Final Report

Accuracy Assessment for the Reclassification of the NOAA Florida Keys mapping: ROI 2 (Key West)

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Submitted by: Brian K. Walker, Principal Investigator.
Ian Rodericks, Research Assistant
Amanda Costaregni, Research Assistant

National Coral Reef Institute
Nova Southeastern University Oceanographic Center
8000 North Ocean Drive, Dania Beach, FL 33004

Prepared for: Steven O. Rohmann, Ph.D.

Office of National Marine Sanctuaries NOS/NOAA
1305 East West Hwy, #11415, Silver Spring, MD 20910

EXECUTIVE SUMMARY

This report describes the methodologies, analyses, and results for an independent accuracy assessment of a thematic benthic habitat map produced by NOAA for the Lower Florida Keys. It is a reanalysis of a previous accuracy assessment for a different classification scheme. Over the course of the Florida Keys mapping project, NOAA amended part of the classification scheme. The original scheme for mapping benthic cover was a tiered approached where certain benthic cover categories were given priority over others (e.g. coral was most important). Recently, this was modified to a dominant benthic cover scheme where the habitat is characterized by the single most dominant cover type and all habitats are characterized for percent cover of coral. No new data were collected for this effort. The exact same data and data analyses from Walker and Foster (2010) were used to evaluate the accuracy of the reclassified map. The same analyses are currently underway for accuracy assessment area 1 from Walker and Foster (2009).

The field work was performed by National Coral Reef Institute scientists between the dates of June 7 and June 15, 2009. The accuracy assessment was conducted within a 249.6 km^2 corridor (ROI-2) between Sand Key and Eastern Sambo that extended from the shoreline intertidal zone, through Hawk Channel and the reef tract, before terminating on the outer bank/shelf escarpment at a depth of approximately 33m. A total of 533 sampling stations were visited, of which 476 were used in the accuracy assessment. The sites were selected using a stratified random sampling protocol that equally distributed sampling points amongst the detailed structure categories. Most sites were sampled by deploying a weighted drop camera with the vessel drifting in idle and recording 30-120 seconds of dGPS-referenced video. The shallowest sites were sampled by snorkel, waverunner, or kayak, using a hand-held dGPS for navigation and a housed camera to record video. Each sampling station was given a Detailed Structure and Biological Cover assignment in the field. These field classifications were reevaluated post-survey during a systematic review of video and photographic data, designed to ensure consistency within classifications. The efficacy of the benthic habitat map was assessed by a number of classification metrics derived from error matrices of the Major and Detailed levels of Geomorphological Structure and Biological Cover. The overall, producer's, and user's accuracies were computed directly from the error matrices. The overall accuracy of the ROI-2 benthic habitat map was 89.3% and 83.2% at the Major and Detailed levels of Structure respectively, and 85.5% and 73.1% at the Major and Detailed levels of cover. The known map proportions, i.e. relative areas of mapped classes, were used to remove the bias introduced to the producer's and user's accuracies by differential sampling intensity (points per unit area). The overall accuracy at the Major and Detailed levels of Structure changed to 91.3% and 82.4%. The overall accuracy at the Major and Detailed levels of cover changed to 79.1% and 71.0%. The overall accuracies were also adjusted to the number of map categories using the Tau coefficient. Tau is a measure of the improvement of the classification scheme over a random assignment of polygons to categories, bounded between -1 (0% overall accuracy for 2 map categories) and 1 (100% accuracy for any number of categories). The Tau coefficients were 0.786 ± 0.056 and 0.813 ± 0.037 at the Major and Detailed levels of Structure, and 0.819 ± 0.040 and 0.709 ± 0.043 at the Major and Detailed levels of cover. The reclassified map classified the percent coral cover for every polygon, thus coral cover was evaluated separately. Total accuracy for Coral was 91.4% and 92.5% after adjusting for map marginal proportions. The accuracy varied greatly between the two coral categories present. User's and Producer's accuracies for Coral 0%-<10% were near or over 95%. Conversely, Coral 10%-<50% user's and producer's accuracies were less than 70% and 50.4% in the case of adjusted producer's accuracy. The adjustment for map proportions is very relevant here due to the large disparity of area between the two classes and the disproportionate sampling. The map contained 152.8 km^2 of Coral 0%-<10% and 12.6 km^2 of Coral 10%-<50%. Further 421 of AA points were in Coral 0%-<10% and 55 were in Coral 10%-<50%. Interestingly there were no occurrences of Coral 50%-<90% and 90%-100% in ROI-2. There was some confusion between coral classes where 18 locations mapped as Coral 10%-<50% were actually Coral 0%-<10% and 23 locations mapped as Coral 0%-<10% were found to be Coral 10%-<50%.

INTRODUCTION

As part of a regional mapping and monitoring effort in the Florida Keys, NOAA required an independent accuracy assessment to statistically test the accuracy of the GIS-based benthic habitat map recently produced for the Lower Keys. Resources, budgets, and logistical constraints precluded a comprehensive assessment of the entire mapped area, thus biogeographically-representative corridors within the total benthic habitat map area were selected for performing the accuracy assessment (Congalton, 1991; Stehman and Czaplewski, 1998). The corridors 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. As the Florida Keys benthic habitat mapping effort proceeds, the area of mapped benthic habitats gets considerably larger than the area assessed for accuracy, making it important to evaluate new areas for accuracy.

This report is a reanalysis of a previous accuracy assessment for a different classification scheme. Over the course of the Florida Keys mapping project, NOAA amended part of the classification scheme. The original scheme for mapping benthic cover was a tiered approached where certain benthic cover categories were given priority over others (e.g. coral was most important). Recently, this was modified to a dominant benthic cover scheme where the habitat is characterized by the single most dominant cover type and all habitats are characterized for percent cover of coral (Figure 1). No new data were collected for this effort. The exact same data and data analyses from Walker and Foster (2010) were used to evaluate the accuracy of the reclassified map. The same analyses are currently underway for accuracy assessment area 1 from Walker and Foster (2009).

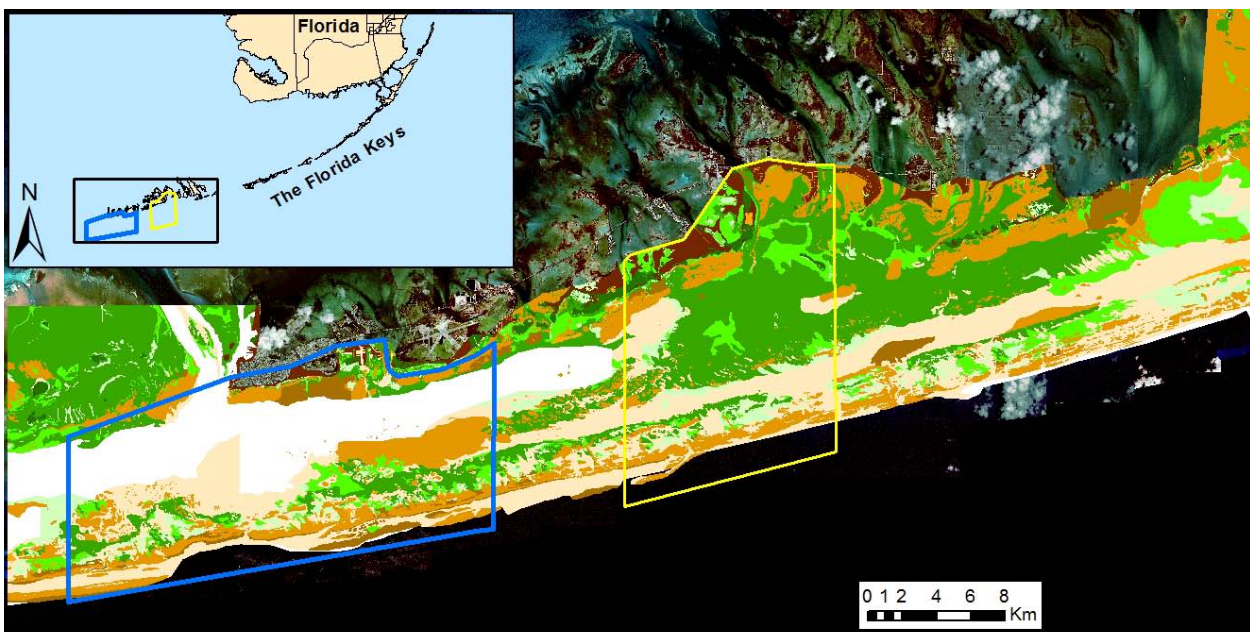

Figure 1. Accuracy Assessment Area 1 (ROI-1) (yellow) and Area 2 (ROI-2) (Blue), within the overall NOAA mapped region of the Lower FL Keys. ROI-2 is the focus of this report and included the region between Sand Key and Eastern Sambo from the shoreline intertidal zone to the outer bank/shelf escarpment at a depth of approximately 33m.

