Final Report

Accuracy Assessment and Monitoring for NOAA Florida Keys mapping ROI 2 (Key West)

February 10, 2010

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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. 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 km² 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 479 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 88.7% and 82.9% at the Major and Detailed levels of Structure respectively, and 68.7% and 64.7% 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 90.8% and 81.3%. The overall accuracy at the Major and Detailed levels of cover changed to 71.0% and 67.9%. 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 0.775 ± 0.057 and 0.810 ± 0.037 at the Major and Detailed levels of Structure, and 0.635 ± 0.048 and 0.626 ± 0.045 at the Major and Detailed levels of cover. The ROI-2 results were then combined with ROI-1 to give the total map accuracy for the larger region (Cudjoe Key to Key West). The regional overall accuracy of the combined accuracy assessments was 91.3% and 84.5% at the Major and Detailed levels of Structure respectively, and 74.4% and 70.5% at the Major and Detailed levels of cover. Adjusting to the map proportions improved the overall accuracies to 94.0% and 86.5% at the Major and Detailed levels of Structure, and to 80.2% and 78.0% at the Major and Detailed levels of cover. The Tau coefficients of the combined efforts were 0.827 ± 0.036 and 0.828 ± 0.025 at the Major and Detailed levels of Structure, and 0.701 ± 0.032 and 0.688 ± 0.031 at the Major and Detailed levels of cover.

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 details the procedures and findings of the accuracy assessment for the second corridor (ROI-2) conducted by scientists from the National Coral Reef Institute (NCRI) at Nova Southeastern University Oceanographic Center and combined results from the total accuracy assessments performed to date (ROI-1 and ROI-2) (Figure 1). It builds upon a successful, prior accuracy assessment conducted by the National Coral Reef Institute in January 2009 near American Shoals (ROI-1) (Walker and Foster, 2009).

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.

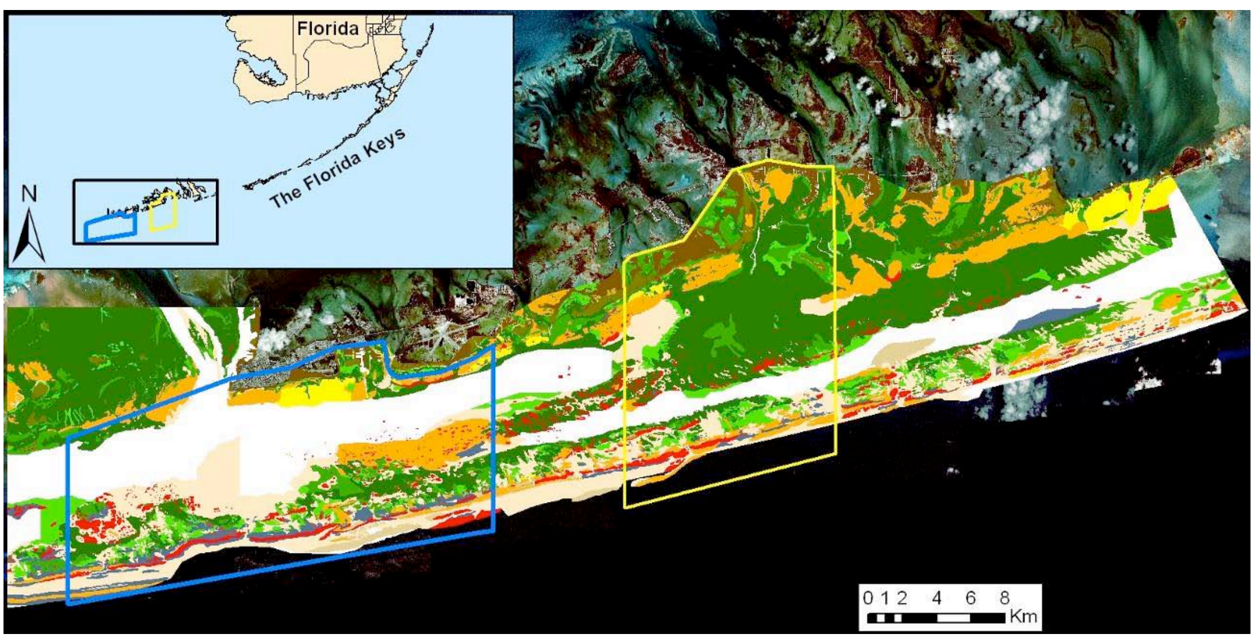

Figure 1. Accuracy Assessment Area 1 (ROI-1) (yellow) and Area 2 (ROI-2) (Blue), within the overall NOAA mapped region of the Lower FL Keys. ROI-1 included the seaward seafloor south of Cudjoe and Sugarloaf Keys including American Shoals. ROI-2 included the region between Sand Key and Eastern Sambo from the shoreline intertidal zone to the outer bank/shelf escarpment at a depth of approximately 33m.

METHODOLOGY

2.1 CLASSIFICATION SCHEME (FROM ROHMANN 2008)

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 most recent developments in 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 to calibrate the two teams and reduce confusion between habitat definitions. NCRI scientists applied this knowledge with success during the AA for ROI-1 (Walker and Foster, 2009) which showed high agreement in many categories throughout the first AA. Both AA's assessed two map attributes using the same assessment locations: one to assess geomorphological structure and one to assess biological cover. The classification schemes used in the AA are listed below and more information can be found in Rohmann (2008).

Coral Ecosystem Geomorphological Structures

Unconsolidated Sediment

Sand: Coarse sediment typically found in areas exposed to currents or wave energy. Sand is associated with several zones including shoreline intertidal, bank/shelf, ridges and swales, and forereef.

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

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

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

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

Individual Patch Reef: Distinctive single patch reefs that are larger than or equal to 625 sq m (0.0625 ha).

Aggregate Patch Reefs: Clustered patch reefs that, individually, are too small (less than the 625 sq m MMU) or are too close together to map separately and, therefore, are combined using the 0.4 ha MMU.

Aggregate Reef: High relief lacking sand channels of spur and groove.

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

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

Rock/Boulder: Solid carbonate blocks and/or boulders or volcanic rock.

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

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

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

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

Live Coral

Continuous (90%-100% Cover; a whole lot)
Patchy (Discontinuous) Live Coral (50%-<90% Cover, a lot)
Sparse (Discontinuous) Live Coral (10%-<50% Cover; a little)

Seagrass

Continuous (90%-100% Cover; a whole lot)
Patchy (Discontinuous) Seagrass (50%-<90% Cover; a lot)
Sparse (Discontinuous) Seagrass(10%-<50% Cover; a little)

Macroalgae

Continuous (90%-100% Cover; a whole lot)
Patchy (Discontinuous) Macroalgae (50%-<90% Cover; a lot)
Sparse (Discontinuous) Macroalgae (10%-<50% Cover; a little)

Coralline Algae

Continuous (90%-100% Cover; a whole lot)
Patchy (Discontinuous) Encrusting/Coralline Algae (50%-<90% Cover; a lot)
Sparse (Discontinuous) Encrusting/Coralline Algae (10%-<50% Cover; a little)

Turf

Continuous (90%-100% Cover; a whole lot)
Patchy (Discontinuous) Turf (50%-<90% Cover; a lot)
Sparse (Discontinuous) Turf (10%-<50% Cover; a little)

Emergent Vegetation

Marsh
Mangrove

Uncolonized

Continuous (90%-100% uncolonized)

2.2 ACCURACY ASSESSMENT

Data Collection

The region of interest for the ROI-2 accuracy assessment corridor was approximately 249.6 km^2, representing 27.5% of the total area (907 km^2) 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 km^2) . However, the areas of known mapped habitats were nearly equal (ROI-2 = 168 km^2; ROI-1 = 167.9 km^2). The total area (excluding unknown) of the two accuracy assessments equaled 335.9 km^2, 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. Sites that differed between field notes and map classification were evaluated both in GIS and from video to determine possible source of disagreement.

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 42 random locations visited in Unknown habitat were not part of the error analyses.

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 53.4% of the total area of known seafloor habitats mapped in AA ROI-2, but only 30.3% (145/479) of the accuracy assessment points. Conversely, the Rubble category accounted for only 1.85% of the total mapped area of known seafloor habitats and 16.5% (79/479) of the accuracy assessment points. This amounted to a sampling intensity of 1.6 points per km^2 (145/88.2) for the very large Sand category versus 25.9 points per km^2 (79/3.05) 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 0.534 (88.24 km^2/165.2 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 (Appendix 1). Of the 533 stations visited, 479 were used for the accuracy assessment. The majority of excluded samples were due to intentionally visiting unknown areas (n=42).

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 88.7% at the Major Structure level (Table 1). The Tau coefficient for equal probability of group membership (T_e) was 0.775 ± 0.057 (α=0.05), i.e. the rate of misclassifications at the Major Structure level was 77.5% 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 90.8% ± 2.6 (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), 181 of 225 ground-truthed Soft samples were correctly classified as Soft bottom habitats. The remaining 44 samples were incorrectly classified as Hard. The un-adjusted producer's accuracy was therefore equal to 181/225 = 80.4%. However, the known map marginal proportions of the Soft habitats were 60.04%, versus 39.6% 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 (44*0.396/288=0.0605 and 181*0.604/191=0.5724), increasing producer's accuracy from 80.4% to 90.4%.

Detailed Geomorphological Structure

Error matrices for Detailed Geomorphological Structure are presented in Tables 3 and 4. The overall accuracy (P_o) was 82.9% at the Detailed Structure level (Table 3). The Tau coefficient for equal probability of group membership (T_e) was 0.810 ± 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 81.3% ± 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 68.7% at the Major Cover level (Table 5). The Tau coefficient for equal probability of group membership (T_e) was 0.635 ± 0.048 (α=0.05), i.e. the rate of misclassifications at the Major Cover level was 63.5% 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 71.0% ± 5.6 (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 64.7% at the Detailed Cover level (Table 7). The Tau coefficient for equal probability of group membership (T_e) was 0.626 ± 0.045 (α=0.05), i.e. the rate of misclassifications at the Detailed Cover level was 62.6% less than would be expected from random assignment of polygons to categories. T_e more closely approached P_o at the Detailed level (r = 11) than at the Major level (r = 7), 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 67.9% ± 5.7 (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 88.7%. The Tau coefficient for equal probability of group membership (T_e) was 0.775, with a 95% Confidence Interval of 0.718– 0. 832.

