Image Interpretation and Development of Coral Reef Habitat Maps for the Main Hawaiian Islands

Project Completion Report

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Center for Coastal Monitoring and Assessment

1305 East-West Highway

Silver Spring, MD 20910

Prepared by:

Analytical Laboratories of Hawaii

1320 Aalapapa Dr.

Kailua, Hawaii 96734

Tel: (808) 262-2417

FAX: (808) 262-7027

e-mail: miles@interpac.net

General Excise Tax #: 30091234

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List of Acronyms

ALH	Analytical Laboratories of Hawaii
APTI	Applied Power Technologies, Inc.
CLIN	Contract Line Item Number
CORS	Continually Operating Reference System
CRAMP	Coral Reef Assessment and Monitoring Program
CSDGM	Content Standard for Digital Geospatial Meadata
DOQ	Digital Ortho Quarter Quadrangle
EPIRB	Emergency Position Indicating Radio Beacon
ESRI	Environmental Systems Research Institute
FGDC	Federal Geographic Data Committee
G&O	Greenhorn & O'Mara, Inc.
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
SOW	Scope of Work
USGS	United States Geological Service
UTM	Universe Transverse Mercator
WGS	World Geodetic System

1. Introduction and Background

NOAA's National Ocean Service (NOS) and National Geodetic Survey (NGS) have acquired color aerial photography and hyperspectral imagery (HSI) for the near shore waters 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.

A primary product of this effort is a benthic habitat map in geographic information system (GIS) format produced by visual interpretation of the remotely sensed image data. These benthic habitat mapping products have been generated by manual delineation of habitats from color aerial photographs, AURORA hyperspectral and IKONOS multispectral satellite digital imagery. In all cases, benthic features have been classified using a hierarchical Coral Reef Habitat Classification Scheme. The scheme has been prepared from consultation, meetings and workshops that included the key coral reef biologists, mapping experts and professionals in the State of Hawaii. The Coral Reef Habitat Classification Scheme that was developed by NOAA for the Florida Keys, Puerto Rico and US Virgin Islands was used as a starting point for this work. The joint mapping effort between ALH and NOS has enabled NOS to develop a rigorous scope of work for future benthic habitat mapping efforts in the US Pacific.

A comparison of the accuracy of benthic habitat maps in GIS format produced by visually interpreting the remotely sensed image data has been completed. In this work, important similarities and differences between the types of imagery tested are identified. Scientifically sound statistical comparisons of the benthic habitat maps are presented and conclusions are drawn that can be integrated into long term coral reef mapping objectives.

The results of this comparison have been integrated into the methods for routine production of benthic habitat maps and have been used to produce benthic habitat maps of all of the remotely sensed data collected during the year 2000 NOAA image acquisition mission.

2. Approach

2.1 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, mapping experts and professionals in the State of Hawaii. The Benthic Habitat Classification Scheme that was developed by NOAA for the Florida Keys, Puerto Rico and the US Virgin Islands was used as a starting point for this work. This classification scheme was influenced by many factors including but not limited to:

- Consultation with State, academic and private sector partners
- Requests of the management community
- NOS's coral reef mapping experiences
- Existing classification schemes for the Pacific and Hawaiian Islands and other coral reef ecosystems
- Quantitative habitat data for the Hawaiian Islands
- 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 classification scheme defines benthic communities based on two attributes: large geographic zones that are composed of smaller habitats. Zone refers to benthic community location and habitat refers only to substrate and/or cover type. 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 (e.g. man-made structures)

These have been subdivided to include a total of 28 habitats that comprise the detailed coral reef 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

2.2 Remotely Sensed Imagery

Three types of remotely sensed imagery were acquired by NOAA and provided to ALH. Color aerial photography and hyperspectral imagery (HSI) was collected by NOAA using instrumentation installed onboard the dual port NOAA AOC Citation II aircraft. These data were collected during the year 2000 NOAA remote sensing data acquisition mission in Hawaii. IKONOS satellite imagery was procured from Space Imaging, Inc. and processed by NOS.

Color aerial photography was scanned at pixel size of one meter (1 m^2) and provided to the contractor as either discrete or mosaiced orthorectified images in GeoTIFF format.

The hyperspectral image data were collected using the AURORA HSI data acquisition system provided by Applied Power Technologies, Inc. (APTI). Navigation data were incorporated using the Applanix inertial navigation system (INS). The imaging system collects 72 ten nm bands in the visible and near infrared spectral range with the pixel size at three meters (9 m^2). 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. Band combinations were selected which optimized benthic habitat information in shallow and deep water and the scenes were converted into RGB composites. The shallow band IDs and centers were configured as:

1) Band 17 at 508.319 nm
2) Band 22 at 547.918 nm
3) Band 27 at 605.516 nm

The deep band IDs and centers were configured as:

1) Band 11 at 450.001 nm
2) Band 22 at 547.918 nm
3) Band 33 at 663.835 nm

The scenes were then georeferenced to the appropriate UTM Zone WGS 84 datum and mosaiced using Scene Stitcher, a stand-alone software program produced by APTI.

The IKONOS satellite imagery was provided to ALH georeferenced and optimized to remove atmospheric and water column effects. These data were provided at a resolution of 4 meter (16 m^2) pixels.

2.3 Spatial Data Acquisition

Collection of new GPS data was needed to complete this work. Methods that accommodate levels of accuracy needed to meet the objectives of each task were used.

New GPS data was collected to facilitate ground control for calibration of airborne GPS used during acquisition of color aerial photography. A sub sample of these data were also used to establish the accuracy of the resulting orthorectified mosaiced color aerial photography that was included in the suite of remotely sensed imagery used during delineation of habitat boundaries.

