Benthic Habitats of the Hawaiian Islands

A Comparison of Accuracy of Digital Habitat Maps Prepared from Remote Sensing Imagery

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Outline

Figures

Tables

Detailed Habitat Abbreviations

LSeaGr	Continuous Seagrass (90% to 1000% Cover)
MSeaGr	Patchy (Discontinuous Seagrass) (50% to <90% Cover)
HSeaGr	Patchy (Discontinuous Seagrass) (10% to <50% Cover)
LMacAl	Continuous Macroalgae (90% to 1000% Cover)
MMacAl	Patchy (Discontinuous Macroalgae) (50% to <90% Cover)
HMacAl	Patchy (Discontinuous Macroalgae) (10% to <50% Cover)
LinReef	Linear Reef
AgCr	Aggregated Coral
SnG	Spur and Groove
InPtRf	Individual Patch Reef
AgPtRf	Aggregated Patch Reef
SCRUS	Scattered Coral/ Rock in Unconsolidated Sediment
ColPv	Colonized Pavement
ColBa	Colonized Volcanic Rock/Boulder
ColPvSC	Colonized Pavement with Sand Channels
RR	Reef Rubble
UnColPv	Uncolonized Pavement
UnColBa	Uncolonized Volcanic Rock/Boulder
UnColPvSC	Uncolonized Pavement with Sand Channels
HCorAl	Continuous Encrusting/Coralline Algae (90% to 1000% Cover)
MCorAl	Patchy (Discontinuous) Encrusting/Coralline Algae (50% to <90% Cover)
LCorAl	Patchy (Discontinuous) Encrusting/Coralline Algae (10% to <50% Cover)
EmgVg	Emergent Vegetation
Artf	Artificial

List of Acronyms

ALH	Analytical Laboratories of Hawaii
APTI	Applied Power Technologies, Inc.
CRAMP	Coral Reef Assessment and Monitoring Program
ESRI	Environmental Systems Research Institute
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GPS	Global Positioning System
HDAR	Hawaii Department of Aquatic Resources
HIMB	Hawaii Institute of Marine Biology
HSI	Hyperspectral Imagery
INS	Inertial Navigation System
MMU	Minimum Mapping Unit
MSL	Mean Sea Level
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
RGB	Red Green Blue
UTM	Universe Transverse Mercator
WGS	World Geodetic System

I. Introduction and Background

NOAA's National Ocean Service (NOS) and National Geodetic Survey (NGS) have acquired color aerial photography, hyperspectral imagery (HSI) and IKONOS satellite imagery for the near shore waters of portions of the eight Main Hawaiian Islands. The images are being used to create maps of the region's marine resources including coral reefs and other important habitats for fisheries, tourism and aspects of the coastal economy. Accurate habitat maps are necessary for resource managers to make informed decisions about the protection and use of these areas. Analytical Laboratories of Hawaii (ALH) has been contracted to provide mapping and other services to meet the goals of this project.

Remotely sensed imagery that may be suitable for mapping coral reef habitats can be acquired from a wide variety of platforms and imaging systems, each having it's own strengths and limitations. It is important to identify the technical merits of each, as models that consider cost of acquisition and processing as well as compatibility of the map output with NOAA coral reef habitat mapping objectives must be developed.

The primary product of this effort is an assessment and comparison of the accuracy of benthic habitat maps in ArcView geographic information system (GIS) format produced by visually interpreting the remotely sensed image data. In this work, important similarities and differences between the types of imagery tested are identified. Scientifically sound statistical comparisons of the coral reef habitat maps are presented and conclusions are drawn that can be integrated into long term coral reef mapping objectives.

The results of this work have been integrated into the methods for production of the coral reef habitat maps and have been used to process all of the data collected during the year 2000 NOAA image acquisition mission.

II. Approach

A. Survey Design

Three types of remotely sensed imagery were tested:

- Color aerial photography scanned to 1 meter pixel size,
- AURORA hyperspectral imagery processed to 3 meter pixel size and
- IKONOS satellite imagery acquired at 4 meter pixel size.

Four test areas were examined. Each area extends from shore to a depth of approximately 30 meters to the ends of the test area described here. The first was located on the Kona Coast in the District of South Kohala on the west side of the island of Hawaii. It extends from Kawaihae Harbor to Kiholo Bay (Figure 1). The second study area is located in Kaneohe Bay on the island of Oahu (Figure 2). It extends from the Sam Pan Channel on the south end of the bay to Chinaman's Hat on the north end of the bay. The third area is on the Island of Maui from Maalaea Harbor to Makena Beach (Figure 3) and the fourth is on the south shore of the Island of Molokai, Palaau to the Kaunakakai Pier (Figure 4). Mapping and collection of accuracy assessment data have been completed for all study areas and the results of this work are presented.

B. Development of the Hawaii Benthic Habitat Classification Scheme

These benthic habitat maps were produced by manual delineation of habitats from the remotely acquired imagery. The benthic features were classified using a hierarchical Coral Reef Habitat Classification Scheme. The scheme was prepared through consultation, meetings and workshops that included the key coral reef biologists and mapping experts and professionals in the State of Hawaii. The Coral Reef Habitat Classification Scheme that was developed by NOAA for the Caribbean and Gulf of Mexico was used as a starting point for this work. This classification scheme was influenced by many factors including but not limited to:

1. Requests of the management community
2. NOS's coral reef mapping experiences
3. Existing classification schemes for the Pacific and Hawaiian Islands and other coral reef ecosystems
4. Quantitative habitat data for the Hawaiian Islands
5. Minimum mapping unit of one acre and anticipated limitations of the data

If a feature (e.g., habitat) cannot be detected or seen in the photographs, hyperspectral or IKONOS satellite imagery, it is not included in the scheme.

The major habitats for the scheme that has been developed for the eight Main Hawaiian Islands include:

Unconsolidated Sediments
Submerged Aquatic Vegetation
Coral Reef and Hard Bottom
Other Delineations

These have been subdivided to include a total of 28 habitats that comprise the detailed coral reef benthic habitat classification system for the eight Main Hawaiian Islands.

These include:

- Unconsolidated Sediments
  - Sand
  - Mud
- Submerged Aquatic Vegetation
  - Macroalgae (fleshy or turf)
    - Continuous Macroalgae (90%-100% Cover)
    - Patchy (Discontinuous) Macroalgae (50%-<90% Cover)
    - Patchy (Discontinuous) Macroalgae (10%-<50% Cover)
  - Seagrass
    - Continuous (90%-100% Cover)
    - Patchy (Discontinuous) Seagrass (50%-<90% Cover)
    - Patchy (Discontinuous) Seagrass (10%-<50% Cover)
- Coral Reef and Hard Bottom
  - Coral Reef and Colonized Hard Bottom
    - Linear Reef
    - Aggregated Coral
    - Spur and Groove
    - Individual Patch Reef
    - Aggregated Patch Reef
    - Scattered Rock and Coral in Unconsolidated Sediment
    - Colonized Pavement
    - Colonized Volcanic Rock/Boulder
    - Colonized Pavement with Sand Channels
  - Uncolonized Hard Bottom
    - Reef Rubble
    - Uncolonized Pavement
    - Uncolonized Volcanic Rock/Boulder
    - Uncolonized Pavement with Sand Channels
  - Encrusting/Coralline Algae
    - Continuous Encrusting/Coralline Algae (90%-100% cover)
    - Patchy (Discontinuous) Encrusting/Coralline Algae (50%-<90% cover)
    - Patchy (Discontinuous) Encrusting/Coralline Algae (10%-<50% cover)

- Other Delineations
  - Land
  - Emergent Vegetation
  - Artificial
  - Unknown

Thirteen zones have been developed as:

Shoreline Intertidal
Vertical Wall
Reef Flat
Back Reef
Reef Crest
Fore Reef
Lagoon
Bank/Shelf
Channel
Dredged
Land
Bank/Shelf Escarpment
Unknown

C. Habitat Map Accuracy Assessment

Recognizing that the purpose of this study was to determine the relative accuracy of maps generated from photointerpretation of the three sources of remotely sensed imagery, an accuracy assessment system was designed and executed to quantify this important characteristic. Statistical analysis methods have been applied that have been developed by other researchers (Hudson and Ramm 1987, Congalton, 1991). Rosenfield et al. (1982). In these works, it has been determined that a statistically valid data set, at 90% to 95% confidence interval, is obtained where at least 50 field habitat observations have been completed per major habitat type. The accuracy assessment is prepared from a matrix that compares the habitat assigned to a polygon that was generated from the interpretation of the image with that of the determination from field observation. Traditionally, the data is organized into columns that represent the field habitat validation data and the rows are organized into the interpretation of the images. The overall accuracy is typically measured by dividing the total correct determinations by the total number of assessments. This result only incorporates the major diagonal of the table and excludes the omission and commission errors where as the Kappa analysis (Cohen, 1960) indirectly incorporates the off-diagonal elements as a product of the row and column marginals. Furthermore, the Tau analysis generates a similar statistic as Kappa but compensates for unequal probabilities of groups or for differences in numbers of groups (Ma and Redmond, 1995). This assessment lends itself to statistical analysis wherein the photointerpreter's determination is assigned a probability that it occurred at random. These values can then be contrasted to generate a Z statistic representing the probability that the accuracy of the maps is dissimilar at a particular confidence interval. In the work conducted here, a 95% confidence interval has been applied. Producer's accuracy (the probability of a reference pixel being correctly classified) and users accuracy (the probability that a particular pixel will be correct when field checked) has been included.

