Final Report

Accuracy Assessment and Monitoring for NOAA Florida Keys mapping AA ROI-1 (Hawk Channel near American Shoal)

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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 January 21and 28, 2009. The accuracy assessment was conducted within a 179 km² corridor that extended from the shoreline intertidal zone, through Hawk Channel and the American Shoal reef tract, before terminating on the outer bank/shelf escarpment at a depth of 33m. A total of 503 sampling stations were visited. The sites were selected using the stratified random sampling protocol established for the recent Hawaiian Islands mapping program. 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 or kayak, using a hand-held dGPS for navigation and a housed camera to record video. After a post-survey video review, each sampling station was assigned to a Detailed map category of Geomorphological Structure and Biological Cover. Each station was also assigned to a Major map category of Structure and Cover, moving one level up the hierarchical classification scheme. Error matrices were prepared for the Major and Detailed levels of Geomorphological Structure and Biological Cover. The efficacy of the benthic habitat map was assessed by a number of classification metrics. The overall, producer's, and user's accuracies were computed directly from the error matrices. The overall accuracy of the Lower Florida Keys benthic habitat map was 93.9% and 86.2% at the Major and Detailed levels of Structure respectively, and 80.1% and 76.4% 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 rates. This increased the overall accuracy to 97.1% and 91.5% at the Major and Detailed levels of Structure, and to 85.0% and 82.4% at the Major and Detailed levels of cover. 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 0.879 ± 0.043 and 0.845 ± 0.035 at the Major and Detailed levels of Structure, and 0.768 ± 0.042 and 0.749 ± 0.040 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 a biogeographically representative corridor within the total benthic habitat map area was selected for performing the accuracy assessment (Congalton, 1991; Stehman and Czaplewski, 1998). This corridor not only captured a wide diversity of habitats, but was also characterized by frequent transitions between habitat types. This method ensured that a well-distributed, representative set of monitoring locations were surveyed. The area of the accuracy assessment corridor (AA ROI-1) was approximately 179 km², representing 20% of the total area of the Lower Keys benthic habitat map (Figure 1). This report details the procedures and findings of the accuracy assessment conducted by scientists from the National Coral Reef Institute (NCRI) at Nova Southeastern University Oceanographic Center between the dates of January 21-28, 2009.

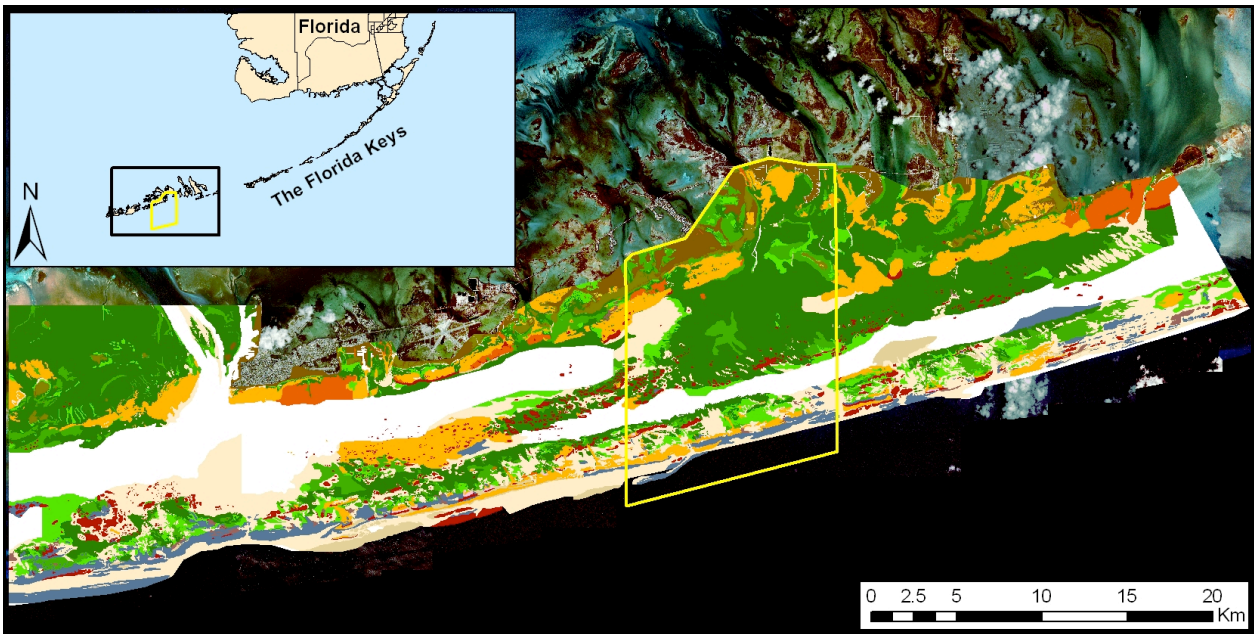

Figure 1. Accuracy Assessment Area 1 (AA ROI-1) (yellow), within the overall NOAA mapped region of the Lower FL Keys. This area included the seaward seafloor south of Cudjoe and Sugarloaf Keys including American Shoals.

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 calibrate the two teams to ease confusion between habitat definitions. The AA 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

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 class using Hawth's tools in ArcGIS at a minimum distance of 30 m apart. Four of the 16 classes that occurred in the test area were too small to allow for these criteria. In those four habitat classes, 37 points were placed in each, a 30 m buffer was drawn around each point, and the points were moved to optimize the most samples per habitat while moving or deleting the fewest points. To accommodate a robust AA using Detailed Geomorphological Structure, locations were added to ensure each Structure category contained at least 20 samples. This yielded 508 total sample target locations.

Underwater video from a drop camera was taken at each site within AA ROI-1, 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 an 80 GB 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 sand habitats were generally short while heterogeneous reef 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.

A few underwater targets were not practically accessible by survey vessel or kayak. 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. All observed EV sites were varying degrees of mangrove density. 2 days of significant hiking along Sugarloaf Key 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 of each video was entered into a database with the field notes and plotted in GIS resulting in a point layer of 503 locations. 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.

Those structural and biological cover classes in the classification scheme that were not found in the Lower Keys draft benthic habitat map were excluded from the accuracy analysis. Further exclusions were Detailed Geomorphological Structure classes Artificial, Land, Rock/Boulder, Unclassified, and Unknown. Although 25 Unknown random locations were visited, they were not part of the 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. 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, due to the potential for bias from the stratified random sampling protocol (Hay 1979, van Genderen 1978, van Genderen 1977). While stratification ensures adequate representation of all map categories, it has the undesired effect of introducing bias into the error matrix. Stratification involved 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-1 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, eg. the percentage of times that substrate known to be sand was correctly interpreted as sand. In this report, one of the most common producer's errors was mapping areas of pavement with sand channels as spur and groove reef. 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, one of the most common user's errors was mapping areas of coral and macroalgae cover as turf. 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 how small some of the map categories were, 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 within the representative area (AA ROI-1). 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 the same as categories with very small extents. For example, the Detailed Structure categories of Mud and Sand accounted for 84% of the total mapped area of AA RO-1, but only 56% [(133+137)/478] of the accuracy assessment points. Conversely, the Aggregated Patch Reef category accounted for only 0.53% of the mapped area and 4.2% of the accuracy assessment points. This amounts to a sampling intensity of 4.6 points per km^2 for the very large Mud+Sand category versus 24.0 points per km^2 for Aggregated Patch Reef.

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-1) and were exclusive to categories present in the error matrix, which reduced total area from 179 to 156 km^2. For the example of Detailed Structure category Sand, π_i was 0.278 (43.44 km^2/156.1km^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

The final number of ground validation samples was 503 (Appendix 1). This differed from the original targets due to the inaccessibility of certain targets and a corrupted video file on one occasion.

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 93.9% at the Major Structure level (Table 1). The Tau coefficient for equal probability of group membership (T_e) was 0.879 ± 0.043 (α=0.05), i.e. the rate of misclassifications at the Major Structure level was 87.9% 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 97.1% ± 1.3 (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.