MAP (i)	*MAJOR STRUCTURE*	TRUE (GROUND-TRUTHED) (j): hard	soft	n_{i-}	USERS Accuracy (%)
	hard	**244**	44	288	**84.7**
	soft	10	**181**	191	**94.8**
	n_{-j}	254	225	**479** <= n	
	PRODUCERS Accuracy (%)	**96.1**	**80.4**	P_o **88.7%**	

$T_e = 0.775 \pm 0.057$

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 90.8% with a 95% Confidence Interval of 88.2% – 93.4%.

MAP (i)	*MAJOR STRUCTURE*	TRUE (GROUND-TRUTHED) (j): hard	soft	π_i	USERS Accuracy (%)	USERS CI (± %)
	hard	**0.3355**	0.0605	0.396	**84.7**	**4.2**
	soft	0.0316	**0.5724**	0.604	**94.8**	**3.2**
	n_{-j}	0.367	0.633	**1.000** <= n		
	PRODUCERS Accuracy (%)	**91.4**	**90.4**	P_o **90.8%**		
	PRODUCERS CI (± %)	**4.9**	**2.4**	**CI (±) 2.6%**		

Table 3. Error matrix for Detailed Geomorphological Structure. The overall accuracy (P_o) was 82.9%. The Tau coefficient for equal probability of group membership (T_e) was 0.810, with a 95% Confidence Interval of 0.773 – 0.847. Blank cells indicate 0 occurrences.

DETAILED STRUCTURE / MAP DATA (i) — TRUE (GROUND-TRUTHED) (j)	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	**13**				1	2		6		22	**59.1**
Aggregated Patch Reef		**11**				1		6		18	**61.1**
Individual Patch Reef			**15**					1	1	17	**88.2**
Spur and Groove	1			**42**						43	**97.7**
Rubble	1				**74**			4		79	**93.7**
Pavement	6	1	3	4	1	**68**		18	8	109	**62.4**
Pav w/ Sand Channels							**0**			0	**n/a**
Sand	1	2	3		1	2		**129**	7	145	**89.0**
Mud			1						**45**	46	**97.8**
n_{-j}	22	14	22	46	77	73	0	164	61	**479** <= n	
PRODUCERS Accuracy (%)	**59.1**	**78.6**	**68.2**	**91.3**	**96.1**	**93.2**	**n/a**	**78.7**	**73.8**	P_o 82.9%	

T_e = 0.810 ± 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 81.3% with a 95% Confidence Interval of 77.5% – 85.1%. Blank cells indicate 0 occurrences.

DETAILED STRUCTURE / MAP DATA (i) — TRUE (GROUND-TRUTHED) (j)	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	**0.0221**				0.0017	0.0034		0.0102		0.037	**59.1**	**21.0**
Aggregated Patch Reef		**0.0131**				0.0012		0.0071		0.021	**61.1**	**23.0**
Individual Patch Reef			**0.0160**					0.0011	0.0011	0.018	**88.2**	**15.6**
Spur and Groove	0.0009			**0.0368**						0.038	**97.7**	**4.6**
Rubble	0.0002				**0.0173**			0.0009		0.018	**93.7**	**5.5**
Pavement	0.0145	0.0024	0.0072	0.0097	0.0024	**0.1641**		0.0434	0.0193	0.263	**62.4**	**9.3**
Pav w/ Sand Channels							**0.0000**			0.000	**n/a**	**n/a**
Sand	0.0037	0.0074	0.0111		0.0037	0.0074		**0.4752**	0.0258	0.534	**89.0**	**5.2**
Mud			0.0015						**0.0684**	0.070	**97.8**	**4.3**
n_{-j}	0.041	0.023	0.036	0.046	0.025	0.176	0.000	0.538	0.115	**1.000** <= n		
PRODUCERS Accuracy (%)	**53.4**	**57.2**	**44.6**	**79.2**	**68.9**	**93.2**	**n/a**	**88.3**	**59.7**	P_o 81.3%		
PRODUCERS CI (± %)	**19.8**	**30.0**	**19.7**	**16.2**	**25.8**	**6.2**	**n/a**	**3.5**	**12.1**	CI (±) 3.8%		

Table 5. Error matrix for Major Biological Cover. The overall accuracy (P_o) was 68.7%. The Tau coefficient for equal probability of group membership (T_e) was 0.635, with a 95% Confidence Interval of 0.587 – 0.683. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — MAJOR COVER	Coral	Sea Grass	Macro algae	Coralline Algae	Turf	Emerg Veg	Un-Colonized	n_{i-}	USERS Accuracy (%)
Coral	**36**	4	5		8		2	55	**65.5**
Seagrass	2	**98**	5		3		9	117	**83.8**
Macroalgae	14	9	**52**		1		4	80	**65.0**
Coralline Algae				**0**				0	**n/a**
Turf	7	6	47		**76**		12	148	**51.4**
Emerg Veg						**37**		37	**100.0**
UnColonized		3	6		3		**30**	42	**71.4**
n_{-j}	59	120	115	0	91	37	57	**479** <= n	
PRODUCERS Accuracy (%)	**61.0**	**81.7**	**45.2**	**n/a**	**83.5**	**100.0**	**52.6**	P_o **68.7%**	

T_e = 0.635 ± 0.048

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 71.0% with a 95% Confidence Interval of 65.4% – 76.6%. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — MAJOR COVER	Coral	Sea Grass	Macro algae	Coralline Algae	Turf	Emerg Veg	Un-Colonized	π_i	USERS Accuracy (%)	USERS CI (± %)
Coral	**0.0503**	0.0056	0.0070		0.0112		0.0028	0.077	**65.5**	**12.8**
Seagrass	0.0049	**0.2380**	0.0121		0.0073		0.0219	0.284	**83.8**	**6.8**
Macroalgae	0.0342	0.0220	**0.1271**		0.0024		0.0098	0.196	**65.0**	**10.7**
Coralline Algae				**0.0000**				0.000	**n/a**	**n/a**
Turf	0.0053	0.0046	0.0357		**0.0578**		0.0091	0.113	**51.4**	**8.2**
Emerg Veg						**0.0024**		0.002	**100.0**	**0.0**
UnColonized		0.0235	0.0469		0.0235		**0.2347**	0.329	**71.4**	**13.9**
n_{-j}	0.095	0.294	0.229	0.000	0.102	0.002	0.278	**1.000** <= n		
PRODUCERS Accuracy (%)	**53.1**	**81.1**	**55.5**	**n/a**	**56.6**	**100.0**	**84.3**	P_o **71.0%**		
PRODUCERS CI (± %)	**11.4**	**8.4**	**10.2**	**n/a**	**16.4**	**0.0**	**6.1**	**CI (±) 5.6%**		

Table 7. Error matrix for Detailed Biological Cover, L = 10-<50%, M = 50-<90%, H = 90-100%. The overall accuracy (P_o) was 64.7%. The Tau coefficient for equal probability of group membership (T_e) was 0.626, with a 95% Confidence Interval of 0.581 – 0.671. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — DETAILED COVER		Coral			Seagrass			Macroalgae			Coralline Algae		Turf			Emergent Vegetation			Un-colonized	n_{i-}	USERS Accuracy (%)
		L	M	H	L	M	H	L	M	H	L	M	L	M	H	L	M	H			
Coral	L	**35**	1		1	1	2	4	1				4	3	1				2	55	**63.6**
	M		**0**																	0	**n/a**
	H			**0**																0	**n/a**
Seagrass	L	2			**25**				1					1					6	35	**71.4**
	M				1	**34**		3					1	1					2	42	**81.0**
	H				1		**37**		1										1	40	**92.5**
Macro Algae	L	10					3	**20**	4	1				1					3	42	**47.6**
	M	4			2		4		**27**										1	38	**71.1**
	H									**0**										0	**n/a**
Coralline Algae	L										**0**									0	**n/a**
	M											**0**								0	**n/a**
Turf	L	1			1	1	1	4	2	1			**9**	1					5	26	**34.6**
	M	2			2	1		22	9				1	**52**	4				1	94	**55.3**
	H	4						3	6					5	**4**				6	28	**0.1**
Emergent Vegetation	L															**0**				0	**n/a**
	M																**0**			0	**n/a**
	H																	**37**		37	**100.0**
Uncolonized					2	1		1	3	2				3					**30**	42	**71.4**
n_{-j}		58	1	0	35	38	47	57	54	4	0	0	15	67	9	0	0	37	57	**479**	<= n
PRODUCERS Accuracy (%)		**60.3**	**0.0**	**n/a**	**71.4**	**89.5**	**78.7**	**35.1**	**50.0**	**0.0**	**n/a**	**n/a**	**60.0**	**77.6**	**44.4**	**n/a**	**n/a**	**100.0**	**52.6**	P_o	**64.7%**

T_e = 0.626 ± 0.045

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 67.9% with a 95% Confidence Interval of 62.2% - 73.6%. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i)

DETAILED COVER		Coral			Seagrass			Macroalgae			Coralline Algae		Turf			Emergent Vegetation			Un-colonized	π_i	USERS Accuracy	USERS CI
		L	M	H	L	M	H	L	M	H	L	M	L	M	H	L	M	H			(%)	(± %)
Coral	L	**0.049**	0.001		0.001	0.001	0.003	0.006	0.001				0.006	0.004	0.001				0.003	0.0769	**63.6**	**13.0**
	M		**0.000**																	0.0000	**n/a**	**na**
	H			**0.000**																0.0000	**n/a**	**n/a**
Seagrass	L	0.003			**0.042**				0.002					0.002					0.010	0.0591	**71.4**	**15.3**
	M				0.002	**0.055**		0.005					0.002	0.002					0.003	0.0681	**81.0**	**12.1**
	H				0.004		**0.145**		0.004										0.004	0.1570	**92.5**	**8.3**
Macro Algae	L	0.038					0.011	**0.076**	0.015	0.004				0.004					0.011	0.1604	**47.6**	**15.4**
	M	0.004			0.002		0.004		**0.025**										0.001	0.0352	**71.1**	**14.7**
	H									0.000										0.0000	**n/a**	**n/a**
Coralline Algae	L										**0.000**									0.0000	**n/a**	**n/a**
	M											**0.000**								0.0000	**n/a**	**n/a**
Turf	L	0.000			0.000	0.000	0.000	0.001	0.000	0.000			**0.002**	0.000					0.001	0.0051	**34.6**	**18.7**
	M	0.002			0.002	0.001		0.018	0.007				0.001	**0.043**	0.003				0.001	0.0775	**55.3**	**10.3**
	H	0.004						0.003	0.006					0.005	**0.004**				0.006	0.0299	**0.1**	**13.2**
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**
Uncolonized					0.016	0.008		0.008	0.023	0.016				0.023					**0.235**	0.3286	**71.4**	**13.9**
$n_{\cdot j}$		0.100	0.001	0.000	0.068	0.065	0.163	0.117	0.085	0.020	0.000	0.000	0.010	0.083	0.009	0.000	0.000	0.002	0.275	**1.000**	<= n	
PRODUCERS Accuracy (%)		**48.8**	**0.0**	**n/a**	**61.6**	**84.3**	**88.9**	**65.4**	**29.4**	**0.0**	**n/a**	**n/a**	**18.0**	**51.5**	**47.6**	**n/a**	**n/a**	**100.0**	**85.2**	P_o	67.9%	
PRODUCERS CI(± %)		**12.0**	**0.0**	**n/a**	**21.8**	**20.5**	**7.6**	**12.9**	**11.8**	**n/a**	**n/a**	**n/a**	**14.3**	**18.1**	**32.3**	**n/a**	**n/a**	**0.0**	**6.2**	CI(±)	5.7%	

Table 9. Error matrix of ROI-1 and ROI-2 combined for Major Geomorphological Structure. The overall accuracy (P_o) was 91.3%. The Tau coefficient for equal probability of group membership (T_e) was 0.827, with a 95% Confidence Interval of 0.791– 0. 863.