This work directly relates to many of the NOAA Coral Reef Conservation Program's newly developed guiding principles in their roadmap for the future. It directly addresses coral reef management needs based on sound science, takes an ecosystem-level approach to coral reef conservation by capturing data across all mapped benthic habitats in the region at specific locations that can be used to qualitatively evaluate the different habitats, and implements its objectives through strong partnerships. Furthermore, it supports two of CRCP's new priorities by providing a baseline dataset that can be used for future studies identifying impacts of land-based sources of pollution and of climate change in the lower Keys.

METHODOLOGY

2.1 CLASSIFICATION SCHEME (FROM ZITELLO ET AL. 2009)

The classification scheme used herein was designed by NOAA and its partners for the benthic habitat mapping program initiated in 1999. A meeting was held on June 11 and 12, 2008 to update the NCRI scientists performing the AA on the sampling protocol and the map classification scheme. The two day workshop involved one day of discussions and presentations and one day of field demonstrations. The knowledge gained from this workshop helped calibrate the two teams (mapping and AA) and reduce confusion between habitat definitions. NCRI scientists applied this knowledge with success during the AA for ROI-1 (Walker and Foster, 2009) and ROI-2 (Walker and Foster, 2010) which showed high agreement in many categories. Both AA's assessed two map attributes using the same assessment locations: one to assess geomorphological structure and one to assess biological cover. Since then the map polygons were reclassified to a dominant cover classification scheme. The reclassified classification scheme used in the AA is listed below and more information can be found in Zitello et al. (2009).

Coral Ecosystem Geomorphological Structures

Unconsolidated Sediment: Areas of the seafloor consisting of small particles (<.25 m) with less than 10% 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, zooanthids 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.

Coralline Algae: An area with 10% or greater coverage of any combination of numerous species of encrusting or coralline algae. May occur along reef crest, in shallow back reef, relatively shallow waters on the bank/shelf zone, and at depth. Broad enough coverage to constitute dominant biological cover in a MMU is particularly rare in the U.S. Caribbean.

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.

<u>Percent Cover</u>

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).

<u>Live coral cover classes</u>

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.

2.2 ACCURACY ASSESSMENT

This section describes the methods for the original data collection and analyses which are also applicable to the reclassification analyses.

Data Collection

The region of interest for the ROI-2 accuracy assessment corridor was approximately 249.6 km², representing 27.5% of the total area (907 km²) of the Lower Keys benthic habitat map at the time of the survey (Figure 1). Its size was determined by having a similar footprint of mapped sea floor habitats (excluding unknown) as ROI-1. Due to the larger proportion of unknown classifications in ROI-2, the total size of the ROI-2 sampling corridor was much greater than that of ROI-1 (182.7 km²). However, the areas of known mapped habitats were nearly equal (ROI-2 = 168 km²; ROI-1 = 167.9 km²). The total area (excluding unknown) of the two accuracy assessments equaled 335.9 km², 37% of the total mapped area at the time of the surveys.

Target locations for the accuracy assessment (AA) procedure were determined by a GIS-based, stratified random sampling (StRS) technique. The draft benthic habitat polygons were merged by Detailed Biological Cover class so that there was one polygon group per class. 37 points were randomly placed within each Detailed Biological Cover classes in the map using Hawth's tools in ArcGIS at a minimum distance of 30 m apart. To accommodate a robust AA using Detailed Geomorphological Structure, locations were added or haphazardly moved to ensure each Detailed Structure category contained at least 20 samples. This yielded 533 total sample target locations. The Boulder class was not large enough therefore 12 targets at 30 m apart were chosen to optimize the number of samples.

All sites were sampled between the dates of June 7 and June 15, 2009. Underwater video from a drop camera was taken at each site within AA ROI-2, provided the location was safely accessible by the survey vessel. The sampling procedure 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 with 2 SBAS (Satellite Based Augmentation Systems) (e.g. WAAS, EGNOS, etc.) channels and real-time accuracy of <1 m 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 second to two minute video clips were recorded directly to a digital video recorder in MPEG4 video format at 720x480 resolution and 30fps. Video length depended on the habitat type and vessel drift. Videos of large, homogeneous habitats were generally short while heterogeneous habitats, especially edges, were typically longer. 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 two-seat ocean 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 on waterproof paper from the kayak.

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 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 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.

Aside from underwater targets, emergent vegetation (EV) was assessed in this effort as well. 2 days of hiking were performed to assess many of the emergent vegetation sites. Accessible EV targets were visited and confirmed by still pictures. Many EV targets were practically inaccessible and were either moved to accessible areas or confirmed by getting as close to the target as possible either by survey vessel, car, or foot.

Data Evaluation

The GPS location at the start and end of each video were entered into a database with the field notes and plotted in GIS resulting in a point layer of the 533 sites. These data were then spatially joined to the benthic habitat layer to identify the map classification for each point. All sites were evaluated for structure, cover, and coral cover both in GIS and video/images to classify the habitat at each site. These were then statistically compared to the map classification to gauge accuracy.

Sampling locations that fell close to polygon boundaries were all included as it was assumed that the probability of error contributing to false negatives was equal to the probability of error contributing to false positives. However negative points were moved if they were within 3 m of an edge and the video data justified the relocation (e.g. the video showed a transition to the next habitat). This was a rare occurrence.

Detailed Geomorphological Structure classes Artificial, Land, Rock/Boulder, Unclassified, and Unknown were excluded from the accuracy analysis. Furthermore the 45 random locations visited in Unknown habitat were not part of the error analyses, resulting in 476 locations for statistical analysis.

Accuracy Assessment Analyses

A number of statistical analyses were used to characterize the thematic accuracy of the Lower Keys benthic habitat map. A total of eight error matrices were prepared for the attributes of Geomorphological Structure and Biological Cover, at the Major and Detailed levels of classification, for both ROI-2 and the combined corridors. Overall accuracy, producer's accuracy, and user's accuracy were computed directly from the error matrices (Story and Congalton 1986). Direct interpretation of these producer's and overall accuracies can be problematic, as the stratified random sampling protocol can potentially introduce bias (Hay 1979, van Genderen 1978, van Genderen 1977). Stratification ensures adequate representation of all map categories, by assigning an equal number of accuracy assessment to each map category, using the draft benthic habitat map as a guide. This caused rare map categories to be sampled at a greater rate (observations per unit area) than common map categories. The bias introduced by differential sampling rates was removed using the method of Card (1982), which utilizes the known map marginal proportions, i.e. the relative areas of map categories. The map marginal proportions were calculated as the area of each map category divided by the total area within the AA ROI-2 boundaries. The map marginal proportions were also utilized in the computation of confidence intervals for the overall, producer's, and user's accuracies (Card 1982). The efficacy of the habitat map was further examined by computation of the Tau coefficient, which adjusted the overall accuracies based on the number of map categories, allowing for statistical comparison of error matrices of different sizes (Ma and Redmond 1995). As a classification metric, Tau is a measure of the improvement of the classification scheme over a random assignment of polygons to categories, bounded between -1 (0% overall accuracy for 2 map categories) and 1 (100% accuracy for any number of categories).

