with data collection.

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1 Introduction

For centuries, maps have provided important information concerning the distribution of resources across space. Maps help us to measure the extent and distribution of resources, analyze resource interactions, identify suitable locations for specific actions (e.g., development or preservation), and plan future events (Congalton and Green, 1999). Habitat mapping is a broad term encompassing maps produced from broad visual or acoustic surveys of the seabed, to mapping of defined biological assemblages or 'biotopes' (e.g. coral reef, sea-grass bed, mussel bed, etc.) (Lunetta and Lyon, 2004). Habitat maps can be derived from a variety of remotely sensed data including aerial photography, satellite imagery, LIDAR, and acoustic surveys (Goodman, Purkis, and Phinn, 2013). Mapping seafloor habitats specifically (e.g. coral reefs, essential fish habitat, seagrass) is known as benthic habitat mapping and has been a primary objective of marine resource managers since the Sustainable Fisheries Act outlined its importance in 1996. Such benthic maps provide an understanding of the distribution and extent of marine habitats, facilitating visualization of the seascape and inventories of important natural resources (Walker, 2012) and may provide important information about a number of reef characteristics, such as overall structure and morphology, abundance and distribution of living coral, and distribution and types of sediment (Field and Chavez, 2001). Reliable benthic habitat maps can help answer questions such as which habitats are important to fish stocks as fish nurseries or birthing grounds? (Le Pape, 2014); what are the biogeographic distributions of fish (Fisco, 2016) or benthic organisms? (Klug, 2015); but most importantly, habitat maps are used to help make informed choices about how to manage our marine resources (Cogan, 2009). Resource managers use coral reef benthic habitat maps as a useful planning tool that facilitates the identification of representative reef systems (McNeill, 1994) and allows ecologically relevant management boundaries to be located (Kenchington, 1978).

Validation of mapping outputs is necessary to assure accurate and reliable maps (Green, Mumby, Edwards, and Clark, 2000). This validation is often called an accuracy assessment (AA). There are many reasons for performing an AA. The simplest reason is the desire to know how well the maps depict reality. Additionally an AA can provide feedbacks that can help improve mapping techniques and procedures by identifying and correcting the sources of errors and comparing various techniques, algorithms, analysts, or interpretations to test which is best. Finally, if the information derived from the habitat map is to be used in some decision-making process, then it is critical that some measure of its quality be known (Congalton and Green, 1999).

An inadequate or absent AA is a common limitation of most benthic habitat mapping efforts, and this may be responsible for their limited use by managers (Roelfsema, 2006). Goodman and Purkis (2013) noted that out of 80 peer-reviewed studies on benthic habitat mapping, only 38 included an AA. Their review determined that the costs of doing an independent AA were relatively high compared to the total cost of the overall habitat mapping effort and therefore were often omitted from the mapping efforts.

In the early days of mapping, one of the main objectives were to develop better cameras and other instruments (Congalton, 1993). Stephen Hopkins Spurr in "*Aerial Photographs in Forestry*" stated "Once the map has been prepared from the photographs, it must be checked on the ground. If preliminary reconnaissance has been carried out, and a map prepared carefully from good quality photographs, ground checking may be confined to those stands whose classification could not be agreed upon in the office, and to those stands passed through en route to these doubtful stands" (Spurr, 1948). In other words, a qualitative visual check to see if the map looks right was recommended. In the 1950's researchers saw a need to quantify their photo interpretations to promote their discipline as a science (Colwell, 1955; Katz, 1952; Sammi, 1950; Young, 1955). These researchers collaborated and developed techniques for one of the first accuracy assessments (AA) that was conducted and published by Young and Stoeckler (1956). The term accuracy is used to express the degree of 'correctness' of a map or classification. A map may be considered accurate if it provides a relatively unbiased representation of the land cover of the region it portrays. A confusion matrix or "error matrix" provides the basis on which to statistically examine map accuracy (Foody, 2002).

The purpose of this study is to assess the accuracy of the 2014 NOAA Coral Reef Ecosystems Habitat map by comparing a qualitative, drop camera, to a quantitative, *in situ*, data set. Accuracy assessments have been previously done using either qualitative or quantitative reference data, but no benthic AA study has had both reference data sets to compare.

1.1 Error Matrix

The error matrix is an effective accuracy assessment tool because it provides a starting point for a series of statistical techniques to further examine accuracy (Congalton and Green 1999). An error matrix compares information from reference sites, places where qualitative or quantitative AA data were collected, to information on a map for a number of sample areas. An error matrix is a square array of numbers set out in rows and columns that express the labels of samples assigned to a particular category in one classification relative to the labels of samples assigned to a particular category in another classification. One of the classifications, usually the columns, contains the field verified data and is termed the “reference data” or “ground-truthed” data (Table 1).

Table 1. Example of an error matrix.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**495**	84	579	**85.5**
	soft	9	**0**	9	**0.0**
	n_{-j}	504	84	**588**	**<=** n
	PRODUCERS Accuracy (%)	**98.2**	**0.0**	P_o	**84.2%**

Table 1 is an example of a simple error matrix with two map categories (hard and soft) where the rows represent the map classification and the columns represent the reference data, or ground-truthed data, verified via video or *in situ* field surveys. In this example, 504 sites were classified as hard by field assessments and 84 as soft. The map correctly classified 495 of the 504 hard sites, but 0 out of 84 sites were correctly classified as soft. The error matrix provides information on the errors of each map class, as well as the entire map. The individual errors are known as errors of inclusion (commission errors) and errors of exclusion (omission errors). Every error is an omission from the correct class and a commission to a wrong class (Congalton, 2001). An omission error occurs when a ground-truthed site is omitted from the class to which it belongs. In Table 1, an omission error example is that 9 sites ground-truthed as hard were not classified in the map as hard. A commission error occurs when a ground-truthed site is included in an incorrect class. In Table 1, the 9 sites that were ground-truthed as hard were incorrectly classified in the map as soft. In addition to showing errors of omission and commission, the error matrix can be used to compute overall accuracy, producer's accuracy, and user's accuracy (Story and Congalton, 1986). Overall accuracy is the sum of the major diagonal (i.e. the correctly classified samples) divided by the total number of samples in the error matrix. The overall accuracy is the most commonly reported AA statistic. Producer's (P_o) and user's accuracies are ways of representing individual class accuracies instead of just the overall classification accuracy (Congalton, 2001). A producer's accuracy is the probability of a ground-truthed data point being classified correctly, whereas the user's accuracy is the probability of the map classification at a sample site being correct. The user's and producer's accuracies are then used to assess misclassification characteristics such as omission and commission errors. Understanding the overall, user's and producer's accuracy values is essential for interpreting habitat maps, determining if they are useable for a specific application, and understanding which map classes are mapped more accurately than others (Goodman et al., 2013). An error matrix is also used to calculate a kappa coefficient (KHAT) and a Tau coefficient (T). The kappa coefficient is a statistical measure of the actual agreement minus chance agreement and measures how well the classification sample reflects the actual data. A kappa value of 0.0 is obtained when agreement between the reference data and a classification result is the same as the agreement that would occur from chance alone. The upper limit of kappa is 1.0, which occurs only when there is perfect agreement (Rosenfield, 1986). Kappa values below 0.5 may suggest that the results of the AA do not actually reflect the validity of the data. The Tau coefficient (T) is believed to provide a superior measure of classification accuracy than the kappa coefficient and P_o (Ma and Redmond, 1995). The Tau coefficient is a measure of the improvement of classification accuracy over a random assignment of map units to map categories (Ma and Redmond, 1995). As the number of map categories increases, the probability of random agreement diminishes, and T_e approaches P_o.

1.2 Sampling scheme

When designing an accuracy assessment, there are several factors to consider that may affect the outcome of the map assessment. Verifying every portion of a map is almost always impractical and cost prohibitive (Congalton, 2001). The selection of a proper and efficient survey design to collect valid reference data is one of the most challenging and important components of any AA because the design will determine both the cost and the statistical rigor of the assessment (Congalton, 2001). Surveying units, which can be points or areas, define the spatial extent of the reference data used to calibrate and validate a map product and its map classes (Stehman and Czapleqski, 1998). The number of surveys required for each map class to produce a statistically valid analysis requires a balance between what is statistically sound in terms of probability sampling, and what is practically achievable due to the logistical challenges sampling in the coral reef environment such as sea conditions, equipment limitations, and remoteness of some sample areas (Goodman et al., 2013). Congalton (2001) suggests a minimum of 50 validation samples per discrete mapping category, however the minimum number should increase when the study area is larger than 4,000 km^2 or when more than 12 categories are mapped. This approach has been adopted as the default sampling design in the majority of satellite and image-based habitat map applications to date (Goodman et al., 2013).

In order to have a random selection of independent samples, a procedure needs to be applied to assure that the different mapping categories in a given study area have equal probabilities of being sampled. Common probability sampling schemes are simple random, systematic, stratified random, and stratified systematic unaligned sampling (Congalton and Green, 1999). Simple random sampling is the most statistically robust because all classes on the map are given an equal probability, and the selection of one location or habitat does not influence which is selected next. However; simple random sampling can be vulnerable to sampling error because the randomness of the selection may result in a sample that does not reflect the makeup of the overall map (Congalton and Green, 1999). For example, one habitat could be sampled many more times than others or certain habitats could have not been sampled. Simple random sampling requires large numbers of samples and is often not applicable in the marine environment due to the logistical challenges such as limited resources (e.g., boats, skilled people, and equipment), access to survey areas, and remoteness of survey areas (Goodman et al., 2013; Purkis and Klemas, 2011). Stratified random sampling schemes (Figure 1) are more frequently implemented in marine environments, as field surveys can be designed within the limits of the aforementioned logistic challenges (Stehman and Czapleqski, 1998). With stratified random sampling, some prior knowledge about the study area is used to divide the area into groups or strata, and then each strata is randomly sampled. Stratified random sampling increases the efficiency of the surveys (Plourde, 2003). Stratified random sampling ensures that all strata, no matter how small the area, will be included in the AA.

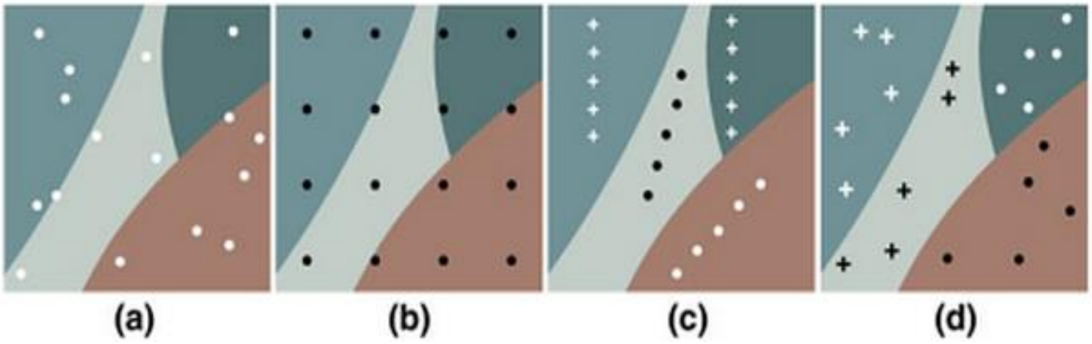

Figure 1. Example of four sampling schemes: (a) simple random (b) systematic, (c) stratified systematic unaligned and (d) stratified random. (Goodman and Purkis 2013).

Stratified random sampling can sometimes be impractical, because stratified random samples can only be selected after the map has been completed (i.e. when the location of the strata are known). This limits the AA reference data to being collected late in the project instead of in conjunction with the collection of training data, or data originally collected to create the map, which often increases the costs of the project (Congalton and Green, 1999).

The most appropriate accuracy assessment in the marine environment will depend on the following questions (Roelfsema et al., 2006):

-What benthic classes do you need to survey?

Benthic classes can vary from species level to description of geomorphic zones.

-What resources are available to conduct the accuracy assessment?

This concerns available funding for: logistics, equipment and people.

-What scale of the accuracy assessment is required?

This is determined by the area to be covered, the type of information to be mapped, and the spatial resolution of the sensor or aerial image used (Andréfouët and Claereboudt, 2000). When making field observations for comparison to aerial data, the issue of scale becomes an important factor. Diver or video observation typically takes place on a scale of meters, while remote observations are made at the kilometer scale. Individuals making the field verification should bear in mind that they will see small habitat changes within an area likely to have been given a single habitat attribute by the mapper (Finkbeiner, Stevenson, and Seaman, 2001).

-What type of benthic environment is to be mapped?

The effectiveness of a survey is influenced by a number of factors, some of which include: water clarity, water depth, currents, and leeward or windward position. Protected areas can be accessed any time, others require careful planning. Surface and underwater conditions influence safety. Existing field survey data, if suitable for the type of mapping application, may also be used in the AA, reducing survey costs and effort (Roelfsema et al., 2006). Though existing field survey data may be used for an AA after the map has been completed, there are limitations. Existing data are older than those being used to create the new map. Changes at the benthic level will not be reflected in the existing data. However, differences in the error matrix caused by the changes will be incorrectly assumed to be caused by map error (Congalton and Green, 1999).

1.3 Quantitative Accuracy Assessment

Accuracy assessments in the coral reef environment can be time consuming and result in high costs due to a combination of boat time, variable weather and sea conditions, and diving and/or snorkeling requirements (Goodman et al., 2013). The main goal of an AA is to implement a statistically defensible sampling design that is cost-effective and addresses the multitude of objectives that multiple users and applications of the map generate (Lunetta and Lyon, 2004). A quantitative AA consists of the identification and measurement of map errors and involves the comparison of a site on a map against reference information (i.e. *in situ* data) for the same site. The reference data is assumed to be correct. In the field of benthic habitat mapping, collecting *in situ* data for every spatial unit is the most accurate form of reference data for a quantitative AA, but funding limitations prohibits the assessment of every spatial unit on the map (Congalton and Green, 1999). When collecting *in situ* data for comparison to aerial image data, the issue of scale becomes an important factor. *In situ* and underwater video observations take place on a scale of meters, sometimes even centimeters, while remote observations are generally made at the kilometer scale (Finkbeiner et al., 2001).

This issue of scale is addressed in the mapping methodologies (e.g. minimum mapping unit). A minimum mapping unit (MMU) is the size of dimensions for features to be mapped as lines or areas for a given map scale. Measuring and understanding the sources of associated errors contained within each map is essential to determine the error levels and reliability of the finished map (Congalton and Green, 1999). The smaller the MMU is, the greater resolution mappers can get from images. Deciding on the MMU to be used is a balance between providing maps with sufficient detail to meet the requirements of the mapping objectives and the time and cost needed to produce the map (Purkis and Klemas, 2011). The size of the MMU selected will be a trade-off between the desire to map small features (e.g. individual coral heads or patch reefs) that may be important to habitat interpretation versus the time required to identify and classify all features of this size visible in the data. The smaller the MMU adopted, the more individual features there will be to map and the more expensive the project will be (Purkis and Klemas, 2011).