	MAJOR STRUCTURE	**TRUE (GROUND-TRUTHED) (j)** hard	soft	n_{i-}	USERS Accuracy (%)
MAP (i)	**hard**	**426**	70	496	**85.9**
MAP (i)	**soft**	13	**448**	461	**97.2**
	n_{-j}	439	518	**957** **<=** n	
	PRODUCERS Accuracy (%)	**97.0**	**86.5**	P_o **91.3%**	

$$T_e = 0.827 \pm 0.036$$

Table 10. Error matrix of ROI-1 and ROI-2 combined 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 94.0% with a 95% Confidence Interval of 92.6% – 95.4%.

	MAJOR STRUCTURE	**TRUE (GROUND-TRUTHED) (j)** hard	soft	π_i	USERS Accuracy (%)	USERS CI (± %)
MAP (i)	**hard**	**0.2406**	0.0395	0.280	**85.9**	**3.1**
MAP (i)	**soft**	0.0203	**0.6996**	0.720	**97.2**	**1.5**
	n_{-j}	0.261	0.739	**1.000** **<=** n		
	PRODUCERS Accuracy (%)	**92.2**	**94.7**	P_o **94.0%**		
	PRODUCERS CI (± %)	**3.9**	**1.1**	**CI (±) 1.4%**		

Table 11. Error matrix of ROI-1 and ROI-2 combined for Detailed Geomorphological Structure. The overall accuracy (P_o) was 84.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.828, with a 95% Confidence Interval of 0.803 – 0.8853. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — ***DETAILED STRUCTURE***	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	**72**		1		1	3		9		86	**83.7**
Aggregated Patch Reef		**26**				2		10		38	**68.4**
Individual Patch Reef			**28**					2	2	32	**87.5**
Spur and Groove	1			**54**			9			64	**84.4**
Rubble	1				**89**	3		4		97	**91.8**
Pavement	6	1	3	4	1	**107**		22	15	159	**67.3**
Pav w/ Sand Channels	3					1	**10**	6		20	**50.0**
Sand	1	2	5		1	3		**244**	22	278	**87.8**
Mud			1					3	**179**	183	**97.8**
n_{-j}	84	29	38	58	92	119	19	300	218	**957**	<= n
PRODUCERS Accuracy (%)	**85.7**	**89.7**	**73.7**	**93.1**	**96.7**	**89.9**	**52.6**	**81.3**	**82.1**	P_o	**84.5%**

T_e = 0.828 ± 0.025

Table 12. Error matrix of ROI-1 and ROI-2 combined 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 86.5% with a 95% Confidence Interval of 84.3% – 88.7%. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — DETAILED STRUCTURE	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	**0.0254**		0.0004		0.0004	0.0011		0.0032		0.030	**83.7**	**8.0**
Aggregated Patch Reef		**0.0093**				0.0007		0.0036		0.014	**68.4**	**15.1**
Individual Patch Reef			**0.0128**					0.0009	0.0009	0.015	**87.5**	**11.7**
Spur and Groove	0.0003			**0.0188**			0.0031			0.022	**84.4**	**9.1**
Rubble	0.0001				**0.0110**	0.0004		0.0005		0.012	**91.8**	**5.6**
Pavement	0.0069	0.0011	0.0034	0.0046	0.0011	**0.1224**		0.0252	0.0172	0.182	**67.3**	**7.4**
Pav w/ Sand Channels	0.0008					0.0003	**0.0028**	0.0017		0.006	**50.0**	**22.4**
Sand	0.0015	0.0029	0.0074		0.0015	0.0044		**0.3597**	0.0324	0.410	**87.8**	**3.9**
Mud			0.0017					0.0051	**0.3033**	0.310	**97.8**	**2.2**
$n_{\cdot j}$	0.035	0.013	0.026	0.023	0.014	0.129	0.006	0.400	0.354	**1.000** <= n		
PRODUCERS Accuracy (%)	**72.5**	**69.4**	**49.8**	**80.4**	**78.7**	**94.7**	**46.9**	**90.0**	**85.7**	**P_o**	**86.5%**	
PRODUCERS CI (± %)	**13.3**	**25.0**	**16.6**	**15.6**	**21.4**	**4.0**	**21.4**	**2.7**	**3.8**	**CI (±)**	**2.2%**	

Table 13. Error matrix of ROI-1 and ROI-2 combined for Major Biological Cover. The overall accuracy (P_o) was 74.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.701, with a 95% Confidence Interval of 0.669 – 0.733. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — MAJOR COVER	Coral	Sea Grass	Macro algae	Coralline Algae	Turf	Emerg Veg	Un-Colonized	n_{i-}	USERS Accuracy (%)
Coral	**68**	5	6		8		3	90	**75.6**
Seagrass	4	**204**	15		3		16	242	**84.3**
Macroalgae	18	23	**115**		4		7	167	**68.9**
Coralline Algae			7	**0**	7		1	15	**0.0**
Turf	22	7	57		**123**		18	227	**54.2**
Emerg Veg						**103**		103	**100.0**
UnColonized		5	6		3		**99**	113	**87.6**
n_{-j}	112	244	206	0	148	103	144	**957**	**<= n**
PRODUCERS Accuracy (%)	**60.7**	**83.6**	**55.8**	**n/a**	**83.1**	**100.0**	**68.8**	**P_o**	**74.4%**

T_e = 0.701 ± 0.032

Table 14. Error matrix of ROI-1 and ROI-2 combined 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 80.2% with a 95% Confidence Interval of 77.3% – 83.1%. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — MAJOR COVER	Coral	Sea Grass	Macro algae	Coralline Algae	Turf	Emerg Veg	Un-Colonized	π_i	USERS Accuracy (%)	USERS CI (± %)
Coral	**0.0374**	0.0028	0.0033		0.0044		0.0017	0.050	**75.6**	**9.1**
Seagrass	0.0077	**0.3914**	0.0288		0.0058		0.0307	0.464	**84.3**	**4.7**
Macroalgae	0.0165	0.0211	**0.1054**		0.0037		0.0064	0.153	**68.9**	**7.2**
Coralline Algae			0.0000	**0.0000**	0.0000		0.0000	0.000	**0.0**	**0.0**
Turf	0.0073	0.0023	0.0189		**0.0407**		0.0060	0.075	**54.2**	**6.6**
Emerg Veg						**0.0131**		0.013	**100.0**	**0.0**
UnColonized		0.0108	0.0130		0.0065		**0.2145**	0.245	**87.6**	**6.2**
n_{-j}	0.069	0.428	0.169	0.000	0.061	0.013	0.259	**1.000**	**<= n**	
PRODUCERS Accuracy (%)	**54.3**	**91.4**	**62.2**	**n/a**	**66.7**	**100.0**	**82.7**	**P_o**	**80.2%**	
PRODUCERS CI (± %)	**9.2**	**2.8**	**7.2**	**n/a**	**12.3**	**0.0**	**5.2**	**CI (±)**	**2.9%**	

Table 15. Error matrix of ROI-1 and ROI-2 combined for Detailed Biological Cover, L = 10-<50%, M = 50-<90%, H = 90-100%. The overall accuracy (P_o) was 70.5%. The Tau coefficient for equal probability of group membership (T_e) was 0.688, with a 95% Confidence Interval of 0.657 – 0.719. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — DETAILED COVER		Coral			Seagrass			Macroalgae			Coralline Algae		Turf			Emergent Vegetation			Un-colonized	n_{i-}	USERS Accuracy (%)
		L	M	H	L	M	H	L	M	H	L	M	L	M	H	L	M	H			
Coral	L	**61**	6	1	2	1	2	4	2				4	3	1				3	90	**67.8**
	M		**0**																	0	**n/a**
	H			**0**																0	**n/a**
Seagrass	L	3			**57**			2	2					1					11	76	**75.0**
	M				2	**67**		6					1	1					3	80	**83.8**
	H	1			1	2	**75**	2	3										2	86	**87.2**
Macro Algae	L	14			4	5	5	**54**	5	1			1	3					4	96	**56.3**
	M	4			4		5	4	**51**										3	71	**71.8**
	H									**0**										0	**n/a**
Coralline Algae	L										**0**								1	1	**0.0**
	M							6	1			**0**	1	6						14	**0.0**
Turf	L	1			2	1	1	9	2	1			**11**	3					9	40	**27.5**
	M	17			2	1		24	12				1	**93**	6				3	159	**58.5**
	H	4						3	6					5	**4**				6	28	**14.3**
Emergent Vegetation	L															**24**				24	**100.0**
	M																**8**			8	**100.0**
	H																	**71**		71	**100.0**
Uncolonized					3	2		1	3	2				3					**99**	113	**87.6**
n_{-j}		105	6	1	77	79	88	115	87	4	0	0	19	118	11	24	8	71	144	**957**	**<= n**
PRODUCERS Accuracy (%)		**58.1**	**0.0**	**0.0**	**74.0**	**84.8**	**85.2**	**47.0**	**58.6**	**0.0**	**n/a**	**n/a**	**57.9**	**78.8**	**36.4**	**100.0**	**100.0**	**100.0**	**68.8**	**P_o**	**70.5%**

T_e = 0.688 ± 0.031

Table 16. Error matrix of ROI-1 and ROI-2 combined 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 78.0% with a 95% Confidence Interval of 74.7% - 81.3%. Blank cells indicate 0 occurrences.