As some of the detailed habitat types were encountered in the field in less than 50 assessments, statistical accuracies have not been estimated. However, these data have been summarized as simple percentage of correct determinations.

D. Habitat Map Preparation

Traditional methods of “grease pencil” delineation of photointerpreted habitat classes have been nearly completely replaced by computerized “heads up” digitizing methods. These latter methods have distinct advantages.

- The “heads up” method reduces positional error of the habitat boundaries by eliminating the intermediate digitizing step.
- Productivity is higher.
- Developing an active link between the mapped image and the associated database a GIS is generated.

The application of GIS provides a powerful analytical tool that yields critical information and contributes to the ability of making sensible long-term natural resource management plans. The maps and mapping methods described in this report were developed using Environmental Systems Research Institute (ESRI) ArcView GIS software.

III. Methods

A. Accuracy Assessment Data Collection

Stratified random sampling methods were implemented subsequent to completion of the draft coral reef habitat maps for each image type and for each test area. A polygon of the study area was generated from the coordinates provided in the scope of work (SOW) and the coral reef habitats inside the test area boundaries were digitized. After photointerpretation was complete, the polygons representing detailed habitats were aggregated into major classes and at least 50 random geographically referenced points were created in each. This was done using a random point generator obtained from the ESRI web site. The software generates random points inside an ArcView GIS polygon shape. Waypoint files were generated from these points and all waypoints that could be safely accessed were navigated to using a Trimble GeoExplorer 3 GPS data logger (Figures 1, 2, 3 and 4). Upon arriving at the waypoint, a weighted meter line was dropped, a buoy fastened and site and habitat specific data collection began (Table 1). Three benthic habitat assessments were undertaken. A point assessment was conducted by surveying the one square meter area around the point where the weight dropped. Two area assessments were conducted in an area of a seven-meter radius around the weight. The first assessment identified the most common habitat type within the area and the second identified the second most common habitat type with in the area. The depth of the site was recorded using a hand held depth sounder. Benthic habitat assessments were made using a glass bottom look box, free diving or observing from the surface. All diving was conducted by breath holding or snorkeling on the surface. In areas where waves and sea conditions were prohibitive to safely accessing the waypoint by boat the GPS was placed in a watertight box and swam to the survey point.

The most common habitat observed within an accuracy assessment position was recorded on the GPS data logger using a custom data dictionary designed to meet the specifications of the Coral Reef Habitat Classification Scheme. The second most common habitat and general area descriptions were entered in waterproof notebooks and transferred to the GIS by hand.

B. Spatial Data Quality

Upon arriving at a waypoint, and deployment of the buoyed lead line, GPS logging began. One hundred GPS positions were collected at one-second intervals for each survey site. The positions were averaged to obtain a single survey point. The data were post processed for differential correction.

Data were collected to determine spatial accuracy. Each day, GPS positions were collected at the pier at Kawaihae Harbor at the Kona test area and several others were collected at jetty markers and other monuments. At the Kaneohe Bay study area, easily accessible survey sites were selected and navigated to each day as a spatial control. Also, a GPS position was acquired at the end of the pier leading to the Hawaii Institute of Marine Biology (HIMB) field station, Coconut Island. GPS positions were collected at State of Hawaii Department of Land and Natural Resources Harbors Division monuments on the wharf at Kauanakakai at the Molokai test area and at the lighthouse at Maalaea at the Maui test site.

C. Points of Interest

When an area was encountered where particularly interesting or uncommon habitat was visited, benthic habitat assessments were conducted that were not included in the random point set. These were assigned special numerical site identifiers to distinguish them from the random positions.

D. Observer Objectivity

The Coral Reef Assessment and Monitoring Program (CRAMP) team made all benthic habitat decisions independent of the ALH contractor. During the habitat assessments, the ALH contractor made observations regarding the features in aerial photography and the corresponding habitat types in the field to enhance skills in aerial photointerpretation of these benthic habitats. Furthermore, the CRAMP team independently conducted the assessment of the extent to which the photointerpretation met the field assessment determinations. These data were then used to prepare the statistical contrasts of the accuracy of the maps for each of the test areas for each of the image types.

E. Remote Sensing Data

Technological advances that offer powerful image analysis alternatives and state-of-the-art methods have been employed in this study. Both color aerial photographic data and digital hyperspectral imagery were collected by NOAA using instrumentation installed onboard the dual-port NOAA AOC Citation II aircraft. The color aerial photography was provided to the contractor as discrete georeferenced images or mosaiced orthorectified images in Geo TIFF format scanned at a resolution of one-meter pixel. These were imported to ArcView GIS software using the ESRI Image Analysis extension where manual habitat delineation was conducted.

The hyperspectral image data were collected using the AURORA HSI data acquisition system built by Applied Power Technologies, Inc. (APTI). Navigation data were incorporated using the Applanix inertial navigation system (INS). The camera collects 72 ten nm bands in the visible and near infrared spectral range with the pixel size at three meters. The raw data were provided to the ALH contractor along with the navigational data and spectral processing was conducted using Research Systems, Inc. ENVI software.

RGB composites were prepared and the scenes were then georeferenced to UTM Zone 5 for the Kona test site and UTM Zone 4 for the remainder of the test sites and on WGS 84 datum. These were mosaiced using Scene Stitcher, a stand-alone software program also produced by APTI. The mosaics were then imported to the ArcView GIS system where manual delineation of habitat boundaries was undertaken based on photointerpretation.

The IKONOS satellite imagery was procured from Earth Sat, Inc. and was processed by NOS in preparation for habitat delineation.

Both the hyperspectral and IKONOS imagery were optimized to maximize true color and during the map preparation the color was strategically manipulated to extract the most habitat information. Specific bands combinations have been selected that enhance feature detection in shallow and deep water using hyperspectral imagery and the IKONOS satellite imagery was provided to the contractor processed to remove atmospheric effects and compensate for water column effects.

F. Determination of Field Habitat Type

Dr. Paul Jokiel, director of CRAMP at HIMB, supported by Will Smith, a Ph.D. graduate student in the Department of Geography at the University of Hawaii Manoa, conducted the field habitat assessments. During the field surveys, the contractor conducted general observations correlating habitat type with information in the images and coordinated navigation and data base management.

G. Benthic Habitat Map Preparation

The coral reef benthic habitat maps of the test areas were digitized by delineating photointerpreted habitat boundaries from the imagery provided to the contractor by NOAA. As ESRI ArcView GIS software was used in the preparation of the maps, NOAA staff has developed an editable ArcView extension that allows for a custom habitat classification scheme to be developed based on the user's needs. The software also allows for zone classifications to be included and toggles between the legends of the habitats and zones within the GIS system. This extension was used in the preparation of the habitat map product tested here.

NOAA supplied georeferenced imagery to ALH. Delineation of all habitat boundaries was conducted with the image scale at 1:6,000. This ensures that the level of detail produced by the photointerpreter is uniform throughout the project. Also, NOAA has shown from similar mapping efforts in the Caribbean and Florida Keys, that little additional information is gained from having the image at a smaller scale and the labor intensity increased significantly. Similar logic has been used to determine the minimum mapping unit (MMU) of one acre. The ArcView digitizing extension described above provides the option of setting the MMU area. It informs the photointerpreter when a polygon is being closed that has an area below the selected MMU and provides the option of including or eliminating that polygon.

Discrete multivariate analysis was conducted to compare the accuracy of the visually interpreted map product using the three types of remotely sensed data for each of the test sites.

IV. Results

A. Accuracy Assessment Data Collection

Due to an unusually stormy winter in the Central Pacific during the 2001 to 2002 season, multiple attempts to acquire accuracy assessment data for the Molokai test area were required. Two field missions were planned to collect this data. Due to failed field missions resulting from poor weather, eight field missions were executed to complete this work.

During the month of November 2001, an unusually powerful storm occurred in the Hawaiian Islands. Extensive flooding, road closures and power outages were experienced. The intense rain fall, after fifteen years of near drought conditions in the Hawaiian Islands, resulted in unprecedented mud inundation on the west end of the study area in Molokai. The influx of sediment from the November storm and the series of storms that followed over the next six months made this area inaccessible for the entire project period. As the types of habitats on the west end of the Molokai test area are very similar to those on the east end of the test area, the density of accuracy assessment points was increased on the east end to compensate for the reduced density on the West end (Figure 4). With the exception of the mud inundation on the reef at Molokai, the remainder of the acquisition of field accuracy assessment data proceeded flawlessly.

A total of 304 GPS positions were occupied during the accuracy assessment data acquisition of the Kona pilot study area (Figure 1). At the Kaneohe Bay pilot study area, 393 GPS positions were occupied (Figure 2). Two hundred ninety seven and 231 GPS positions were occupied at the Maui and Molokai test areas respectively (Figures 3 and 4). The total number of detailed and major habitats visited during this tenure, for all test areas, is 1,225. The details of the habitat data have been included in ArcView GIS files that have been included with this work. Summaries of the results of the accuracy assessment have been presented below. All data were collected as planned.