The error matrices were constructed as a square array of numbers arranged in rows (map classification) and columns (true, or ground-truthed classification). The overall accuracy (P_o) was calculated as the sum of the major diagonal, i.e. correct classifications, divided by the total number of accuracy assessment samples. The producer's and user's accuracies are both category-specific. Each diagonal element was divided by the column total to yield a producer's accuracy and by the row total to yield a user's accuracy. The producer's and user's accuracies provide different perspectives on the classification accuracy of a map. The producer's accuracy (omission/exclusion error) indicates how well the mapper classified a particular habitat, e.g. the percentage of times that substrate known to be sand was correctly mapped as sand. In this report, the most common producer's errors in detailed structure were mapping areas known to be sand as a coral reef habitat (Sand column in Table 3). The user's accuracy (commission/inclusion error) indicates how often map polygons of a certain habitat type were classified correctly, eg. the percentage of times that a polygon classified as sand was actually sand. In this report, the most common user's errors in detailed structure were mapping areas known to be something else as pavement (Pavement row in Table 3). The distinction between these two types of error is subtle. For example, the user's accuracy for the map category of sand is calculated as the number of accuracy assessment points that were mapped as sand and later verified to be sand, divided the total number accuracy assessment points that were mapped as sand. But this measure of user's accuracy for mapping sand totally ignores points that were verified to be sand, but mapped as something else, i.e. producer's error.

Considering the uneven distribution of map category area in the map, a simple random assignment of accuracy assessment points would have required an unrealistically large number of points to adequately cover all map categories. The stratified random sampling protocol was used to ensure that each habitat class would be adequately sampled, assigning an equal number of accuracy assessment points to each map category of Detailed Cover within the representative area (AA ROI-2). As previously mentioned, this non-random sampling method introduced bias in the producer's and overall accuracies, as map categories with very large areal extents were sampled at the same rate as categories with very small extents. For example, the Detailed Structure category Sand accounted for 53.2% of the total area of known seafloor habitats mapped in AA ROI-2, but only 30% (143/476) of the accuracy assessment points. Conversely, the Rubble category accounted for only 1.9% of the total mapped area of known seafloor habitats and 16.5% (79/476) of the accuracy assessment points. This amounted to a sampling intensity of 1.6 points per km² (143/88.03 km) for the very large Sand category versus 26.1 points per km^2 (79/3.03 km) for Rubble.

To remove the bias introduced by the stratified random sampling procedure, the overall and producer's accuracies were adjusted to the known areal proportions of map categories (Card 1982). The known map marginal proportions (π_i) were computed from the GIS layer of the draft benthic habitat map for each of the four error matrices, by dividing the area of each category by the total map area. The map areas were calculated within the boundaries of the accuracy assessment corridor (AA ROI-2) and were exclusive to categories present in the error matrix, which reduced total area from 249.6 to 165.2 km^2. For the example of Detailed Structure category Sand, π_i was 0.532 (88.03 km^2/165.4 km^2). The individual cell probabilities, i.e. the product of the original error matrix cell values and π_i, divided by the row marginal (total map classifications per category), were computed for the off-diagonal elements using the following equation:

$$\hat{P}_{ij} = \pi_i n_{ij} / n_{i-}$$

The relative proportions of the cell values within a row of the error matrix were unaffected by this operation, but the row marginals were forced to the known map marginal proportions, i.e. the row total of a particular habitat now equaled the fraction of map area occupied by that habitat, instead of the total number of accuracy assessment points. The estimated true marginal proportions were computed as the sum of individual cell probabilities down each column of the error matrix. The π_i-adjusted overall, producer's, and user's accuracies were then computed from the new error matrix, now populated by individual cell probabilities. The values of the π_i-adjusted overall and producer's accuracies differ by design from those of the original error matrix, as they have been corrected for the areal bias introduced by the stratified random sampling protocol. The variances and confidence intervals of the overall, producer's, and user's accuracies were then computed from the following set of equations:

Overall Variance = $V(\hat{P}_c) = \sum_{i=1}^{r} p_{ii}(\pi_i - p_{ii})/n_{i-})$

Overall Confidence Interval = $\hat{P}_c \pm 2[V(\hat{P}_c)]^{1/2}$

Producer's Variance = $V(\hat{\theta}_{ii}) = p_{ii}\,p_i^{-4}[\,p_{ii}\sum_{j\neq 1}^{r} p_{ij}(\pi_i - p_{ij})/n_{i-} + (\pi_i - p_{ii})(p_i - p_{ii})^2/n_{i-j}\,]$

Producer's Confidence Interval = $\hat{\theta}_{ii} \pm 2[V(\hat{\theta}_{ii})]^{1/2}$

User's Variance = $V(\hat{\lambda}_{ii}) = p_{ii}(\pi_j - p_{ii})/n_{i-}$

User's Confidence Interval = $\hat{\lambda}_{ii} \pm 2[V(\hat{\lambda}_{ii})]^{1/2}$

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). For a supervised classification scheme there are two possible forms of the Tau coefficient, differing only by the estimation of the probability of random agreement (P_r). In one case it is known *a priori* that the probability of class membership differs among map categories, e.g. a previous map that quantified the disproportionate areal extents of habitat classes. In this case, Tau (T_p) is an adjustment of overall accuracy (P_o) by the number of groups (*r*) and the *a priori* probabilities informing the classification. In the other case it is not possible to quantify the *a priori* disparities of group membership. In the case of the Lower Keys benthic habitat map there was no *a priori* information available, and thus a Tau based on equal probability of group membership (T_e) was used to evaluate classification accuracy. In this case, the probability of random agreement simplifies to the reciprocal of the number of map categories (1/*r*), and 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. Values of T_e were calculated as follows:

Tau coefficient for equal probability of group membership = $T_e = (P_o - 1/r) / (1 - 1/r)$

Because there are only two possible outcomes for each accuracy assessment point, i.e. correct or incorrect, the probability distribution of P_o follows a binomial distribution. But when the total number of accuracy assessment samples within the error matrix is large, i.e. $n > 100$, the probability distribution of P_o approximates a normal distribution (Steel and Torrie, 1960). Given that the distribution of P_o approximates normality, it can then be assumed that the distribution of T_e will also approximate normality (Cohen, 1960). And because the individual row values of P_r are fixed before the map is classified, i.e. equal to 1/*r*, they can be treated as constants and a variance can be calculated for Tau (Ma and Redmond 1995):

Variance of Tau coefficient = $\sigma_r^2 = P_o(1 - P_o) / n(1 - P_r)^2$

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

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

RESULTS

A total of 533 ground validation stations were visited. The identity and number of planned targets differed from that of the final targets as a result of the addition of three opportunistic points of interest. Of the 533 stations visited, 476 were used for the accuracy assessment. The majority of excluded samples were due to intentionally visiting unknown areas (n=45).

3.1 GEOMORPHOLOGICAL STRUCTURE

Major Geomorphological Structure

Error matrices for Major Geomorphological Structure are presented in Tables 1 and 2. The overall accuracy (P_o) was 89.3% at the Major Structure level (Table 1). The Tau coefficient for equal probability of group membership (T_e) was 0.786 ± 0.056 (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 polygons to categories. Table 2 is populated by the individual cell probabilities ($\hat{P}_{ij}$), which are the product of the original error matrix cell values and the known map marginal proportions, divided by the row marginal of the original error matrix. The overall accuracy (P_o), corrected for bias using the known map marginal proportions, was 91.3% ± 2.5 (α=0.05) at the Major Structure level. The producer's accuracies, adjusted for known map marginal proportions, are shown for individual map categories. A 95% confidence interval was calculated for each value of producer's and user's accuracy.