Detailed Geomorphological Structure

Error matrices for Detailed Geomorphological Structure are presented in Tables 3 and 4. The overall accuracy (P_o) was 86.2% at the Detailed Structure level (Table 3). The Tau coefficient for equal probability of group membership (T_e) was 0.845 ± 0.035 (α=0.05), i.e. the rate of misclassifications at the Detailed Structure level was 84.5% 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 91.5% ± 2.5 (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.

The Pavement with Sand Channels category clearly demonstrated the effect of adjusting producer's accuracy to the known map marginal proportions. In the original error matrix (Table 3), 10 of 19 ground-truthed samples were correctly classified as Pavement with Sand Channels. The remaining 9 samples were incorrectly classified as Spur and Groove. The un-adjusted producer's accuracy was therefore equal to 10/19 = 52.6%. However, the known map marginal proportions of the Pavement with Sand Channels habitat was nearly twice that of the Spur and Groove habitat (0.011 versus 0.006, Table 4). Therefore, the producer's confusion between these two habitats was exaggerated by over-representation of the Spur and Groove habitat in the ground-truthed Pavement with Sand Channels column. Discrimination between these two categories increased after the error matrix cell values were transformed from the original binomial observations to individual cell probabilities (9*0.006/21=0.0026 and 10*0.011/20=0.0057), increasing producer's accuracy from 52.6% to 68.8%.

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 80.1% at the Major Cover level (Table 5). The Tau coefficient for equal probability of group membership (T_e) was 0.768 ± 0.042 (α=0.05), i.e. the rate of misclassifications at the Major Cover level was 76.8% 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 85.0% ± 4.4 (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 76.4% at the Detailed Cover level (Table 7). The Tau coefficient for equal probability of group membership (T_e) was 0.749 ± 0.040 (α=0.05), i.e. the rate of misclassifications at the Detailed Cover level was 74.9% less than would be expected from random assignment of polygons to categories. T_e more closely approached P_o at the Detailed level (r = 17) 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 82.4% ± 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 93.9%. The Tau coefficient for equal probability of group membership (T_e) was 0.879, with a 95% Confidence Interval of 0.836 – 0. 922.

MAP (i) \ TRUE (GROUND-TRUTHED) (j)	hard	soft	n_{i-}	USERS Accuracy (%)
hard	**182**	26	208	**87.5**
soft	3	**267**	270	**98.9**
n_{-j}	185	293	**478** <= n	
PRODUCERS Accuracy (%)	**98.4**	**91.1**	P_o **93.9%**	
			T_e = **0.879 ± 0.043**	

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 97.1% with a 95% Confidence Interval of 95.8% – 98.4%.

MAP (i) \ TRUE (GROUND-TRUTHED) (j)	hard	soft	π_i	USERS Accuracy (%)	USERS CI (± %)
hard	**0.1378**	0.0197	0.157	**87.5**	**4.6**
soft	0.0094	**0.8332**	0.843	**98.9**	**1.3**
n_{-j}	0.147	0.853	**1.000** <= n		
PRODUCERS Accuracy (%)	**93.6**	**97.7**	P_o **97.1%**		
PRODUCERS CI (± %)	**6.8**	**0.8**	**CI (±) 1.3%**		

Table 3. Error matrix for Detailed Geomorphological Structure. The overall accuracy (P_o) was 86.2%. The Tau coefficient for equal probability of group membership (T_e) was 0.845, with a 95% Confidence Interval of 0.810 – 0.880. Blank cells indicate 0 occurrences.

MAP DATA (i) / DETAILED STRUCTURE	TRUE (GROUND-TRUTHED) (j): Aggregate Reef	Aggregated Patch Reef	Individual Patch Reef	Spur and Groove	Rubble	Pavement	Pav w/ Sand Channels	Sand	Mud	$n_{i\cdot}$	USERS Accuracy (%)
Aggregate Reef	**59**		1			1		3		64	**92.2**
Aggregated Patch Reef		**15**				1		4		20	**75.0**
Individual Patch Reef			**13**					1	1	15	**86.7**
Spur and Groove				**12**			9			21	**57.1**
Rubble					**15**	3				18	**83.3**
Pavement						**39**		4	7	50	**78.0**
Pav w/ Sand Channels	3					1	**10**	6		20	**50.0**
Sand			2			1		**115**	15	133	**86.5**
Mud								3	**134**	137	**97.8**
$n_{\cdot j}$	62	15	16	12	15	46	19	136	157	**478**	<= n
PRODUCERS Accuracy (%)	**95.2**	**100.0**	**81.3**	**100.0**	**100.0**	**84.8**	**52.6**	**84.6**	**85.4**	P_o	**86.2%**
										T_e =	**0.845 ± 0.035**

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 91.5% with a 95% Confidence Interval of 89.0% – 94.0%. Blank cells indicate 0 occurrences.

MAP DATA (i) / DETAILED STRUCTURE	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	**0.0210**		0.0004			0.0004		0.0011		0.023	**92.2**	**6.7**
Aggregated Patch Reef		**0.0040**				0.0003		0.0011		0.005	**75.0**	**19.4**
Individual Patch Reef			**0.0094**					0.0007	0.0007	0.011	**86.7**	**17.6**
Spur and Groove				**0.0034**			0.0026			0.006	**57.1**	**21.6**
Rubble					**0.0042**	0.0008				0.005	**83.3**	**17.6**
Pavement						**0.0749**		0.0077	0.0134	0.096	**78.0**	**11.7**
Pav w/ Sand Channels	0.0017					0.0006	**0.0057**	0.0034		0.011	**50.0**	**22.4**
Sand			0.0042			0.0021		**0.2406**	0.0314	0.278	**86.5**	**5.9**
Mud								0.0124	**0.5519**	0.564	**97.8**	**2.5**
$n_{\cdot j}$	0.023	0.004	0.014	0.003	0.004	0.079	0.008	0.267	0.597	**1.000**	<= n	
PRODUCERS Accuracy (%)	**92.5**	**100.0**	**67.5**	**100.0**	**100.0**	**94.8**	**68.8**	**90.1**	**92.4**	P_o	**91.5%**	
PRODUCERS CI (± %)	**7.4**	**0.0**	**28.9**	**0.0**	**0.0**	**5.4**	**14.5**	**5.5**	**2.8**	**CI (±)**	**2.5%**	

Table 5. Error matrix for Major Biological Cover. The overall accuracy (P_o) was 80.1%. The Tau coefficient for equal probability of group membership (T_e) was 0.768, with a 95% Confidence Interval of 0.726 – 0.810. Blank cells indicate 0 occurrences.

MAP DATA (i) \ TRUE (GROUND-TRUTHED) (j)	Coral	Sea Grass	Macro algae	Coralline Algae	Turf	Emerg Veg	Un-Colonized	n_{i-}	USERS Accuracy (%)
Coral	**32**	1	1				1	35	**91.4**
Seagrass	2	**106**	10				7	125	**84.8**
Macroalgae	4	14	**63**		3		3	87	**72.4**
Coralline Algae			7	**0**	7		1	15	**0.0**
Turf	15	1	10		**47**		6	79	**59.5**
Emerg Veg						**66**		66	**100.0**
UnColonized		2					**69**	71	**97.2**
n_{-j}	53	124	91	0	57	66	87	**478 <= n**	
PRODUCERS Accuracy (%)	**60.4**	**85.5**	**69.2**	**n/a**	**82.5**	**100.0**	**79.3**	**P_o 80.1%**	
								T_e = 0.768 ± 0.042	

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 85.0% with a 95% Confidence Interval of 80.6% – 89.4%. Blank cells indicate 0 occurrences.