Quantitative assessment methods utilizing SCUBA can provide detailed information at each location, (i.e. species richness, coral and gorgonian density, and recruitment) but requires excessive time (15 – 45 min) at a given site. Quantitative AA’s in which divers collect *in situ* data on coral, algae, or seagrass habitats have been utilized in a number of mapping studies (Bruce, 1997; Palandro et al., 2008; Purkis and Riegl, 2005). In Andréfouët’s (2003) evaluation of 10 coral reef maps that were created using IKONOS satellite images, quantitative AA’s were done on each of the finished maps. The number of benthic habitat classes (i.e. seagrass, algae, coral) in each of the maps ranged from 3 to 15. Andréfouët (2003) noted that there was a general linear trend of decreasing accuracy with increasing habitat complexity. As the number of habitat classifications increased, the overall accuracy of the map decreased.

1.4 Qualitative Accuracy Assessment:

A qualitative AA consists of data collection using observations rather than collecting detailed *in situ* data like a quantitative AA. Whether or not AA reference data should be obtained from observations or measurements will be determined by the complexity of the seascape, detail of the classification system, required precision of the AA, and the project budget (Congalton and Green, 1999). The source of reference data collected in a coral reef qualitative AA can be aerial images or underwater photos and video. The type of reference data (i.e. biological cover, geomorphological structure) required will depend upon the complexity of the map classification scheme (Congalton and Green, 1999). As a general rule, the simpler the classification scheme, the simpler the reference data can be. As the level of detail in the map classification scheme increases, so should the complexity of the reference data collection be. Photo interpretation or videography are common qualitative reference data that have been used in a number of studies (Bauer, 2012; Lyons, 2011; Walker, 2013; Walker, 2008; Walker, Rodericks, and Costaregni, 2013). Video can be used to collect data on the relative abundance and percent cover of benthic organisms (Aronson and Swanson, 1997; Sweatman, 1998; Wheaton, Dustan, Jaap, and Porter, 1996). Video data collection has the advantages of increasing the speed of data collection (Jaap and McField, 2001), which provides many more random survey sites than the same cost of quantitative assessments.

1.5 2014 NOAA Florida Keys Coral Reef Ecosystem Habitat Map

The Florida Reef Tract (FRT) spans more than 595 km of coastline from St. Lucie inlet to the Dry Tortugas and, with the exception of isolated banks in the Flower Gardens area in the Gulf of Mexico, represent the only region of extensive coral reef development in the continental United States (Jaap, 1984). Coral reefs provide a suite of socioeconomic and ecological goods and services that benefit people, including: recreation and tourism activities, protection from storm and wave events, and are primary sources of food for some localities. Coral reefs create specialized habitats that provide shelter, food, and breeding sites for numerous plants and animals. Coral reefs are critically important for the ecosystem goods and services they provide to maritime tropical and subtropical nations. In the state of Florida, coral reefs contribute $3.4 billion in sales and income and support 36,000 jobs each year (Johns, Leeworthy, Bell, and Bonn, 2001).

The management of coral reef ecosystems is challenging. Managers must strike a balance between ecosystem protection and allowing people to enjoy and use these natural resources (Monaco et al., 2012). Due to their ecological importance and the continued decline in coral reef ecosystem condition, the United States Coral Reef Task Force was established in 1998 by Presidential Executive Order 13089 to lead U.S. efforts to preserve and protect the biodiversity, health, and social and economic value of U.S. coral reef ecosystems and the marine environment. The Coral Reef Task Force committed to producing comprehensive digital maps of all U.S. shallow, and selected deep water (>30 m), coral reef habitats. The National Oceanic and Atmospheric Administration (NOAA) was directed to lead this mapping work. In 2005, NOAA's National Centers for Coastal Ocean Science (NCCOS), in cooperation with NOAA's Office of National Marine Sanctuaries and state, local, and university partners from Florida, initiated an effort to map and characterize the coral ecosystems of southern Florida. One of the products of that effort, "The Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan" (Rohmann and Monaco, 2005), discussed the need to produce shallow-water (0-40 m) benthic habitat and bathymetric maps of critical areas in the Florida Keys. The NOAA benthic habitat map of the Florida Keys (Figure 2) was created primarily using IKONOS satellite images from 2005-2006 along with field validation incorporating still camera and video (Rohmann and Monaco, 2005). The intention of creating the benthic habitat map was to help local, state and federal decision-makers protect valuable coral reefs, as well as to provide a baseline for identifying future changes in the reef community (Rohmann, 2008).

Figure 2. 2014 NOAA Florida Keys Coral Reef Ecosystems Habitat map outlined in yellow using an MMU of 4,047m^2 *for most benthic habitats with the exception of patch reefs in Hawk Channel which was mapped with an MMU of 625m*^{2}.

1.6 NOAA Map Classification System

The 2014 NOAA Florida Keys Coral Reef Ecosystem Habitat map was produced using a non-hierarchical classification system that defines habitats on four attributes (Table 2):

- Geographic Zone – Refers to each benthic feature's location in relation to the shoreline and the shelf edge and does not address substrate or cover types found within it.
- Geomorphologic Structure – Refers to the predominant physical composition of the feature and does not address location.
- Biological Cover – Refers to what is colonizing benthic features.

- Coral Cover – refers to percent cover of both hard and soft corals within four broad intervals.

Table 2. The classification scheme used by NOAA to map benthic habitats in the Florida Keys (modified from Zitello et al., 2009).

Geographic Zone	Geomorphological Structure	Biological Cover
Land Shoreline Intertidal Lagoon Reef Flat Back Reef Reef Crest Fore Reef Bank/Shelf Bank/Shelf Escarpment Ridges and Swales Channel Dredged Unknown	Coral Reef and Hard Bottom Spur and Groove Individual Patch Reef Aggregate Patch Reefs Aggregate Reef Scattered Coral/Rock Pavement Rock/Boulder Reef Rubble Pavement with Sand Channels Unknown Unconsolidated Sediment Sand Mud Sand with Scattered Coral & Rock Other Delineations Land Artificial Unknown	**Major Cover** Algae Live Coral Coralline Algae Mangrove Seagrass No Cover Unknown **Percent Major Cover** 10% - <50% 50% - <90% 90% - 100% Unknown
		Coral Cover **Percent Coral Cover** 0% - <10% 10% - <50% 50% - <90% 90% - 100% Unknown

1.7 Hypotheses

The purpose of this study is to compare qualitative and quantitative data collection techniques to assess mapping accuracy of the 2014 NOAA Florida Keys Coral Reef Ecosystem Habitat map. Accuracy assessments have been previously done using either qualitative or quantitative reference data, but no benthic AA study has had both reference data sets to compare. In this study, AA statistics were derived from a qualitative data set (Walker et al., 2013) and a quantitative reference data set (Miller, Swanson, and

Chiappone, 2000; Rutten, Chiappone, Swanson, and Miller, 2008) for benthic cover over hard-bottom habitats throughout the Florida Keys. The null hypothesis tested was no difference in accuracy for the two methods used to calculate AA statistics. These data sets were used to create AA matrices based on the 2014 NOAA Florida Keys Coral Reef Ecosystem Habitat Map. If qualitative methods that are more cost efficient and faster to conduct per site are statistically similar to quantitative methods that take longer and are generally more expensive to complete, then future benthic AAs could base their survey design and methods off this study. This study also relates to many of the NOAA Coral Reef Conservation Program's newly developed guiding principles in their roadmap for the future (NOAA 2009) by assessing the 2014 NOAA Florida Keys habitat map data across the different benthic habitats in the Florida Keys. This study could lead to a change of AA techniques for future NOAA mapping efforts and also provide decision makers with sources of error concerning the 2014 NOAA Coral Reef Ecosystem Habitat Map.

2 Material and Methods

2.1 Qualitative data set:

Walker et al, (2013) performed an extensive qualitative AA to assess the NOAA Florida Keys habitat map. As part of a regional mapping and monitoring effort in the Florida Keys, NOAA required an independent AA to statistically test the accuracy of the GIS-based benthic habitat map recently produced for the Florida Keys. Resources, budgets, and logistical constraints precluded a comprehensive assessment of the entire mapped area, so

Walker et al. (2013) used biogeographically-representative corridors within the total benthic habitat map area for performing the AA. The corridors (Regions of Interest (ROIs)) not only captured a wide diversity of habitats, but were also characterized by frequent transitions between habitat types ensuring a well-distributed, representative set of survey locations (Figure 3).

Figure 3. Accuracy Assessment Area 1 (ROI-1) (yellow), Area 2 (ROI-2) (blue), Area 3 (ROI-3) (green), and Area 4 (ROI-4) (purple) within the overall NOAA mapped region of the FL Keys. Each area was assessed individually and all data were combined into one accuracy assessment to represent map accuracy for the entire mapped area. From (Walker et al, 2013)

For all four regions of interest (ROIs) in the Florida Keys (Figure 3), target locations were determined by a GIS-based, stratified random sampling design. AA target points were randomly placed within each Detailed Biological Cover class in the map using Hawth's tools in ArcGIS at a minimum distance of 30 m apart. Video and still photographs were collected on 2023 sites in the Florida Keys. ROIs 1 and 2 data were collected in 2009 and

2010 and ROIs 3 and 4 data were collected in 2012 and 2013. Data collection procedures were consistent between each ROI. Underwater video from a drop camera was taken at each site, provided the location was safely accessible by the survey vessel. The data collection was initiated when the vessel positioned itself within 5 m of the target. A Sea Viewer 950 underwater color video drop camera with a Sea-trak GPS video overlay connected to a Magellan Mobile Mapper CX GPS was lowered to the bottom. Color video was recorded over the side of the stationary/drifting vessel approximately 0.5-2 m from the seafloor. Fifteen seconds to two-minute video clips were recorded directly to a digital video recorder in MPEG4 video format (Figure 4).

Figure 4. Drop camera video recorder setup

Video length depended on the habitat type and vessel drift. Videos of large, homogeneous habitats were generally short, 15-30 seconds, while heterogeneous habitats, especially edges, were typically longer, 1 to 2 minutes. By letting the video camera drift while recording its GPS track, it enabled the observer to see the geomorphological structure and biological cover at a scale closer to the map's minimum map unit which was anywhere from 625 m^2 for patch reefs in Hawk Channel to 4,047 m^2 for most benthic habitats. While the video was being recorded, an observer categorized each site according to the video for Detailed Geomorphological Structure and Biological Cover into a database. Not all sites were accessible by survey vessel. Sites in the water that were too shallow were accessed using a kayak. The kayak was launched from the survey vessel as close to the target as possible. The observers paddled to the target using a waterproof Garmin 76CSx GPS with WAAS correction (<3 m accuracy) as a guide. At the target, a digital camera in an underwater housing was used to take pictures and/or video of the site. Descriptive notes about the site were recorded from the kayak on waterproof paper. Several widespread, shallow-water sites that were inaccessible by boat and not practical for kayaking were visited by wave runner. Navigation to these sites was the same as by kayaking. At each site a short video clip from a digital camera was taken either at the surface or by snorkel. Bottom type was usually confirmed by free diving at these inaccessible locations. A few underwater targets were not practically accessible by any means. In these cases, the sites were moved to more easily accessible location within the same polygon if possible or to another polygon of the same category. All sites (Figure 5) were evaluated for structure, biological cover, and coral cover both in GIS and video/images to classify the habitat at each site.

Walker et al. (2013) classified their qualitative data according to the NOAA classification scheme (Table 2) and used error matrices to get Overall, User's, and Producer's accuracies for the categories of geomorphological structure, biological cover, and live coral cover.

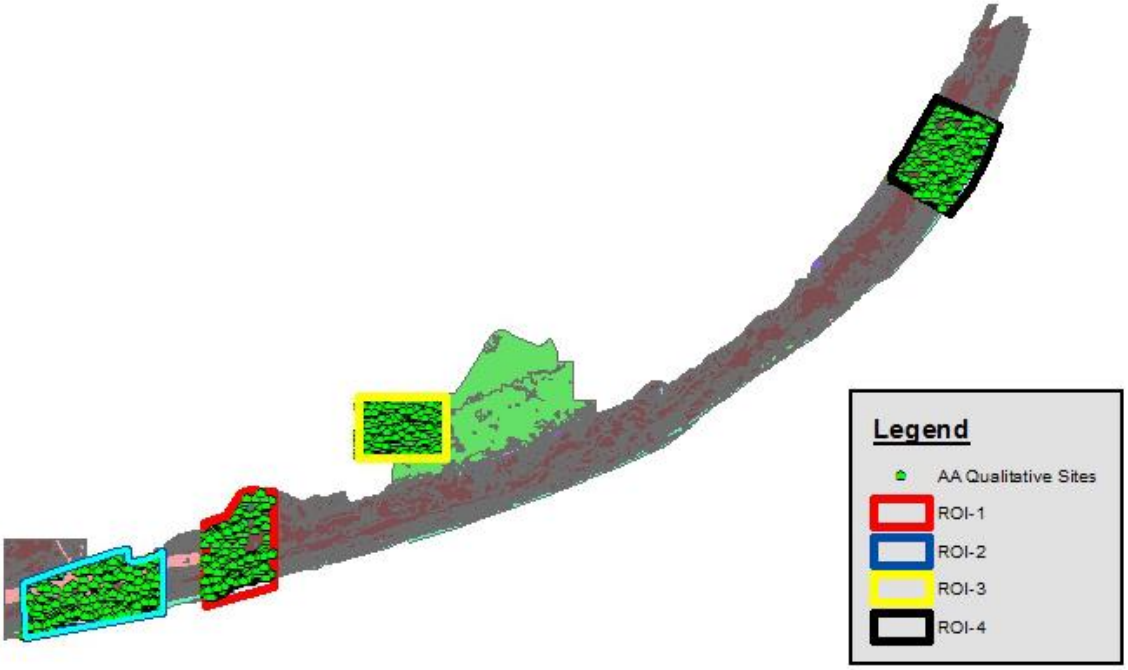

Figure 5. GIS map of Walker et al (2013) AA site locations in green.

2.2 Classification scheme

Evaluation of these AA sites were based on the NOAA classification scheme (Table 2). The classification scheme was designed by NOAA and its partners for the benthic habitat mapping program initiated in 1999 but amended in 2008. Below is the classification scheme taken from (Zitello et al. 2009) of the NOAA Florida Keys map based on geomorphological structure, biological cover, and live coral cover.

Coral Ecosystem Geomorphological Structures

Unconsolidated Sediment: Areas of the seafloor consisting of small particles (<.25 m) with less than10% cover of large stable substrate. Detailed structure classes of softbottom include *Sand, Mud,* and *Sand with Scattered Coral and Rock.*

Sand: Coarse sediment typically found in areas exposed to currents or wave energy. Particle sizes range from 1/16 – 256 mm, including pebbles and cobbles (Wentworth 1922).