The Major Structure error matrix clearly demonstrated the effect of adjusting producer's accuracy to the known map marginal proportions. In the original error matrix (Table 1), 180 of 222 ground-truthed Soft samples were correctly classified as Soft bottom habitats. The remaining 42 samples were incorrectly classified as Hard. The un-adjusted producer's accuracy was therefore equal to 180/222 = 81.1%. However, the known map marginal proportions of the Soft habitats were 60.05%, versus 39.5% for Hard habitats (Table 2). Therefore, the producer's confusion between these two habitats was exaggerated by a disproportionately high sampling of Hard habitats that had a disproportionately lower contribution to the total area. Discrimination between these two categories increased after the error matrix cell values were transformed from the original binomial observations to individual cell probabilities (42*0.395/287=0.0605 and 180*0.605/189=0.5762), increasing producer's accuracy from 81.1% to 90.9%.

Detailed Geomorphological Structure

Error matrices for Detailed Geomorphological Structure are presented in Tables 3 and 4. The overall accuracy (P_o) was 83.2% at the Detailed Structure level (Table 3). The Tau coefficient for equal probability of group membership (T_e) was 0.813 ± 0.037 (α=0.05), i.e. the rate of misclassifications at the Detailed Structure level was 81% less than would be expected from random assignment of polygons to categories. T_e more closely approached P_o at the Detailed level (r = 9) than at the Major level (r = 2), reflecting the diminishing probability of random agreement with increasing map categories. Table 4 is populated by the individual cell probabilities ($\hat{P}_{ij}$), which are the product of the original error matrix cell values and the known map marginal proportions, divided by the row marginal of the original error matrix. The overall accuracy (P_o), corrected for bias using the known map marginal proportions, was 82.4% ± 3.8 (α=0.05) at the Detailed Structure level. The producer's accuracies, adjusted for known map marginal proportions, are shown for individual map categories. A 95% confidence interval was calculated for each value of producer's and user's accuracy.

3.2 BIOLOGICAL COVER

Major Biological Cover

Error matrices for Major Biological Cover are presented in Tables 5 and 6. The overall accuracy (P_o) was 85.5% at the Major Cover level (Table 5). The Tau coefficient for equal probability of group membership (T_e) was 0.819 ± 0.040 (α=0.05), i.e. the rate of misclassifications at the Major Cover level was 81.9% less than would be expected from random assignment of polygons to categories. Table 6 is populated by the individual cell probabilities ($\hat{P}_{ij}$), which are the product of the original error matrix cell values and the known map marginal proportions, divided by the row marginal of the original error matrix. The overall accuracy (P_o), corrected for bias using the known map marginal proportions, was 79.1% ± 5.5 (α=0.05) at the Major Cover level. The producer's accuracies, adjusted for known map marginal proportions, are shown for individual map categories. A 95% confidence interval was calculated for each value of producer's and user's accuracy.

Detailed Biological Cover

Error matrices for Detailed Biological Cover are presented in Tables 7 and 8. The overall accuracy (P_o) was 73.1% at the Detailed Cover level (Table 7). The Tau coefficient for equal probability of group membership (T_e) was 0.709 ± 0.043 (α=0.05), i.e. the rate of misclassifications at the Detailed Cover level was 70.9% less than would be expected from random assignment of polygons to categories. T_e more closely approached P_o at the Detailed level (r = 13) than at the Major level (r = 5), reflecting the diminishing probability of random agreement with increasing map categories. Table 8 is populated by the individual cell probabilities ($\hat{P}_{ij}$), which are the product of the original error matrix cell values and the known map marginal proportions, divided by the row marginal of the original error matrix. The overall accuracy (P_o), corrected for bias using the known map marginal proportions, was 71.0% ± 5.5 (α=0.05) at the Detailed Cover level. The producer's accuracies, adjusted for known map marginal proportions, are shown for individual map categories (user's accuracies are unaffected). A 95% confidence interval was calculated for each value of producer's and user's accuracy.

Detailed Coral Cover

Error matrices for Detailed Coral Cover are presented in Tables 9 and 10. The overall accuracy (P_o) was 91.4% at the Detailed Cover level (Table 9). The Tau coefficient for equal probability of group membership (T_e) was 0.885 ± 0.034 (α=0.05), i.e. the rate of misclassifications at the Detailed Cover level was 88.5% less than would be expected from random assignment of polygons to categories. Table 10 is populated by the individual cell probabilities ($\hat{P}_{ij}$), which are the product of the original error matrix cell values and the known map marginal proportions, divided by the row marginal of the original error matrix. The overall accuracy (P_o), corrected for bias using the known map marginal proportions, was 92.5% ± 2.3 (α=0.05) at the Detailed Cover level. The producer's accuracies, adjusted for known map marginal proportions, are shown for individual map categories (user's accuracies are unaffected). A 95% confidence interval was calculated for each value of producer's and user's accuracy.

Table 1. Error matrix for 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 0.730– 0. 842.

		TRUE (GROUND-TRUTHED) (j)			
	MAJOR STRUCTURE	**hard**	**soft**	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**245**	42	287	**85.4**
	soft	9	**180**	189	**95.2**
	n_{-j}	254	222	**476**	**<= *n***
	PRODUCERS Accuracy (%)	**96.5**	**81.1**	P_o	**89.3%**

$T_e = 0.786 \pm 0.056$

Table 2. Error matrix for Major Geomorphological Structure (using individual cell probabilities P_{ij}). The overall accuracy, corrected for bias using the known map marginal proportions (π_i), was 91.3% with a 95% Confidence Interval of 88.8% – 93.8%.

		TRUE (GROUND-TRUTHED) (j)				
	MAJOR STRUCTURE	**hard**	**soft**	π_i	**USERS Accuracy (%)**	**USERS CI (± %)**
MAP (i)	**hard**	**0.3372**	0.0578	0.395	**85.4**	**4.2**
	soft	0.0288	**0.5762**	0.605	**95.2**	**3.1**
	n_{-j}	0.366	0.634	**1.000**	**<= *n***	
	PRODUCERS Accuracy (%)	**92.1**	**90.9**	P_o	**91.3%**	
	PRODUCERS CI (± %)	**4.7**	**2.4**	**CI (±)**	**2.5%**	

Table 3. Error matrix for Detailed Geomorphological Structure. The overall accuracy (P_o) was 83.2%. The Tau coefficient for equal probability of group membership (T_e) was 0.813, with a 95% Confidence Interval of 0.776 – 0.850. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

DETAILED STRUCTURE (MAP DATA (i))	Aggregate Reef	Aggregated Patch Reef	Individual Patch Reef	Spur and Groove	Rubble	Pavement	Pav w/ Sand Channels	Sand	Mud	n_{i-}	USERS Accuracy (%)
Aggregate Reef	**14**				1	4		9		28	**50.0**
Aggregated Patch Reef		**8**				1		3		12	**66.7**
Individual Patch Reef			**15**					1	1	17	**88.2**
Spur and Groove	1			**42**						43	**97.7**
Rubble	1				**72**			6		79	**91.1**
Pavement	5	3	2	3	1	**72**		16	6	108	**66.7**
Pav w/ Sand Channels							**0**			0	**n/a**
Sand	1	2	3		1	1		**128**	7	143	**89.5**
Mud			1						**45**	46	**97.8**
n_{-j}	22	13	21	45	75	78	0	163	59	**476 <= *n***	
PRODUCERS Accuracy (%)	**63.6**	**61.5**	**71.4**	**93.3**	**96.0**	**92.3**	**n/a**	**78.5**	**76.3**	**P_o 83.2%**	