MAP DATA (i) \ TRUE (GROUND-TRUTHED) (j)	Coral	Sea Grass	Macro algae	Coralline Algae	Turf	Emerg Veg	Un-Colonized	π_i	USERS Accuracy (%)	USERS CI (± %)
Coral	**0.0188**	0.0006	0.0006				0.0006	0.021	**91.4**	**9.5**
Seagrass	0.0105	**0.5554**	0.0524				0.0367	0.655	**84.8**	**6.4**
Macroalgae	0.0050	0.0174	**0.0782**		0.0037		0.0037	0.108	**72.4**	**9.6**
Coralline Algae			0.0001	**0.0000**	0.0001		0.0000	0.000	**0.0**	**0.0**
Turf	0.0068	0.0005	0.0045		**0.0212**		0.0027	0.036	**59.5**	**11.0**
Emerg Veg						**0.0244**		0.024	**100.0**	**0.0**
UnColonized		0.0044					**0.1517**	0.156	**97.2**	**3.9**
n_{-j}	0.041	0.578	0.136	0.000	0.025	0.024	0.195	**1.000 <= n**		
PRODUCERS Accuracy (%)	**45.9**	**96.1**	**57.6**	**n/a**	**84.8**	**100.0**	**77.6**	**P_o 85.0%**		
PRODUCERS CI (± %)	**17.8**	**1.8**	**13.9**	**n/a**	**14.5**	**0.0**	**10.9**	**CI (±) 4.4%**		

Table 7. Error matrix for Detailed Biological Cover, L = 10-<50%, M = 50-<90%, H = 90-100%. The overall accuracy (P_o) was 76.4%. The Tau coefficient for equal probability of group membership (T_e) was 0.749, with a 95% Confidence Interval of 0.709 – 0.789. Blank cells indicate 0 occurrences.

		TRUE (GROUND-TRUTHED) (j)																		
DETAILED COVER		Coral			Seagrass			Macroalgae		Coralline Algae		Turf			Emergent Vegetation			Un-colonized	$n_{i\,-}$	USERS Accuracy (%)
		L	M	H	L	M	H	L	M	L	M	L	M	H	L	M	H			
MAP DATA (i) Coral	L	26	5	1	1				1									1	35	74.3
Coral	M		0																0	n/a
Coral	H			0															0	n/a
Seagrass	L	1			32			2	1									5	41	78.0
Seagrass	M				1	33		3										1	38	86.8
Seagrass	H	1				2	38	2	2									1	46	82.6
Macro algae	L	4			4	5	2	34	1			1	2					1	54	63.0
Macro algae	M				2		1	4	24									2	33	72.7
Coralline Algae	L									0								1	1	0.0
Coralline Algae	M							6	1		0	1	6						14	0.0
Turf	L				1			5				2	2					4	14	14.3
Turf	M	15						2	3				41	2				2	65	63.1
Turf	H													0					0	n/a
Emergent Vegetation	L														24				24	100.0
Emergent Vegetation	M															8			8	100.0
Emergent Vegetation	H																34		34	100.0
Uncolonized					1	1												69	71	97.2
n_{-j}		47	5	1	42	41	41	58	33	0	0	4	51	2	24	8	34	87	478 <= n	
PRODUCERS Accuracy (%)		55.3	0.0	0.0	76.2	80.5	92.7	58.6	72.7	n/a	n/a	50.0	80.4	0.0	100.0	100.0	100.0	79.3	P_o 76.4%	

T_e = 0.749 ± 0.040

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 82.4% with a 95% Confidence Interval of 76.7% - 88.1%. Blank cells indicate 0 occurrences.

		TRUE (GROUND-TRUTHED) (j)																			
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	L	M	L	M	H	L	M	H				
MAP DATA (i) Coral	L	0.015	0.003	0.001	0.001				0.001									0.001	0.0206	74.3	14.8
Coral	M		0.000																0.0000	n/a	na
Coral	H			0.000															0.0000	n/a	n/a
Seagrass	L	0.002			0.061			0.004	0.002									0.009	0.0779	78.0	12.9
Seagrass	M				0.003	0.088		0.008										0.003	0.1014	86.8	11.0
Seagrass	H	0.010				0.021	0.393	0.021	0.021									0.010	0.4757	82.6	11.2
Macro algae	L	0.007			0.007	0.009	0.004	0.064	0.002			0.002	0.004					0.002	0.1010	63.0	13.1
Macro algae	M				0.000		0.000	0.001	0.005									0.000	0.0070	72.7	15.5
Coralline Algae	L									0.000								0.000	2.15E-05	0.0	0.0
Coralline Algae	M							0.000	0.000		0.000	0.000	0.000						0.0001	0.0	0.0
Turf	L				0.000			0.001				2.6E-4	0.000					0.001	0.0016	14.3	18.7
Turf	M	0.008						0.001	0.002				0.021	0.001				0.001	0.0338	63.1	12.0
Turf	H													0.000					0.0000	n/a	n/a
Emergent Vegetation	L														1.5E-4				0.00E+00	100.0	0.0
Emergent Vegetation	M															1.8E-5			0.00E+00	100.0	0.0
Emergent Vegetation	H																0.024		0.0243	100.0	0.0
Uncolonized					0.002	0.002												0.152	0.1561	97.2	3.9
$n_{\cdot j}$		0.043	0.003	0.001	0.074	0.120	0.397	0.099	0.032	0.000	0.000	0.002	0.025	0.001	0.000	0.000	0.024	0.179	1.000	<= n	
PRODUCERS Accuracy (%)		35.7	0.0	0.0	81.8	73.2	99.0	64.4	16.0	n/a	n/a	12.4	84.0	0.0	100.0	100.0	100.0	84.9	P_o	82.4%	
PRODUCERS CI (± %)		19.2	0.0	0.0	11.3	18.4	1.3	20.5	15.0	n/a	n/a	25.6	17.4	0.0	0.0	0.0	0.0	10.9	CI (±)	5.7%	

DISCUSSION

4.1 GEOMORPHOLOGICAL STRUCTURE

Major Geomorphological Structure

The Major Geomorphological Structure attributes were mapped with the greatest accuracy as indicated by the overall accuracy (93.9%), the overall accuracy adjusted for known map marginal proportions (97.1%), and the Tau coefficient (0.879), which adjusted for the number of map categories (Tables 1 and 2). Of the 29 classification errors, 26 were due to Unconsolidated Sediment being found in polygons classified as Coral Reef/Colonized Hardbottom.

Although recent changes to the NOAA classification scheme precluded a direct comparison, the accuracy of the Lower Keys map was comparable to other NOAA mapping programs. 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, 4.2% higher than the Lower Keys (but only 1.0% higher after adjusting the Lower Keys for known map marginal proportions). The overall accuracy was also consistent with other nearby regional mapping AAs 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).

Detailed Geomorphological Structure

The 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 (86.2%), the overall accuracy adjusted for known map marginal proportions (91.5%), and the Tau coefficient (0.845) (Tables 3 and 4). The overall accuracy was slightly less than that reported for Miami-Dade (90.5%), which utilized a similar classification scheme and a stratified random sampling protocol (Walker, 2009). The overall accuracy was also slightly less than the 90.0% reported for the Hawaiian Islands AA (Smith et al., unpublished data). In the Lower Keys, most of the user's and producer's accuracies were very high; the producer's accuracy was 100% for Aggregated Patch Reef, Spur & Groove, and Rubble, and 9 of the 18 user's and producer's accuracies were above 90%.

The largest single polygon error existed between the Pavement with Sand Channels and Spur & Groove categories (Figure 3). Nine of the nineteen points validated as Pavement with Sand Channels were mapped as Spur & Groove (Table 3). Eight of these nine errors came from a single polygon classified as Spur & Groove (Figure 3, bottom center). The geomorphology seen in the eight misclassified videos closely resembled those of the adjacent Pavement with Sand Channels polygon extending westward along the same reef line, and more closely followed the definition of Pavement with Sand Channels given in the classification scheme. The decision between Pavement with Sand Channels and Spur & Groove was subjective because it was mainly a degree of feature relief. Three samples within the disputed polygon were ground-truthed as Spur & Groove indicating that within-polygon variation of relief was high.