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i): DETAILED COVER		Coral			Seagrass			Macroalgae			Coralline Algae		Turf			Emergent Vegetation			Un-colonized	π_i	USERS Accuracy (%)	USERS CI (± %)
		L	M	H	L	M	H	L	M	H	L	M	L	M	H	L	M	H				
Coral	L	**0.034**	0.003	0.001	0.001	0.001	0.001	0.002	0.001				0.002	0.002	0.001				0.002	0.0495	**67.8**	**9.9**
	M		**0.000**																	0.0000	**n/a**	**n/a**
	H			**0.000**																0.0000	**n/a**	**n/a**
Seagrass	L	0.003			**0.051**			0.002	0.002					0.001					0.010	0.0682	**75.0**	**9.9**
	M				0.002	**0.071**		0.006					0.001	0.001					0.003	0.0843	**83.8**	**8.2**
	H	0.004			0.004	0.007	**0.272**	0.007	0.011										0.007	0.3118	**87.2**	**7.2**
Macro Algae	L	0.019			0.005	0.007	0.007	**0.074**	0.007	0.001			0.001	0.004					0.005	0.1315	**56.3**	**10.1**
	M	0.001			0.001		0.002	0.001	**0.015**										0.001	0.0215	**71.8**	**10.7**
	H									**0.000**										0.0000	**n/a**	**n/a**
Coralline Algae	L										**0.000**								0.000	0.0000	**0.0**	**0.0**
	M							0.000	0.000			**0.000**	0.000	0.000						0.0001	**0.0**	**0.0**
Turf	L	0.000			0.000	0.000	0.000	0.001	0.000	0.000			**0.001**	0.000					0.001	0.0035	**27.5**	**14.1**
	M	0.006			0.001	0.000		0.008	0.004				0.000	**0.033**	0.002				0.001	0.0563	**58.5**	**7.8**
	H	0.002						0.002	0.003					0.003	**0.002**				0.003	0.0154	**14.3**	**13.2**
Emergent Vegetation	L															**0.000**				0.0001	**100.0**	**0.0**
	M																**0.000**			0.0000	**100.0**	**0.0**
	H																	**0.013**		0.0130	**100.0**	**0.0**
Uncolonized					0.006	0.004		0.002	0.006	0.004				0.006					**0.214**	0.2448	**87.6**	**6.2**
***n*-j**		0.069	0.003	0.001	0.072	0.090	0.281	0.106	0.050	0.006	0.000	0.000	0.006	0.050	0.005	0.000	0.000	0.013	0.248	**1.000**	**<= *n***	
PRODUCERS Accuracy (%)		**49.0**	**0.0**	**0.0**	**71.0**	**78.4**	**96.6**	**69.9**	**30.7**	**0.0**	**n/a**	**n/a**	**16.3**	**65.6**	**45.2**	**100.0**	**100.0**	**100.0**	**86.5**	**P_o**	**78.0%**	
PRODUCERS CI(± %)		**9.8**	**n/a**	**n/a**	**12.3**	**11.7**	**2.2**	**9.4**	**10.4**	**n/a**	**n/a**	**n/a**	**13.3**	**13.0**	**29.6**	**0.0**	**0.0**	**0.0**	**4.8**	**CI(±)**	**3.3%**	

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 (88.7%), the overall accuracy adjusted for known map marginal proportions (90.8%), and the Tau coefficient (0.775), which adjusted for the number of map categories (Tables 1 and 2). Of the 54 classification errors, 44 were due to Unconsolidated Sediment being found in polygons classified as Coral Reef/Colonized Hardbottom. Although the overall level of accuracy was high, these results were lower than ROI-1 in all aspects; -5.2% overall accuracy, -6.3% adjusted overall accuracy, and -0.104 Tau coefficient (Walker and Foster, 2009).

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, 9.4% higher than ROI-2, but 7.3% 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 second highest level of accuracy, lower than Major Structure but higher than Major and Detailed Biological Cover, as indicated by the overall accuracy (82.9%), the overall accuracy adjusted for known map marginal proportions (81.3%), and the Tau coefficient (0.810) (Tables 3 and 4). The overall accuracy was 7.6% less than that reported for ROI-1, which utilized the same classification scheme and methodology (Walker and Foster, 2009). The overall accuracy was also 7.1% 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%.

Aggregate Reef had the lowest user's accuracy (59.1%) of all classes in ROI-2. Although the total number of occurrences was low, 9 of 22 sites mapped as Aggregate Reef were found to be Sand (6), Rubble (1), or Pavement (2). 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 the lowest producer's accuracy (also 59.1%) of all classes. Nine of 22 sites ground-truthed as Aggregate Reef were mapped as other habitats; Spur & Groove (1), Rubble (1), Pavement (6), 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 (41) (Table 3). While the largest single error was mapping Sand habitat as Pavement (18 of 41), seven other categories were found within mapped Pavement polygons including Aggregate Reef (6), Aggregated Patch Reef (1), Individual Patch Reef (3), Spur & Groove (4), Rubble (1), Sand (18) and Mud (8). 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 5 of 73 locations groundtruthed as Pavement occurring in other polygon classes; Aggregate Reef (2), Aggregated Patch Reef (1), and Sand (2).

Sand was the second-most variable habitat mapped even though it had relatively high user accuracy (89%). Polygons mapped as Sand contained six other categories; Aggregate Reef (1), Aggregated Patch Reef (2), Individual Patch Reef (3), Rubble (1), Pavement (2) 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 (6), Aggregated Patch Reef (6), Individual Patch Reef (1), Rubble (4), and Pavement (18). 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 third highest level of accuracy, lower than the Major and Detailed Geomorphological Structure attributes and slightly higher than Detailed Cover, as indicated by the overall accuracy (68.7%), the overall accuracy adjusted for known map marginal proportions (71.0%), and the Tau coefficient (0.635) (Tables 5 and 6). Many of the errors for Major Cover in ROI-2 were much higher than ROI-1 as evident in the 11.4% decrease in overall map accuracy, the 14% decrease when adjusted for map marginal proportions, and a 0.133 lower Tau coefficient. Only two of five user's accuracies and three of five producer's accuracies were greater than 80%.

These results also 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 25% and 22% difference respectively. Similarly, Smith et al. (unpublished data) reported an overall accuracy of 92.1% for Major Cover, 23.4 % higher than ROI-2. The gap lessened to 21.1% after adjusting for known map marginal proportions.

The allocation of sample points among Major Biological Cover categories in the Lower Keys was notably unbalanced, due to the absence of certain Detailed Cover categories from the map. With the exception of the Uncolonized category, there are three levels of Detailed Cover within each Major Cover category. If all Detailed categories are present in the map, collapsing the three Detailed categories into a single Major category would not create a bias. However, not all Detailed categories were represented in the Lower Keys map. The map did not include 8 of the possible 19 classes, including; Coral 90-100%, Coral 50-<90%, Macroalgae 90-100%, all 3 levels of Coralline Algae, Emergent Vegetation 10-50%, and Emergent Vegetation 50-90%. The Major Cover categories with fewer than three Detailed Cover categories received a smaller share of accuracy assessment points. While this bias was ameliorated by adjusting for known map marginal proportions (Card 1982), the potential effects of under-sampling remained.

Aside from Emergent Vegetation, almost every Major Cover class was confused with each other except there were no polygons mapped as Uncolonized that were groundtruthed as Coral. The single largest error in the analysis was forty-seven points mapped as Turf that were found to be Macroalgae (Table 5). This was the main contributor to a very low producer's accuracy for Macroalgae (45.2%). These errors occurred throughout many polygons in the map over the entire range of Turf mapped polygons, yet shallow reef crests had a high concentration of errors (19); Eastern Sambo (9), Middle Sambo (7), and Rock Piles (3). The distinction between Macroalgae and Turf was often difficult to make. The definitions of these two habitats are not mutually-exclusive, as several genera appear in both and the distinction between the two was often based on whether the vegetative canopy was "low lying" and "lacking an upright thali" (Rohmann 2008). *Dictyota spp*., listed in both the Macroalgae and Turf definitions, often seemed to bridge the gap between the two categories, depending on its canopy height. Compounding the category definition problems was that Macroalgae cover is 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 Macroalgae had high producer's errors. This was also seen in ROI-1. Although 24% better than ROI-2, Macroalgae producer's errors were the second lowest between classes in ROI-1 (69.2% from Walker and Foster, 2009).

The user's accuracy for Turf was 51.4% (Table 5). Though mostly due to the 47 points mapped as Turf that were ground-truthed as Macroalgae, there were 25 other errors found in Turf polygons, including 12 sites ground-truthed as Uncolonized, 7 as Coral, and 6 as Seagrass. Conversely, Turf producer's accuracy was relatively high (83.5%), yet once adjusted for proportional area, it dropped 26.9%. Macroalgae user's accuracy was also low (65%) having confusion between Coral (14), Seagrass (9), Turf (1), and Uncolonized (4). Macroalgae producer's accuracy was also low (45.2%) and map marginal proportion correction did not help it much (55.5%). These results indicate that mapping algae cover was difficult and that algal cover in ROI-2 likely varies more than the map polygons indicate.

Coral user's and producer's errors were also low, 65.5% and 61.0% respectively. Coral polygons contained almost all other mapped habitats, including Seagrass (4), Macroalgae (5), Turf (8), and Uncolonized (2), and unmapped Coral was found in three other mapped habitat types including Seagrass (2), Macroalgae (14), and Turf (7). The low producer and user accuracies, high number of errors, and the high variability of confusion between Coral and other classes indicates that Coral was a difficult class to discern in the imagery and that Coral cover in ROI-2 likely varies more than the map polygons indicate.

Uncolonized producer's accuracy was 52.6%; 26.7% less than in ROI-1. Twenty-seven locations found to be Uncolonized in the groundtruthing were mapped as one of four other habitats; Coral (2), Seagrass (9), Macroalgae (4), and Turf (12). The low accuracy in this category was partly due to the large proportion of Uncolonized in ROI-2 as evinced by correcting for map marginal proportions, which raised the accuracy to 84.3% (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 (64.7%), the overall accuracy adjusted for known map marginal proportions (67.9%), and the Tau coefficient (0.626). 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 significantly increase the overall accuracy for ROI-2.

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 Seagrass were also high, particularly for the 50-<90% and 90-100% cover categories.