T_e = 0.813 ± 0.037

Table 4. Error matrix for Detailed Geomorphological Structure (using individual cell probabilities P_{ij}). The overall accuracy, corrected for bias using the known map marginal proportions (π_i), was 82.4% with a 95% Confidence Interval of 78.6% – 86.2%. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

DETAILED STRUCTURE (MAP DATA (i))	Aggregate Reef	Aggregated Patch Reef	Individual Patch Reef	Spur and Groove	Rubble	Pavement	Pav w/ Sand Channels	Sand	Mud	π_i	USERS Accuracy (%)	USERS CI (± %)
Aggregate Reef	**0.0202**				0.0014	0.0058		0.0130		0.040	**50.0**	**18.9**
Aggregated Patch Reef		**0.0129**				0.0016		0.0048		0.019	**66.7**	**27.2**
Individual Patch Reef			**0.0159**					0.0011	0.0011	0.018	**88.2**	**15.6**
Spur and Groove	0.0009			**0.0367**						0.038	**97.7**	**4.6**
Rubble	0.0002				**0.0167**			0.0014		0.018	**91.1**	**6.4**
Pavement	0.0121	0.0073	0.0048	0.0073	0.0024	**0.1742**		0.0387	0.0145	0.261	**66.7**	**9.1**
Pav w/ Sand Channels							**0.0000**			0.000	**n/a**	**n/a**
Sand	0.0037	0.0074	0.0112		0.0037	0.0037		**0.4763**	0.0260	0.532	**89.5**	**5.1**
Mud			0.0016						**0.0713**	0.073	**97.8**	**4.3**
n_{-j}	0.037	0.028	0.034	0.044	0.024	0.185	0.000	0.535	0.113	**1.000 <= *n***		
PRODUCERS Accuracy (%)	**54.4**	**46.8**	**47.5**	**83.5**	**68.7**	**94.0**	**n/a**	**89.0**	**63.1**	**P_o 82.4%**		
PRODUCERS CI (± %)	**21.3**	**24.7**	**21.4**	**15.7**	**26.4**	**5.0**	**n/a**	**3.4**	**12.6**	**CI (±) 3.8%**		

Table 5. Error matrix for Major Biological Cover. The overall accuracy (P_o) was 85.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.819, with a 95% Confidence Interval of 0.779 – 0.859. Blank cells indicate 0 occurrences.

MAP DATA (i) / MAJOR COVER	TRUE (GROUND-TRUTHED) (j) Coral	Sea Grass	Algae	Emerg Veg	No Cover	$n_{i\text{-}}$	USERS Accuracy (%)
Coral	**0**					0	**n/a**
Seagrass		**96**	11		9	116	**82.8**
Algae	1	19	**247**		15	282	**87.6**
Emerg Veg				**37**		37	**100.0**
No Cover		5	9		**27**	41	**65.9**
$n_{\text{-}j}$	1	120	267	37	51	**476** <= n	
PRODUCERS Accuracy (%)	**0.0**	**80.0**	**92.5**	**100.0**	**52.9**	**P_o 85.5%**	

T_e = 0.819 ± 0.040

Table 6. Error matrix for Major Biological Cover (using individual cell probabilities P_{ij}). The overall accuracy, corrected for bias using the known map marginal proportions (π_i), was 79.1% with a 95% Confidence Interval of 73.6% – 84.6%. Blank cells indicate 0 occurrences.

MAP DATA (i) / MAJOR COVER	TRUE (GROUND-TRUTHED) (j) Coral	Sea Grass	Algae	Emerg Veg	No Cover	π_i	USERS Accuracy (%)	USERS CI (± %)
Coral	**0**					0.000	**n/a**	**n/a**
Seagrass		**0.2363**	0.0271		0.0222	0.286	**82.8**	**7.0**
Algae	0.0014	0.0258	**0.3354**		0.0204	0.383	**87.6**	**3.9**
Emerg Veg				**0.0024**		0.002	**100.0**	**0.0**
No Cover		0.0401	0.0723		**0.2168**	0.329	**65.9**	**14.8**
$n_{\text{-}j}$	0.001	0.302	0.435	0.002	0.259	**1.000** <= n		
PRODUCERS Accuracy (%)	**0.0**	**78.2**	**77.1**	**100.0**	**83.6**	**P_o 79.1%**		
PRODUCERS CI (± %)	**n/a**	**9.3**	**8.1**	**0.0**	**6.4**	**CI (±) 5.5%**		

Table 7. Error matrix for Detailed Biological Cover, L = 10-<50%, M = 50-<90%, H = 90-100%. The overall accuracy (P_o) was 73.1%. The Tau coefficient for equal probability of group membership (T_e) was 0.709, with a 95% Confidence Interval of 0.666 – 0.752. Blank cells indicate 0 occurrences.

MAP DATA (i)	DETAILED COVER	Coral L	Coral M	Coral H	Seagrass L	Seagrass M	Seagrass H	Algae L	Algae M	Algae H	Emergent Vegetation L	Emergent Vegetation M	Emergent Vegetation H	No Cover	n_{i-}	USERS Accuracy (%)
Coral	L	**0**													0	**n/a**
Coral	M		**0**												0	**n/a**
Coral	H			**0**											0	**n/a**
Seagrass	L				**25**				4					7	36	**69.4**
Seagrass	M					**33**		2	4					1	40	**82.5**
Seagrass	H				1	1	**36**		1					1	40	**90.0**
Algae	L							**4**	10	2				4	20	**20.0**
Algae	M	1			4	6	4	3	**162**	9				6	195	**83.1**
Algae	H					1	4		33	**24**				5	67	**35.8**
Emergent Vegetation	L										**0**				0	**n/a**
Emergent Vegetation	M											**0**			0	**n/a**
Emergent Vegetation	H												**37**		37	**100.0**
No Cover					3	2		1	6	2				**27**	41	**65.9**
n_{-j}		1	0	0	33	43	44	10	220	37	0	0	37	51	**476**	**<= *n***
PRODUCERS Accuracy (%)		**0.0**	**n/a**	**n/a**	**75.8**	**76.7**	**81.8**	**40.0**	**73.6**	**64.9**	**n/a**	**n/a**	**100.0**	**52.9**	**P_o**	**73.1%**

TRUE (GROUND-TRUTHED) (j)

T_e = 0.709 ± 0.043

Table 8. Error matrix for Detailed Biological Cover (using individual cell probabilities P_{ij}); L = 10-<50%, M = 50-<90%, H = 90-100%. The overall accuracy, corrected for bias using the known map marginal proportions (π_i), was 71.0% with a 95% Confidence Interval of 65.5% - 76.5%. Blank cells indicate 0 occurrences.

		TRUE (GROUND-TRUTHED) (j)															
DETAILED COVER		**Coral**			**Seagrass**			**Algae**			**Emergent Vegetation**			**No Cover**	π_i	**USERS Accuracy (%)**	**USERS CI (± %)**
		L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**				
MAP DATA (i) **Coral**	**L**	**0.000**													0.0000	**n/a**	**n/a**
	M		**0.000**												0.0000	**n/a**	**n/a**
	H			**0.000**											0.0000	**n/a**	**n/a**
Seagrass	**L**				**0.042**				0.007					0.012	0.0605	**69.4**	**15.4**
	M					**0.057**		0.003	0.007					0.002	0.0691	**82.5**	**12.0**
	H				0.004	0.004	**0.140**		0.004					0.004	0.1560	**90.0**	**9.5**
Algae	**L**							**0.001**	0.002	0.000				0.001	0.0039	**20.0**	**17.9**
	M	0.002			0.006	0.009	0.006	0.005	**0.250**	0.014				0.009	0.3014	**83.1**	**5.4**
	H					0.001	0.005		0.038	0.028				0.006	0.0776	**35.8**	**11.7**
Emergent Vegetation	**L**										**0.000**				0.0000	**n/a**	**n/a**
	M											**0.000**			0.0000	**n/a**	**n/a**
	H												**0.002**		0.0024	**100.0**	**0.0**
No Cover					0.024	0.016		0.008	0.048	0.016				**0.217**	0.3292	**65.9**	**14.8**
$n_{\cdot j}$		0.002	0.000	0.000	0.076	0.087	0.151	0.017	0.356	0.058	0.000	0.000	0.002	0.250	**1.000** <= n		
PRODUCERS Accuracy (%)		**0.0**	**n/a**	**n/a**	**55.1**	**65.2**	**92.8**	**4.7**	**70.3**	**47.8**	**n/a**	**n/a**	**100.0**	**86.7**	**P_o**	**71.0%**	
PRODUCERS CI (± %)		**n/a**	**n/a**	**n/a**	**21.4**	**18.7**	**4.7**	**6.2**	**7.9**	**21.3**	**n/a**	**n/a**	**0.0**	**5.7**	**CI (±)**	**5.5%**	