The Pavement with Sand channels category had the lowest user's accuracy (50 %). Half of the points within this category were found to be something else. Three locations were identified as Aggregate Reef in the videos. These occurred in one polygon adjacent to the southern portion of the Spur & Groove polygon mentioned above and West of another Aggregate Reef polygon (Figure 3). Five locations were

identified as sand with varying levels of seagrass spread out between 4 polygons. One of the polygons contained another sample that supported the Pavement with Sand Channel classification, but there was little justification for the other three polygons. It is possible that seagrass patch morphology in these areas mimicked the Pavement with Sand Channel signature in the imagery. Intermittent sand and seagrass striations were evident in three of the videos which could have led to the confusion in interpretation.

4.2 BIOLOGICAL COVER

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 (80.1%), the overall accuracy adjusted for known map marginal proportions (85.0%), and the Tau coefficient (0.768) (Tables 5 and 6). No nearby regional mapping efforts utilized a similar biological cover classification scheme and were thus incomparable to the Lower Keys mapping program. The recent Hawaiian Islands mapping effort is the only NOAA mapping program to utilize a comparable biological cover classification scheme, but again the distinct geology and ecology of Hawaii confounds direct comparison to the Lower Keys map. Issues of geology and ecology aside, Smith et al. (unpublished data) reported an overall accuracy of 92.1% for Major Cover, 12.0 % higher than the Lower Keys (the gap lessened to 7.1% after adjusting the Lower Keys 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 the two highest levels of Coral, nor the highest level of Macroalgae, Turf, and Coralline Algae. The Major Cover categories with fewer than three Detailed Cover categories received a smaller share of accuracy assessment points. This bias was ameliorated by adjusting for known map marginal proportions (Card 1982).

Two general areas of classification errors combined to reduce the overall accuracy of Detailed Cover by a total of 8.0%. The first group of errors came from samples ground-truthed as Coral but mapped as Turf, Seagrass, or Macroalgae (21 samples). The second group of errors came from samples ground-truthed as Macroalgae but mapped as Coral, Turf, or Seagrass (21 samples). Other low error percentage classes in the Lower Keys Major Cover analysis were the User's accuracy for Turf (59.5%) and adjusted producer's accuracy for Coral (45.9%) and Macroalgae (57.6%). Reasons for these errors are addressed the Detailed Cover section.

Another notable category was Coralline algae. Together, the two levels of Coralline Algae Cover accounted for only 0.0171% of the area of AA ROI-1 (Table 6). The only two polygons of Coralline Algae were populated with 23 points spaced a minimum of 30 m apart. Eight of these points were inaccessible. Of the 15 target locations sampled, none were validated as Coralline algae. Seven were classified as Macroalgae, seven as Turf Algae, and one as Uncolonized. Despite being two orders of magnitude smaller than the next largest habitat (Coral), this mapping error reduced overall accuracy by 3.1% (15/478). Adjusting to the known map marginal proportions reduced this penalty to -.0171% (0/1.71E-4).

Oversampling of rare habitats also worked in favor of overall accuracy, provided the accuracy was relatively high. For example, the Emergent Vegetation 10-<50% category accounted for only 0.0146% of the area of AA ROI-1 (Table 8), but contributed 5.02% (24/478) to the overall accuracy (Table 7). Adjusting to known map marginal proportions reduced the contribution of this very small category to 0.0146% (1.46E-4/1.0).

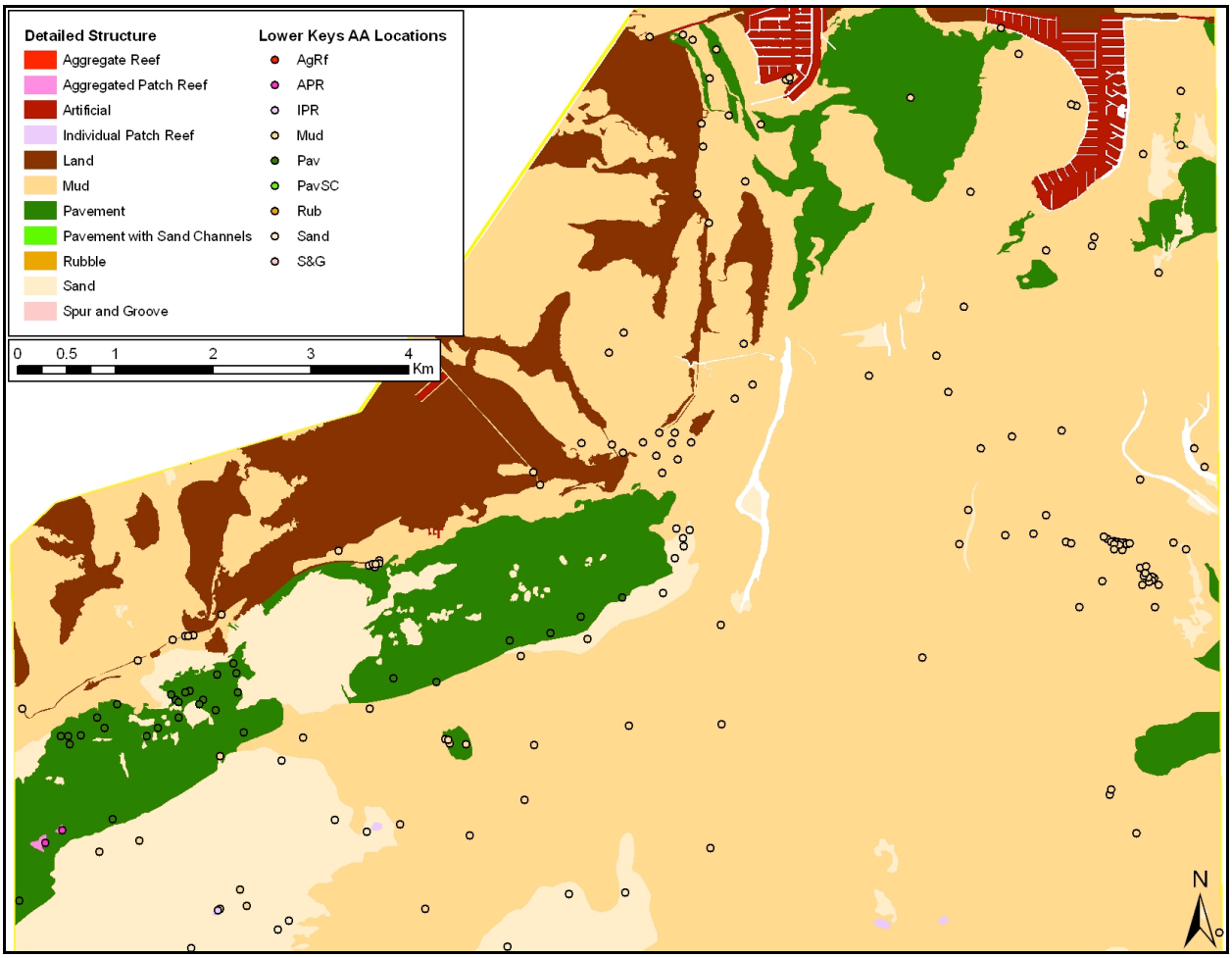

Figure 2. Nearshore NOAA Lower Keys benthic habitat map classified by Detailed Structure with the AA locations classified by their Accuracy Assessment ID for Detailed Geomorphological Structure.