The greatest single-class confusion existed between the Macroalgae 10%-<50% and Turf 50%-<90% categories (Table 7). 22 points validated as Macroalgae 10%-<50% were mapped as Turf 50%-<90%. Many of these errors occurred in the shallow rubble habitats along the outer reef margin where most of the habitat was mapped Turf 50%-<90%. The user's accuracy for Turf 50%-<90% (55.3%) showed that it was difficult to distinguish this category. Given that 31 of 94 samples in Turf 50%-<90% polygons were Macroalgae, it is likely that denser patches of Macroalgae exist in these areas that weren't captured in the map. Whether those denser patches of Macroalagal cover are larger than the minimum mapping unit or have a significant temporal component is unknown.

Twenty locations mapped as Coral 10%-<50% were found to be other habitats resulting in low user's accuracy for the category (63.6%). This was the result of confusion with nine other map categories including 8 in Turf and 5 in Macroalgae. This was a much different result from ROI-1 where Coral 10%-<50% was only mistaken for Seagrass, Macroalgae, and Uncolonized one time. Also different from ROI-1 where 6 locations had higher levels of Coral, ROI-2 groundtruthing only found one location of Coral 50%-<90% and none as Coral 90%-100%. Thus confusion within the Coral class was less than ROI-1 but confusion with other habitats was higher. The Coral category in this classification scheme was unique in that it accounted for both the soft coral canopy and live hard corals. Only the combination of the two could yield such high estimations of coral cover in the Lower FL Keys.

The lowest user's accuracy in the mapping was for Turf 90%-100% (0.1%). A substantial portion of the hard bottom habitats in the Bank/Shelf zone in the eastern part of ROI-2 was mapped as Turf 90%-100%. These features were found to be much more variable than the map depicted. Of the 28 Turf 90%-100% sites sampled, 4 were Coral, 9 were Macroalgae, 6 were Uncolonized, and 5 were Turf 50-<90%. Given that Turf 90-100% means there is less than 10% of all other categories combined, it is difficult to conceive that this category would cover such vast expanses of hard bottom habitat.

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 Coral, Turf, Macroalgae, and/or Uncolonized and some Seagrass was found in other habitat polygons, but these errors were relatively infrequent. Seagrass 10%-<50% had the lowest producer's accuracy among all Seagrass classes and was confused with seven other Cover types. Adjusting for map marginal proportions further lowered the accuracy 9.8% to 61.6%.

Another source of Biological Cover confusion was revealed by the producer's accuracy of the Uncolonized category. While the known map marginal producer's accuracy was high (84.3%), 27 sites validated as Uncolonized were mapped as something else (Table 7). Nine Detailed Cover habitat types contained Uncolonized groundtruthing sites, including 12 in various Turf categories. 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, Turf was most frequently used to characterize the 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 Uncolonized, however without recent imagery, the extent of these changes remains unknown.

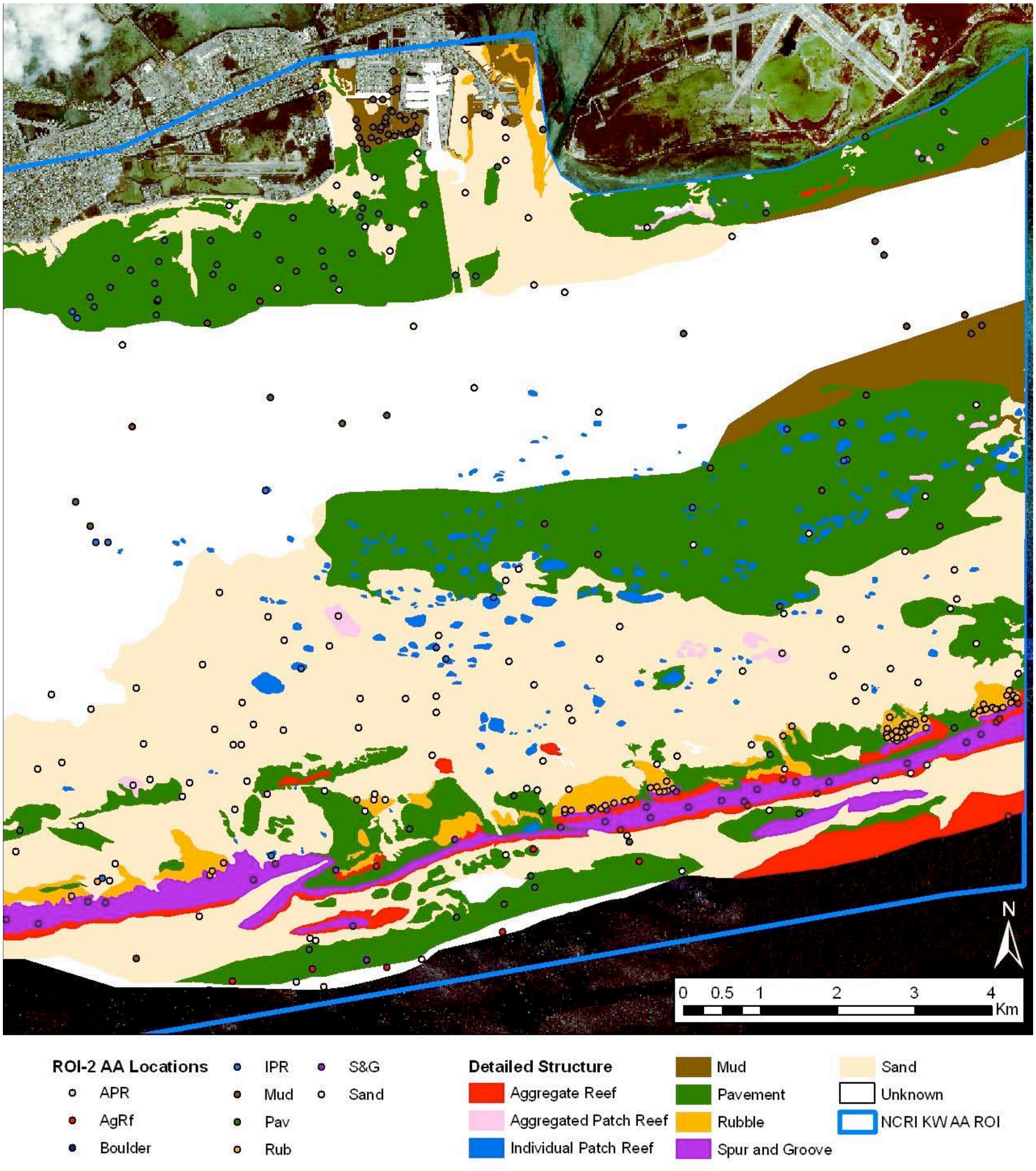

Figure 2. Eastern ROI-2 of the NOAA Lower Keys benthic habitat map classified by Detailed Structure with the AA locations classified by their Accuracy Assessment ID for Detailed Geomorphological Structure.

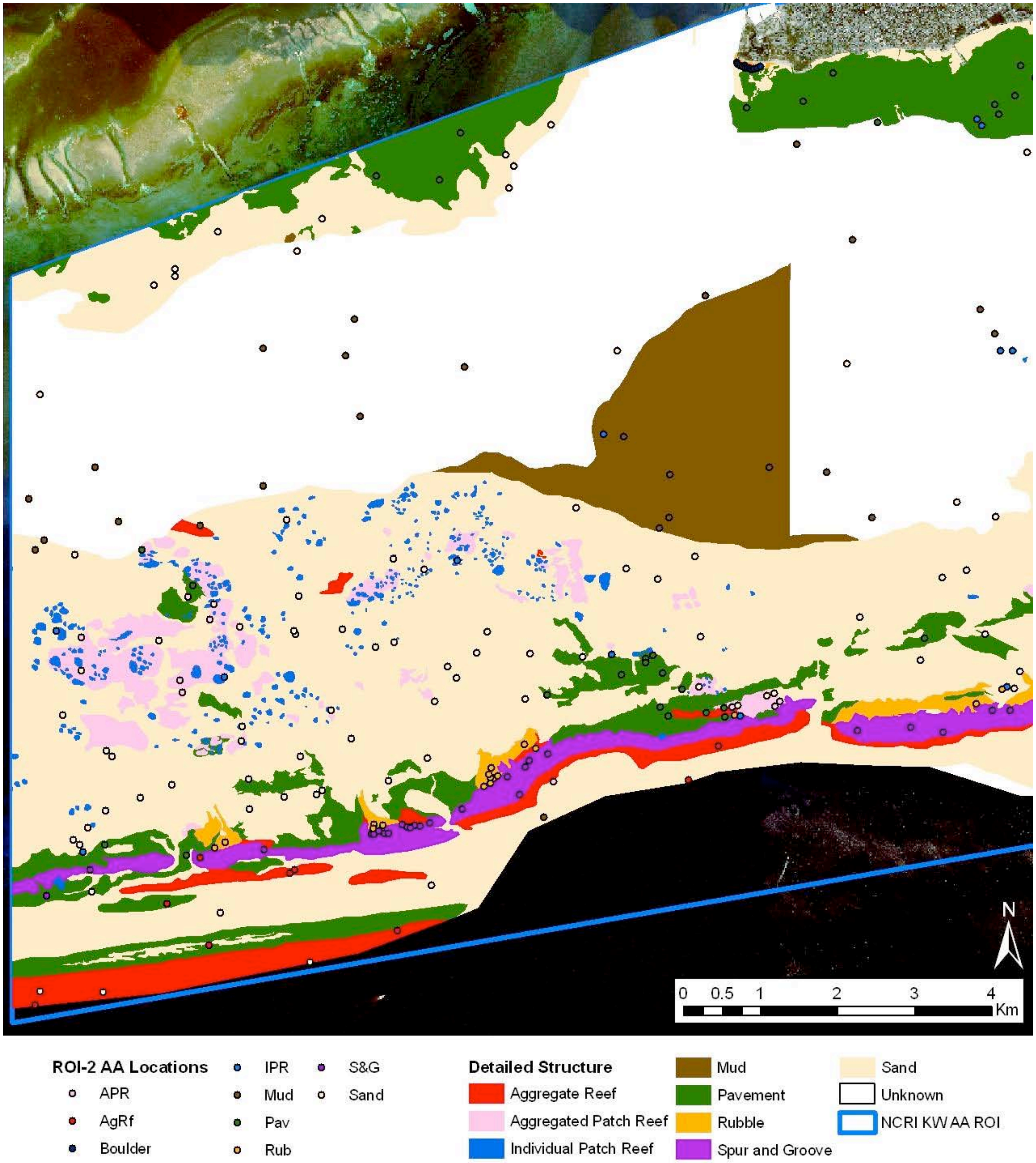

Figure 3. Western ROI-2 of the NOAA Lower Keys benthic habitat map classified by Detailed Geomorphological Structure with the AA locations classified by their Accuracy Assessment ID for Detailed Geomorphological Structure.