Mud: Fine sediment often associated with river discharge and build-up of organic material in areas sheltered from high-energy waves and currents. Particle sizes range from <1/256 – 1/16 mm (Wentworth 1922).

Coral Reef and Hardbottom: Areas of both shallow and deep-water seafloor with solid substrates including bedrock, boulders and deposition of calcium carbonate by reef building organisms. Substrates typically have no sediment cover, but a thin veneer of sediment may be present at times especially on low relief hardbottoms. Detailed structure classes include *Rock Outcrop, Boulder, Spur and Groove, Individual Patch Reef, Aggregated Patch Reefs, Aggregate Reef, Reef Rubble, Pavement, Pavement with Sand Channels,* and *Rhodoliths*.

Spur and Groove: Structure 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 (approximately 1 meter or more) relative to pavement with sand channels and are separated from each other by 1-5 meters of sand or hardbottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the *Fore Reef* zone.

Individual Patch Reef: Patch reefs are 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. *Individual Patch Reefs* are larger than or equal to the MMU.

Aggregate Patch Reefs: Having the same defining characteristics as an *Individual Patch Reef*. This class refers to clustered patch reefs that individually are too small (less than the MMU) or are too close together to map separately. Where aggregated patch reefs share sand halos, the halo is included in the polygon.

Aggregate Reef: 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.

Scattered Coral/Rock in Unconsolidated Sediment: 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*.

Pavement: Flat, low-relief, solid carbonate rock with coverage of algae, hard coral, gorgonians, zoanthids or other sessile vertebrates that are dense enough to partially obscure the underlying surface. On less colonized Pavement features, rock may be covered by a thin sand veneer or turf algae.

Rock/Boulder: Aggregation of loose carbonate or volcanic rock fragments that have been detached and transported from their native beds. Individual boulders range in diameter from 0.25 – 3 m as defined by the Wentworth scale (Wentworth 1922).

Reef Rubble: 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, Back Reef* or *Reef Flat* zones. Less often, *Reef Rubble* can occur in low density aggregations on broad offshore sand areas.

Pavement with Sand Channels: Habitats of pavement with alternating sand/surge channel formations that are oriented perpendicular to the *Reef Crest* or *Bank/Shelf Escarpment*. The sand/surge channels of this feature have low vertical relief (approximately less than 1 meter) 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 *Bank/Shelf* zone.

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.

Land: Terrestrial features above the spring high tide line.

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

Florida Classification Hierarchical Biological Cover Component

Cover classes refer only to the dominant biological component colonizing the surface of the feature and do not address location (e.g., on the shelf or in the lagoon) or structure type. Habitats or features that cover areas smaller than the MMU were not considered. The cover types are defined in a collapsible hierarchy ranging from eight major classes (*Algae*, *Seagrass*, *Live Coral*, *Mangrove*, *Coralline Algae*, *No Cover*, *Unclassified* and *Unknown*), combined with a modifier describing the distribution of the dominant cover type throughout the polygon (*10%- <50%*, *50%-<90%*, and *90%-100%*). It is important to reinforce that the modifier represents a measure of the level of patchiness of the biological cover at the scale of delineation and not the density observed by divers in the water. For example, a seagrass bed can be described as covering 90%- 100% of a given polygon, but may have sparse densities of shoots when observed by divers.

Algae: Substrates with 10% or greater distribution of any combination of numerous species of red, green, or brown algae. May be turf, fleshy or filamentous species. Occurs throughout many zones, especially on hardbottoms with low coral densities and softbottoms in deeper waters of the *Bank/Shelf* zone.

Seagrass: Habitat with 10% or more of the mapping unit dominated by any single species of seagrass (e.g. *Syringodium* sp., *Thalassia* sp., and *Halophila* sp.) or a combination of several species.

Live Coral: Substrates colonized with 10% or greater live reef building corals and other organisms including scleractinian corals (e.g., *Acropora* sp.) and octocorals (e.g., *Briareum* sp.).

Mangrove: This habitat is comprised of semi-permanently, seasonally or tidally flooded coastal areas occupied by any species of mangrove. Mangrove trees are halophytes; plants that thrive in and are especially adaptedmto salty conditions.

No Cover: Substrates not covered with a minimum of 10% of any of the other biological cover types. This habitat is usually found on sand or mud bottoms. Overall, *No Cover* is estimated at 90%-100% of the bottom with the possibility of some very low density biological cover.

Unclassified: A different biological cover type, such as upland, deciduous forest, that is not included in this habitat classification scheme dominates the area. Most often used on polygons defined as *Land* with terrestrial vegetation.

Unknown: Biological cover is indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

Percent Cover

10% - <50%

Discontinuous cover of the major biological type with breaks in coverage that are too diffuse to delineate or result in isolated patches of a different dominant biological cover that are too small (smaller than the MMU) to be mapped as a different feature. Overall cover of the major biological type is estimated at 10% - <50% of the polygon feature.

50% - <90%

Discontinuous cover of the major biological type with breaks in coverage that are too diffuse to delineate or result in isolated patches of a different dominant biological cover that are too small (smaller than the MMU) to be mapped as a different feature. Overall cover of the major biological type is estimated at 50% - <90% of the polygon feature.

90% - 100%

Major biological cover type with nearly continuous (90-100%) coverage of the substrate. May include areas of less than 90% major cover on 10% or less of the total area that are too small to be mapped independently (less than the MMU).

Live coral cover classes

Four distinct and non-overlapping percent live coral classes were identified that can be mapped through visual interpretation of remotely sensed imagery. This attribute is an additional biological cover modifier used to maintain information on the percent cover of live coral, both scleractinian and octocorals, even when it is not the dominant cover type. In order to provide resource managers with additional information on this cover type of critical concern, four range classes were used (*0% - <10%, 10% - <50%, 50% - <90%*, and *90% - 100%*). Hardbottom features are classified into these range classes based on the amount of combined scleractinian and octocoral present in a polygon. Distinction of scleractinian coral versus octocoral was limited by the current state of remote sensing technology and could not be separated in the *Live Coral Cover* modifier.

0% - <10%: Live coral cover of less than 10% of hardbottom substrate at a scale several meters above the seafloor.

10% - <50%: Live coral cover between 10% and 50% of hardbottom substrate at a scale several meters above the seafloor.

50% - <90%: Live coral cover between 50% and 90% of hardbottom substrate at a scale several meters above the seafloor.

90% - 100%: Continuous live coral consisting of 90% or greater cover of the hardbottom substrate at a scale several meters above the seafloor.

Not Applicable: An estimate of percent live coral cover is not appropriate for this particular feature. Only occurs in areas describing the terrestrial environment.

Unknown: Percent estimate of coral cover is indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

2.3 Quantitative data set:

Miller, Swanson, and Chiappone (2000), Miller, Chiappone, and Rutten (2009) and Rutten, Chiappone, Swanson, and Miller (2008) from the years of 1999, 2002, 2005, and 2009 collected *in situ* data from 556 sites throughout the Florida Keys from the southwest of Key West to the northern end of Biscayne Park to quantify the distribution, abundance, size, and condition of benthic coral reef organisms. A geographic information system (GIS) containing digital layers for benthic habitat (Florida Marine Research Institute 1998) bathymetry, and no-take marine reserve boundaries was used to facilitate delineation of the sampling survey domain, strata, and sample units. Habitats were sampled using a stratified random sampling design that partitioned the Florida Keys by benthic habitat type, regional sector, and management zone (Smith, Swanson, Chiappone, Miller, and Ault, 2011). For all of the sites sampled, coordinates were randomly generated in a GIS using available benthic habitat and bathymetry data for the sampling domain. The habitat strata selected for the 1999-2009 sampling periods incorporated most of the hard-bottom and coral reef habitat types from inshore of Hawk Channel to ~13m depth along the reef tract. The sampling events did not include back reef rubble, nearshore hardbottom, seagrass, or deeper (> 15 m) fore-reef areas. Habitats sampled were inshore and mid-channel patch reefs, offshore patch reefs, shallow (<6 m) hard-bottom, inner line reef tract spur and groove from Grecian Rocks northward to Turtle Reef, shallow (<6 m) high-relief spur and groove along the platform margin, and deeper fore-reef habitats from 7-13 m depth. Data were collected using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) method by a two to three-member team that conducted these surveys using SCUBA for up to seven hours a day with an average of 3 sites per day. At each site, four 15 m transects (1 m wide belt centered on each transect covering a 60 m^2 area) were deployed. At each 15 m transect, benthic cover was assessed by sampling 100 points spaced 15 cm apart. Variables measured included density, size, and condition of benthic coral reef organisms. Surveys included inventory of depth and topographic complexity; species richness of stony corals, gorgonians, and sponges; percent cover of abiotic (e.g. sand and rubble) and biotic (e.g. algae, sponges, stony corals, gorgonians) components; stony coral density, colony size, and condition; juvenile coral density and size; gorgonian density and gorgonian host occupation patterns by flamingo-tongue snails; density and size of urchins; density of anemones and corallimorpharians; and density of selected mollusks (sea slugs, nudibranchs, and certain gastropods).

Not all of these variables were assessed from Miller et al. (2000) and Rutten et al. (2008) surveys during 1999 - 2009. For this study, just the biotic cover and the geomorphological structure of the site were used. Since Miller et al. (2000) and Rutten et. al (2008) had multiple stations on the same site without crossing habitats, all species data on each station were summed and divided by the number of stations on each site (Miller et al. 2000; Rutten et al. 2008). This gave a mean cover for each species recorded on each site. Since Miller et al. (2000) and Rutten et al. (2009) data set was not used to create the 2014 NOAA Florida Keys Coral Reef Ecosysten Habitat map, they are regarded as independent and therefore do not compromise the conventions of accuracy assessment as described by Congalton (1999).

For this study, Miller et al. (2000) and Rutten et al. (2008) *in situ* data from 1999 - 2009 were categorized with NOAA's classification scheme of geomorphological structure, biological and coral cover, and by percentage classes (*0% - <10%, 10% - <50%, 50% - <90%, and 90% - 100%*) for biological and coral cover. Miller et al. (2000) and Rutten et al. (2008) data were input into the same field data sheet used by Walker et al. (2013). Due to difficulty in categorizing detailed geomorphological structure in Miller et al. (2000) and Rutten et al. (2008) site descriptions, error matrices for detailed structure (i.e. spur and groove, pavement, pavement w/sand channels) were omitted from this analysis. However, this study did include error matrices for major structure, (i.e. hard or soft-bottom), major and detailed cover, and detailed coral cover. This study also included error matrices for Miller et al. (2000) and Rutten et al. (2008) data from 2005 - 2009 since earlier-collected *in situ* benthic cover data before the map was created could possibly introduce bias in the results due to major storm activity that occurred before 2005.

In this study, when comparing Walker et al. (2013) qualitative to Miller et al. (2000) and Rutten et al. (2008) quantitative sampled sites, the backcountry area (ROI 3) was not surveyed by Miller et al. (2000) and Rutten et al. (2008). In order to have a fair comparison, ROI-3 sites were omitted in this study (Figure 6). Miller et al. (2000) and Rutten et al. (2008) did not survey the nearshore habitats, so this study omitted those Walker et al. (2013) sites that were nearshore (Figure 6). Miller et al. (2000) and Rutten et al. (2008) also only surveyed hard-bottom sites, so all mapped soft-bottom, emergent vegetation, and seagrass sites from Walker et al. (2013) data set were also omitted from this study (Figure 6). In this study, Miller et al. (2000) and Rutten et al. (2008) and Walker et al. (2013) sites in the ROIs were compared using error matrices. Error matrices combining all of Miller et al. (2000) and Rutten et al. (2008) sites throughout the entire NOAA mapped space were also created but cannot be directly compared to any of Walker et al. (2013) error matrices since no data in the Walker et al., (2013) report were collected outside the ROIs.

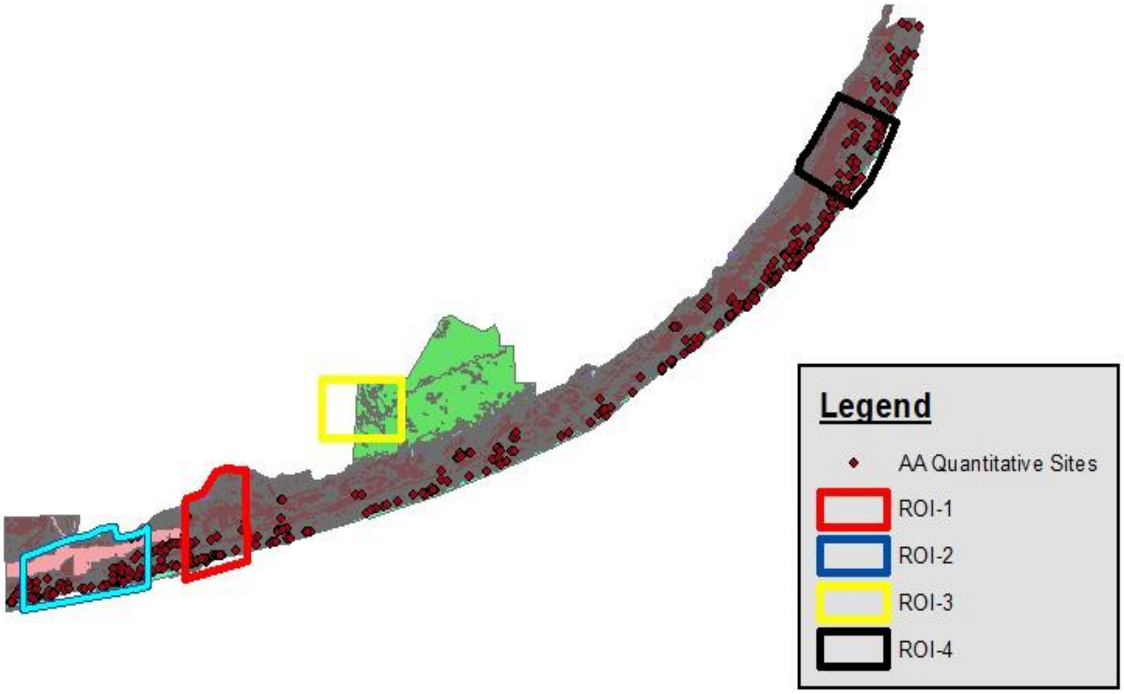

Figure 6. GIS map of Quantitative site locations in red.