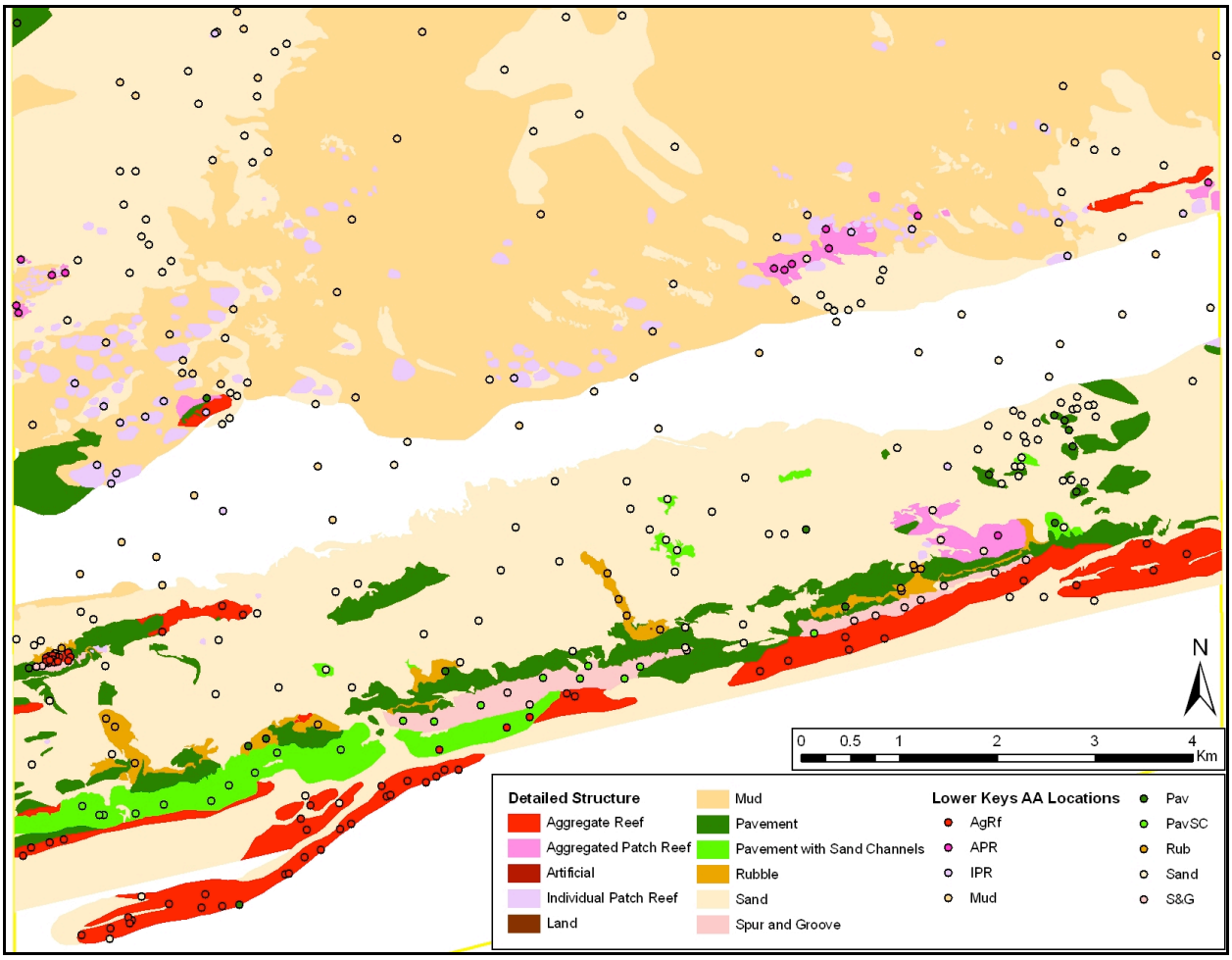

Figure 3. Offshore NOAA Lower Keys benthic habitat map classified by Detailed Geomorphological Structure with the AA locations classified by their Accuracy Assessment ID for Detailed Geomorphological Structure.

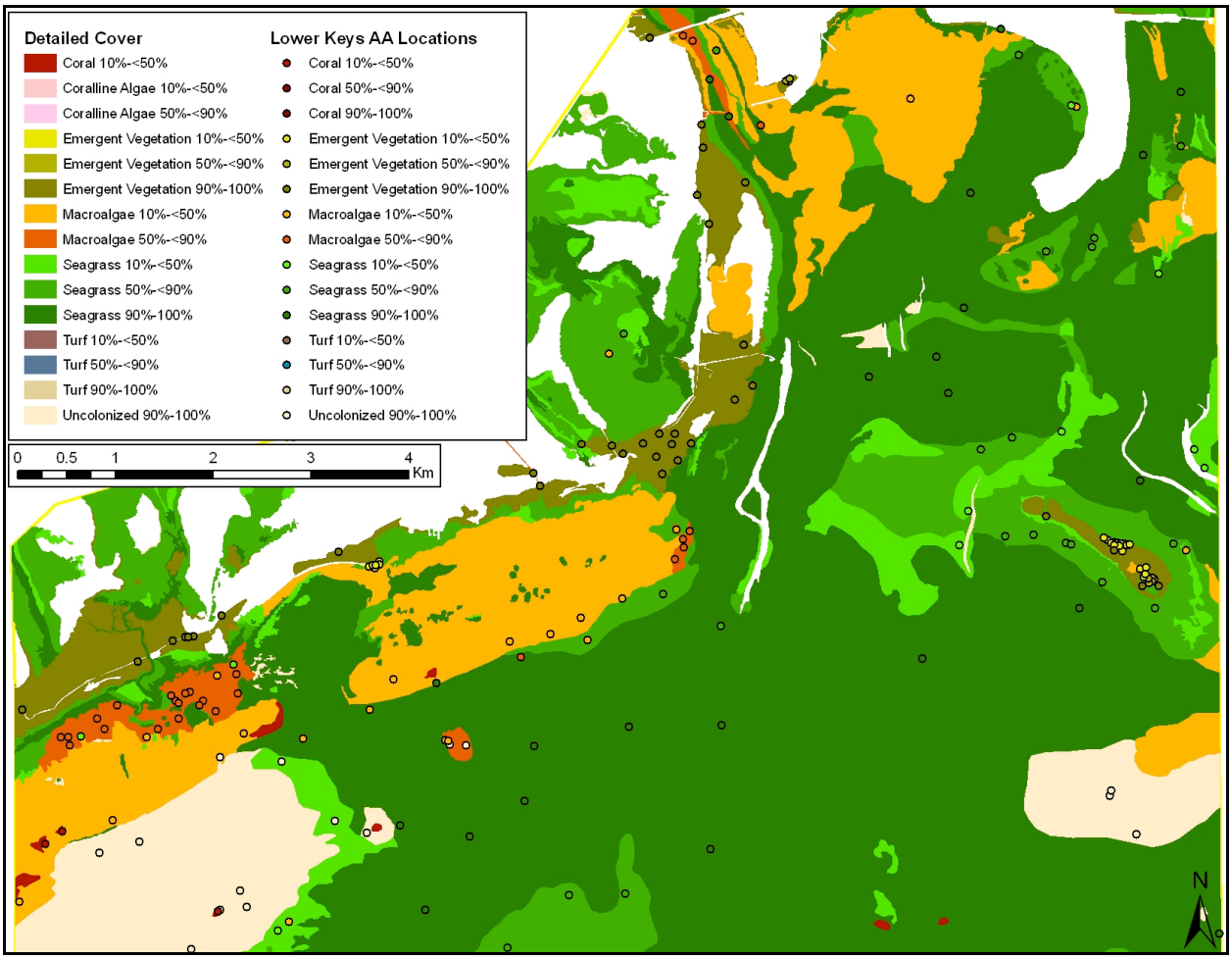

Figure 4. Nearshore NOAA Lower Keys benthic habitat map classified by Detailed Biological Cover with the AA locations classified by their Accuracy Assessment ID for Detailed Biological Cover.