B. Benthic Habitat Map Preparation

Benthic coral reef habitat maps were prepared from airborne color aerial photography, airborne hyperspectral imagery and IKONOS satellite imagery. One map was prepared for each image type for each of the test sites resulting in a set of 12 maps. These maps are complete. They consist of 2,776 topologically clean polygons. These GIS data are free of overlaps, sliver polygons, void polygons and adjacency. FGDC compliant metadata summaries have been written for each file. The database has been designed to be compliant with NOAA Internet publication.

C. Comparison of Results

The CRAMP team has completed the determination of the extent of correct vs. incorrect habitat interpretations. Accuracy of photointerpretation of major coral reef habitats for each of the image types and for each of the test areas are presented here (Tables 3, 4, 5 and 6) and the results of the accuracy assessments for the four test areas have been combined (Table 7).

The three types of imagery were acquired during different days with different weather conditions. The habitat type for the portions of the test area that were not interpretable due to cloud cover, glint or water quality were classified as “unknown”. The accuracy assessment points that fell within polygons with the habitat type of "unknown" were not included in the accuracy analysis. As a result, the total number of accuracy assessment points varies between the imagery types within a single test area.

The Kappa and Tau statistic for the major habitat types for each pilot study area are included. From Table 7 it can be seen that the percent overall accuracy of photointerpretation of color aerial photography, IKONOS satellite and hyperspectral imagery is 90.7%, 86.5% and 89.0% respectively.

The results of the Z test, which reveals the probability of the confidence that there is no difference between the accuracy of the maps in the contrast, are also presented (Table 8). A contrast result of an absolute value of 1.96 or less indicates a 95% confidence that there is no significant difference between the accuracy of the maps being compared. It can be seen that 3 of the 4 contrasts between the accuracy of maps prepared from 1 meter color aerial photography and 3 meter hyperspectral imagery resulted in a insignificant difference. The contrasts conducted between maps prepared from 3 meter hyperspectral and 4 meter IKONOS satellite imagery all showed insignificant differences. Two of the 4 contrasts conducted between maps prepared from 1 meter color aerial photography and 4 meter IKONOS satellite imagery resulted in significant difference at 95% confidence interval. When all four sites were combined, there was no significant difference between the map accuracy when contrasting color aerial photography and hyperspectral imagery or when contrasting hyperspectral imagery with IKONOS satellite imagery. The contrast between color aerial photography and IKONOS satellite imagery yielded an absolute Z value of 3.07 indicating that there is a significant difference between the accuracy of habitat maps produced from these image sources. The results are not included in this report, but there were no significant differences between the accuracy of any of the map products when tested at 90% confidence.

The accuracy of the habitat maps prepared from these three image types when examining the detailed level of the classification scheme are represented here as a simple percentage of the number of correct calls divided by the total assessments conducted (Tables 9 thru 20). These tables not only show the number correct and incorrect calls but also show the incorrectly selected habitat type. This allows observation of the most common errors made and provides important understanding of what the limitations are of each imagery type when extracting visually interpreted coral reef habitat information.

V. Discussion

This work addresses the accuracy of extracting coral reef habitat map information by visual interpretation of color aerial photography, AURORA hyperspectral and IKONOS satellite imagery. The results of these comparisons indicate that little significant difference exists between the accuracy of the coral reef habitat maps generated from the visual interpretation of the color aerial photography and hyperspectral imagery provided to the contractor. They also show that a significant difference exists between the accuracy of maps generated by visual interpretation of color aerial photography with a resolution of 1 meter per pixel and IKONOS satellite imagery with a resolution of 4 meter pixel size. When examining the detailed habitat data the common error patterns can be identified by examination of incorrect calls (Tables 9 thru 20).

Reduced accuracy at the detailed level of the classification scheme only impacts the major habitat accuracy if the erroneous call is in a different major class. Many of the common errors in this data set occur at the modifier (percent cover) level of the classification scheme. In Table 14, 30 of 84 10%-<50% macroalgae field assessments were interpreted as 50%-<90% macroalgae. This misinterpretation of percent cover contributed lowered accuracy at the detailed level but does not impact the accuracy report of the major classes.

An error that impacts the accuracy of the major classifications is illustrated in Table 13 where 16 of 29 10-<50% macroalgae field assessment are interpreted as uncolonized pavement. In this error, the major habitat class of Submerged Aquatic Vegetation is misinterpreted as Coral Reef and Hard Bottom. This was the most common error that contributed reduced accuracy at the major habitat level. This type of error is complex. While confusing 10-<50% macroalgae and uncolonized pavement impacts the accuracy of major classes, it is actually a modifier error. The determining factor in the decision of which of these classes to use is the percent cover of macroalgae. If the algal cover is less than 10% then the area is attributed as uncolonized pavement. If the algal cover is greater than 10% it is attributed as 10%-<50% macroalgae. Thus, modifier error can impact the accuracy of the major classes.

When considering all of the incorrect classifications made in each imagery type, it becomes apparent that confusion between macroalgae and uncolonized pavement constitutes the majority of the error. In the color aerial photography maps, 46.6% of the error was due to this source. In the hyperspectral maps 52.7% and in the IKONOS maps 61.0% of all the error was associated with these two habitats.

It is important to recognize that some macroalgae species are ephemeral. Seasonal algal density varies due to water motion, nutrient and light level, grazing intensity and other factors. Substrate that may be heavily populated by fleshy macroalgae during low wave periods may be nearly devoid of algal cover after severe storms. This transient nature can result in field assessment that inaccurately reflects the dominant habitat that was in place when the imagery was collected. While field assessment can not always be conducted at the same time imagery is collected this variable should be minimized as much as possible.

It is also recognized that each test area was digitized using each of the three image types resulting in repetitive photointerpretation of the same area. The possibility of introduction of bias due to increased familiarity from this repeated exposure has been considered and precautions taken to minimize any effect. First, the order of image type from which maps were prepared proceeded from the lowest resolution, IKONOS satellite imagery, to the highest resolution, color aerial photography. This minimized the exposure of the interpreter to being influenced by having seen imagery that may have been "learned". Also, this bias was minimized, as little "learning" was possible since the interpreter was reasonable familiar with the test areas prior to any exposure to imagery. Further more, independent of "learning" the features of a test area, the interpreter can only delineate features that can be identified in the scene. Thus, it is the interpreter's opinion that, while familiarity with the test area does improve accuracy of the mapped product, these test results were biased very little.

Other errors that contributed to the loss of accuracy at the detailed level include the loss of feature recognition at lower image resolution. Incorrect classification of geophysical features such as sand channels does not impact the major classes. The reduced accuracy of the maps generated from photointerpretation of IKONOS imagery was primarily a result of ability to resolve texture. Thirteen of 16 field assessments of "artificial" were delineated as "land" in the Kaneohe Bay IKONOS data. This low accuracy resulted from not being able to distinguish shore-hardened areas. These long narrow features are not clearly identifiable when viewing imagery of 4 meter pixel resolution.

The work conducted here was not designed to analyze the difference in map accuracy based on pixel size independent of color of an image or vise versa. While the two are statistically inseparable in this work, extensive exposure to these data led the photointerpreter to observations that may be noteworthy. Both image color and pixel size has been carefully observed during this work.