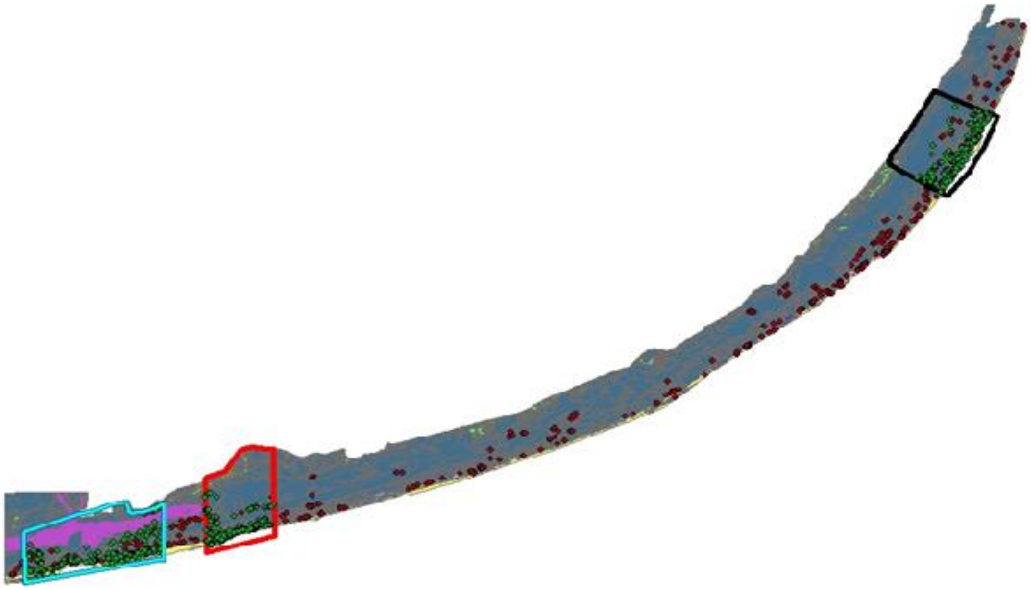

Figure 7. GIS map of both study sites without ROI-3, nearshore, soft-bottom, and emergent vegetation sites omitted

2.4 Accuracy Assessment Analyses

To test the accuracy of each ROI and the entire NOAA Florida Keys map, quantitatively and qualitatively, a number of statistical analyses were used. Error matrices were prepared for the attributes of geomorphological structure at the major level of classification, biological cover at the major and detailed level, and coral cover at the detailed level. Overall accuracy, producer's accuracy, and user's accuracy were computed directly from the error matrices (Story and Congalton, 1986).

2.5 Tau Coefficient

The Tau coefficient (T_e) was also calculated for this analysis. Tau is a measure of the improvement of classification accuracy over a random assignment of map units to map categories (Ma and Redmond, 1995). The T_e generates a statistic with a value ranging from +1 to -1. Values closer to zero indicate less agreement or association between map classes and field sample stations. Values of +1 or -1 indicate complete agreement. In this analysis, T_e is simply an adjustment of P_o by the number of map categories. As the number of categories increases, the probability of random agreement diminishes, and T_e approaches P_o. The general form of the T_e for equal class probability is:

$$T_e = \frac{\text{overall classification accuracy} - \text{equal probability of class assignment}}{1 - \text{equal probability of class assignment}}$$

Confidence intervals were then calculated for each Tau coefficient at the 95% confidence level (1-α), using the following generalized form:

$$95\%\ CI = T_e \pm Z_{\alpha/2}(\sigma_r^2)^{0.5}$$

3 Results

A total of 588 qualitative and 551 quantitative sites were analyzed. The results for each region of interest (ROI) and combined regions of interest are presented in this section (Table 3Table 34) for qualitative and quantitative data sets. Results from all quantitative data from 1999-2009 and a subset from 2005-2009 for the entire map are presented in

Table *35* Table 42. Results from all qualitative and quantitative data are presented in Table 43.

3.1 Geomorphological Structure ROI-1

The overall accuracies (P_o) for the qualitative data on Major Geomorphological Structure in ROI-1 were 89.3% and 86.8% for the quantitative data (Table 3 and Table 4). The Tau coefficient for equal probability of group membership (T_e) was 0.786 ± 0.094 (α=0.05), i.e. the rate of misclassifications at the Major Structure level was 78.6% less than would be expected from random assignment of sites to categories. The Tau coefficient for quantitative data was 0.737 ± 0.215 (α=0.05).

3.1.1 Biological Cover ROI-1

The overall accuracies (P_o) for qualitative Major and Detailed Biological Cover in ROI-1 were 86.9% and 74.4% respectively (Table 5 and Table 7). Overall accuracies for quantitative Major and Detailed cover were 86.8% and 55.3% respectively (Table 6Table 8). The Tau coefficient for equal probability of group membership (T_e) for qualitative data were 0.836 ± 0.064 at the major and 0.723 ± 0.071 (α=0.05) for detailed covers. Tau coefficients for quantitative data were 0.836 ± 0.134 at the major and 0.515 ± 0.171 (α=0.05) for detailed covers.

3.1.2 Coral Cover ROI-1

The overall accuracies (P_o) for Detailed Coral cover in ROI-1 were 73.2% for qualitative data and 60.5% for quantitative data (Table 9Table 10). The Tau coefficients for equal probability of group membership (T_e) for qualitative data were 0.643 ± 0.089 and 0.474 ± 0.207 (α=0.05) for quantitative data.

Table 3. Error matrix for qualitative ROI 1 Major Geomorphological Structure. The overall accuracy (P_o) was 89.3%. The Tau coefficient for equal probability of group membership (T_e) was 0.786, with a 95% Confidence Interval of 0.692– 0. 880.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**150**	15	165	**90.9**
	soft	3	**0**	3	**0.0**
	n_{-j}	153	15	**168**	**<=** n
	PRODUCERS Accuracy (%)	**98.0**	**0.0**	P_o	**89.3%**

$T_e = 0.786 \pm 0.094$

Table 4. Error matrix for quantitative ROI 1 Major Geomorphological Structure. The overall accuracy (P_o) was 86.8%. The Tau coefficient for equal probability of group membership (T_e) was 0.737, with a 95% Confidence Interval of 0.522– 0. 952.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**33**	0	33	**100.0**
	soft	5	**0**	5	**0.0**
	n_{-j}	38	0	**38**	**<=** n
	PRODUCERS Accuracy (%)	**86.8**	**0.0**	P_o	**86.8%**

$T_e = 0.737 \pm 0.215$

Table 5. Error matrix for qualitative ROI 1 Major biological cover. The overall accuracy (P_o) was 86.9%. The Tau coefficient for equal probability of group membership (T_e) was 0.836, with a 95% Confidence Interval of 0.772– 0. 900.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	$n_{i\cdot}$	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass			3			3	**0.0**
	Algae	4	7	**146**		8	165	**88.5**
	Emerg Veg						0	**n/a**
	No Cover					**0**	0	**n/a**
	$n_{\cdot j}$	4	7	149	0	8	**168 <= *n***	
	PRODUCERS Accuracy (%)	**0.0**	**0.0**	**98.0**	**n/a**	**0.0**	**P_o 86.9%**	

T_e = 0.836 ± 0.064

Table 6. Error matrix for quantitative ROI 1 Major biological cover. The overall accuracy (P_o) was 86.8%. The Tau coefficient for equal probability of group membership (T_e) was 0.836, with a 95% Confidence Interval of 0.702– 0. 970.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	$n_{i\cdot}$	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass			3			3	**0.0**
	Algae			**33**			33	**100.0**
	Emerg Veg						0	**n/a**
	No Cover			2		**0**	2	**0.0**
	$n_{\cdot j}$	0	0	38	0	0	**38 <= *n***	
	PRODUCERS Accuracy (%)	**n/a**	**n/a**	**86.8**	**n/a**	**n/a**	**P_o 86.8%**	

T_e = 0.836 ± 0.134

Table 7. Error matrix for qualitative ROI 1 Detailed biological cover. The overall accuracy (P_o) was 74.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.723, with a 95% Confidence Interval of 0.652– 0. 794.

			TRUE (GROUND-TRUTHED) (j)														
DETAILED COVER			**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n i -**	**USERS Accuracy (%)**
			L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			
MAP DATA (i)	**Coral**	**L**	**0**													0	**n/a**
		M		**0**												0	**n/a**
		H			**0**											0	**n/a**
	Seagrass	**L**				**0**				2						2	**0.0**
		M					**0**									0	**n/a**
		H						**0**		1						1	**0.0**
	Algae	**L**				1			**1**	9					1	12	**8.3**
		M	1	3		3	3		2	**115**	4				7	138	**83.3**
		H								6	**9**					15	**60.0**
	Emergent Vegetation	**L**										**0**				0	**n/a**
		M											**0**			0	**n/a**
		H												**0**		0	**n/a**
	No Cover														**0**	0	**n/a**
n - j			1	3	0	4	3	0	3	133	13	0	0	0	8	**168 <= *n***	
PRODUCERS Accuracy (%)			**0.0**	**0.0**	**n/a**	**0.0**	**0.0**	**n/a**	**33.3**	**86.5**	**69.2**	**n/a**	**n/a**	**n/a**	**0.0**	**P_o 74.4%**	

T_e = 0.723 ± 0.071

Table 8. Error matrix for quantitative ROI 1 Detailed biological cover. The overall accuracy (P_o) was 55.3%. The Tau coefficient for equal probability of group membership (T_e) was 0.515, with a 95% Confidence Interval of 0.344– 0. 686.

			TRUE (GROUND-TRUTHED) (j)														
DETAILED COVER			**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n i -**	**USERS Accuracy (%)**
			L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			
MAP DATA (i)	**Coral**	**L**	**0**													0	**n/a**
		M		**0**												0	**n/a**
		H			**0**											0	**n/a**
	Seagrass	**L**				**0**										0	**n/a**
		M					**0**									0	**n/a**
		H						**0**	1	2						3	**0.0**
	Algae	**L**							**0**							0	**n/a**
		M							1	**21**	10					32	**65.6**
		H								1	**0**					1	**0.0**
	Emergent Vegetation	**L**										**0**				0	**n/a**
		M											**0**			0	**n/a**
		H												**0**		0	**n/a**
	No Cover								1	1					**0**	2	**0.0**
n - j			0	0	0	0	0	0	3	25	10	0	0	0	0	**38 <= *n***	
PRODUCERS Accuracy (%)			**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**0.0**	**84.0**	**0.0**	**n/a**	**n/a**	**n/a**	**n/a**	**P_o 55.3%**	

T_e = 0.515 ± 0.171

Table 9. Error matrix for qualitative ROI 1 Detailed Coral Cover. The overall accuracy (P_o) was 73.2%. The Tau coefficient for equal probability of group membership (T_e) was 0.643, with a 95% Confidence Interval of 0.554– 0.732. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

CORAL COVER		**Coral**				n_{i-}	**USERS Accuracy (%)**
		0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i) Coral	**0-<10%**	**95**	15			110	**86.4**
	10-<50%	24	**28**	5	1	58	**48.3**
	50-<90%			**0**		0	**n/a**
	>90%				**0**	0	**n/a**
n_{-j}		119	43	5	1	**168**	**<= *n***
PRODUCERS Accuracy (%)		**79.8**	**65.1**	**0.0**	**0.0**	P_o	**73.2%**

T_e = **0.643 ± 0.089**

Table 10. Error matrix for quantitative ROI 1 Detailed Coral Cover. The overall accuracy (P_o) was 60.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.474, with a 95% Confidence Interval of 0.267– 0.681. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

CORAL COVER		**Coral**				n_{i-}	**USERS Accuracy (%)**
		0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i) Coral	**0-<10%**	**19**	9			28	**67.9**
	10-<50%	6	**4**			10	**40.0**
	50-<90%			**0**		0	**n/a**
	>90%				**0**	0	**n/a**
n_{-j}		25	13	0	0	**38**	**<= *n***
PRODUCERS Accuracy (%)		**76.0**	**30.8**	**n/a**	**n/a**	P_o	**60.5%**

T_e = **0.474 ± 0.207**

3.2 Geomorphological Structure ROI-2

The overall accuracies (P_o) for Major Geomorphological Structure in ROI-2 were 83.1% for the qualitative and 87.6% for the quantitative data (Table 11 Table 12). The Tau coefficients for equal probability of group membership (T_e) for qualitative data was 0.663 ± 0.094 and 0.752 ± 0.126 (α=0.05) for quantitative data.

3.2.1 Biological Cover ROI-2

The overall accuracies (P_o) for qualitative Major and Detailed Biological Cover in ROI-2 were 87.2% and 70.4% respectively (Table 13Table 15). Overall accuracies for quantitative Major and Detailed cover were 86.7% and 53.3% respectively (Table 14Table 16). The Tau coefficient for equal probability of group membership (T_e) for qualitative data were 0.841 ± 0.052 at the major and 0.679 ± 0.062 (α=0.05) for detailed covers. Tau coefficients for quantitative data were 0.833 ± 0.081 at the major and 0.494 ± 0.103 (α=0.05) for detailed covers.

3.2.2 Coral Cover ROI-2

The overall accuracies (P_o) for qualitative Detailed Coral cover were 86% and 54.3% for quantitative data (Tables 17 and 18). The Tau coefficients for equal probability of group membership (T_e) for qualitative data were 0.813 ± 0.058 and 0.390 ± 0.127 (α=0.05) for quantitative data.