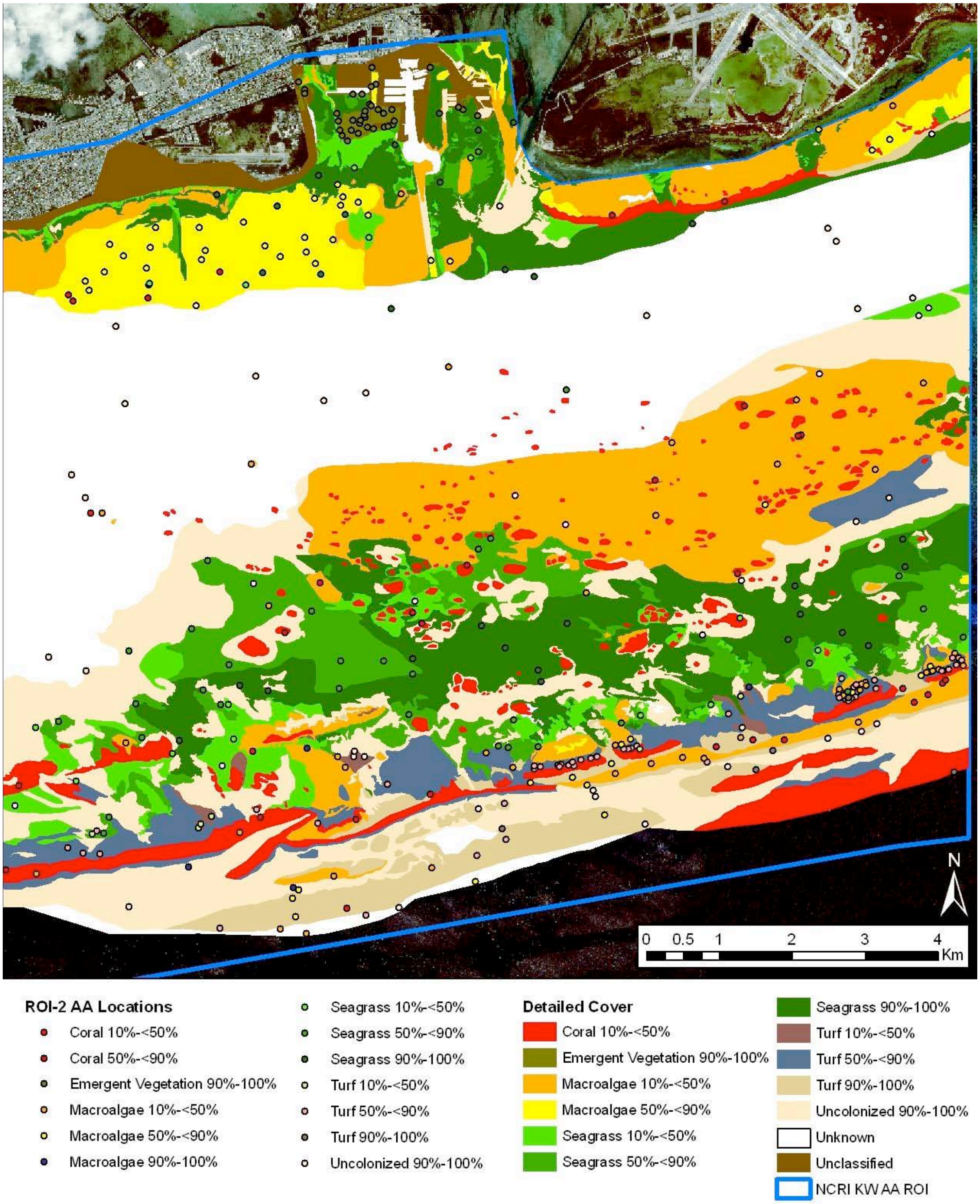

Figure 4. Eastern ROI-2 of the NOAA Lower Keys benthic habitat map classified by Detailed Biological Cover with the AA locations classified by their Accuracy Assessment ID for Detailed Biological Cover.

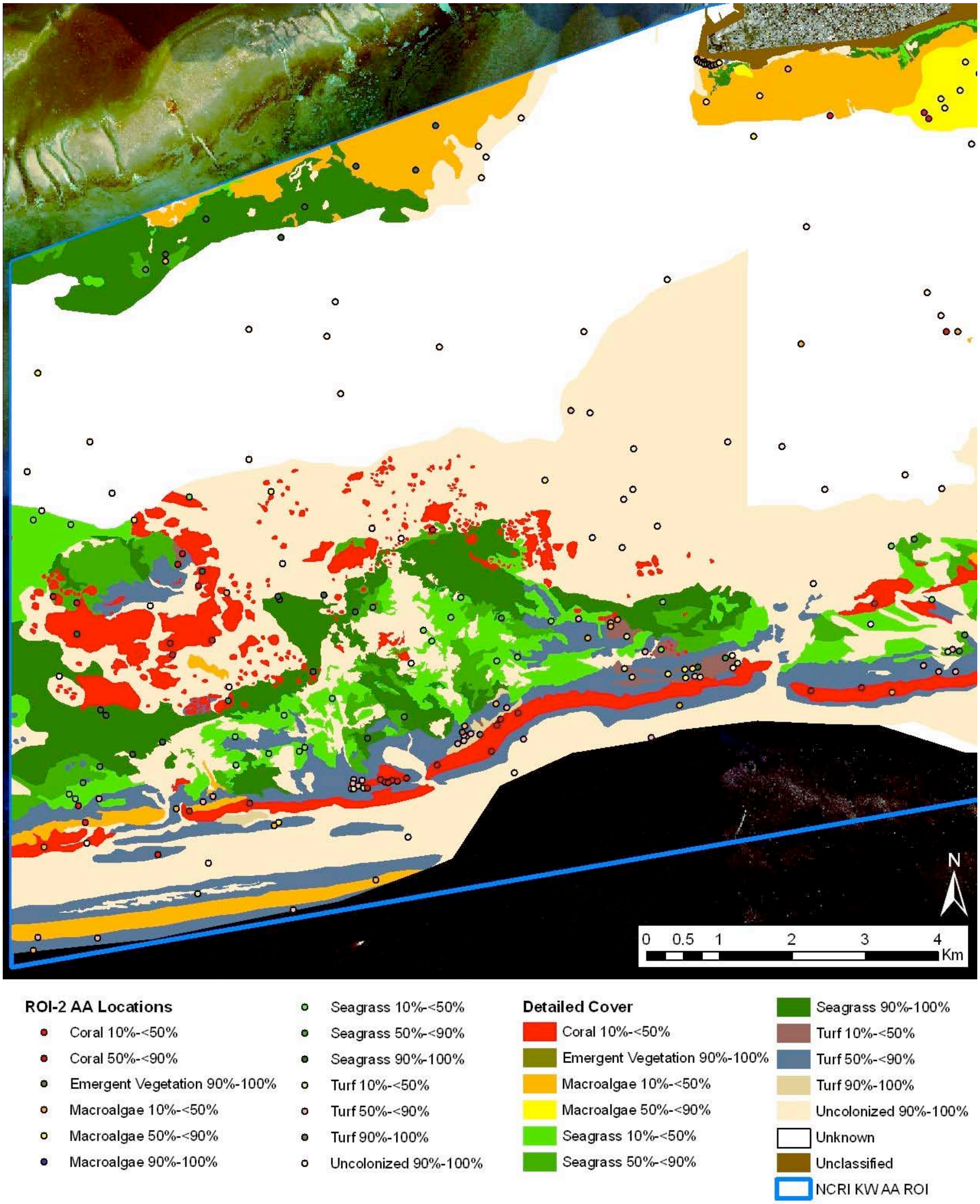

Figure 5. Western ROI-2 of the NOAA Lower Keys benthic habitat map classified by Detailed Biological Cover with the AA locations classified by their Accuracy Assessment ID for Detailed Biological Cover.

4.3 ROI-1 & 2 COMBINED GEOMORPHOLOGICAL STRUCTURE

Combined Major Geomorphological Structure

Thus far, two accuracy assessments have been conducted for smaller regions of interest in the larger draft NOAA FL Keys benthic habitat map because resources, budgets, and logistical constraints precluded a comprehensive assessment of the entire mapped area. These areas were chosen as biogeographically-representative corridors within the total benthic habitat map area and 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.

Since the assessments were conducted under the same methodologies, they are not only directly comparable, but combinable as well. Each assessment stands alone as a good measure of map accuracy for their given region, however the combination of ROI-1 and ROI-2 is a better determination of the accuracy of the entire NOAA benthic habitat maps for the Lower FL Keys. Although the overall results appear to be the average between ROI-1 and ROI-2, it was not so. Combining the data *a priori* and then analyzing them in a new error matrix gave values different from the mean of two error tables in ROI-1 and ROI-2. This was especially obvious with the results from the tables adjusted for map marginal proportions. This analysis required the combination of the areas of each habitat type from both ROIs which changed their proportions to the total combined mapped area; therefore the combined analysis is not simply a mean of the two previous accuracy assessments.

The combined Major Geomorphological Structure attributes were mapped with a high level of overall accuracy (91.3%), overall accuracy adjusted for known map marginal proportions (94.0%), and Tau coefficient (0.827) (Tables 9 and 10). This compares well to other NOAA mapping efforts, including Kendall et al. (2001) (93.6%), Smith et al. (unpublished data) (98.1%), and Zitello et al. (2009) (96.7%).Of the 957 sampled locations, 83 classification errors were identified; 70 Unconsolidated Sediment sites were mapped as Coral Reef/Colonized Hardbottom and 13 vice versa.

Combined Detailed Geomorphological Structure

Similar to ROI-1 and ROI-2, the combined Detailed Geomorphological Structure attributes were mapped at the second highest level of accuracy as indicated by the overall accuracy (84.5%), the overall accuracy adjusted for known map marginal proportions (86.5%), and the Tau coefficient (0.828) (Tables 11 and 12). The overall accuracy was 1.2% less than that reported for St. Johns (85.7%, Zitello et al. 2009) and 5.5% less than the Hawaiian Islands AA (Smith et al., unpublished data).

In the combined analysis, 13 of the 16 user's and producer's accuracies were greater than 80% and 4 of those were greater than 90%. Sand was the most frequent producer's error having 56 locations mapped as some other habitat including 22 Pavement, 10 Aggregated Patch Reef, and 9 Aggregate Reef. These errors could have been exacerbated by the sampling scale bias (not sampling at MMU) or the time lag between image collection, mapping, and assessment. Interestingly, 22 areas mapped as Sand were found to have Mud whereas only 3 areas mapped as Mud were Sand. The producer's accuracy was not drastically affected by these errors due to the large number of correctly mapped samples in the Sand polygons. Adjusting for map marginal proportions increased the producer's accuracy of Sand 8.7% and Mud 3.6%.