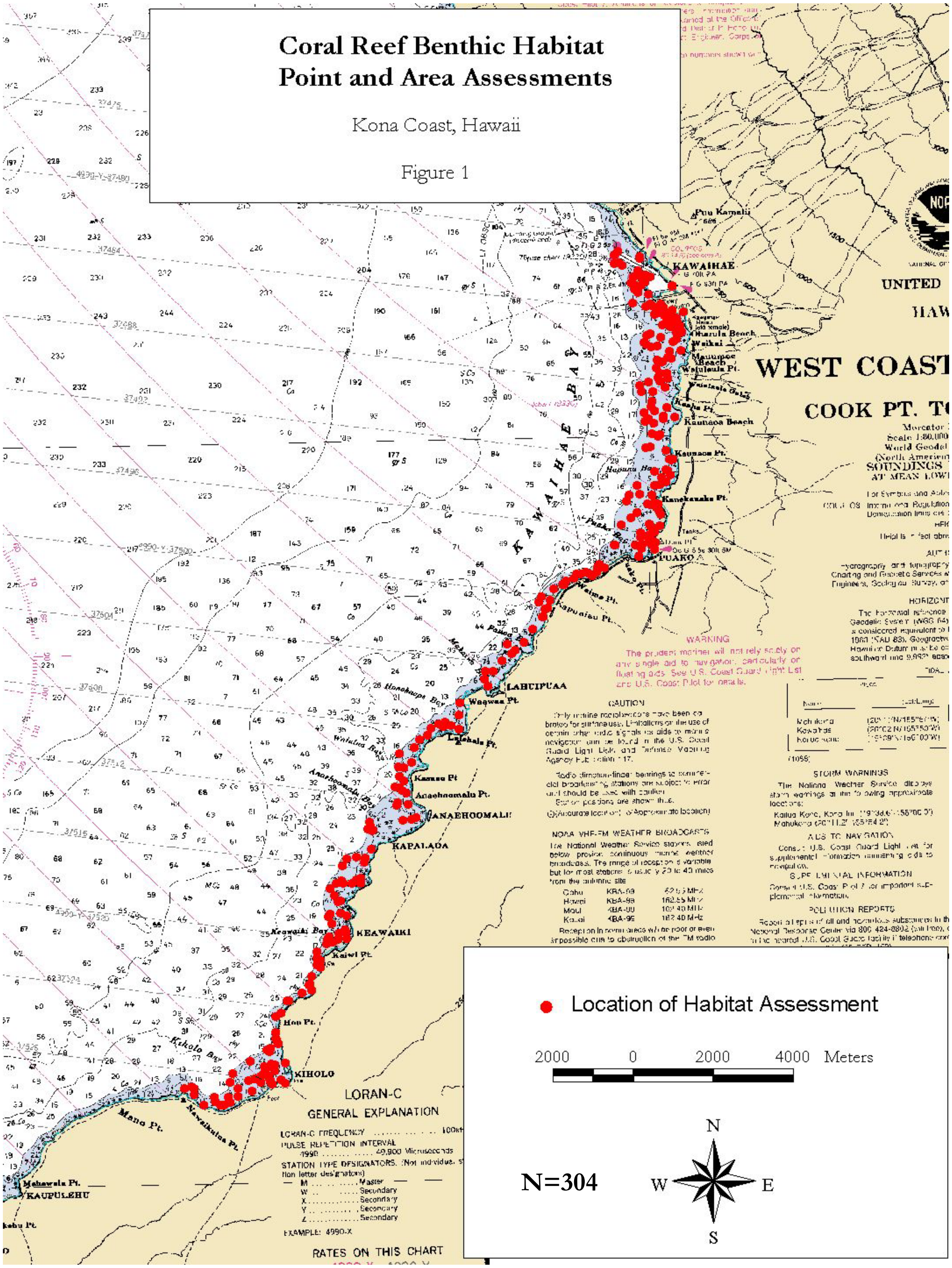
In general, it may be stated that pixel size impacts the ability to interpret features in an image more than color when an image is displayed in true color. However, without recognizing that manipulation of the large number of bands in a hyperspectral image and optimizing bandwidth in a multispectral image introduces some compensation for the lower resolution, very important observations would be overlooked. The imagery types used in this work have been optimized to maximize true color and during the map preparation the color has been strategically manipulated to extract the most habitat information. Specific bands combinations have been selected that enhance feature detection in shallow and deep water using hyperspectral imagery. The IKONOS satellite imagery has been provided to the contractor preprocessed to remove atmospheric effects and compensated for water column effects. Though not scientifically tested here, it is believed that if this work had addressed variable pixel size within the same imagery source, the statistical differences between the accuracy of these maps would have been much more significant. These spectral enhancements have resulted in considerable compensation for the reduced resolution due to pixel size.

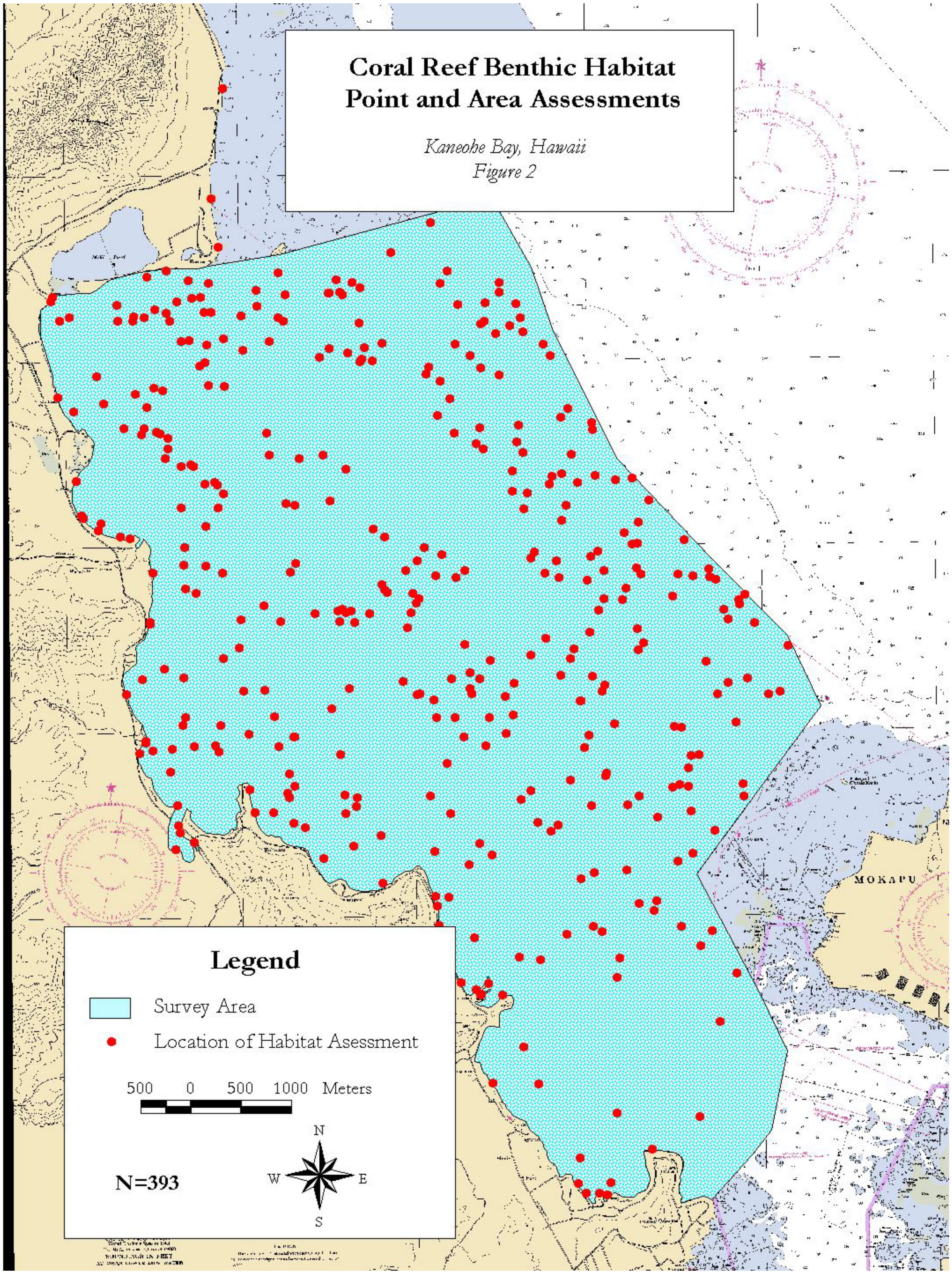
While it may be intuitive that smaller pixel size improves resolution and higher accuracy of the mapped product results, it may be less obvious that the relationship is not a function of the linear dimension of the pixel but of the area of the pixel. The 1 meter color aerial photography may be 16 times more resolved than the 4 meter IKONOS imagery. Although the linear pixel size of the hyperspectral imagery is only slightly different than the IKONOS satellite imagery, the area of the pixel differs by nearly 50%. Taken in this context the conclusion that accuracy of the maps produced from 1 meter pixel data were significantly more accurate than the maps generated from 4 meter pixel data when applying a 95% confidence interval comes as no surprise. However, the results show that when applying a 90% confidence interval there are no significant differences between the accuracy of any of the maps. Thus, it appears that the ability to generate coral reef habitat maps with an overall accuracy of 90% at a 95% confidence interval is reaching a threshold using imagery with 3 meter pixel size allowing for spectral enhancement of the imagery with reduced resolution.

Increasing the intensity of field observation can compensate for this decrease. Habitat maps prepared from IKONOS satellite imagery should be accompanied by field observations wherever possible and if field observations are not feasible, accuracy standards should be assigned accordingly.

VI. Conclusion

The ability of a photointerpreter to extract coral reef habitat information that meets the major habitat classes of the NOAA Classification Scheme for Benthic Habitats of the Main Eight Hawaiian Islands, applying visual interpretation of remotely sensed imagery, is reaching a threshold at a resolution of a 3 meter pixel. IKONOS satellite imagery with a 4 meter pixel can be interpreted to an overall major habitat accuracy of 90% if the interpreter has adequate field knowledge of the coral reef area being mapped and targets ground validation investigations where detailed habitat decisions impact the accuracy of major habitat classification.