Table 11. Error matrix for Qualitative ROI 2 Major Geomorphological Structure. The overall accuracy (P_o) was 83.1%. The Tau coefficient for equal probability of group membership (T_e) was 0.663, with a 95% Confidence Interval of 0.569– 0.757.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**202**	36	238	**84.9**
	soft	5	**0**	5	**0.0**
	n_{-j}	207	36	**243**	<= n
	PRODUCERS Accuracy (%)	**97.6**	**0.0**	P_o	**83.1%**

$T_e = 0.663 \pm 0.094$

Table 12. Error matrix for Quantitative ROI 2 Major Geomorphological Structure. The overall accuracy (P_o) was 87.6%. The Tau coefficient for equal probability of group membership (T_e) was 0.752, with a 95% Confidence Interval of 0.626– 0.878.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**92**	0	92	**100.0**
	soft	13	**0**	13	**0.0**
	n_{-j}	105	0	**105**	<= n
	PRODUCERS Accuracy (%)	**87.6**	**0.0**	P_o	**87.6%**

$T_e = 0.752 \pm 0.126$

Table 13. Error matrix for Qualitative ROI 2 Major biological cover. The overall accuracy (P_o) was 87.2%. The Tau coefficient for equal probability of group membership (T_e) was 0.841, with a 95% Confidence Interval of 0.789– 0. 893.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass		**2**	6			8	**25.0**
	Algae		10	**210**		15	235	**89.4**
	Emerg Veg						0	**n/a**
	No Cover					**0**	0	**n/a**
	n_{-j}	0	12	216	0	15	**243**	**<=** n
	PRODUCERS Accuracy (%)	**n/a**	**16.7**	**97.2**	**n/a**	**0.0**	P_o	**87.2%**

T_e = 0.841 ± 0.052

Table 14. Error matrix for Quantitative ROI 2 Major biological cover. The overall accuracy (P_o) was 86.7%. The Tau coefficient for equal probability of group membership (T_e) was 0.833, with a 95% Confidence Interval of 0.752– 0. 914.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass			8			8	**0.0**
	Algae			**91**			91	**100.0**
	Emerg Veg						0	**n/a**
	No Cover			6		**0**	6	**0.0**
	n_{-j}	0	0	105	0	0	**105**	**<=** n
	PRODUCERS Accuracy (%)	**n/a**	**n/a**	**86.7**	**n/a**	**n/a**	P_o	**86.7%**

T_e = 0.833 ± 0.081

Table 15. Error matrix for Qualitative ROI 2 Detailed biological cover. The overall accuracy (P_o) was 70.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.679, with a 95% Confidence Interval of 0.617– 0. 741.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i)	***DETAILED COVER***	Coral			Seagrass			Algae			Emergent Vegetation			No Cover	n_{i-}	USERS Accuracy (%)
		L	M	H	L	M	H	L	M	H	L	M	H			
Coral	L	**0**													0	**n/a**
	M		**0**												0	**n/a**
	H			**0**											0	**n/a**
Seagrass	L				**0**				3						3	**0.0**
	M					**2**			2						4	**50.0**
	H						**0**		1						1	**0.0**
Algae	L							**4**	10	2				4	20	**20.0**
	M				4	5	1	1	**155**	9				6	181	**85.6**
	H								19	**10**				5	34	**29.4**
Emergent Vegetation	L										**0**				0	**n/a**
	M											**0**			0	**n/a**
	H												**0**		0	**n/a**
No Cover														**0**	0	**n/a**
	n $_{-j}$	0	0	0	4	7	1	5	190	21	0	0	0	15	**243** <= ***n***	
	PRODUCERS Accuracy (%)	**n/a**	**n/a**	**n/a**	**0.0**	**28.6**	**0.0**	**80.0**	**81.6**	**47.6**	**n/a**	**n/a**	**n/a**	**0.0**	**P_o 70.4%**	

T_e = 0.679 ± 0.062

Table 16. Error matrix for Quantitative ROI 2 Detailed biological cover. The overall accuracy (P_o) was 53.3%. The Tau coefficient for equal probability of group membership (T_e) was 0.494, with a 95% Confidence Interval of 0.391– 0. 597.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i)	***DETAILED COVER***	Coral			Seagrass			Algae			Emergent Vegetation			No Cover	n_{i-}	USERS Accuracy (%)
		L	M	H	L	M	H	L	M	H	L	M	H			
Coral	L	**0**													0	**n/a**
	M		**0**												0	**n/a**
	H			**0**											0	**n/a**
Seagrass	L				**0**				1	2					3	**0.0**
	M					**0**		1	2						3	**0.0**
	H						**0**		1	1					2	**0.0**
Algae	L							**0**							0	**n/a**
	M							1	**45**	22					68	**66.2**
	H								12	**11**					23	**47.8**
Emergent Vegetation	L										**0**				0	**n/a**
	M											**0**			0	**n/a**
	H												**0**		0	**n/a**
No Cover								1	4	1				**0**	6	**0.0**
	n $_{-j}$	0	0	0	0	0	0	3	65	37	0	0	0	0	**105** <= ***n***	
	PRODUCERS Accuracy (%)	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**0.0**	**69.2**	**29.7**	**n/a**	**n/a**	**n/a**	**n/a**	**P_o 53.3%**	

T_e = 0.494 ± 0.103

Table 17 Error matrix for Qualitative ROI 2 Detailed Coral Cover. The overall accuracy (P_o) was 86.0%. The Tau coefficient for equal probability of group membership (T_e) was 0.813, with a 95% Confidence Interval of 0.755– 0.871. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

CORAL COVER			Coral				n_{i-}	USERS Accuracy (%)
			0-<10%	10-<50%	50-<90%	>90%		
MAP DATA (i)	Coral	0-<10%	**172**	16			188	**91.5**
		10-<50%	18	**37**			55	**67.3**
		50-<90%			**0**		0	**n/a**
		>90%				**0**	0	**n/a**
n_{-j}			190	53	0	0	**243**	**<= n**
PRODUCERS Accuracy (%)			**90.5**	**69.8**	**n/a**	**n/a**	**P_o**	**86.0%**

$$T_e = 0.813 \pm 0.058$$

Table 18. Error matrix for Quantitative ROI 2 Detailed Coral Cover. The overall accuracy (P_o) was 54.3%. The Tau coefficient for equal probability of group membership (T_e) was 0.390, with a 95% Confidence Interval of 0.263– 0.517. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

CORAL COVER			Coral				n_{i-}	USERS Accuracy (%)
			0-<10%	10-<50%	50-<90%	>90%		
MAP DATA (i)	Coral	0-<10%	**42**	20			62	**67.7**
		10-<50%	28	**15**			43	**34.9**
		50-<90%			**0**		0	**n/a**
		>90%				**0**	0	**n/a**
n_{-j}			70	35	0	0	**105**	**<= n**
PRODUCERS Accuracy (%)			**60.0**	**42.9**	**n/a**	**n/a**	**P_o**	**54.3%**

$$T_e = 0.390 \pm 0.127$$

3.3 Geomorphological Structure ROI-4

The overall accuracies (P_o) for the qualitative data on Major Geomorphological Structure in ROI-4 were 80.8% and 83.8% for the quantitative data (Tables 19 and 20). The Tau coefficients for equal probability of group membership (T_e) for qualitative data was 0.616 ± 0.116 and 0.675 ± 0.162 (α=0.05) for quantitative data.

3.3.1 Biological Cover ROI-4

The overall accuracies (P_o) for qualitative Major and Detailed Biological Cover in ROI-4 were 81.4% and 78% respectively (Table 21 and 23). Overall accuracies for quantitative major and detailed cover were 82.5% and 45% respectively (Table 22Table 24). The Tau coefficient for equal probability of group membership (T_e) for qualitative data were 0.767 ± 0.072 at the major and 0.761 ± 0.066 (α=0.05) for detailed covers. Tau coefficients for quantitative data were 0.781 ± 0.104 at the major and 0.404 ± 0.118 (α=0.05) for detailed covers.

3.3.2 Coral Cover ROI-4

The overall accuracies (P_o) for qualitative detailed cover were 37.3% and 32.5% for quantitative data (Table 25 and 26). . The Tau coefficients for equal probability of group membership (T_e) for qualitative data were 0.164 ± 0.095 and 0.100 ± 0.137 (α=0.05) for quantitative data.

Table 19. Error matrix for Qualitative ROI 4 Major Geomorphological Structure. The overall accuracy (P_o) was 80.8%. The Tau coefficient for equal probability of group membership (T_e) was 0.616, with a 95% Confidence Interval of 0.500– 0.732.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**143**	33	176	**81.3**
	soft	1	**0**	1	**0.0**
	n_{-j}	144	33	**177**	**<=** n
	PRODUCERS Accuracy (%)	**99.3**	**0.0**	P_o	**80.8%**

$T_e = 0.616 \pm 0.116$

Table 20. Error matrix for Quantitative ROI 4 Major Geomorphological Structure. The overall accuracy (P_o) was 83.8%. The Tau coefficient for equal probability of group membership (T_e) was 0.675, with a 95% Confidence Interval of 0.513– 0.837.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**67**	0	67	**100.0**
	soft	13	**0**	13	**0.0**
	n_{-j}	80	0	**80**	**<=** n
	PRODUCERS Accuracy (%)	**83.8**	**n/a**	P_o	**83.8%**

$T_e = 0.675 \pm 0.162$

Table 21. Error matrix for Qualitative ROI 4 Major biological cover. The overall accuracy (P_o) was 81.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.767, with a 95% Confidence Interval of 0.695– 0.839.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass			1			1	**0.0**
	Algae	1	30	**144**		1	176	**81.8**
	Emerg Veg						0	**n/a**
	No Cover					**0**	0	**n/a**
	n_{-j}	1	30	145	0	1	**177**	**<= n**
	PRODUCERS Accuracy (%)	**0.0**	**0.0**	**99.3**	**n/a**	**0.0**	**P_o**	**81.4%**

T_e = 0.767 ± 0.072

Table 22. Error matrix for Quantitative ROI 4 Major biological cover. The overall accuracy (P_o) was 82.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.781, with a 95% Confidence Interval of 0.677– 0.885.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass			6			6	**0.0**
	Algae	1		**66**			67	**98.5**
	Emerg Veg						0	**n/a**
	No Cover			7		**0**	7	**0.0**
	n_{-j}	1	0	79	0	0	**80**	**<= n**
	PRODUCERS Accuracy (%)	**0.0**	**n/a**	**83.5**	**n/a**	**n/a**	**P_o**	**82.5%**

T_e = 0.781 ± 0.104

Table 23. Error matrix for Qualitative ROI 4 Detailed biological cover. The overall accuracy (P_o) was 78.0%. The Tau coefficient for equal probability of group membership (T_e) was 0.761, with a 95% Confidence Interval of 0.695– 0.827.

TRUE (GROUND-TRUTHED) (j)

DETAILED COVER			**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n_{i-}**	**USERS Accuracy (%)**
			L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			
MAP DATA (i)	**Coral**	**L**	**0**													0	**n/a**
		M		**0**												0	**n/a**
		H			**0**											0	**n/a**
	Seagrass	**L**				**0**										0	**n/a**
		M					**0**				1					1	**0.0**
		H						**0**								0	**n/a**
	Algae	**L**					2	1	**0**	2	3					8	**0.0**
		M		1		3	18	4		**111**					1	138	**80.4**
		H					2		1		**27**					30	**90.0**
	Emergent Vegetation	**L**										**0**				0	**n/a**
		M											**0**			0	**n/a**
		H												**0**		0	**n/a**
	No Cover														**0**	0	**n/a**
n_{-j}			0	1	0	3	22	5	1	113	31	0	0	0	1	**177**	**<= *n***
PRODUCERS Accuracy (%)			**n/a**	**0.0**	**n/a**	**0.0**	**0.0**	**0.0**	**0.0**	**98.2**	**87.1**	**n/a**	**n/a**	**n/a**	**0.0**	**P_o**	**78.0%**

T_e = 0.761 ± 0.066

Table 24. Error matrix for Quantitative ROI 4 Detailed biological cover. The overall accuracy (P_o) was 45.0%. The Tau coefficient for equal probability of group membership (T_e) was 0.745, with a 95% Confidence Interval of 0.725– 0.765.

TRUE (GROUND-TRUTHED) (j)

DETAILED COVER			**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n_{i-}**	**USERS Accuracy (%)**
			L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			
MAP DATA (i)	**Coral**	**L**	**0**													0	**n/a**
		M		**0**												0	**n/a**
		H			**0**											0	**n/a**
	Seagrass	**L**				**0**										0	**n/a**
		M					**0**			2						2	**0.0**
		H						**0**		3	1					4	**0.0**
	Algae	**L**							**0**							0	**n/a**
		M	1							**35**	28					64	**54.7**
		H								2	**1**					3	**33.3**
	Emergent Vegetation	**L**										**0**				0	**n/a**
		M											**0**			0	**n/a**
		H												**0**		0	**n/a**
	No Cover									6	1				**0**	7	**0.0**
n_{-j}			1	0	0	0	0	0	0	48	31	0	0	0	0	**80**	**<= *n***
PRODUCERS Accuracy (%)			**0.0**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**72.9**	**3.2**	**n/a**	**n/a**	**n/a**	**n/a**	**P_o**	**45.0%**

T_e = 0.404 ± 0.118

Table 25. Error matrix for Qualitative ROI 4 Detailed Coral Cover. The overall accuracy (P_o) was 37.3%. The Tau coefficient for equal probability of group membership (T_e) was 0.164, with a 95% Confidence Interval of 0.069– 0.259. Blank cells indicate 0 occurrences.

		TRUE (GROUND-TRUTHED) (j)					
	CORAL COVER	**Coral**				n_{i-}	**USERS Accuracy (%)**
		0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i) **Coral**	**0-<10%**	**15**	18			33	**45.5**
	10-<50%	87	**51**	6		144	**35.4**
	50-<90%			**0**		0	**n/a**
	>90%				**0**	0	**n/a**
	n_{-j}	102	69	6	0	**177**	**<=** ***n***
	PRODUCERS Accuracy (%)	**14.7**	**73.9**	**0.0**	**n/a**	P_o	**37.3%**

$T_e = 0.164 \pm 0.095$

Table 26. Error matrix for Quantitative ROI 4 Detailed Coral Cover. The overall accuracy (P_o) was 32.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.100, with a 95% Confidence Interval of 0– 0.237. Blank cells indicate 0 occurrences.

		TRUE (GROUND-TRUTHED) (j)					
	CORAL COVER	**Coral**				n_{i-}	**USERS Accuracy (%)**
		0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i) **Coral**	**0-<10%**	**15**	5			20	**75.0**
	10-<50%	49	**11**			60	**18.3**
	50-<90%			**0**		0	**n/a**
	>90%				**0**	0	**n/a**
	n_{-j}	64	16	0	0	**80**	**<=** ***n***
	PRODUCERS Accuracy (%)	**23.4**	**68.8**	**n/a**	**n/a**	P_o	**32.5%**

$T_e = 0.100 \pm 0.137$

3.4 Geomorphological Structure ROIs 1, 2, and 4 combined

The overall accuracies (P_o) for the qualitative Major Geomorphological Structure data in ROIs 1, 2, and 4 combined were 84.2% and 86.1% for the quantitative data (Table 27Table 28). The Tau coefficients for equal probability of group membership (T_e) for qualitative data was 0.807 ± 0.035 and 0.815 ± 0.058 ($\alpha=0.05$) for quantitative data.

3.4.1 Biological Cover ROIs 1, 2, and 4 combined

The overall accuracies (P_o) for qualitative Major and Detailed Biological Cover in ROIs 1, 2, and 4 combined were 85.4% and 73.8% respectively (Table 29Table 31). Overall accuracies for quantitative major and detailed cover were 85.2% and 50.7% respectively (Table 30Table 32). The Tau coefficient for equal probability of group membership (T_e) for qualitative data were 0.807 ± 0.035 at the major and 0.676 ± 0.038 ($\alpha=0.05$) for detailed covers. Tau coefficients for quantitative data were 0.815 ± 0.058 at the major and 0.466 ± 0.071 ($\alpha=0.05$) for detailed covers.

3.4.2 Coral Cover ROIs 1, 2, and 4 combined

The overall accuracies (P_o) for qualitative Detailed Coral cover in ROIs 1, 2, and 4 were 70.4% and 47.5% for quantitative data (Table 33Table 34). The Tau coefficients for equal probability of group membership (T_e) for qualitative data were 0.605 ± 0.047 and 0.300 ± 0.087 ($\alpha=0.05$) for quantitative data.