Table 9. Error matrix for Detailed Coral Cover. The overall accuracy (P_o) was 91.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.885, with a 95% Confidence Interval of 0.851 – 0.919. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

CORAL COVER		**Coral** 0-<10%	10-<50%	50-<90%	>90%	n_{i-}	**USERS Accuracy (%)**
MAP DATA (i) Coral	0-<10%	**398**	23			421	**94.5**
	10-<50%	18	**37**			55	**67.3**
	50-<90%			**0**		0	**n/a**
	>90%				**0**	0	**n/a**
n_{-j}		416	60	0	0	**476 <= *n***	
PRODUCERS Accuracy (%)		**95.7**	**61.7**	**n/a**	**n/a**	**P_o 91.4%**	

$T_e = 0.885 \pm 0.034$

Table 10. Error matrix for Detailed Coral Cover (using individual cell probabilities P_{ij}). The overall accuracy, corrected for bias using the known map marginal proportions (π_i), was 92.5% with a 95% Confidence Interval of 90.2% - 94.8%. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

CORAL COVER		**Coral** 0-<10%	10-<50%	50-<90%	>90%	π_i	**USERS Accuracy (%)**	**USERS CI (± %)**
MAP DATA (i) Coral	0-<10%	**0.873**	0.050			0.9237	**94.5**	**2.2**
	10-<50%	0.025	**0.051**			0.0763	**67.3**	**12.7**
	50-<90%			**0.000**		0.0000	**n/a**	**n/a**
	>90%				**0.000**	0.0000	**n/a**	**n/a**
n_{-j}		0.898	0.102	0.000	0.000	**1.000 <= *n***		
PRODUCERS Accuracy (%)		**97.2**	**50.4**	**n/a**	**n/a**	**P_o**	**92.5%**	
PRODUCERS CI (± %)		**1.0**	**11.2**	**n/a**	**n/a**	**CI (±)**	**2.3%**	

DISCUSSION

4.1 ROI-2 GEOMORPHOLOGICAL STRUCTURE

ROI-2 Major Geomorphological Structure

The Major Geomorphological Structure attributes in ROI-2 were mapped with the greatest accuracy as indicated by the overall accuracy (89.3%), the overall accuracy adjusted for known map marginal proportions (91.3%), and the Tau coefficient (0.786), which adjusted for the number of map categories (Tables 1 and 2). Of the 51 classification errors, 42 were due to Unconsolidated Sediment being found in polygons classified as Coral Reef/Colonized Hardbottom. These results were approximately 0.5% higher than the previous AA of the same area under the old classification scheme (Walker and Foster, 2010). This was mostly due to one particular area of the map where the polygons were changed to unknown which contained 3 previously misclassified locations.

The ROI-2 overall accuracy for Major Structure was similar to other NOAA mapping efforts, although recent changes to the NOAA classification scheme precluded a direct comparison to most. Kendall et al. (2001) reported a very similar overall Major Structure accuracy of 93.6% for the NOAA Puerto Rico and Virgin Island maps. The Hawaiian Islands AA used the same classification scheme, but its distinctive geology and ecology confounded direct comparison to the Lower Keys AA. These issues aside, Smith et al. (unpublished data) reported an overall accuracy of 98.1% for Major Structure, 9.1% higher than ROI-2, and 9.3% higher after adjusting for known map marginal proportions. And finally, the NOAA St. John effort reported 96% total map accuracy for Major Geomorphologic Structure (Zitello et al., 2009). They adopted the methods reported in Walker and Foster (2009) to adjust for map marginal proportions, which increased the overall accuracy to 96.7%.

The overall accuracy in ROI-2 was also consistent with other nearby regional mapping accuracies implementing similar classification schemes. Walker et al. (2008) reported an overall map accuracy of 89.6% for Broward County, FL; Riegl et al. (2005) reported an overall accuracy of 89.2% for Palm Beach County, FL; and the recently completed Miami-Dade County map overall accuracy was 93.0% (Walker 2009).

ROI-2 Detailed Geomorphological Structure

The ROI-2 Detailed Geomorphological Structure attributes were mapped at the third highest level of accuracy, lower than Major Structure and Cover but higher Detailed Cover, as indicated by the overall accuracy (83.2%), the overall accuracy adjusted for known map marginal proportions (82.4%), and the Tau coefficient (0.813) (Tables 3 and 4). The overall accuracy was 7.5% less than the 90.0% reported for the Hawaiian Islands AA (Smith et al., unpublished data). Yet, in ROI-2, 8 of the 16 user's and producer's accuracies were greater than 80% and 6 of those were greater than 90%.

The reclassified map had slightly (0.36%) higher total accuracies than the previous map (Walker and Foster 2010). Most of the differences were due to slight changes in the map that reduced the number of errors. For example, Aggregated Patch Reefs previously contained 18 AA locations, whereas the reclassified map only contained 12. Conversely, Aggregate Reef AA locations were increased from 22 to 28 locations. The differences of each reclassified map polygon were not inspected or compared to the previous map to determine the cause of all the differences in the AA. This was not an issue given the similarity in accuracies between the old and the new assessments.

Aggregate Reef had the lowest user's accuracy (50.0%) of all classes in ROI-2. Although the total number of occurrences was low, 14 of 28 sites mapped as Aggregate Reef were found to be Sand (9), Rubble (1), or Pavement (4). Of the six found to be Sand, three occurred in very deep water (>35 m) which is beyond the usual limits of satellite imagery visual interpretation. The other three Sand sites were along the mapped forereef south of Middle Sambo in approximately 23 m depth. Features in these depths can also be difficult to discern depending on water clarity and lighting in the imagery.

Aggregate Reef also had one of the lowest producer's accuracy (63.9%) of all classes. Eight of 22 sites ground-truthed as Aggregate Reef were mapped as other habitats; Spur & Groove (1), Rubble (1), Pavement (5), and Sand (1) (Table 3). Most of these points occurred on the Bank/Shelf zone south of the main reef tract in water depths >15 m. Ground-truthing showed that the Pavement polygons mapped in this zone were variable in morphology with some parts of the polygons having Pavement morphology and others having Aggregate Reef and Spur & Groove (Figure 2).

Although not the lowest user's accuracy, areas mapped as Pavement were most frequently confused with other habitats (36) (Table 3). While the largest single error was mapping Sand habitat as Pavement (16 of 36), seven other categories were found within mapped Pavement polygons including Aggregate Reef (5), Aggregated Patch Reef (3), Individual Patch Reef (2), Spur & Groove (3), Rubble (1), Sand (16) and Mud (6). This demonstrates that Pavement was a difficult category to map and was much more variable than the other Detailed Structure Classes. Conversely, Pavement producer's errors were quite low having only 6 of 78 locations groundtruthed as Pavement occurring in other polygon classes; Aggregate Reef (4), Aggregated Patch Reef (1), and Sand (1).