Coral Reef Benthic Habitat
Point and Area Assessments
Kona Coast, Hawaii
Figure 1
Location of Habitat Assessment
2000 0 2000 4000 Meters
N
W
E
S
N=304
WEST COAST
COOK PT. T
KAWAIHAE
PUAKO
LAHUIPUAA
ANAEHOOMALU
KAPALAOA
KEAWAIKI
KIHOLO
KAUPULEHU
LORAN-C
GENERAL EXPLANATION
RATES ON THIS CHART


Coral Reef Benthic Habitat
Point and Area Assessments
Kaneohe Bay, Hawaii
Figure 2
MOKAPU
Legend
Survey Area
Location of Habitat Asessment
500 0 500 1000 Meters
N
W
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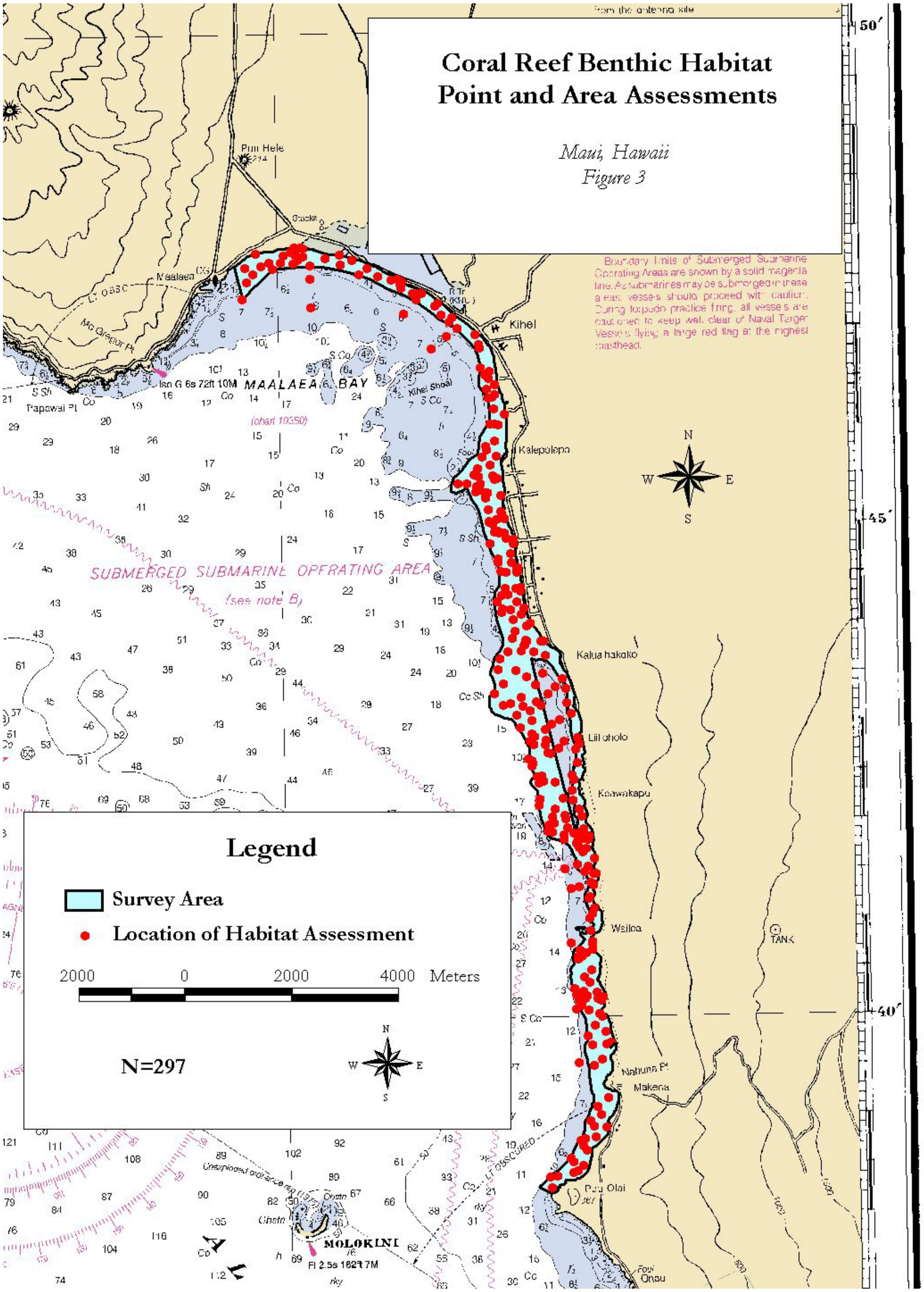
N=393


Coral Reef Benthic Habitat
Point and Area Assessments
Maui, Hawaii
Figure 3
Legend
Survey Area
Location of Habitat Assessment
2000 0 2000 4000 Meters
N=297
MAALAEA BAY
SUBMERGED SUBMARINE OPERATING AREA
Kihei
Kalepolepo
Kalua hakoko
Makena
MOLOKINI

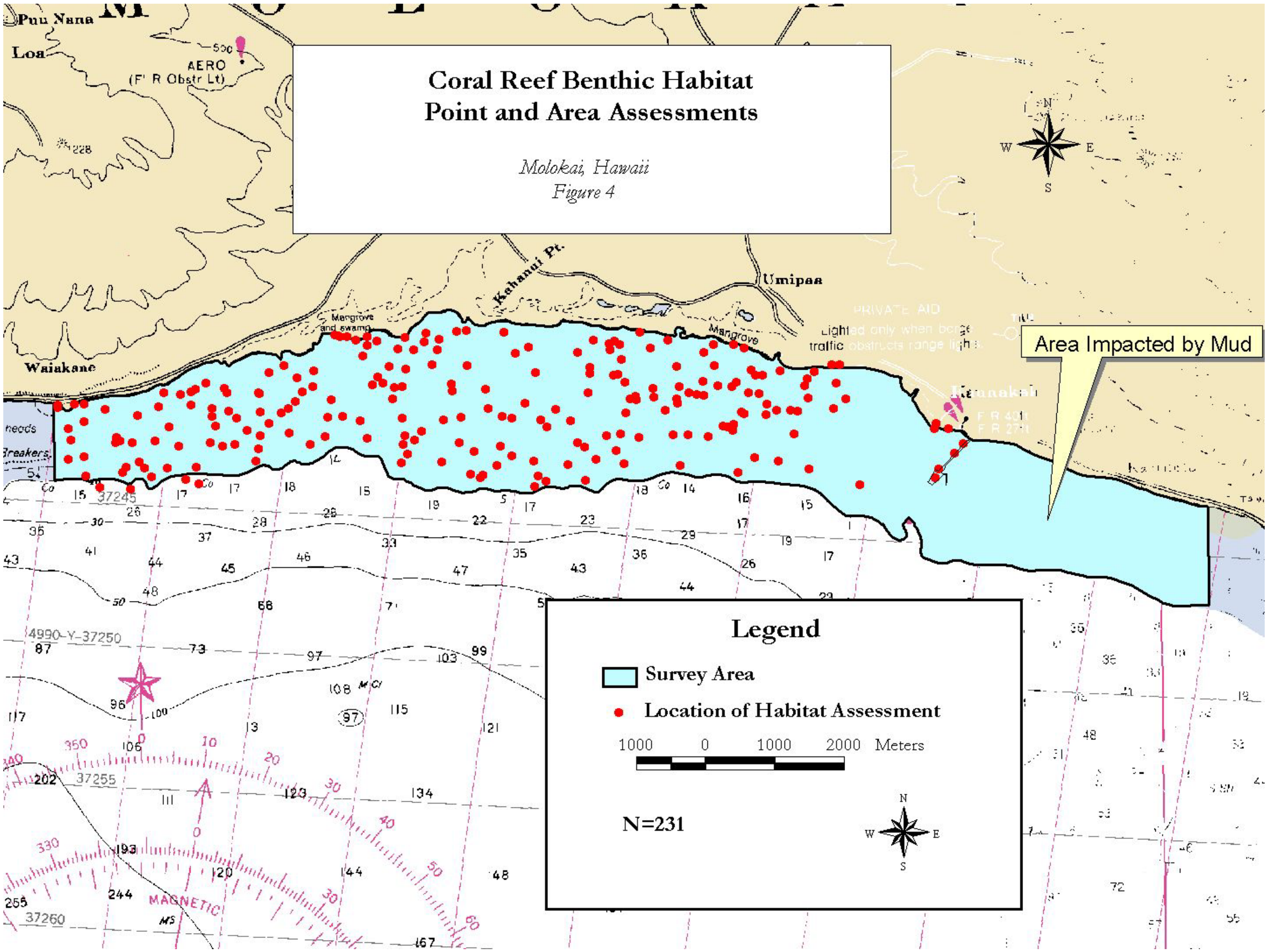

Coral Reef Benthic Habitat
Point and Area Assessments
Molokai, Hawaii
Figure 4
Area Impacted by Mud
Legend
Survey Area
Location of Habitat Assessment
1000 0 1000 2000 Meters
N=231
Kahanui Pt.
Umipaa
Waiakane
Puu Nana
Loa
AERO
(F R Obstr Lt)
Mangrove
MAGNETIC

Table 1. Data collected at each random site during benthic habitat classification surveys

Site Data	Habitat Data
Study Area	Point Habitat Type (0.5 meter radius)
Site ID	Area 1 Habitat Type (7 meter radius)
GPS Date	Area 2 Habitat Type (7 meter radius)
GPS Time	Dominant Coral Species
GPS Position	Dominant SAV Species
GPS Statistics	Estimated Live Coral Cover
Depth	Estimated SAV Cover
Photo Information	Area Description
Assessment Methods	