Table 27. Error matrix for Qualitative ROIs 1, 2, and 4 Combined Major Geomorphological Structure. The overall accuracy (P_o) was 84.2%. The Tau coefficient for equal probability of group membership (T_e) was 0.645, with a 95% Confidence Interval of 0.586– 0.704.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**495**	84	579	**85.5**
	soft	9	**0**	9	**0.0**
	n_{-j}	504	84	**588**	**<=** n
	PRODUCERS Accuracy (%)	**98.2**	**0.0**	P_o	**84.2%**

$T_e = 0.645 \pm 0.059$

Table 28. Error matrix for Quantitative ROIs 1, 2, and 4 Combined Major Geomorphological Structure. The overall accuracy (P_o) was 86.1%. The Tau coefficient for equal probability of group membership (T_e) was 0.722, with a 95% Confidence Interval of 0.631– 0.813.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**192**	0	192	**100.0**
	soft	31	**0**	31	**0.0**
	n_{-j}	223	0	**223**	**<=** n
	PRODUCERS Accuracy (%)	**86.1**	**n/a**	P_o	**86.1%**

$T_e = 0.722 \pm 0.091$

Table 29. Error matrix for Qualitative ROIs 1, 2, and 4 Combined Major biological cover. The overall accuracy (P_o) was 85.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.807, with a 95% Confidence Interval of 0.772– 0. 842.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass		**2**	10			12	**16.7**
	Algae	5	47	**500**		24	576	**86.8**
	Emerg Veg						0	**n/a**
	No Cover					**0**	0	**n/a**
	n_{-j}	5	49	510	0	24	**588** <= n	
	PRODUCERS Accuracy (%)	**0.0**	**4.1**	**98.0**	**n/a**	**0.0**	P_o **85.4%**	

T_e = 0.807 ± 0.035

Table 30. Error matrix for Quantitative ROIs 1, 2, and 4 Combined Major biological cover. The overall accuracy (P_o) was 85.2%. The Tau coefficient for equal probability of group membership (T_e) was 0.815, with a 95% Confidence Interval of 0.757– 0.873.

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass			17			17	**0.0**
	Algae	1		**190**			191	**99.5**
	Emerg Veg						0	**n/a**
	No Cover			15		**0**	15	**0.0**
	n_{-j}	1	0	222	0	0	**223** <= n	
	PRODUCERS Accuracy (%)	**0.0**	**n/a**	**85.6**	**n/a**	**n/a**	P_o **85.2%**	

T_e = 0.815 ± 0.058

Table 31. Error matrix for Qualitative ROIs 1, 2, and 4 Combined Detailed biological cover. The overall accuracy (P_o) was 73.8%. The Tau coefficient for equal probability of group membership (T_e) was 0.676, with a 95% Confidence Interval of 0.638– 0. 714.

TRUE (GROUND-TRUTHED) (j)

DETAILED COVER			**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n i -**	**USERS Accuracy (%)**
			L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			
MAP DATA (i)	**Coral**	**L**	**0**													0	**n/a**
		M		**0**												0	**n/a**
		H			**0**											0	**n/a**
	Seagrass	**L**				**0**				5						5	**0.0**
		M					**2**			2	1					5	**40.0**
		H						**0**		2						2	**0.0**
	Algae	**L**				1	2	1	**5**	21	5				5	40	**12.5**
		M	1	4		10	26	5	3	**381**	13				14	457	**83.4**
		H					2		1	25	**46**				5	79	**58.2**
	Emergent Vegetation	**L**										**0**				0	**n/a**
		M											**0**			0	**n/a**
		H												**0**		0	**n/a**
	No Cover														**0**	0	**n/a**
n - j			1	4	0	11	32	6	9	436	65	0	0	0	24	**588**	**<= *n***
PRODUCERS Accuracy (%)			**0.0**	**0.0**	**n/a**	**0.0**	**6.3**	**0.0**	**55.6**	**87.4**	**70.8**	**n/a**	**n/a**	**n/a**	**0.0**	**P_o**	**73.8%**

T_e = 0.676 ± 0.038

Table 32. Error matrix for Quantitative ROIs 1, 2, and 4 Combined Detailed biological cover. The overall accuracy (P_o) was 50.7%. The Tau coefficient for equal probability of group membership (T_e) was 0.466, with a 95% Confidence Interval of 0.395– 0. 537.

TRUE (GROUND-TRUTHED) (j)

DETAILED COVER			**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n i -**	**USERS Accuracy (%)**
			L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			
MAP DATA (i)	**Coral**	**L**	**0**													0	**n/a**
		M		**0**												0	**n/a**
		H			**0**											0	**n/a**
	Seagrass	**L**				**0**				1	2					3	**0.0**
		M					**0**		1	4						5	**0.0**
		H						**0**	1	6	2					9	**0.0**
	Algae	**L**							**0**							0	**n/a**
		M	1						2	**101**	60					164	**61.6**
		H								15	**12**					27	**44.4**
	Emergent Vegetation	**L**										**0**				0	**n/a**
		M											**0**			0	**n/a**
		H												**0**		0	**n/a**
	No Cover								2	11	2				**0**	15	**0.0**
n - j			1	0	0	0	0	0	6	138	78	0	0	0	0	**223**	**<= *n***
PRODUCERS Accuracy (%)			**0.0**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**0.0**	**73.2**	**15.4**	**n/a**	**n/a**	**n/a**	**n/a**	**P_o**	**50.7%**

T_e = 0.466 ± 0.071

Table 33. Error matrix for Qualitative ROIs 1, 2, and 4 Combined Detailed Coral Cover. The overall accuracy (P_o) was 70.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.605, with a 95% Confidence Interval of 0.558– 0.652. Blank cells indicate 0 occurrences.

CORAL COVER			**TRUE (GROUND-TRUTHED) (j)**					
			Coral				**n_{i-}**	**USERS Accuracy (%)**
			0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i)	**Coral**	**0-<10%**	**334**	49			383	**87.2**
		10-<50%	129	**118**	11	1	259	**45.6**
		50-<90%			**0**		0	**n/a**
		>90%				**0**	0	**n/a**
n_{-j}			463	167	11	1	**642**	**<= *n***
PRODUCERS Accuracy (%)			**72.1**	**70.7**	**0.0**	**0.0**	**P_o**	**70.4%**

T_e = 0.605 ± 0.047

Table 34. Error matrix for Quantitative ROIs 1, 2, and 4 Combined Detailed Coral Cover. The overall accuracy (P_o) was 47.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.100, with a 95% Confidence Interval of 0.213– 0.387. Blank cells indicate 0 occurrences.

CORAL COVER			**TRUE (GROUND-TRUTHED) (j)**					
			Coral				**n_{i-}**	**USERS Accuracy (%)**
			0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i)	**Coral**	**0-<10%**	**76**	34			110	**69.1**
		10-<50%	83	**30**			113	**26.5**
		50-<90%			**0**		0	**n/a**
		>90%				**0**	0	**n/a**
n_{-j}			159	64	0	0	**223**	**<= *n***
PRODUCERS Accuracy (%)			**47.8**	**46.9**	**n/a**	**n/a**	**P_o**	**47.5%**

T_e = 0.300 ± 0.087

3.5 Geomorphological Structure for Entire Keys 1999-2009 and 2005-2009

The overall accuracies (P_o) for 1999-2009 quantitative Major Geomorphological Structure data throughout the Florida Keys were 83.6% and 83.3% for the 2005-2009 data (

Table *35*Table 36). The Tau coefficients for equal probability of group membership (T_e) for 1999-2009 quantitative data were 0.672 ± 0.062 and 0.667 ± 0.082 (α=0.05) for 2005-2009 data.

3.5.1 Biological Cover for Entire Keys 1999-2009 and 2005-2009

The overall accuracies (P_o) for 1999-2009 quantitative Major and Detailed Biological Cover data throughout the Florida Keys were 82% and 51.2% respectively (Table 377 and 39). The overall accuracies for 2005-2009 quantitative Major and Detailed Biological Cover data throughout the Florida Keys were 81.4% and 53.5% respectively (Tables 38 and 40). The Tau coefficients for equal probability of group membership (T_e) for 1999-2009 quantitative data were 0.775 ± 0.040 at the major and 0.471 ± 0.045 (α=0.05) for the detailed level of biological cover.

3.5.2 Coral Cover for Entire Keys 1999-2009 and 2005-2009

The overall accuracies (P_o) for quantitative Detailed Coral Cover from the 1999-2009 data set were 50.1% and 52.5% for 2005-2009 data (Table 411Table 422). The Tau coefficients for equal probability of group membership (T_e) for 1999-2009 quantitative data were 0.335 ± 0.056 and 0.367 ± 0.073 (α=0.05) for the 2005-2009 data.

Table 35. Error matrix for Miller Quantitative 1999-2009 Entire Florida Keys Major Geomorphological Structure. The overall accuracy (P_o) was 83.6%. The Tau coefficient for equal probability of group membership (T_e) was 0.672, with a 95% Confidence Interval of 0.610– 0.734.

1999-2009 Data Set

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	***n_{i-}***	**USERS Accuracy (%)**
MAP (i)	**hard**	**459**	0	459	**100.0**
	soft	90	**0**	90	**0.0**
	n_{-j}	549	0	**549**	**<= *n***
	PRODUCERS Accuracy (%)	**83.6**	**n/a**	**P_o**	**83.6%**

T_e = 0.672 ± 0.062

Table 36. Error matrix for Miller Quantitative 2005-2009 Entire Florida Keys Major Geomorphological Structure. The overall accuracy (P_o) was 83.3%. The Tau coefficient for equal probability of group membership (T_e) was 0.667, with a 95% Confidence Interval of 0.585– 0.749.

2005-2009 Data Set

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	***n_{i-}***	**USERS Accuracy (%)**
MAP (i)	**hard**	**265**	0	265	**100.0**
	soft	53	**0**	53	**0.0**
	n_{-j}	318	0	**318**	**<= *n***
	PRODUCERS Accuracy (%)	**83.3**	**n/a**	**P_o**	**83.3%**

T_e = 0.667 ± 0.082

Table 37. Error matrix for Miller Quantitative Entire Florida Keys Major biological cover. The overall accuracy (P_o) was 82.0%. The Tau coefficient for equal probability of group membership (T_e) was 0.775, with a 95% Confidence Interval of 0.735– 0.815.

1999-2009 Data Set

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**		2			2	**0.0**
	Seagrass			55			55	**0.0**
	Algae	7		**452**			459	**98.5**
	Emerg Veg						0	**n/a**
	No Cover	1		34		**0**	35	**0.0**
	n_{-j}	8	0	543	0	0	**551**	**<=** n
	PRODUCERS Accuracy (%)	**0.0**	**n/a**	**83.2**	**n/a**	**n/a**	P_o	**82.0%**

T_e = 0.775 ± 0.040

Table 38. Error matrix for Miller Quantitative 2005-2009 Entire Florida Keys Major biological cover. The overall accuracy (P_o) was 81.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.775, with a 95% Confidence Interval of 0.715– 0.821.

2005-2009 Data Set

		TRUE (GROUND-TRUTHED) (j)						
	MAJOR COVER	**Coral**	**Sea Grass**	**Algae**	**Emerg Veg**	**No Cover**	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i)	**Coral**	**0**					0	**n/a**
	Seagrass			36			36	**0.0**
	Algae	6		**259**			265	**97.7**
	Emerg Veg						0	**n/a**
	No Cover			17		**0**	17	**0.0**
	n_{-j}	6	0	312	0	0	**318**	**<=** n
	PRODUCERS Accuracy (%)	**0.0**	**n/a**	**83.0**	**n/a**	**n/a**	P_o	**81.4%**

T_e = 0.768 ± 0.053

Table 39. Error matrix for Miller Quantitative Entire Florida Keys Detailed biological cover. The overall accuracy (P_o) was 51.2%. The Tau coefficient for equal probability of group membership (T_e) was 0.471, with a 95% Confidence Interval of 0.426– 0.516.

1999-2009 Data Set

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i)

DETAILED COVER		**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n_{i-}**	**USERS Accuracy**
		L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			**(%)**
Coral	**L**	**0**							2						2	**0.0**
	M		**0**												0	**n/a**
	H			**0**											0	**n/a**
Seagrass	**L**				**0**			2	9	1					12	**0.0**
	M					**0**		1	11	1					13	**0.0**
	H						**0**	3	24	3					30	**0.0**
Algae	**L**	1						**0**	5	1					7	**0.0**
	M	5	1					13	**268**	122					409	**65.5**
	H								29	**14**					43	**32.6**
Emergent Vegetation	**L**										**0**				0	**n/a**
	M											**0**			0	**n/a**
	H												**0**		0	**n/a**
No Cover		1						2	23	9				**0**	35	**0.0**
n_{-j}		7	1	0	0	0	0	21	371	151	0	0	0	0	**551**	**<= *n***
PRODUCERS Accuracy (%)		**0.0**	**0.0**	**n/a**	**n/a**	**n/a**	**n/a**	**0.0**	**72.2**	**9.3**	**n/a**	**n/a**	**n/a**	**n/a**	**P_o**	**51.2%**

T_e = 0.471 ± 0.045

Table 40. Error matrix for Miller Quantitative 2005-2009 Entire Florida Keys Detailed biological cover. The overall accuracy (P_o) was 53.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.496, with a 95% Confidence Interval of 0.437– 0.555.

2005-2009 Data Set

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i)

DETAILED COVER		**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	**n_{i-}**	**USERS Accuracy**
		L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**			**(%)**
Coral	**L**	**0**													0	**n/a**
	M		**0**												0	**n/a**
	H			**0**											0	**n/a**
Seagrass	**L**				**0**			2	6						8	**0.0**
	M					**0**			9	1					10	**0.0**
	H						**0**		16	2					18	**0.0**
Algae	**L**	1						**0**	4						5	**0.0**
	M	4	1					10	**164**	59					238	**68.9**
	H								16	**6**					22	**27.3**
Emergent Vegetation	**L**										**0**				0	**n/a**
	M											**0**			0	**n/a**
	H												**0**		0	**n/a**
No Cover								1	13	3				**0**	17	**0.0**
n_{-j}		5	1	0	0	0	0	13	228	71	0	0	0	0	**318**	**<= *n***
PRODUCERS Accuracy (%)		**0.0**	**0.0**	**n/a**	**n/a**	**n/a**	**n/a**	**0.0**	**71.9**	**8.5**	**n/a**	**n/a**	**n/a**	**n/a**	**P_o**	**53.5%**

T_e = 0.496 ± 0.059

Table 41. Error matrix for Miller Quantitative Entire Florida Keys Combined Detailed Coral Cover. The overall accuracy (P_o) was 50.1%. The Tau coefficient for equal probability of group membership (T_e) was 0.335, with a 95% Confidence Interval of 0.279– 0.391. Blank cells indicate 0 occurrences.

1999-2009 Data Set

TRUE (GROUND-TRUTHED) (j)

	CORAL COVER	**Coral**				n_{i-}	**USERS Accuracy (%)**
		0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i) **Coral**	**0-<10%**	**170**	79			249	**68.3**
	10-<50%	195	**106**	1		302	**35.1**
	50-<90%			**0**		0	**n/a**
	>90%				**0**	0	**n/a**
	n_{-j}	365	185	1	0	**551**	**<=** ***n***
	PRODUCERS Accuracy (%)	**46.6**	**57.3**	**0.0**	**n/a**	P_o	**50.1%**

T_e = **0.335 ± 0.056**

Table 42. Error matrix for Miller Quantitative 2005-2009 Entire Florida Keys Combined Detailed Coral Cover. The overall accuracy (P_o) was 52.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.367, with a 95% Confidence Interval of 0.294– 0.440. Blank cells indicate 0 occurrences.