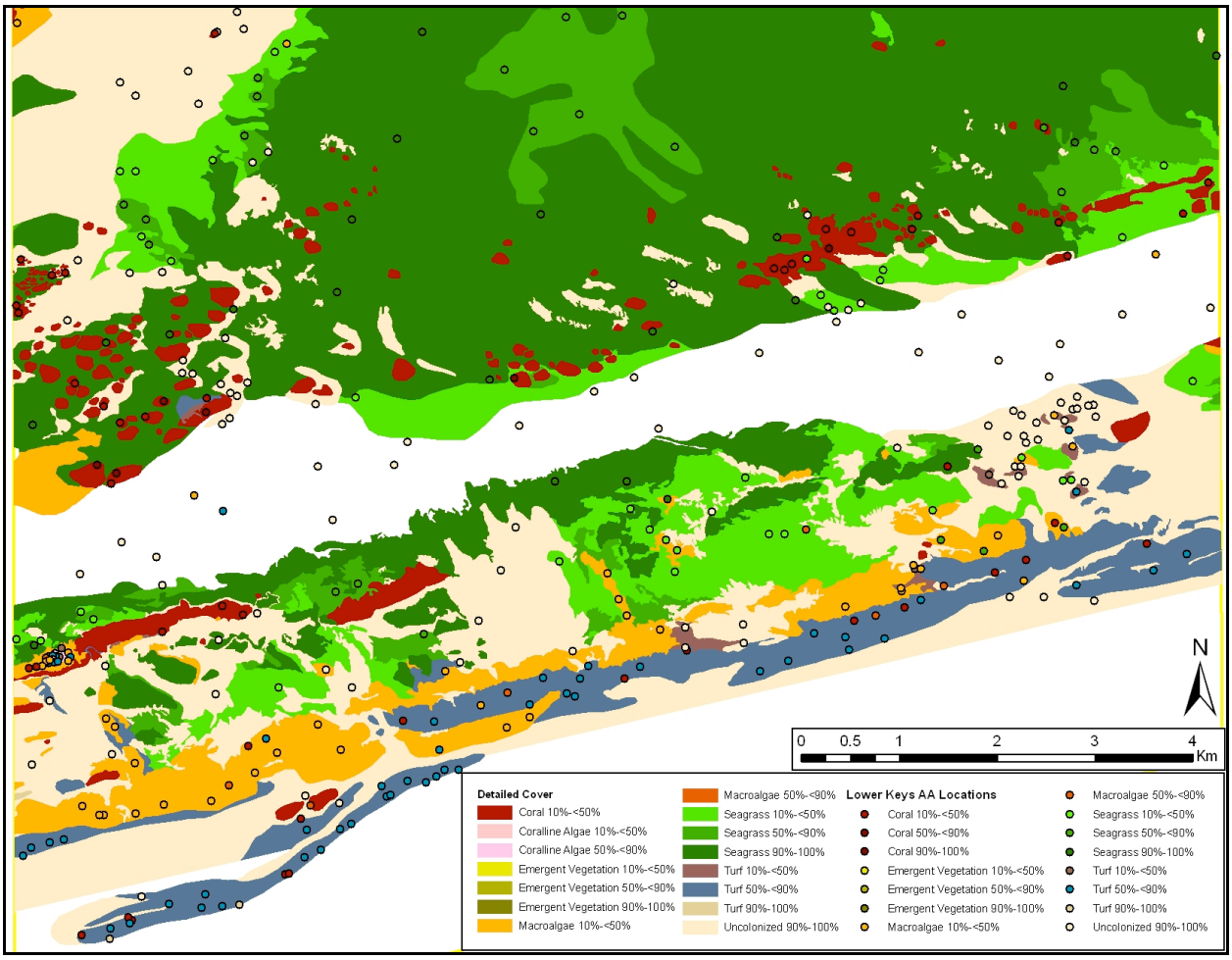

Figure 5. Offshore NOAA Lower Keys benthic habitat map classified by Detailed Biological Cover with the AA locations classified by their Accuracy Assessment ID for Detailed Biological Cover.

Detailed Biological Cover

The Detailed Biological Cover attributes were mapped at the lowest level of accuracy as indicated by the overall accuracy (76.4%), the overall accuracy adjusted for known map marginal proportions (82.4%), and the Tau coefficient (0.749). Smith et al. (unpublished data) reported a 7.1% higher overall accuracy (83.5%) for Detailed Cover in the Hawaiian Islands mapping (but only 1.1% higher after adjusting the Lower Keys for the known map marginal proportions). No nearby regional mapping efforts utilized a similar biological cover classification scheme, and were thus incomparable to the Lower Keys mapping program.

The three levels of Emergent Vegetation all had 100% user's and producer's classification accuracies. All 66 ground-truthed samples were composed of varying degrees 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 90-100% cover category.

The greatest single-class confusion existed between the Coral 10%-<50% and Turf 50%-<90% categories (Table 4). 15 points validated as Coral 10%-<50% were mapped as Turf 50%-<90%. 14 of these errors occurred along the outer reef margin where most of the habitat was mapped Turf 50%-<90%. The user's accuracy for Turf 50%-<90% (63.1%) showed that it was difficult to distinguish this category from the Coral and Macroalgae categories. Given that 24 of 65 samples in this habitat were either Coral or Macroalgae, it is likely that denser patches of these habitats exist in this area that weren't captured in the map. Whether those denser patches are larger than the minimum mapping unit is unknown.

The low user's accuracy (74.3%) of the Coral 10%-<50% category was primarily the result of the exclusion of the Coral 50%-<90% and Coral 90%-100% categories from the map. Five of the samples mapped as Coral 10%-<50% were validated as Coral 50%-<90% and one was validated as Coral 90%-100%. The six samples with high levels of coral cover were characterized by numerous hard coral colonies and abundant soft corals. 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 Keys. The six samples validated as >50% coral cover occurred on patch reefs north of Hawk Channel (Figure 5). It is unknown whether the 6 areas validated as >50% cover are larger than the minimum mapping unit, but the data should be reviewed and changes to the map should be considered for some of these individual patch reefs.

The greatest degree of confusion in the Detailed Biological Cover AA came from the two Macroalgae classes. Macroalgae cover is known to be much more ephemeral than Seagrass and Coral. Changes in water chemistry, sea state, temperature, and seasons can lead to drastic changes in macroalgae cover over short time scales. Macroalgae was also the most cosmopolitan of the Biological Cover categories. It occupied both hard and soft substrates and was mixed with other cover classes (e.g. seagrass, coral, etc.) at varying levels. Another source of confusion might have been the definitions of the Macroalgae and Turf categories. Several genuses of algae appear in both groups in the classification scheme and the only true difference, canopy height, is subjective. Macroalgae was confused with Coral, Turf Algae, and Uncolonized, but was mostly confused with Seagrass. 14 of the 29 user's errors for Macroalgae were with the two Seagrass categories (Table 7). Seagrass also accounted for 10 of the 28 Macroalgae producer's errors. The user's accuracies of the Macroalgae 10%-<50% and 50%-<90% categories were generally good (63.0% and 72.7%, respectively), but the known map marginal producer's accuracy of the 50%-<90% category was very low (16%) due to high sampling intensity within a relatively small map area (0.7% of AA ROI-1 area).

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 (84.9%), 18 sites

validated as Uncolonized were mapped as something else (Table 7). These Uncolonized errors were almost exclusively Sand and Mud structures that were confused with Pavement with Sand Channels, Pavement, Aggregated Patch Reef, and Aggregate Reef. It is unknown if these areas were larger than the minimum mapping unit 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, Pavement with Sand Channels was defined by having low relief and significant amounts of sand nearby, thus 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 mapped hardbottom communities were found to be Sand or Mud, however without recent imagery, the extent of these changes remains unknown.

Some large-scale changes were noted in the 2006 imagery that were not reflected in the map nor the AA (Figure 6). Most notably the mangrove cover on Lois Island changed during that time period, presumably due to extreme storm conditions during hurricanes Katrina and Wilma. The white arrows indicate the affected area. The habitat map (middle) reflects the 2005 image (top) where the island appeared to be mostly solid mangroves near the arrows, yet the 2006 images showed that a large gap formed in the center of the island, completely devoid of trees. Since this is a coral reef benthic habitat map, these changes may not be relevant to the overall mapping effort, however they do indicate that large-scale changes have occurred in the recent past within the mapped area.