Table 2. Summary of major and detailed habitat types encountered during field surveys at each test area

Habitat Type (Major Habitats in Bold Face Type)	Kona	KBay	Maui	Molokai
			Survey Area	
Unconsolidated Sediment	**100**	**104**	**136**	**54**
Sand	98	47	136	51
Mud	3	51		3
Submerged Aquatic Vegetation	**4**	**83**	**55**	**48**
ContinuousSeagrass (10%-<50%)	3	4		
Patchy Seagrass (50%-<90%)	1			
Patchy Seagrass (90%-100%)				
Continuous Macroalgae (10%-<50%)		62	35	39
Patchy Macroalgae (50%-<90%)		9	18	9
Patchy Macroalgae (90%-100%)		3	2	
Coral Reef and Hardbottom	**185**	**181**	**106**	**101**
Linear Reef				
Spur and Groove	5			1
Patch Reef (Individual)		6		
Patch Reef (Aggregated)				
Scattered C/R in Unconsol. Sed.	5	10		12
Aggregated Coral	67	20	49	48
Colonized Pavement	11	27	12	12
Col. Volcanic Rock/Boulder	54		20	
Col. Pav. With Sand Chan.	1	35		
Reef Rubble	5	2	1	3
Uncol. Pavement		56	18	19
Uncol. Volcanic Rock/Boulder	18	5	6	
Uncol. Pavement w/Sand Chan.		7		
Continuous Coralline Algae (10%-<50%)	9	14		4
Patchy Coralline Algae (50%-<90%)	7			
Patchy Coralline Algae (90%-100%)	1			
Other Delineations	**14**	**25**	**0**	**28**
Emergent Vegetation		8		22
Artificial	14	17		6

Table 3. Users and producers accuracy of coral reef habitat map products generated from photointerpretation of major coral reef habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Kona test area

KONA TEST SITE	accuracy	color	IKONOS	HSI
Unconsolidated Sediment	user	98.11%	81.67%	100.00%
	producer	86.67%	85.96%	83.33%
Submerged Aquatic Vegetation	user	NA	NA	NA
	producer	NA	NA	NA
Coral Reef and Hard Bottom	user	92.59%	92.20%	90.24%
	producer	95.69%	91.36%	94.87%
Other Delineations	user	100.00%	100.00%	100.00%
	producer	100.00%	90.00%	100.00%
Over all	**overall**	93.91%	90.24%	92.40%
	Kappa	0.89	0.82	0.86
	Tau	0.89	0.83	0.87
95% Confidence Limits	**lower**	91.90%	87.99%	90.18%
	upper	94.72%	91.44%	93.39%

Table 4. Users and producers accuracy of coral reef habitat map products generated from photointerpretation of major coral reef habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Kaneohe Bay test area

KANEOHE BAY TEST SITE	accuracy	color	IKONOS	HSI
Unconsolidated Sediment	user	82.50%	86.00%	96.15%
	producer	86.84%	91.49%	96.15%
Submerged Aquatic Vegetation	user	82.50%	80.20%	75.58%
	producer	86.84%	86.17%	89.04%
Coral Reef and Hard Bottom	user	83.92%	75.27%	88.42%
	producer	78.43%	66.67%	77.78%
Other Delineations	user	100.00%	95.00%	100.00%
	producer	90.00%	90.48%	100.00%
Over all	**overall**	86.02%	81.53%	86.99%
	Kappa	0.81	0.76	0.83
	Tau	0.82	0.77	0.83
95% Confidence Limits	**lower**	83.72%	78.99%	84.45%
	upper	87.49%	83.31%	88.49%

Table 5. Users and producers accuracy of coral reef habitat map products generated from photointerpretation of major coral reef habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Maui test area

MAUI TEST SITE	accuracy	color	IKONOS	HSI
Unconsolidated Sediment	user	95.73%	93.14%	92.93%
	producer	93.33%	90.48%	90.20%
Submerged Aquatic Vegetation	user	89.83%	89.29%	84.75%
	producer	91.38%	92.59%	89.29%
Coral Reef and Hard Bottom	user	85.45%	82.35%	85.98%
	producer	87.04%	83.17%	85.98%
Other Delineations	user	NA	100.00%	100.00%
	producer	NA	100.00%	100.00%
Over all	**overall**	90.56%	88.12%	88.35%
	Kappa	0.86	0.83	0.83
	Tau	0.87	0.84	0.84
95% Confidence Limits	**lower**	0.88	0.86	0.86
	upper	0.92	0.90	0.90

Table 6. Users and producers accuracy of coral reef habitat map products generated from photointerpretation of major coral reef habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Molokai test area

MOLOKAI TEST SITE	accuracy	color	IKONOS	HSI
Unconsolidated Sediment	user	95.24%	91.84%	86.44%
	producer	93.02%	95.74%	91.07%
Submerged Aquatic Vegetation	user	91.07%	80.77%	81.13%
	producer	91.07%	84.00%	89.58%
Coral Reef and Hard Bottom	user	93.41%	83.75%	89.87%
	producer	94.44%	79.76%	81.61%
Other Delineations	user	100.00%	100.00%	100.00%
	producer	100.00%	100.00%	100.00%
Over all	**overall**	94.04%	86.89%	88.02%
	Kappa	0.92	0.83	0.84
	Tau	0.92	0.84	0.85
95% Confidence Limits	**lower**	91.70%	83.91%	85.20%
	upper	94.85%	88.52%	89.52%

Table 7. Users and producers accuracy of coral reef habitat map products generated from photointerpretation of major coral reef habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for all test areas combined

ALL TEST SITES	accuracy	color	IKONOS	HSI
Unconsolidated Sediment	user	94.19%	88.42%	93.71%
	producer	92.41%	90.76%	90.54%
Submerged Aquatic Vegetation	user	87.18%	82.78%	79.80%
	producer	90.43%	87.37%	89.27%
Coral Reef and Hard Bottom	user	89.27%	85.60%	88.89%
	producer	89.27%	82.75%	86.92%
Other Delineations	user	100.00%	98.18%	100.00%
	producer	97.96%	94.74%	100.00%
Over all	**overall**	90.74%	86.52%	88.97%
	Kappa	0.87	0.82	0.85
	Tau	0.87	0.83	0.85
95% Confidence Limits	**lower**	89.73%	85.35%	87.84%
	upper	91.46%	87.43%	89.80%

Table 8. Summary of the probability that photointerpretation of coral reef habitat from color aerial photography, hyperspectral and IKONOS Satellite imagery are equivalent: P = 0.05 or less with significant difference highlighted

	Image Type	color	IKONOS	HSI
MAUI	**color**		0.999012	-0.61662
	IKONOS			-0.08237
	HSI			
MOLOKAI	**color**		2.621557	-2.37355
	IKONOS			-0.29216
	HSI			
KBay	**color**		1.567347	-0.3975
	IKONOS			-1.89231
	HSI			
Kona	**color**		2.012551	0.80843
	IKONOS			-1.17298
	HSI			
OVERALL	**COLOR**		-3.07086	1.42364
	IKONOS			-1.59611
	HSI			

Significant difference based on z statistic

Table 9. Accuracy if photointerpretation of detailed coral reef habitats using color aerial photography of the Kona test area

Color - Kona Detailed Habitats

POLYGON ATTRIBUTE	FIELD ASSESSMENT														
	AgCr	Artf	ColBa	ColPv	ColPvSC	HCorAl	SCRUS	LCorAl	MCorAl	Mud	SAND	SnG	UnColBa	**Row Totals**	**User's Accuracy**
AgCr	**82**		16	4					1		4			**107**	**77%**
Artf		**10**												**10**	**100%**
ColBa	2		**50**				2				3		2	**59**	**85%**
ColPv				**0**										**0**	**NA**
ColPvSC	1				**1**									**2**	**50%**
HCorAl						**0**								**0**	**NA**
SCRUS							**0**							**0**	**NA**
LCorAl	1							**1**	1					**3**	**33%**
MCorAl						2		1	**5**					**8**	**63%**
Mud										**1**				**1**	**100%**
SAND	1										**51**			**52**	**98%**
SnG												**11**		**11**	**100%**
UnColBa			4								1		**21**	**26**	**81%**
Column Totals	**87**	**10**	**70**	**4**	**1**	**2**	**2**	**2**	**7**	**1**	**59**	**11**	**23**	**279**	
Producer's Accuracy	**94%**	**100%**	**71%**	**0%**	**100%**	**0%**	**0%**	**50%**	**71%**	**100%**	**86%**	**100%**	**91%**		

Detailed Overall Accuracy **83.5%**

Table 10. Accuracy of photointerpretation of detailed coral reef habitats using hyperspectral imagery of the Kona test area