2005-2009 Data Set

TRUE (GROUND-TRUTHED) (j)

	CORAL COVER	**Coral**				n_{i-}	**USERS Accuracy (%)**
		0-<10%	**10-<50%**	**50-<90%**	**>90%**		
MAP DATA (i) **Coral**	**0-<10%**	**89**	42			131	**67.9**
	10-<50%	108	**78**	1		187	**41.7**
	50-<90%			**0**		0	**n/a**
	>90%				**0**	0	**n/a**
	n_{-j}	197	120	1	0	**318**	**<=** ***n***
	PRODUCERS Accuracy (%)	**45.2**	**65.0**	**0.0**	**n/a**	P_o	**52.5%**

T_e = **0.367 ± 0.073**

Table 43. Overall accuracies (percent) and confidence intervals for each ROI, All ROIs combined, and Entire Map by AA technique. Also Quantitative AA results for 1999-2009 and a subset from 2005-2009.

Habitat	**ROI-1**		**ROI-2**		**ROI-4**		**All ROIs**		**Entire Map**	
Data Set	**Qualitative**	**Quantitative**	**Qualitative**	**Quantitative**	**Qualitative**	**Quantitative**	**Qualitative**	**Quantitative**	Quantitative	
									1999-2009	**2005-2009**
Major Structure	89.3 ±7.3	86.8 ±0	83.1 ±11	87.6 ±0	80.8 ±10.3	83.8 ±0	84.2 ±16.9	86.1 ±0	83.6 ±0	83.3 ±0
Major Cover	86.9 ±5.1	86.8 ±0	87.2 ±9.7	86.7 ±0	81.4 ±10.2	82.5 ±1.9	85.4 ±16.4	85.2 ±1.9	82.0 ±5.2	81.4 ±4.8
Detailed Cover	74.4 ±9.7	55.3 ±5.3	70.4 ±11.5	53.3 ±9.1	78.0 ±9.3	45.0 ±8.1	73.8 ±18.7	50.7 ±13.4	51.2 ±20.1	53.5 ±14.8
Coral Cover	73.2 ±10.5	60.5 ±5.8	86.0 ±10.3	54.3 ±9.6	37.3 ±12.8	32.5 ±7.1	70.4 ±20.6	47.5 ±13.4	50.1 ±22.1	52.5 ±17.2

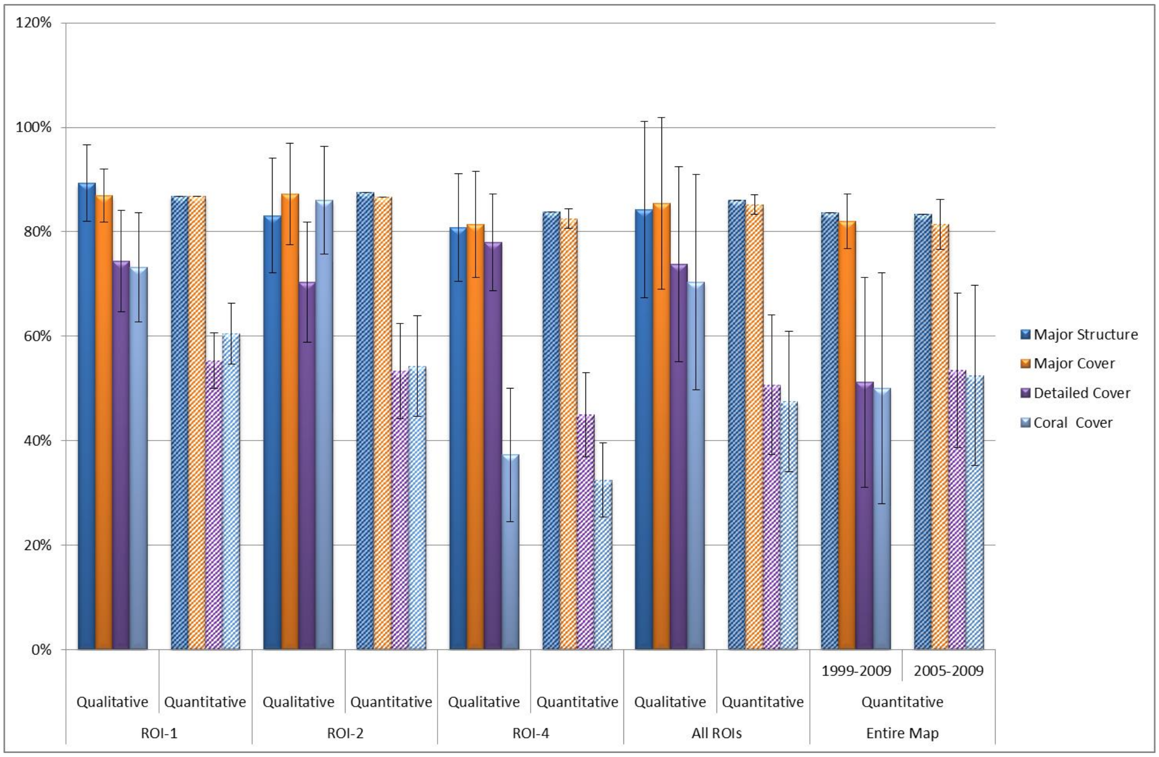

Figure 8. Overall accuracies and confidence intervals for each ROI, All ROIs, and Entire Map by AA technique. Also Quantitative AA results for 1999-2009 and a subset from 2005-2009.

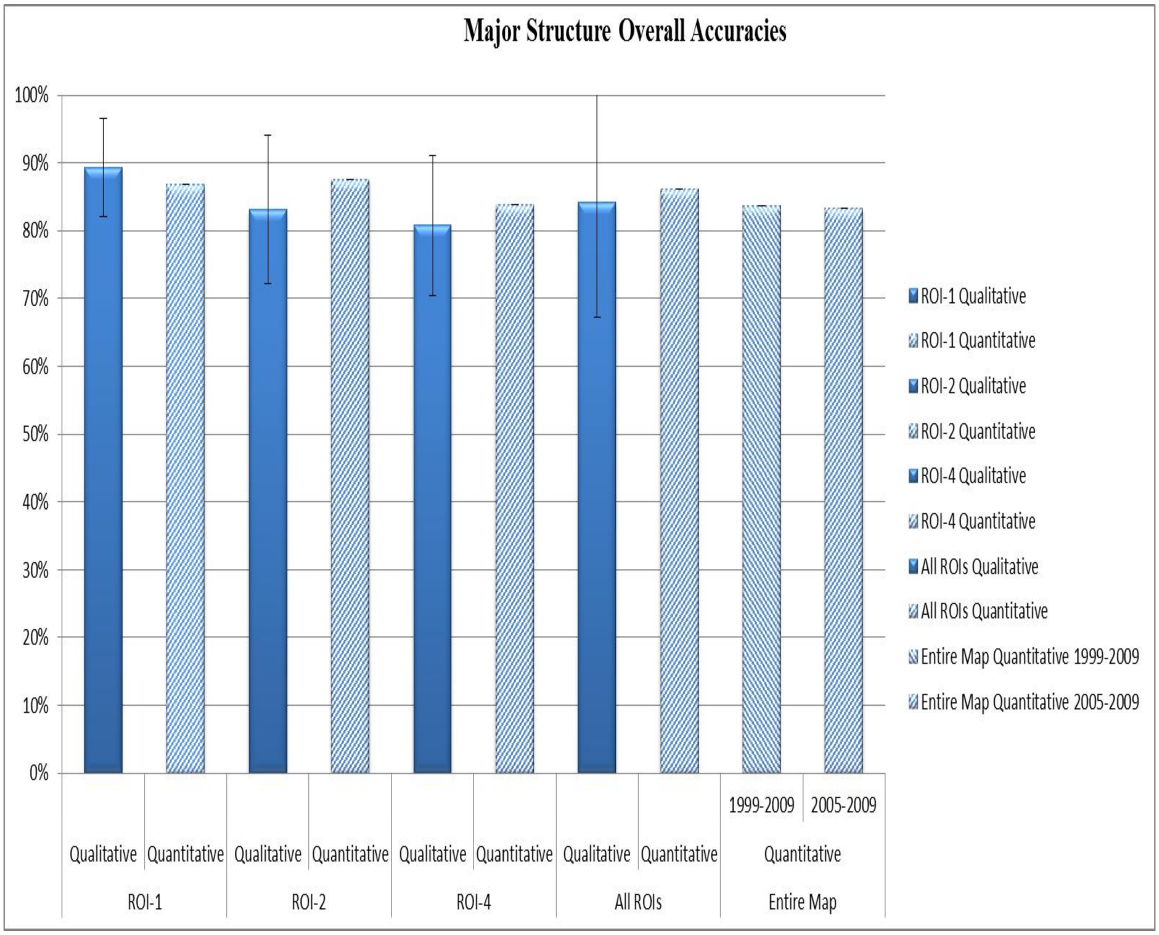

Figure 9. Major Structure overall accuracies for each ROI, All ROIs, and Entire Map by AA technique. Also Quantitative AA results for 1999-2009 and a subset from 2005-2009.

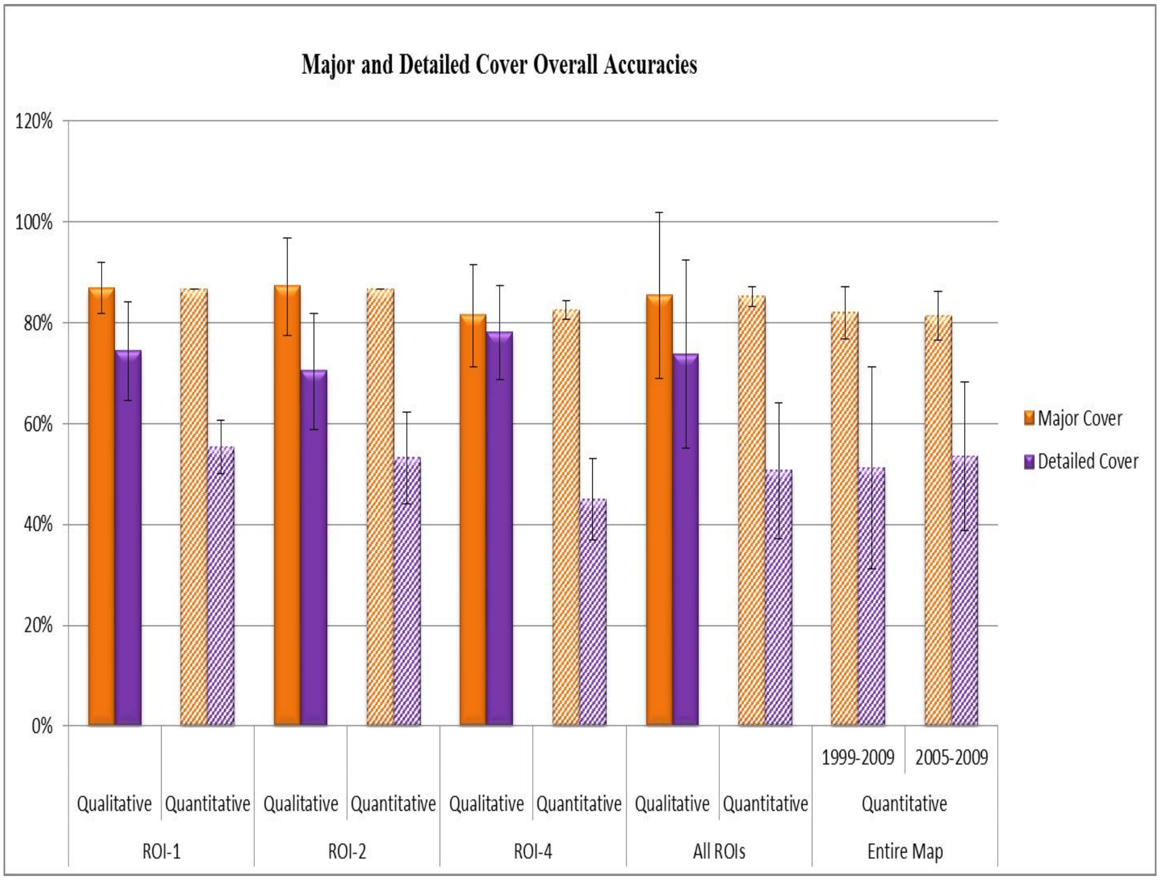

Figure 10. Major and Detailed Biological Cover overall accuracies for each ROI, All ROIs, and Entire Map by AA technique. Also Quantitative AA results for 1999-2009 and a subset from 2005-2009.

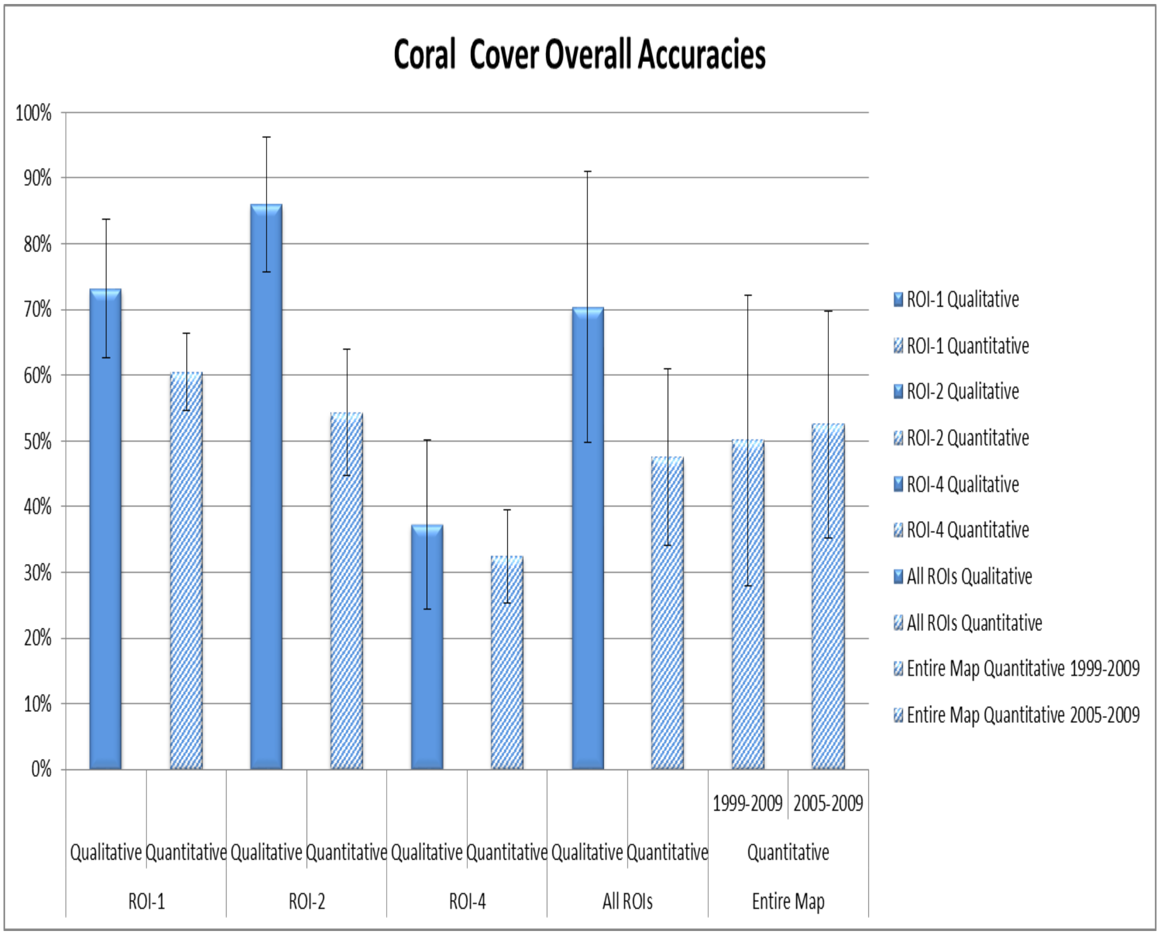

Figure 11. Detailed Coral Cover overall accuracies for each ROI, All ROIs, and Entire Map by AA technique. Also Quantitative AA results for 1999-2009 and a subset from 2005-2009.