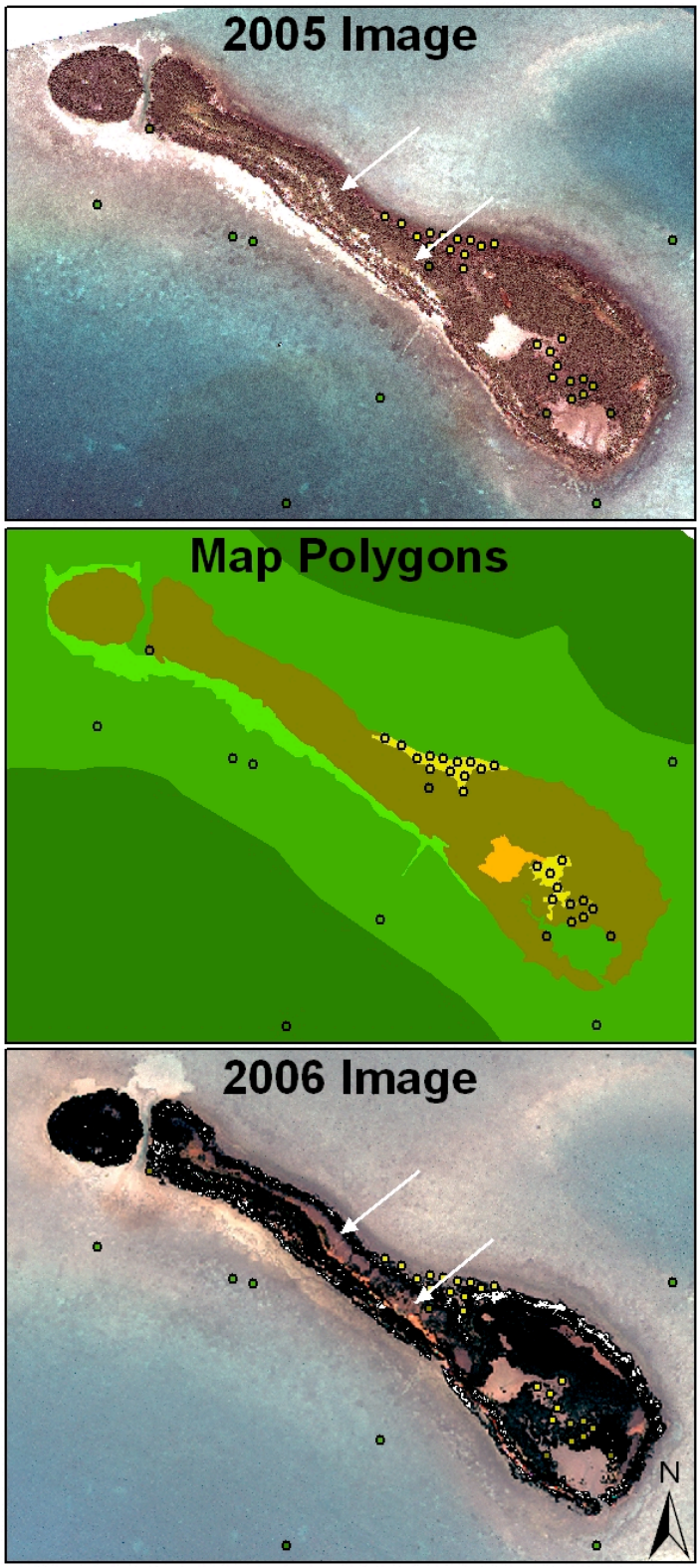

Figure 6. A time series of Lois Island from May 2005 to August 2006. White arrows indicate solid area of trees in 2005 that were absent in 2006; evidence of large-scale changes in the mapped area.

4.3 POINT V. TRANSECT

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

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

In the Lower Keys AA, 43 sites fell within 3 m of a polygon edge; 8.5% of the total AA sites. Of the 43, 6 were incorrect with regard to cover (13.9%) and 2 were incorrect with regard to detailed structure (4.7%). The low incidence of error of sites within 3 m of the boundaries suggests that the accuracy of the edges was high and the inclusion of habitat transitions in the sampling design did not impair the AA outcomes

4.4 AA ROI-1 ACCURACY REPRESENTATION FOR THE ENTIRE MAPPED AREA

Resources, budgets, and logistical constraints precluded a comprehensive assessment of the entire mapped area, thus a biogeographically representative corridor within the total benthic habitat map area was selected for performing the accuracy assessment (Congalton, 1991; Stehman and Czaplewski, 1998). This corridor not only captured a wide diversity of habitats, but was also characterized by frequent transitions between habitat types. Every Biological Cover habitat in the entire Lower Keys map was represented in the sample area (AA ROI-1) (Appendix 2) and all but one Geomorphological Structure were present (Rock/Boulder). The percent contribution of Biological Cover classes in AA ROI-1 and the total mapped area were very similar (Appendix 3). The most obvious differences were in Seagrass 90%-100% and Unknown. Seagrass 90%-100% comprised 40.6% of AA ROI-1 but only 28.3% of the entire

mapped area, whereas Unknown comprised 8.1% of AA ROI-1 but 20.5% of the entire area. Otherwise the percent contributions of Biological Cover habitats to the totals were similar.

Every Geomorphological Structure was present in AA ROI-1 except for Rock/Boulder. This was one 0.01 sq km polygon located at the southwestern tip of Key West and thus could not be included unless that was the surveyed area. Major differences in percent contributions of Geomorphological Structures were Mud (48.2% in AA ROI-1 v. 20.9% in entire map area), Unknown (8.1% v. 20.5%), Sand (23.8% v. 35.1%), and Pavement (8.2% v. 15.5%). All other classes were small in their relative percent contributions to the total and similar between AA ROI-1 and the entire mapped area

The true error of non-sampled portions of the map is ultimately unknown and further sampling in these areas of the map will allow for a better understanding of the entire map accuracy, however, the accuracy assessment in AA ROI-1 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 as well as AA ROI-1; 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.

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

Detailed Geomorphologic Structure:

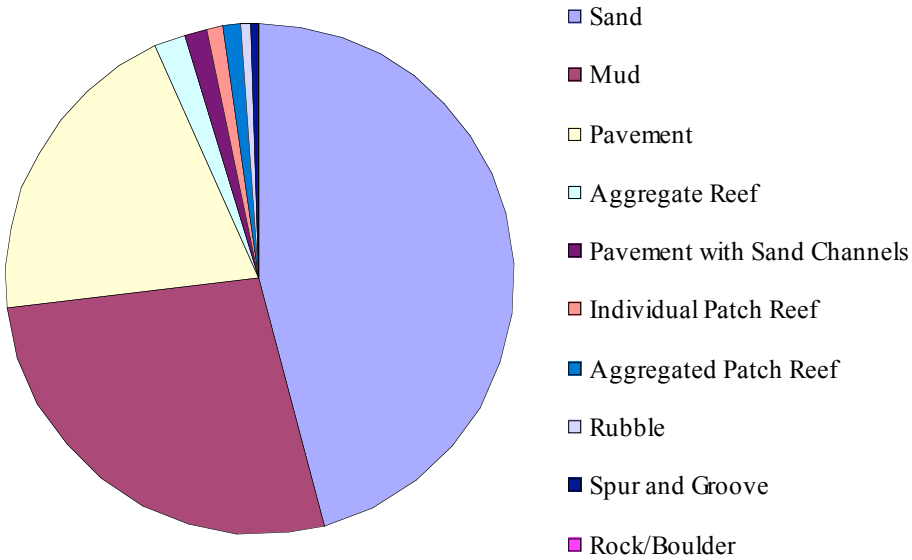
Class	Target Locations Total	Final Locations Total
Aggregate Reef	42	64
Aggregated Patch Reef	20	20
Artificial	Not Targeted	Not Targeted
Individual Patch Reef	22	15
Land	Not Targeted	Not Targeted
Mud	139	137
Pavement	113	50
Pavement with Sand Channels	20	20
Reef Rubble	21	18
Rock/Boulder	N/A	N/A
Sand	86	133
Scattered Coral/Rock in Unconsolidated Sediment	N/A	N/A
Spur & Groove	20	21
Unknown	25	25

Detailed Biological Cover:

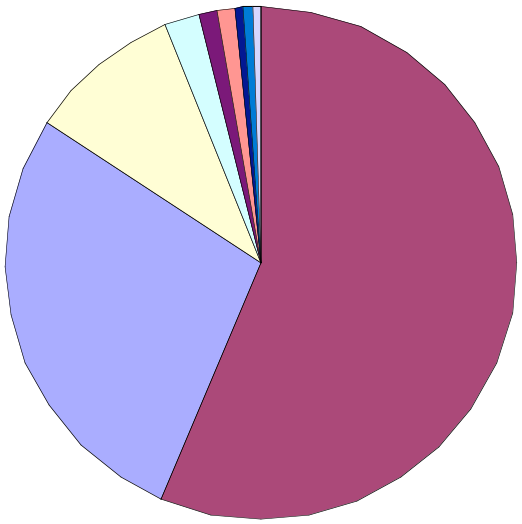
Class	Target Locations Total	Final Locations Total
Live Coral 90%-100%	N/A	N/A
Live Coral 50%-<90%	N/A	N/A
Live Coral 10%-<50%	41	35
Seagrass 90%-100%	37	46
Seagrass 50%-<90%	37	38
Seagrass 10%-<50%	37	41
Macroalgae 90%-100%	N/A	N/A
Macroalgae 50%-<90%	37	33
Macroalgae 10%-<50%	55	54
Coralline Algae 90%-100%	N/A	N/A
Coralline Algae 50%-<90%	20	14
Coralline Algae 10%-<50%	3	1
Turf Algae 90%-100%	37	N/A
Turf Algae 50%-<90%	37	65
Turf Algae 10%-<50%	37	14
Emergent Vegetation 90%-100%	36	34
Emergent Vegetation 50%-<90%	8	8
Emergent Vegetation 10%-<50%	24	24
Uncolonized 90%-100%	37	71
Unknown	25	25
Total	**508**	**503**

Appendix 2. Detailed Structure in Total Mapped Area (left) and AA ROI-1 (right).

Percent of assessed Detailed Structure for the entire mapped area.



Percent of assessed Detailed Structure for AA ROI-1.



Total Map Area

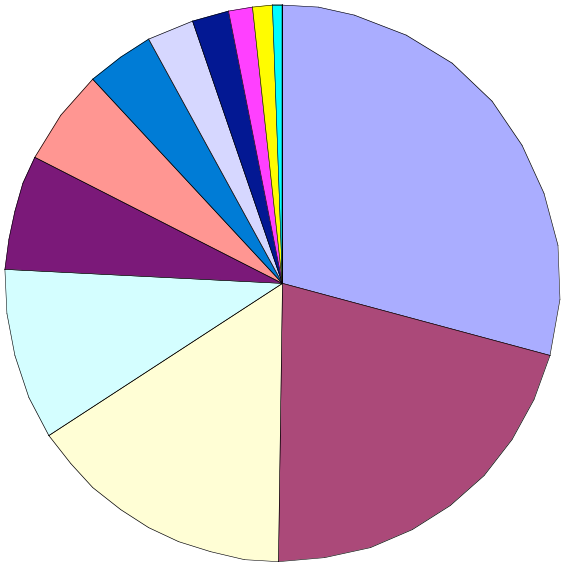
D_STRUCT	AREA (m²)	% of Total
Aggregate Reef	12025241.13	1.33%
Aggregated Patch Reef	6769247.87	0.75%
Artificial	2935178.07	0.32%
Individual Patch Reef	8522554.60	0.94%
Land	23858089.90	2.63%
Mud	189711525.32	20.91%
Pavement	140983038.54	15.54%
Pavement with Sand Channels	10339902.71	1.14%
Rock/Boulder	10133.28	0.00%
Rubble	4671094.75	0.51%
Sand	318080882.71	35.06%
Spur and Groove	3358192.35	0.37%
Unknown	185904260.84	20.49%
Total	907169342.06	100.00%

AA ROI-1 Area

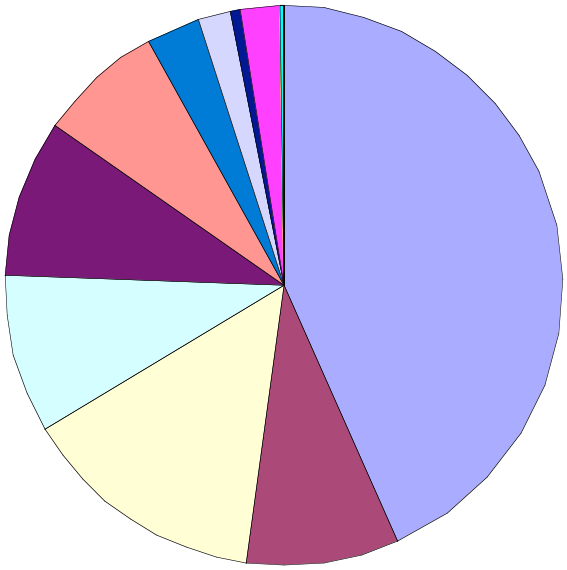
D_STRUCT	AREA (m²)	% of Total
Aggregate Reef	3555233.34	1.95%
Aggregated Patch Reef	834337.50	0.46%
Artificial	1571307.13	0.86%
Individual Patch Reef	1696861.73	0.93%
Land	10271598.68	5.62%
Mud	88098495.46	48.21%
Pavement	14984396.11	8.20%
Pavement with Sand Channels	1781642.10	0.97%
Rubble	788453.05	0.43%
Sand	43441587.70	23.77%
Spur and Groove	942334.92	0.52%
Unknown	14776707.10	8.09%
Total	182742954.80	100.00%

Appendix 3. Detailed Cover in Total Mapped Area (left) and AA ROI-1 (right).

Percent of assessed Detailed Cover for the entire mapped area.



Percent of assessed Detailed Cover for AA ROI-1.



- Seagrass 90%-100%
- Unknown Unknown
- Uncolonized 90%-100%
- Macroalgae 10%-<50%
- Seagrass 50%-<90%
- Seagrass 10%-<50%
- Turf 50%-<90%
- Coral 10%-<50%
- Macroalgae 50%-<90%
- Emergent Vegetation 90%-100%
- Turf 90%-100%
- Turf 10%-<50%
- Coralline Algae 50%-<90%

Total Map Area

COVER	AREA (m²)	% of total
Coral 10%-<50%	24470451.22	2.70%
Coralline Algae 10%-<50%	303543.24	0.03%
Coralline Algae 50%-<90%	309906.48	0.03%
Emergent Vegetation 10%-<50%	157442.01	0.02%
Emergent Vegetation 50%-<90%	46884.32	0.01%
Emergent Vegetation 90%-100%	13109859.65	1.45%
Macroalgae 10%-<50%	88660660.06	9.77%
Macroalgae 50%-<90%	17667732.71	1.95%
Seagrass 10%-<50%	48910046.11	5.39%
Seagrass 50%-<90%	59351860.48	6.54%
Seagrass 90%-100%	256892278.50	28.32%
Turf 10%-<50%	2976637.62	0.33%
Turf 50%-<90%	34347327.29	3.79%
Turf 90%-100%	11185403.35	1.23%
Unclassified	26793267.97	2.95%
Uncolonized 90%-100%	136081780.20	15.00%
Unknown Unknown	185904260.84	20.49%
Total	907169342.06	100.00%

AA ROI-1 Area

COVER	AREA (m²)	% of total
Coral 10%-<50%	3217287.99	1.76%
Coralline Algae 10%-<50%	3362.36	0.00%
Coralline Algae 50%-<90%	23343.31	0.01%
Emergent Vegetation 10%-<50%	22771.67	0.01%
Emergent Vegetation 50%-<90%	2921.71	0.00%
Emergent Vegetation 90%-100%	3787764.74	2.07%
Macroalgae 10%-<50%	15767902.99	8.63%
Macroalgae 50%-<90%	1089389.11	0.60%
Seagrass 10%-<50%	12156986.42	6.65%
Seagrass 50%-<90%	15836842.05	8.67%
Seagrass 90%-100%	74265677.29	40.64%
Turf 10%-<50%	290064.03	0.16%
Turf 50%-<90%	5271644.90	2.88%
Turf 90%-100%	9280.84	0.01%
Unclassified	11842905.81	6.48%
Uncolonized 90%-100%	24378102.49	13.34%
Unknown Unknown	14776707.10	8.09%
Total	182742954.80	100.00%