Hyperspectral - Kona Detailed Habitats

		FIELD ASSESSMENT													Row Totals	User's Accuracy
		AgCr	ColBa	ColPv	ColPvSC	SCRUS	SandG	HCorAl	MCorAl	LCorAl	SAND	Mud	UnColBa	Artf		
POLYGON ATTRIBUTE	AgCr	**72**	8	4		2			1	1	4				**92**	**78%**
	ColBa	6	**59**								4		2		**71**	**83%**
	ColPv			**0**											**0**	**NA**
	ColPvSC	1			**1**						1				**3**	**33%**
	SCRUS					**0**									**0**	**NA**
	SandG						**1**								**1**	**100%**
	HCorAl							**0**	2						**2**	**0%**
	MCorAl	1						3	**1**	1					**6**	**17%**
	LCorAl	1							2	**1**					**4**	**25%**
	SAND										**49**				**49**	**100%**
	Mud											**1**			**1**	**100%**
	UnColBa		4								1		**21**		**26**	**81%**
	Artf													**8**	**8**	**100%**
Column Totals		**81**	**71**	**4**	**1**	**2**	**1**	**3**	**6**	**3**	**59**	**1**	**23**	**8**	**263**	
Producer's Accuracy		**89%**	**83%**	**0%**	**100%**	**0%**	**100%**	**0%**	**17%**	**33%**	**83%**	**100%**	**91%**	**100%**		

Detailed Overall Accuracy **81.4%**

Table 11. Accuracy of photointerpretation of detailed coral reef habitats using IKONOS Satellite imagery of the Kona test area

IKONOS - Kona Detailed Habitats

POLYGON ATTRIBUTE	FIELD ASSESSMENT														Row Totals	User's Accuracy
	AgCr	Artf	ColBa	ColPvSC	ColPv	HCorAl	LCorAl	RR	MCorAl	Mud	SAND	SnG	SCRUS	UnColBa		
AgCr	**76**		2	1	7						3		2		**91**	**84%**
Artf		**9**													**9**	**100%**
ColBa	3		**57**		2						1		1	2	**66**	**86%**
ColPvSC	1		2	**2**											**5**	**40%**
ColPv					**2**										**2**	**100%**
HCorAl						**0**									**0**	**NA**
LCorAl	1						**0**								**1**	**0%**
RR								**0**							**0**	**NA**
MCorAl						2	3		**6**						**11**	**55%**
Mud	1									**3**	1				**5**	**60%**
SAND	7	1						1			**45**	1			**55**	**82%**
SnG	1				2		1		1			**10**			**15**	**67%**
SCRUS											1		**0**		**1**	**0%**
UnColBa			3						1		3			**19**	**26**	**73%**
Column Totals	**90**	**10**	**64**	**3**	**13**	**2**	**4**	**1**	**8**	**3**	**54**	**11**	**3**	**21**	**287**	
Producer's Accuracy	**84%**	**90%**	**89%**	**67%**	**15%**	**0%**	**0%**	**0%**	**75%**	**100%**	**83%**	**91%**	**0%**	**90%**		

Detailed Overall Accuracy 79.8%

Table 12. Accuracy of photointerpretation of detailed coral reef habitats using color aerial photography of the Kaneohe Bay test area

Color - Kaneohe Bay Detailed Habitats

POLYGON ATTRIBUTE	FIELD ASSESSMENT															Row Totals	User's Accuracy
	AgCr	Artf	ColPv	ColPvSC	HMacAl	InPtRf	LCorAl	LMacAl	LSeaGr	MMacAl	Mud	RR	SAND	UnColPv	UnColPvSC		
AgCr	**5**															**5**	**100%**
Artf		**9**														**9**	**100%**
ColPv			**11**							1				8		**20**	**55%**
ColPvSC			13	**51**										1	3	**68**	**75%**
HMacAl					**1**											**1**	**100%**
InPtRf						**14**										**14**	**100%**
LCorAl							**5**									**5**	**100%**
LMacAl								**37**		1			1	10		**49**	**76%**
LSeaGr									**0**							**0**	**NA**
MMacAl					1			19		**6**				3		**29**	**21%**
Mud	1	1			1		1		1		**62**		1			**68**	**91%**
RR								1				**0**	1			**2**	**0%**
SAND							1	1	2		1		**24**	1		**30**	**80%**
UnColPv	3			1				4				1		**18**		**27**	**67%**
UnColPvSC															**2**	**2**	**100%**
Column Totals	**9**	**10**	**24**	**52**	**3**	**14**	**7**	**62**	**3**	**8**	**63**	**1**	**27**	**41**	**5**	**329**	
Producer's Accuracy	**56%**	**90%**	**46%**	**98%**	**33%**	**100%**	**71%**	**60%**	**0%**	**75%**	**98%**	**0%**	**89%**	**44%**	**40%**		

Detailed Overall Accuracy 74.5%

Table 13. Accuracy of photointerpretation of detailed coral reef habitats using hyperspectral imagery of the Kaneohe Bay test area

Hyperspectral - KBay Detailed Habitats

	FIELD ASSESSMENT															Row	User's
POLYGON ATTRIBUTES	AgCr	Artf	ColPv	ColPvSC	HMacAl	InPtRf	LCorAl	LMacAl	LSeaGr	MMacAl	Mud	SAND	UnColBa	UnColPv	UnColPvSC	Totals	Accuracy
AgCr	**4**							1		1						**6**	**67%**
Artf		**8**														**8**	**100%**
ColPv			**4**													**4**	**100%**
ColPvSC			14	**30**										1		**45**	**67%**
HMacAl		1			**1**											**2**	**50%**
InPtRf						**14**										**14**	**100%**
LCorAl							**6**									**6**	**100%**
LMacAl			1					**45**	1	1		3		16		**67**	**67%**
LSeaGr									**0**							**0**	**NA**
MMacAl								13		**4**				1		**18**	**22%**
Mud							1				**57**	1				**59**	**97%**
SAND									1			**17**		1		**19**	**89%**
UnColBa													**1**			**1**	**100%**
UnColPv			1	1				4		1				**10**		**17**	**59%**
UnColPvSC															**3**	**3**	**100%**
Column Totals	**4**	**9**	**20**	**31**	**1**	**14**	**7**	**63**	**2**	**7**	**57**	**21**	**1**	**29**	**3**	**269**	
Producer's Accuracy	**100%**	**89%**	**20%**	**97%**	**100%**	**100%**	**86%**	**71%**	**0%**	**57%**	**100%**	**81%**	**100%**	**34%**	**100%**		

Detailed Overall Accuracy 75.8%

Table 14. Accuracy of photointerpretation of detailed coral reef habitats using IKONOS Satellite imagery of the Kaneohe Bay test area

IKONOS - KBay Detailed Habitats

		FIELD ASSESSMENT																Row Totals	User's Accuracy
		AgCr	Artf	ColPv	ColPvSC	EmgVg	HMacAl	InPtRf	LCorAl	LMacAl	MMacAl	Land	Mud	RR	SAND	UnColPv	UnColPvSC		
POLYGON ATTRIBUTES	AgCr	**7**																**7**	**100%**
	Artf		**3**															**3**	**100%**
	ColPv	1		**3**	4					2					1			**11**	**27%**
	ColPvSC				**2**											1	2	**5**	**40%**
	EmgVg					**2**												**2**	**100%**
	HMacAl						**0**											**0**	**NA**
	InPtRf							**16**										**16**	**100%**
	LCorAl								**2**	1								**3**	**67%**
	LMacAl	4							2	**42**	4			1	3	5		**61**	**69%**
	MMacAl	2					1		2	30	**4**				1			**40**	**10%**
	Land		13			1						**0**	1					**15**	**0%**
	Mud	1				2	1						**56**	2	2			**64**	**88%**
	RR													**0**				**0**	**NA**
	SAND	1								7					**28**			**36**	**78%**
	UnColPv			4	3					2					2	**34**	1	**46**	**74%**
	UnColPvSC				5												**0**	**5**	**0%**
Column Totals		**16**	**16**	**7**	**14**	**5**	**2**	**16**	**6**	**84**	**8**	**0**	**57**	**3**	**37**	**40**	**3**	**314**	
Producer's Accuracy		**44%**	**19%**	**43%**	**14%**	**40%**	**0%**	**100%**	**33%**	**50%**	**50%**	**NA**	**98%**	**0%**	**76%**	**85%**	**0%**		

Detailed Overall Accuracy 63.38%

Table 15. Accuracy of photointerpretation of detailed coral reef habitats using color aerial photography of the Maui test area

Color- Maui Detailed Habitats

	FIELD ASSESSMENT											Row Totals	User's Accuracy
POLYGON ATTRIBUTE	AgCr	ColBa	ColPv	UnColBa	HMacAl	LMacAl	SCRUS	MMacAl	RR	SAND	UnColPv		
AgCr	**44**	2	7			1			1	1	3	**59**	**75%**
ColBa	2	**18**		3						1		**24**	**75%**
ColPv	3	1	**5**			1					2	**12**	**42%**
UnColBa				**0**								**0**	**NA**
HMacAl					**1**							**1**	**100%**
LMacAl						**29**		8		2	2	**41**	**71%**
SCRUS							**1**					**1**	**100%**
MMacAl	1				1	4		**10**				**16**	**63%**
RR									**0**			**0**	**NA**
SAND	3					4				**112**	1	**120**	**93%**
UnColPv				2						1	**9**	**12**	**75%**
Column Totals	**53**	**21**	**12**	**5**	**2**	**39**	**1**	**18**	**1**	**117**	**17**	**286**	
Producer's Accuracy	**83%**	**86%**	**42%**	**0%**	**50%**	**74%**	**100%**	**56%**	**0%**	**96%**	**53%**		