Sand was the second-most variable habitat mapped even though it had relatively high user accuracy (89.5%). Polygons mapped as Sand contained six other categories; Aggregate Reef (1), Aggregated Patch Reef (2), Individual Patch Reef (3), Rubble (1), Pavement (1) and Mud (7). Discerning the difference between Sand and Mud was a challenge in the videos because the distinction ultimately depends on the Wentworth scale (*i.e.*, differences in grain size). Since sediment was not collected at each site, a judgment call was made based on how much plume was created by the camera hitting the bottom, the presence of certain flora and fauna, and occasionally by direct inspection of the seabed. Given the difficulty of classifying the drop-video samples, it would seem that visually distinguishing sand and mud from satellite images would be very difficult, and that it would be necessary to rely on other information such as biogeographic zone or energy regime.

Sand had the most frequent and variable producer's errors in the map. Thirty-five sites ground-truthed as Sand were mapped as one of five other classes; Aggregate Reef (9), Aggregated Patch Reef (3), Individual Patch Reef (1), Rubble (6), and Pavement (16). This was a very similar outcome to the ROI-1 map (Walker and Foster, 2009). Sand and Hardbottom can typically be distinguished with a high degree of success in shallow, clear water (Kendall et al. 2001, Zitello et al. 2009). Having lower than expected success in mapping Sand may have come from several sources. First, the errors could have arisen from a scaling mismatch between the mapping and the accuracy assessment. The minimum mapping unit (mmu) for the mapping was 0.4 hectares (4046 m^2). It was neither practical nor feasible to survey each accuracy assessment point at that scale, however to account for some of the difference, the vessel was allowed to drift at each location to get a better understanding of the general area instead of one particular point. Since the accuracy assessment point was not surveyed at the mmu, it is unknown whether the point was smaller than the mmu and should not be included as an error. All videos were assumed to represent the habitat at each location, therefore, if only Sand was seen throughout the video, it was considered a Sand site. Sand patches smaller than the mmu may have been large enough to be deemed a Sand habitat in the video, which would unfairly increase the producer's error for Sand.

The second possible source of error for Sand comes from the mapping protocol. The images being used to map ROI-2 were acquired over a time series between 2005 and 2006. NOAA's visual interpretation methodology is a time consuming process that can take up to a year or more for a given portion of the map to be drawn, groundtruthed and finalized, creating a lag time between image collection and map publication. For example, the ROI-1 map was created in 2007-2008 and assessed for accuracy in early 2009, but the data upon which the maps are based are from 2006 and earlier. Thus the maps being released in 2010 are based on four year old data. This time lag can have significant impact on the accuracy of the maps. Low relief habitats can often be covered and uncovered by sand movement during large storm events (Walker and Foster 2009, Walker 2009, Walker et al. 2008, Gilliam 2007) and the ephemeral nature of the system, especially in low relief pavement and seagrass habitats, likely contributed to some of the map errors. For example, the area in southern Miami-Dade is very dynamic and recent mapping showed large changes over a 3 year period, where large areas on the order of several thousand square meters that used to be dense seagrass were now sand (Walker 2009). Furthermore, Walker and Foster (2009) found large changes in satellite images in ROI-1 between 2005 and 2006. Some large-scale changes were noted in the 2006 imagery that were not reflected in the map nor the AA, presumably due to extreme storm conditions during hurricanes Katrina and Wilma indicating that large-scale changes have occurred in the recent past within the mapped area. These types of changes throughout the region affect the benthic habitat map accuracy and may degrade it over time. The longer the time lag between data collection and map creation, the more probability there is for errors to be introduced into the map based on temporal changes in habitat through time and not actual mapping methodological errors. Nonetheless they are errors in the map and are considered so in the accuracy assessment.

4.2 ROI-2 BIOLOGICAL COVER

ROI-2 Major Biological Cover

The Major Biological Cover attributes were mapped at the second highest level of accuracy, lower than the Major Geomorphological Structure and higher than Detailed Structure and Cover, as indicated by the overall accuracy (85.5%), the overall accuracy adjusted for known map marginal proportions (79.1%), and the Tau coefficient (0.819) (Tables 5 and 6). Major Cover total accuracy was 19.6% higher in the reclassified map versus the previous assessment (68.7%) (Walker and Foster 2010). One of the main reasons for this difference was the combining of Macroalgae and Turf algae into one class, Algae. The previous assessment had 48 errors in the confusion between these two categories and 91 total confusion errors. The reclassified map reduced these to 55 confusion errors.

The other cause for the increase in accuracy was in the Coral category. The previous map was a scheme mapping Coral as the highest priority, thus any site containing over 10% coral was considered Coral habitat. In the reclassified map, which goes by the dominant cover type, there were no polygons in ROI-2 mapped as Coral. All of the polygons previously classified as Coral were not considered dominated by coral and changed cover type. The previous map had 55 AA locations in polygons mapped as Coral whereas the reclassified map had none. There was one instance where a site mapped as Algae dominant was considered Coral dominant from the video. This is much different from the previous assessment where there were 42 confusion errors between Coral and other habitats.

Total map accuracy for Major Cover ranked low amongst other comparable recent studies. Zitello et al. (2009) reported a 93.7% total accuracy for St. John (93.0% adjusted for map marginal proportions); a 8.8% and 8.1% difference respectively. Similarly, Smith et al. (unpublished data) reported an overall accuracy of 92.1% for Major Cover, 7.1 % higher than ROI-2.

The allocation of sample points among Major Biological Cover categories in the Lower Keys was notably unbalanced. The reclassification of Coral habitats to other types and the combination of Macroalgae and Turf algae into one category exacerbated the unequal sampling between Major Cover categories. The final AA sites were located most frequently in Algae polygons (282) and less in Seagrass (116), No Cover

(41), and Emergent Vegetation (37). While this bias was ameliorated by adjusting for known map marginal proportions (Card 1982), the extreme disproportional sampling may have potential effects.

Aside from Emergent Vegetation, almost every Major Cover class was confused with each other except there were no polygons mapped as No Cover that were groundtruthed as Coral. The single largest confusion in the analysis was nineteen points mapped as Algae that were found to be Seagrass (Table 5). The distinction between Algae and Seagrass was challenging. It is rare to find seagrass without algae interspersed. Seagrass and many types of algae often cohabitate, making them difficult to distinguish in imagery. Furthermore, Algae cover is highly variable, typically ephemeral, and can significantly change temporally and with large energy regimes or nutrient inputs into an area. Due to the time lag between data collection, mapping, and accuracy assessment, it is not surprising that Algae had high confusion.

No Cover producer's accuracy was 52.9%. Twenty-four locations found to be No Cover in the groundtruthing were mapped as one of two other habitats; Seagrass (9) and Algae (15). The low accuracy in this category was partly due to the large proportion of No Cover in ROI-2 as evinced by correcting for map marginal proportions, which raised the accuracy to 83.6% (Table 6).

ROI-2 Detailed Biological Cover

Detailed Biological Cover attributes were mapped at the lowest level of accuracy for ROI-2 as indicated by the overall accuracy (73.1%), the overall accuracy adjusted for known map marginal proportions (71.0%), and the Tau coefficient (0.709). These results were less than those for ROI-1 (76.4% overall accuracy, 82.4% overall adjusted accuracy, and 0.749Tau) and much less than St. Johns (81.7%, Zitello et al. 2009) and Hawaii mapping where Smith et al. (unpublished data) reported an 83.5% overall accuracy, 18.8% higher. Adjusting the data for the known map marginal proportions did not substantially increase the overall accuracy for ROI-2.

The reclassified total map accuracy was 11.5% better than the previous assessment (Walker and Foster 2010) for many of the same reasons Major Cover was higher. The lack of Coral habitats and the combination of algae classes substantially reduced confusion in the map.

Emergent Vegetation was mapped the best having 100% user's and producer's classification accuracies. All 37 ground-truthed samples were composed of high mangrove cover. Presumably, the lack of an overlying water column accounted for the high classification scores. The producer's and user's accuracies for dense Seagrass (90-100%) were also high followed by medium Seagrass (50%-<90) and light (10%-<50%).