Pavement had the second lowest user's accuracy and was confused by every other habitat except Pavement with Sand Channels. Thirty-seven of the 52 errors were either Sand or Mud indicating that either large-scale sediment movement has occurred or that Pavement was difficult to distinguish from Unconsolidated Sediments in the imagery.

Unlike the ROI-2analysis, the map marginal proportion corrections improved the results of the combined Detailed Structure (Table 12). This correction was applied because it was necessary to correct for the imbalance of habitats throughout the map. Although 6 of the 9 producer's accuracies were decreased by this adjustment, the overall map accuracy increased by 2%.

4.4 ROI-1 & 2 COMBINED BIOLOGICAL COVER

Combined Major Biological Cover

The combined Major Biological Cover attributes were mapped at the third highest level of accuracy; overall accuracy (74.4%), overall accuracy adjusted for known map marginal proportions (80.2%), and Tau coefficient (0.701) (Tables 13 and 14). These results ranked low amongst other comparable recent studies. Zitello et al. (2009) reported 93.7% total accuracy for St. John and 93.0% after adjusted for map marginal proportions; a 19.3% and 12.8% difference respectively. This comparison isn't quite fair however given that Macroalgae and Turf algae were combined in St. Johns. Combining algae classes in the lower Keys raised the overall accuracy to 80.8%, leaving a 12.9% difference.

Similarly, Smith et al. (unpublished data) reported an overall accuracy of 92.1% for Major Cover, 17.7 % higher than the Lower Keys. The gap lessened to 11.9% after adjusting the Lower Keys for known map marginal proportions.

Three of six user's accuracies and three of six producer's accuracies were greater than 80%. Aside from Emergent Vegetation and Coralline Algae, almost every Major Cover class was confused with each other except there were no polygons mapped as Uncolonized that were groundtruthed as Coral. The single largest error in the analysis was 57 points mapped as Turf that were found to be Macroalgae (Table 13). This was the main contributor to a very low producer's accuracy for Macroalgae (55.8%). Please see section 4.2 for further discussion on these errors.

Between the two ROIs many locations found to be Coral were mapped as either Macroalgae or Turf, indicating that Coral cover was much more variable than mapped. Coral user's and producer's errors were low, 75.6% and 54.3% respectively. Coral polygons contained almost all other mapped habitats, including Seagrass (5), Macroalgae (6), Turf (8), and Uncolonized (3), and unmapped Coral was found in three other mapped habitat types including Seagrass (4), Macroalgae (18), and Turf (22). The low producer and user accuracies, high number of errors, and the high variability of confusion between Coral and other classes indicates that Coral was a difficult class to discern in the imagery and that Coral cover likely varies more than the map polygons indicate.

The user's accuracy for Turf was 54.2 % (Table 13). This was mostly due to the 57 points mapped as Turf that groundtruthed as Macroalgae, yet 47 other errors were also found in Turf polygons including 18 Uncolonized, 22 Coral, and 7 Seagrass. Conversely, Turf producer's accuracy was originally high (83.1%), yet once adjusted for proportional area, it dropped 16.4%. Macroalgae user's accuracy was also low (68.9%) having confusion between Coral (18), Seagrass (23), Turf (4), and Uncolonized (7). Macroalgae producer's accuracy was low (55.8%) and map marginal proportion correction did not help it much (62.2%). These results indicate that mapping algae cover was difficult and that algal cover likely varies more than the map polygons indicate. Combining algae categories would improve map accuracies, but confusion between other habitats would remain.

Uncolonized accuracies were fairly high after proportional adjustment; user's = 87.6% and producer's = 82.7%. Forty-five locations groundtruthed as Uncolonized were mapped as one of five other habitats; Coral (3), Seagrass (16), Macroalgae (7), Coralline Algae (1), and Turf (18). The low producer's accuracy in this category was partly due to the large proportion of Uncolonized as evinced by correcting for map marginal proportions, which raised the accuracy 13.9% (Table 14).

Combined Detailed Biological Cover

Detailed Biological Cover attributes were mapped at the lowest level of accuracy as indicated by the overall accuracy (70.5%), the overall accuracy adjusted for known map marginal proportions (78.0%), and the Tau coefficient (0.688). These results were 11.2% less than St. Johns (Zitello et al., 2009) and 13% less than the NOAA Hawaii mapping (Smith et al., unpublished data). Adjusting the data for the known map marginal proportions cut this difference to 3% and 5.5% respectively (Table 15).

Emergent Vegetation was mapped the best having 100% user's and producer's classification accuracies. All 103 ground-truthed samples were composed of varying levels of mangrove cover. Presumably, the lack of an overlying water column accounted for the high classification scores.

The producer's and user's accuracies for Seagrass were also high, particularly for the 50-<90% and 90-100% cover categories. Seagrass was confused with Coral, Macroalgae, and Turf categories indicating some of the variability in Seagrass cover was not captured in the mapping. Yet when adjusted for map proportions, dense Seagrass (90-100%) was 96.6% accurate (Table 16).

Twenty-nine locations mapped as Coral 10%-<50% were found to be other habitats resulting in low user's accuracy for the category (67.8%). This was the result of confusion with eleven other map categories including almost all levels of Turf, Macroalgae, and Seagrass. Coral 10%-<50% also had low producer's accuracies (58.1%) that were exacerbated by adjusting to map proportions (49.0%). These errors mostly stemmed from confusion between Turf 50-<90% (17) and Macroalgae 10-<50% (14). Confusion between these classes was likely because their spectral signatures in satellite imagery are very difficult to distinguish from one another and they occupy many of the same habitat zones and geomorphologic structure types. This is also likely the reason that the lowest user's accuracies in the mapping were for Turf 90%-100% (14.3%), Turf 10-<50% (27.5%), and Macroalgae 10-<50% (56.3%).

The greatest single-class confusion existed between the Macroalgae 10%-<50% and Turf 50%-<90% categories (Table 7). 24 points validated as Macroalgae 10%-<50% were mapped as Turf 50%-<90%. Twenty-two of these errors occurred in ROI-2 and is thus a larger issue in the map around Key West. A discussion of these errors can be found in section 4.2.

Another source of Biological Cover confusion was revealed by the producer's accuracy of the Uncolonized category. While the known map marginal producer's accuracy was high (86.5%), 45 sites validated as Uncolonized were mapped as something else (Table 15). Ten Detailed Cover habitat types contained Uncolonized groundtruthing sites, including 18 in various Turf categories and 16 in Seagrass. As discussed in section 4.2, it is unknown if these areas were larger than the mmu and may have been small patches of unmapped sand within other habitats or if they are due to significant Sand movement over the mapping time lag period.

4.5 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.

In the combined Lower Keys AAs, 86 sites fell within 3 m of a polygon edge; 8.98% of the total AA sites. Of the 86, 13 were incorrect with regard to cover (15.1%) and 6 were incorrect with regard to detailed structure (6.98%). The low incidence of error of sites within 3 m of the boundaries suggests that the accuracy of the edges was similar to the overall error for each category and the inclusion of habitat transitions in the sampling design did not impair the AA outcomes.

4.6 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. Every Biological Cover habitat and Geomorphological Structure in the entire Lower Keys map was represented in the sample area. Major differences in percent contributions of Geomorphological Structures between ROI-1 and ROI-2 were Mud (48.2% v. 4.6%), Unknown (8.1% v. 32.7%), Sand (23.8% v. 35.4%), and Pavement (8.2% v. 17.4%) (Appendix 2). All other classes were small in their relative percent contributions to the total and similar between corridors. However, the percent area of each Geomorphologic Structure was very close to those of the entire mapped area when combining the two corridors. Thus the area in the two combined corridors contained a good representation of the structure habitats and their proportions to the entire mapped area.

The percent contribution of Biological Cover classes in the combined AAs and the total mapped area were very similar (Appendix 3). The most obvious differences were in Seagrass 90%-100%, Unknown, and Coral 10-<50%. Seagrass 90%-100% comprised 40.6% of AA ROI-1 but only 10.4% of ROI-2, whereas Unknown comprised 8.1% of AA ROI-1 but 32.7% of ROI-2. Although a low overall contribution, Coral 10-<50% comprised 5.1% of ROI-2and only 1.8% of ROI-1. Otherwise the percent contributions of Biological Cover habitats to the totals were similar. However, as with Structure, the relative contributions of each habitat to the total in the combined corridors were very similar to those of the entire mapped area, suggesting that the combined corridors were a good representation of the total mapped area in the Lower FL Keys.

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 combined accuracy assessments 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 later 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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Appendix 1. The sum of target and final survey locations per category for both Detailed Geomorphological Structure and Biological Cover. Categories that did not occur in the tested area are noted with N/A.

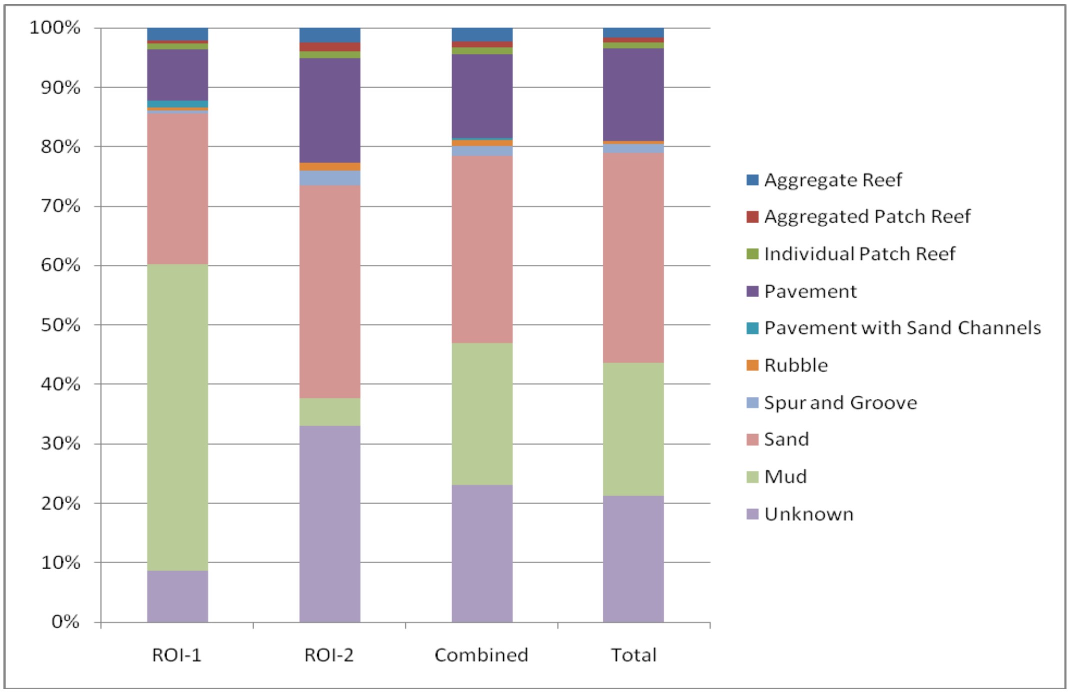
Detailed Geomorphologic Structure:

Class	**Target Location Total**	**Final Location Total**
Aggregate Reef	51	22
Aggregated Patch Reef	20	18
Artificial	Not Targeted	12
Individual Patch Reef	20	17
Land	Not Targeted	Not Targeted
Mud	40	46
Pavement	137	109
Pavement with Sand Channels	20	0
Rubble	33	79
Rock/Boulder	12	0
Sand	140	145
Scattered Coral/Rock in Unconsolidated Sediment	N/A	N/A
Spur & Groove	20	43
Unknown	37	42
Total	**530**	**533**

Detailed Biological Cover:

Class	**Target Location Total**	**Final Location Total**
Live Coral 90%-100%	N/A	N/A
Live Coral 50%-<90%	N/A	N/A
Live Coral 10%-<50%	37	55
Seagrass 90%-100%	37	40
Seagrass 50%-<90%	37	42
Seagrass 10%-<50%	37	35
Macroalgae 90%-100%	N/A	N/A
Macroalgae 50%-<90%	37	38
Macroalgae 10%-<50%	37	42
Coralline Algae 90%-100%	N/A	N/A
Coralline Algae 50%-<90%	37	0
Coralline Algae 10%-<50%	37	0
Turf Algae 90%-100%	49	28
Turf Algae 50%-<90%	37	94
Turf Algae 10%-<50%	37	26
Emergent Vegetation 90%-100%	37	37
Emergent Vegetation 50%-<90%	N/A	N/A
Emergent Vegetation 10%-<50%	N/A	N/A
Uncolonized 90%-100%	37	42
Unclassified	0	12
Unknown	37	42
Total	**530**	**533**

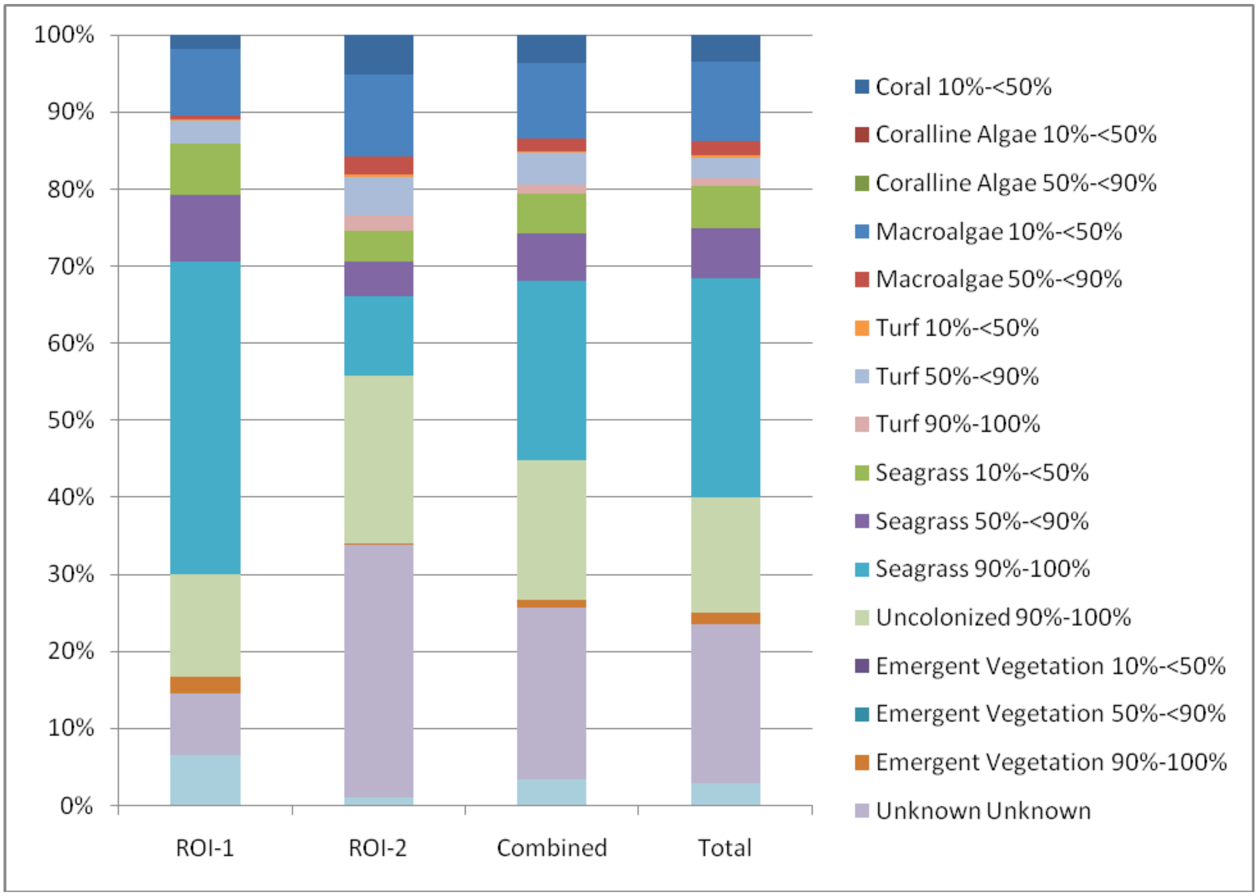
Appendix 2. Detailed Geomorphologic Structure area summaries for ROI-1, ROI-2, the combined AAs, and the total map (m²).



Detailed Structure	ROI-1	ROI-2	Combined	Total
Aggregate Reef	3555233	6179758	9734991.6	14967557.7929
Aggregated Patch Reef	834337	3529695	4364032.4	6759857.4898
Individual Patch Reef	1696862	2987989	4684850.5	8090054.9927
Pavement	14984396	43453794	58438190.0	137351034.8210
Pavement with Sand Channels	1781642	0	1781642.1	267473.8027
Rubble	788453	3049341	3837793.8	5236776.4435
Spur and Groove	942335	6222179	7164514.2	12683512.5537
Sand	43441588	88236270	131677857.4	310851583.4116
Mud	88098495	11548636	99647131.7	197515111.1970
Unknown	14776707	81550045	96326752.6	186640686.2533
Artificial	1571307	48433	1619740.4	2945311.3567
Land	10271599	2775246	13046844.4	23860381.9448

Detailed Structure	ROI-1	ROI-2	Combined	Total
Aggregate Reef	1.9%	2.5%	2.3%	1.6%
Aggregated Patch Reef	0.5%	1.4%	1.0%	0.7%
Individual Patch Reef	0.9%	1.2%	1.1%	0.9%
Pavement	8.2%	17.4%	13.5%	15.1%
Pavement with Sand Channels	1.0%	0.0%	0.4%	0.0%
Rubble	0.4%	1.2%	0.9%	0.6%
Spur and Groove	0.5%	2.5%	1.7%	1.4%
Sand	23.8%	35.4%	30.5%	34.3%
Mud	48.2%	4.6%	23.0%	21.8%
Unknown	8.1%	32.7%	22.3%	20.6%

Appendix 3. Detailed Biological Cover area summaries for ROI-1, ROI-2, the combined AAs, and the total map (m^2).



Detailed Cover	**ROI-1**	**ROI-2**	**Combined**	**Total**
Coral 10%-<50%	3217288	12698984	15916272	30763173.6776
Coralline Algae 10%-<50%	3362	0	3362	0
Coralline Algae 50%-<90%	23343	0	23343	0
Emergent Vegetation 10%-<50%	22772	0	22772	627848.9369
Emergent Vegetation 50%-<90%	2922	0	2922	46884.3211
Emergent Vegetation 90%-100%	3787765	393814	4181579	13109859.6487
Macroalgae 10%-<50%	15767903	26491106	42259009	93828825.8467
Macroalgae 50%-<90%	1089389	5816775	6906164	17708709.9019
Seagrass 10%-<50%	12156986	9758459	21915445	48946120.5518
Seagrass 50%-<90%	15836842	11245824	27082666	59645674.7803
Seagrass 90%-100%	74265677	25935472	100201149	257018991.4274
Turf 10%-<50%	290064	842733	1132797	2249871.7275
Turf 50%-<90%	5271645	12804270	18075915	23708623.7086
Turf 90%-100%	9281	4940997	4950277	9976638.0806
Uncolonized 90%-100%	24378102	54279228	78657330	136091739.8958
Unknown Unknown	14776707	81550045	96326753	186640686.2533
Unclassified	11842906	2823679	14666584.8	26805693.3014

Detailed Cover	ROI-1	ROI-2	Combined	Total
Coral 10%-<50%	1.8%	5.1%	3.7%	3.4%
Coralline Algae 10%-<50%	0.0%	0.0%	0.0%	0.0%
Coralline Algae 50%-<90%	0.0%	0.0%	0.0%	0.0%
Emergent Vegetation 10%-<50%	0.0%	0.0%	0.0%	0.1%
Emergent Vegetation 50%-<90%	0.0%	0.0%	0.0%	0.0%
Emergent Vegetation 90%-100%	2.1%	0.2%	1.0%	1.4%
Macroalgae 10%-<50%	8.6%	10.6%	9.8%	10.3%
Macroalgae 50%-<90%	0.6%	2.3%	1.6%	2.0%
Seagrass 10%-<50%	6.7%	3.9%	5.1%	5.4%
Seagrass 50%-<90%	8.7%	4.5%	6.3%	6.6%
Seagrass 90%-100%	40.6%	10.4%	23.2%	28.3%
Turf 10%-<50%	0.2%	0.3%	0.3%	0.2%
Turf 50%-<90%	2.9%	5.1%	4.2%	2.6%
Turf 90%-100%	0.0%	2.0%	1.1%	1.1%
Uncolonized 90%-100%	13.3%	21.7%	18.2%	15.0%
Unknown Unknown	8.1%	32.7%	22.3%	20.6%
Unclassified	6.5%	1.1%	3.4%	3.0%