Detailed Overall Accuracy 80.1%

Table 16. Accuracy of photointerpretation of detailed coral reef habitats using hyperspectral imagery of the Maui test area

Hyperspectral - Maui Detailed Habitats

		FIELD ASSESSMENT											**Row**	**User's**
		AgCr	ColBa	ColPv	UnColBa	HMacAl	LMacAl	MMacAl	RR	SAND	Artf	UnColPv	**Totals**	**Accuracy**
POLYGON ATTRIBUTE	AgCr	**44**		3			1			2			**50**	**88%**
	ColBa	2	**15**		1					1			**19**	**79%**
	ColPv	2	5	**9**			2			3		3	**24**	**38%**
	UnColBa				**0**								**0**	**NA**
	HMacAl					**2**		1					**3**	**67%**
	LMacAl						**28**	6	1	3		3	**41**	**68%**
	MMacAl					4		**9**		1		1	**15**	**60%**
	RR								**0**				**0**	**NA**
	SAND	2			1			1		**92**		3	**99**	**93%**
	Artf										**1**		**1**	**100%**
	UnColPv				2		1	1				**10**	**14**	**71%**
Column Totals		**50**	**20**	**12**	**4**	**6**	**32**	**18**	**1**	**102**	**1**	**20**	**266**	
Producer's Accuracy		**88%**	**75%**	**75%**	**0%**	**33%**	**88%**	**50%**	**0%**	**90%**	**100%**	**50%**		

Detailed Overall Accuracy 78.9%

Table 17. Accuracy of photointerpretation of detailed coral reef habitats using IKONOS Satellite imagery of the Maui test area

IKONOS - Maui Detailed Habitats

POLYGON ATTRIBUTE	FIELD ASSESSMENT												Row	User's
	AgCr	ColBa	ColPv	UnColBa	HMacAl	Land	LMacAl	SCRUS	MMacAl	RR	SAND	UnColPv	Totals	Accuracy
AgCr	**49**	5	1				1					1	**57**	**86%**
ColBa	1	**9**		2									**12**	**75%**
ColPv	2	2	**5**	2			1				1	1	**14**	**36%**
UnColBa		1		**0**									**1**	**0%**
HMacAl					**0**				1				**1**	**0%**
Land						**1**							**1**	**100%**
LMacAl					1		**26**		8	1	4	1	**41**	**63%**
SCRUS								**0**					**0**	**NA**
MMacAl					1		6		**7**				**14**	**50%**
RR										**0**			**0**	**NA**
SAND	2	1	1				1	1			**95**	1	**102**	**93%**
UnColPv			2				1				5	**10**	**18**	**56%**
Column Totals	**54**	**18**	**9**	**4**	**2**	**1**	**36**	**1**	**16**	**1**	**105**	**14**	**261**	
Producer's Accuracy	**91%**	**50%**	**56%**	**0%**	**0%**	**100%**	**72%**	**0%**	**44%**	**0%**	**90%**	**71%**		

Detailed Overall Accuracy **77.4%**

Table 18. Accuracy of photointerpretation of detailed coral reef habitats using color aerial photography of the Molokai test area

COLOR - Molokai Detailed Habitats

		FIELD ASSESSMENT														Row	User's
		AgCr	SnG	ColPv	Artf	LCorAl	LMacAl	SCRUS	MMacAl	EmgVg	Mud	RR	SAND	LinReef	UnColPv	Totals	Accuracy
POLYGON ATTRIBUTE	AgCr	**27**	1										2			**30**	**90%**
	SnG		**0**													**0**	**NA**
	ColPv	2		**1**												**3**	**33%**
	Artf				**7**											**7**	**100%**
	LCorAl			1		**0**	1									**2**	**0%**
	LMacAl						**38**		4				2		1	**45**	**84%**
	SCRUS							**10**							1	**11**	**91%**
	MMacAl			1			4		**5**				1			**11**	**45%**
	EmgVg									**21**						**21**	**100%**
	Mud										**1**					**1**	**100%**
	RR											**1**				**1**	**100%**
	SAND						2				1		**38**			**41**	**93%**
	LinReef													**37**		**37**	**100%**
	UnColPv							1							**6**	**7**	**86%**
Column Totals		**29**	**1**	**3**	**7**	**0**	**45**	**11**	**9**	**21**	**2**	**1**	**43**	**37**	**8**	**217**	
Producer's Accuracy		**93%**	**0%**	**33%**	**100%**	**NA**	**84%**	**91%**	**56%**	**100%**	**50%**	**100%**	**88%**	**100%**	**75%**		

Detailed Overall Accuracy **88.48%**

Table 19. Accuracy of photointerpretation of detailed coral reef habitats using hyperspectral imagery of the Molokai test area

Hyperspectral- Molokai Detailed Habitats

		FIELD ASSESSMENT														**Row Totals**	**User's Accuracy**
		AgCr	SnG	ColPv	Artf	LCorAl	LMacAl	SCRUS	MMacAl	EmgVg	Mud	RR	SAND	LinReef	UnColPv		
POLYGON ATTRIBUTE	AgCr	**34**		5		1										**40**	**85%**
	SnG		**1**													**1**	**100%**
	ColPv	1		**2**			1	2							2	**8**	**25%**
	Artf				**5**											**5**	**100%**
	LCorAl					**0**										**0**	**NA**
	LMacAl						**25**		2			2	3		1	**33**	**76%**
	SCRUS					1	1	**8**					1		1	**12**	**67%**
	MMacAl			1			10		**6**				1		2	**20**	**30%**
	EmgVg									**21**						**21**	**100%**
	Mud										**2**					**2**	**100%**
	RR											**1**				**1**	**100%**
	SAND	2		1			2		1		1		**48**		2	**57**	**84%**
	LinReef													**6**		**6**	**100%**
	UnColPv					2									**9**	**11**	**82%**
Column Totals		**37**	**1**	**9**	**5**	**4**	**39**	**10**	**9**	**21**	**3**	**3**	**53**	**6**	**17**	**217**	
Producer's Accuracy		**92%**	**100%**	**22%**	**100%**	**0%**	**64%**	**80%**	**67%**	**100%**	**67%**	**33%**	**91%**	**100%**	**53%**		

Detailed Overall Accuracy 77.4%

Table 20. Accuracy of photointerpretation of detailed coral reef habitats using IKONOS Satellite imagery of the Molokai test area

IKONOS - Molokai Detailed Habitats

POLYGON ATTRIBUE	FIELD ASSESSMENT															Row	User's
	AgCr	SnG	ColPv	HMacAl	Artf	LCorAl	LMacAl	SCRUS	MMacAl	EmgVeg	Mud	RR	SAND	LinReef	UnColPv	**Totals**	**Accuracy**
AgCr	**33**	1	3													**37**	**89%**
SnG		**0**														**0**	**NA**
ColPv	1		**1**												1	**3**	**33%**
HMacAl				**0**												**0**	**NA**
Artf					**5**											**5**	**100%**
LCorAl						**0**										**0**	**NA**
LMacAl	1		1	5			**31**	1				1	2		3	**45**	**69%**
SCRUS							3	**7**							1	**11**	**64%**
MMacAl				3					**3**						1	**7**	**43%**
EmgVeg										**20**						**20**	**100%**
Mud											**1**					**1**	**100%**
RR							1					**2**				**3**	**67%**
SAND	1						2	1			2		**42**			**48**	**88%**
LinReef														**7**		**7**	**100%**
UnColPv	1					1	2	3							**12**	**19**	**63%**
Column Totals	**37**	**1**	**5**	**8**	**5**	**1**	**39**	**12**	**3**	**20**	**3**	**3**	**44**	**7**	**18**	**206**	
Producer's Accuracy	**89%**	**0%**	**20%**	**0%**	**100%**	**0%**	**79%**	**58%**	**100%**	**100%**	**33%**	**67%**	**95%**	**100%**	**67%**		

Detailed Overall Accuracy 79.6%

Table 21. Summary of percent accuracy of all sites combined

TEST AREA	IMAGERY TYPE	ACCURACY STATISTICS			
		Major Habitats	Kappa	Tau	Detailed Habitats
Kona	Color	93.9%	0.89	0.89	83.5%
	Hyperspectral	92.4%	0.86	0.87	81.4%
	IKONOS	90.2%	0.82	0.83	80.0%
Kbay	Color	86.2%	0.81	0.82	74.5%
	Hyperspectral	87.0%	0.83	0.83	75.8%
	IKONOS	81.5%	0.76	0.77	63.4%
Maui	Color	90.5%	0.86	0.87	80.1%
	Hyperspectral	88.4%	0.83	0.86	78.9%
	IKONOS	88.1%	0.83	0.84	77.4%
Molokai	Color	94.0%	0.92	0.95	88.5%
	Hyperspectral	88.0%	0.84	0.85	77.4%
	IKONOS	86.9%	0.83	0.84	79.6%
All Areas Combined	Color	90.7%	0.87	0.87	80.8%
	Hyperspectral	89.0%	0.85	0.85	78.1%
	IKONOS	86.5%	0.82	0.83	74.1%

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