Algae cover contributed to most of the errors in the matrix. Fifty-seven errors occurred between Algae cover classes. Nineteen errors were areas of seagrass mapped as Algae. Eleven were Algae mapped as Seagrass. Fifteen were No Cover mapped as Algae. And nine were Algae mapped as No Cover. Algae were included in 86.7% (111) of the total 128 errors found in the assessment. The greatest single-class confusion existed between the Algae 50%-<90% and Algae 90%-100% categories (Table 7). Thirty-three points validated as Algae 50%-<90% were mapped as Algae 90%-100%. The user's accuracy for Algae 90%-100% (35.8%) showed that it was difficult to distinguish this category.

Seagrass user's and producer's accuracies were fairly high and confusion within the Seagrass Detailed Cover classes was minimal. There were a few instances where Seagrass polygons contained Algae or No Cover and some Seagrass was found in other habitat polygons, but these errors were relatively infrequent.

Another source of Biological Cover confusion was revealed by the producer's accuracy of the No Cover category. The reclassified map did not differ substantially with the previous assessment. While the known map marginal producer's accuracy was high (86.7%), 24 sites validated as No Cover were mapped as something else (Table 7). Six Detailed Cover habitat types contained No Cover groundtruthing sites, including 15 in Algae. It is unknown if these areas were larger than the mmu and may have been small patches of unmapped sand within other habitats, however it is also possible that some of these areas have changed significantly since the satellite imagery was collected and the maps were created. For example, Algae was most frequently associated with Pavement polygons. Because Pavement was defined by having low relief, nearby shifting sands in major energy events could create large landscape-level changes in this habitat. Since the satellite imagery was collected, a number of large storms have passed near the area and contributed to localized high energy conditions, including hurricanes Katrina and Wilma. These storms likely shifted large amounts of sand, burying pavement and seagrass and exposing previously buried substrate. This supposition may explain why so many communities mapped as other Cover types were found to be No Cover, however without recent imagery, the extent of these changes remains unknown.

ROI-2 Detailed Coral Cover

Unlike the previous assessment, the percent of Coral Cover (a combination of both the soft coral canopy and live hard corals) was attributed to every polygon in the map, thus a separate analysis was required to evaluate Detailed Coral Cover accuracy. This yielded high total map accuracy (91.4%) (Table 9) and adjusted total map accuracy (92.5%) (Table 10). The accuracy varied greatly between the two categories. User's and Producer's accuracies for Coral 0%-<10% were near or over 95%. Conversely, Coral 10%-<50% user's and producer's accuracies were less than 70% and 50.4% in the case of adjusted producer's accuracy. The adjustment for map proportions is very relevant here due to the large disparity of area between the two classes and the disproportionate sampling. The map contained 152.8 km² of Coral 0%-<10% and 12.6 km² of Coral 10%-<50%. Further 421 of AA points were in Coral 0%-<10% and 55 were in Coral 10%-<50%. Interestingly there were no occurrences of Coral 50%-<90% and 90%-100% in ROI-2. There was some confusion between coral classes where 18 locations mapped as Coral 10%-<50% were actually Coral 0%-<10% and 23 locations mapped as Coral 0%-<10% were found to be Coral 10%-<50%.

4.3 POINT V. TRANSECT

There are no strict rules as to which ground validation sampling methodology works best. Assessments at point locations and areal assessments are equally valid (Stehman and Czaplewski, 1998), but ideally the reference data should be collected at the MMU's scale (Stadelmann, 1994). The Lower Keys mapping protocol dictated that the maps were drawn at a 1:6000 scale with a 625 sq m minimum mapping unit. It was neither practical nor economically feasible to assess the seafloor at this scale. However, assessment at a localized point wasn't ideal because it would not give a good representation of the area surrounding the sample point at the map scale. Localized point ground validation would have been problematic in mixed habitats like Aggregated Patch Reefs where patch reefs may be spread out and might not be visible at all discrete locations in the polygon. For example, a random point may be placed in the polygon such that the video would contain only Unconsolidated Sediments. This would be considered an error in the map, yet the error was caused by the difference in scale between the map and the assessment method rather than a true map error. This could also cause problems in the assessment of Biological Cover which can vary significantly on small spatial scales. In order to address this issue, AA samples in this effort were taken near the random sample location while drifting. The drift allowed for more of the surrounding area to be visited and recorded, thus giving more insight and confidence in the Geomorphological Structure and Biological Cover at a scale closer to the map MMU. This also helped reduced the spatial errors associated with a precise GPS location.

The drifting assessment helped assess the transitions between habitats (i.e. the polygon borders) as well. A certain level of error is inherent in habitat transitions due to the scale of mapping (1:6000) and spatial errors in the imagery and GPS precision (Foody, 2002). Constraining sampling away from polygon boundaries to minimize spatial errors between the imagery and GPS is common practice (Dicks & Lo, 1990; Mickelson, Civco, & Silander, 1998; Richards, 1996; Wickham, O'Neill, Ritters, Wade, & Jones, 1997), however, this strategy, may optimistically bias the results by not assessing the habitat transitions (Congalton & Plourde, 2000; Foody, 2002; Hammond & Verbyla, 1996; Muller et al., 1998; Yang et al., 2000; Zhu et al., 2000). Employing transect sampling and not constraining the samples from polygon edges allowed some component of the habitat transition errors to be captured. Although habitat transitions were not specifically targeted, assessed, or quantified, several occasions were encountered where the boat drifted from one habitat into another and the change was evident in the video. In these instances, the site location was considered the GPS coordinate from the point in the video where the targeted habitat was encountered.

4.4 ACCURACY REPRESENTATION FOR THE ENTIRE MAPPED AREA

Resources, budgets, and logistical constraints precluded a comprehensive assessment of the entire mapped area, thus biogeographically representative corridors within the total benthic habitat map area were selected for performing the accuracy assessment (Congalton, 1991; Stehman and Czaplewski, 1998). These corridors not only captured a wide diversity of habitats, but were also characterized by frequent transitions between habitat types.

The true error of non-sampled portions of the map is ultimately unknown and further sampling in these areas of the map would allow for a better understanding of the entire map accuracy, however, the accuracy assessment ensured that a well-distributed, representative set of monitoring locations were surveyed that closely represented the entire mapped region. For this reason it is thought to be a good measure of the map accuracies for the broader area. Many of the Biological Cover habitats were very small relative to the overall percentage of the entire mapped area; therefore the total map accuracy adjusted for marginal map proportions was likely a better gauge of the overall map accuracy than P_0. This, however, should not diminish the use of Tau as a metric to gauge map accuracy. Adjusting for marginal map proportions does not account for the probabilities of error due to increased number of classes, thus both metrics should be used as a gauge of the overall accuracy of the map products.

The relatively low overall accuracy and the high level of confusion between classes in ROI-2 made it evident that this area was more difficult to map than ROI-1. Because the same methodologies were used for both efforts, the main differences were twofold. Either the longer time lag between image collection, map creation, and accuracy assessment allowed for more changes in the landscape between efforts or that the images were not as good (possibly due to water clarity, sun glint, or clouds). We have already discussed many issues regarding the former, however the latter was likely a critical factor. ROI-2 is known to be more turbid than many other areas in the Keys, especially the area around Hawk Channel and the shipping lanes near Key West. During our assessment, we qualitatively noted extreme variability in water clarity/turbidity depending on our proximity to these areas. Even scuba diving up the forereef slope was extremely poor visibility (<5 m) on a beautiful day with a week of calm seas. The very large area of Unknown polygons in relatively shallow waters throughout ROI-2 suggests that turbidity in the satellite imagery may have been a factor in interpreting large areas of the seafloor and likely contributed to the lower map accuracies in this corridor.

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