4 Discussion

Selection of an optimal accuracy assessment technique for benthic habitat maps requires consideration of the AA technique's strengths and weaknesses in relation to the intended application. While a qualitative AA using benthic videography and photographs can be less expensive, less time consuming, increase the number of survey sites, and provide a permanent visual record, a quantitative *in situ* assessment can provide much more precise measurements at the benthic level (taxonomic resolution and percent cover) and can provide a clearer baseline for future *in situ* studies to monitor changes in benthic community structure (Hughes 1996, Done and Reichelt 1998). In another study (Carleton and Done, 1995) a comparison between video and *in situ* data along the same transects on the central Great Barrier Reef found that video transect data were more cost effective, much faster to conduct per site, and provided a good estimate of major benthic categories over spatial scales of hundreds of meters to kilometers compared to *in situ* data. However, the video data had a much reduced taxonomic resolution for detailed benthic categories. Carleton and Done (1995) also found that reliable accuracy estimates can be obtained by video techniques for broad taxonomic categories of coral reef benthos. Hughes (1996), Done and Reichelt (1998), Carleton and Done (1995) studies support this study's results. While this study did not compare costs involved with each AA technique, an average of 40 more sites were sampled per day with the qualitative AA technique compared to the quantitative AA technique. The qualitative drop camera technique also provides a permanent visual record. However; the quantitative AA technique in this study provides more precise measurements than the qualitative AA and data obtained from the quantitative AA can be used to monitor changes in benthic community structure over time.

In a recent NOAA technical memorandum (Yoklavich and Reynolds, 2015), of a workshop conducted with a broad group of marine scientists, engineers, resource managers, and public policy experts sought input on a variety of survey techniques such as remotely operated vehicles, autonomous underwater vehicles, human-occupied vehicles, towed camera sleds, and human divers using SCUBA. These tools were considered specifically in the context of their use during standardized surveys of benthic organisms and their seafloor habitats. Cost was identified as the primary consideration when selecting a survey tool. The operating limitations of the survey tool, the organisms and habitats of interest, and the availability of the tools and support vessels all were important criteria when evaluating cost and benefits among the different tools. According to the Yoklavich and Reynolds (2015) report, towed camera surveys were found to be less expensive compared to SCUBA surveys, could cover much more area in a shorter amount of time, and also was much less risk to humans. Some drawbacks to using a towed camera survey were the lack of peripheral vision recorded on the camera and low taxonomic diversity identifiable from the observations.

Similarities between AA techniques

This study found that the accuracy was similar using qualitative and quantitative AA techniques for both major and geomorphologic structure and major biological cover (Figures 9 and 10). The less expensive drop camera qualitative assessment technique can therefore be used to obtain accuracy for broad map categories. Previous studies have used qualitative AA techniques for broad categories and acquired a high level of accuracy (Bauer, 2012; Lyons, 2011; Walker and Gilliam, 2013; Walker, 2008; Walker, Rodericks, and Costaregni., 2013).

This study found a reduction in accuracy with increased classification levels in both AA techniques. This result has been observed in many mapping efforts and is the reason the Tao coefficient was devised (Andréfouët et al., 2003; Lunetta and Lyon, 2004; Mumby, and Edwards, 2002; Phinn, 2010; Roelfsema et al., 2006). Andréfouët et al.,(2003) study showed a linear decrease of accuracy with increasing complexity ranging from an average of 77% for 4 –5 classes, 71% for 7– 8 classes, 65% in 9 –11 classes, and 53% for more than 13 classes. Mumby and Edwards (2002) used three different sensors to map coral reef habitat, and found that regardless of the sensor type, overall accuracies decreased with increased classification levels, from 38-52% for 8 classes to 21-37% for 13 classes.

Most of the errors in biological cover classifications for both AA techniques arise from difficulty to distinguish algae and seagrass cover. This type of confusion is documented in previous studies where there was high confusion differentiating seagrass and algae from aerial and satellite imagery (Andréfouët et al., 2003; Mumby, Green, Edwards, and Clark, 1997; Riegl, Moyer, Morris, Virnstein, and Dodge, 2005). In Mumby et al., (1997) study, algal and seagrass habitats were spectrally and spatially confused with one another, resulting in lower overall accuracies than coral and sand habitats. This result is not unusual (Kirkman and Digby, 1988) and has several causes. The photosynthetic pigments in algae and seagrass (e.g. chlorophyll, phycoerythrin and fucoxanthin) have different reflectance characteristics, and satellite spectral bands are generally unsuitable for distinguishing them because at wavelengths of > 580 nm penetration of water is poor, preventing the characteristic reflectance minima and maxima of photosynthetic pigments from being detected (Maritorena and Gentili, 1994).

Differences between AA techniques

This study found that accuracy at the detailed levels of biological cover and detailed coral cover differed between techniques by as much as 23% (Table 43) Assuming that an *in situ* AA is the most accurate form of ground validation (Congalton, 2001), this result shows that an *in situ* quantitative AA should be used when a map consists of detailed categories such as percent biological cover or percent coral cover and high accuracy in these categories is needed. For example; habitat maps with high accuracy in percent biological and coral cover categories were needed to address recent coral bleaching throughout the Saipan Lagoon in the Commonwealth of the Northern Mariana Islands (CNMI) in 2015. Local resource managers from the CNMI requested that the existing habitat map, produced by the University of Guam in 2004 be updated to better understand coral bleaching and other habitat changes over the last decade (Battista, 2015).

Quantitative AA's in which divers collect *in situ* data on coral, algae, or seagrass habitats have been utilized in a number of mapping studies (Bruce et al., 1997; Palandro et al., 2008; Purkis and Riegl, 2005). In the Purkis and Riegl (2005) study, the study area was relatively small, allowing a costlier quantitative AA technique to be used.

The interpretation of video imagery remains largely a manual process and is prone to human subjectivity (Culverhouse and Williams, 2003; Hearn and Healy, 2011). Interpretation of underwater video data requires long periods of concentration where complex and sometimes unavoidably subjective decisions are routinely required (Rattray and Ierodiaconou, 2014). The result of these subjective decisions can lead to a level of uncertainty in the classification assignment of video files (Rattray and Ierodiaconou, 2014). In the Rattray and Ierodiaconou (2014) study, mean overall observer agreement was found to be 98% (±6%), 82% (±12%) and 75% (±17%) for the 2, 4, and 6 class levels of the scheme, respectively. The subjective assignment of class labels to video files likely contributed to the qualitative AA overestimating accuracy in the detailed biological and coral cover category in the present study.

Furthermore, the qualitative AA took into consideration the canopy of soft corals (gorgonians), while the quantitative assessment did not. The 2014 NOAA Florida Keys Coral Reef Ecosystem habitat map combined both hard and soft corals into a single ‘coral cover’ classification and included gorgonian canopy cover in addition to the holdfast as part of the estimate. To account for this, the quantitative gorgonian and coral percent cover data were combined, however the difference in the way gorgonian cover was estimated remained problematic. This issue of trying to quantify gorgonians with canopy height has been studied (Foster and Riegel, 2009). Foster et al. (2009) used an echosounder with Biosonics EcoSAV software to estimate gorgonian cover when creating their map. This technology was not used in the creation of the NOAA map or the qualitative AA.

In this study, the qualitative AA technique showed high accuracy of the detailed coral cover category (Table 43) whereas the quantitative AA accuracy results were low). Since cover estimated from video data can be subjective and overestimated, and the quantitative AA likely underestimated gorgonian cover, the difference in accuracy obtained from this study may reflect more of an extreme than the norm. If the quantitative AA method in this study captured gorgonian canopy, then the difference in accuracy in the detailed coral cover category between the two AA techniques would be less.

Algal cover and proliferation over time in coral reefs is an indicator of reef health since it can reveal decreases in coral cover, overfishing or lack of herbivores (McClanahan and Muthiga, 1998; McCook, 1999), increased nutrification (Lapointe, 1997), and potential synergism among all these factors. The overall low accuracy of detailed cover (Fig. 9) found in both the qualitative and quantitative AA's was caused by the NOAA map producer attempting to use a remote sensing technology that was incapable of distinguishing certain class types such as algae. Using airborne sensors provide a higher spatial and spectral resolution than satellite sensors, providing more spectral information on targets, and thus greater accuracy in detailed coral reef habitat mapping (Mumby et al., 1997). Previous studies have described mapping coral cover in terms of density using high resolution imagery (Ahmad and Neil, 1994; Zainal, 1993). In one study by Catt and Hopley (1988), they were able to achieve a high level of accuracy in mapping percent coral cover by using low altitude aerial photography to create maps. In the case of NOAA creating the Florida Keys map, NOAA used images from IKONOS, a satellite sensor. This would have an impact on accuracy regardless of AA technique.

The issue of the NOAA Florida map scale and the scale at which data were collected for both AA techniques in this study can be a source of error in the accuracies. The quantitative assessment provided a more localized representation of an area than did the qualitative assessment. In the qualitative assessment, the video-camera was allowed to drift which covered an area of benthic cover closer to the Minimum Mapped Unit (MMU) of the NOAA map which was 4,047m^2 (0.4ha) for most benthic habitats with the exception of individual patch reefs in Hawk Channel that were mapped to an MMU of 625 m^2 (0.06 ha). The difference in scale between the map and the way which accuracy assessment data were collected has been previously studied (Kendall et al., 2005). Kendall et al. (2005) compared two separate benthic maps of a study area, one with a relatively large MMU of 4,047m^2 and one with a much smaller MMU of 100 m^2. An *in situ* accuracy assessment was carried out on the study area and it was found that there was a high degree of overlap between the two map scales, but this was only limited to the benthic structure category. Detailed cover categories were not studied in Kendall et al. (2010).

Intra-site algae spatial variability (e.g. patchiness) could also be a reason for the differences between qualitative and quantitative detailed biological cover accuracies shown in this study. The classification techniques commonly used in satellite and aerial image based mapping are assigning each image pixel to a single class. A pixel therefore displays full and complete membership to a single class. Such approaches are only appropriate for the mapping of classes that are discrete, mutually exclusive, and assume the data can be represented in crisp sets (Foody, 1999). On many occasions this will not be the case. In the case of using a coarse spatial resolution sensor, i.e. IKONOS, to create the 2014 NOAA Florida Keys map, each pixel can contain multiple class allocations of algae. This source of error, caused by mixed pixels, has been described in previous studies (Foody, 1999, 2002; Fuller, Groom, and Jones, 1994).

The time interval from when the NOAA Florida Keys map was created and when both AA data sets were collected could have caused some error in the accuracies. Globally averaged land and ocean temperatures in 2005 were the highest on record according to NOAA and NASA analyses. The 2005 hurricane season in the Atlantic and Caribbean was unprecedented, experiencing more than twice the annual average of named tropical storms over the past century and the greatest number of hurricanes in recorded history (Heron, 2008). The waves and tidal water movements from hurricanes scour some areas exposing the solid limestone structure of the reef, which provides a firm foundation on which corals can settle and grow. In other areas, water movement results in the accumulation of sediment and rubble, which is unstable and, therefore, less suitable for coral settlement (Manzello et al., 2007). Low relief habitats can often be covered and uncovered by sand movement during large storm events (Gilliam, 2007; Walker et al., 2008; Walker and Foster, 2009). There is the possibility that sediment could have shifted and habitat types changed between the time of creating the NOAA Florida Keys map and collection of both qualitative and quantitative AA data. In order to address the time-lapse of using quantitative AA data from 1999-2009 when the NOAA map was created from satellite images and ground validation videography in 2005, a subset of quantitative data (Miller et al. 2000; Rutten et al. 2008) from only 2005-2009 was used to create matrices and compared with quantitative data (Miller et al. 2000; Rutten et al. 2008) from 1999-2009. Previous storm events prior to 2005 in the Florida Keys, i.e. hurricane Wilma, might have caused some shifts in biological and coral cover, as well as shifts of sediment onto low-relief hard-bottom. Sample sites for both 1999-2009 and 2005-2009 data sets (Miller et al. 2000; Rutten et al. 2008) were located throughout the entire mapped Florida Keys reef tract and not just the ROIs. Results reported for both data sets were very similar (Figures 8, 9, and 10), <2% difference in all categories.

In summary, the map classification scheme is a primary consideration when choosing an accuracy assessment technique. If ~~a~~ map contains a broad classification (i.e. major structure, major biological cover) then a qualitative AA can achieve good results; however, if a map contains a detailed classification (i.e. biological percent cover), a quantitative AA is necessary.

5 Conclusion

Accuracy assessment data collection must match the classification scheme of the map. When conducting an AA, data collected should be at a similar spatial scale to the map and at a similar classification scheme when trying to determine whether to use a qualitative or quantitative accuracy assessment. If low resolution aerial and/or satellite imagery was used to create a map with a broad classification scheme, then a qualitative AA can ideally be used to assess the map's accuracy. But in the case of creating a map with high resolution imagery with a detailed classification scheme, then a quantitative AA should be used.

In the case of the 2014 NOAA Florida Keys Coral Reef Habitat map where a large area of reef tract was mapped, high resolution imaging to create the maps can be too costly and time consuming. A qualitative AA such as the one that Walker et al. (2013) conducted was closer to the map’s MMU than a localized *in situ* quantitative data collection. The 2014 NOAA Florida Keys Coral Reef Ecosystem Habitat Map should be considered useful in most cases to resource managers. In cases where resource managers have to make localized decisions influenced by algal and coral cover, managers should be aware of the low quantitative accuracies of the map in those detailed categories.

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