GPS data was also acquired for accuracy assessment of the habitat maps and for ground validation used to investigate uncertainties on the photointerpreter's behalf during the decision making process of benthic habitat type. Accuracy assessment data were generated on a random stratified point analysis basis. Ground validation data were generated by selecting specific targets in areas where habitat type was not certain and needed to be examined in the field or where gradients through habitat type resulted in uncertain habitat boundaries.

2.4 Habitat Map Preparation

Traditional methods of stereoplotter digitizing of photointerpreted habitat classes have completely been replaced by computerized on screen digitizing methods. The latter method has distinct advantages.

- It eliminates the intermediate digitizing step reducing positional error of the habitat boundaries.
- Productivity is higher.
- It develops an active link between the mapped image and the associated database. Thus a Geographic Information System (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 (Section 3.2).

2.5 Habitat Map Accuracy Assessment

An accuracy assessment system was designed and executed to quantify the thematic accuracy of the maps generated from each type of remotely sensed imagery. These were then used to determine the significance of the differences between the accuracy of the maps. 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.

2.6 Safety

During all fieldwork, the team placed safety at maximum priority. A safety kit with first aid, spare floatation, emergency flares, drinking water and an emergency position indicating radio beacon (EPIRB) was included on each field mission. All fuel-powered vessels were compliant with US Coast Guard commercial vessel safety regulations.

3. Methods

3.1 Survey Methodologies used to Perform this Work

The tasks in this work required the acquisition of a significant amount of new GPS data. GPS acquisition methods were used that met the level of spatial accuracy needed to complete the task. Less than 1 meter at 95% Sigma Root Mean Square (RMS) horizontal error and 2 meter RMS vertical error was required for ground control positions that were needed for orthorectification of the color aerial photography. Less than 5 meter RMS horizontal error was needed for the accuracy assessment and benthic habitat characterizations positions and vertical data were not required. While positional accuracy of the ground validation data was the same as the accuracy assessment field data, the descriptive information was much more general as the purpose of the ground validation survey was to investigate areas in the imagery where interpretation of the habitat type was uncertain during the delineation of the first draft map (Section 3.1.2).

3.1.1 Reference Systems

All habitat characterization delivered to the Government during this project was provided to be geocentrically registered and within the World Geodetic System 1984 (WGS 84) Geoid model 99. Ground control positions were orthometrically corrected based on North American Vertical Datum of 1988 (NAVD 88). All ground control was tied to a continuously operating base station such as the NGS continuously operating reference system. All spatial data for all islands except the Island of Hawaii were projected in Universal Transverse Mercator (UTM) Zone 4 and data for the Island of Hawaii were projected in Universal Transverse Mercator (UTM) Zone 5.

3.1.2 Acquisition of GPS Data

Ground Control Positions

These GPS data were collected using the highest accuracy methods available to sub-survey quality GPS. For the purpose of this work, survey quality GPS technology was not necessary. Survey quality methods require a base station be established at surveyed benchmarks that are preferably registered. Surveyed benchmarks are not available in most of the areas where this work was conducted. Establishing suitable reference positions would have required months of work on each island. The cost of this approach would have been prohibitive. The method used in this work included acquiring a minimum of 10 minutes of uninterrupted carrier signal from a stationary GPS positioned at feature level without a vertical antenna offset yielded positional accuracy of less than 1 meter RMS and met the accuracy standard needed to complete this work.

A Trimble Geo Explorer 3 was used to collect the GPS data and Trimble Pathfinder Office Software was used for all post processing of the raw GPS data. Attribute information was collected on site using the GPS data logger with a custom data dictionary designed to reflect the NOAA classification scheme for benthic habitats of the Main Hawaiian Islands. The GPS data were post processed for differential correction using a continually operating reference system (CORS). Where access to an area was not available due to either remoteness or U.S. military operations, digital ortho quarter quadrangles (DOQs) were used to obtain the geographic position of features on the ground.

Accuracy Assessment and Ground Validation Habitat Characterization

These data were used as ground truth to determine the accuracy of the maps produced in this work and to refine areas where habitat determination was uncertain. The Trimble Geo Explorer 3 was also used for acquiring these GPS data. Waypoints were generated using a random stratified sampling regime or selected to explore specific features in the imagery. Each waypoint that could be safely occupied was navigated to in a small boat and a buoy deployed. After deployment of the buoy, 100 GPS positions were collected at one second intervals and were averaged to generate a single position. Each feature was populated with site specific data using a custom designed data dictionary and processed using Trimble Pathfinder Software.

3.2 Habitat Delineation, Identification and Mapping Methodologies

The benthic habitat maps were digitized in ArcView GIS format by delineating photointerpreted habitat boundaries from the imagery provided to the contractor by NOAA. NOAA staff has developed an editable ArcView Habitat Digitizing 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 and provides the option of setting the minimum mapping unit (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. This extension was used in the preparation of the habitat map products generated 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 MMU of one acre.

The habitat types are identified by visual interpretation of the imagery. This is conducted based on the color and texture of the features in the imagery as well as the contractor's extensive knowledge of the coral reef systems in the Hawaiian Islands. A detailed description of the methods used for digitizing is included (Appendix A).

The imagery used in this work was optimized to enhance underwater feature visibility. However, automated algorithmic classification of habitats was not conducted in this work.

The map production process was completed in five controlled steps.

1. The first draft map was generated by visual interpretation of the habitat boundaries in the imagery. Areas where habitat determination was uncertain were identified. Waypoints in these areas were generated on the geo-referenced imagery and over laid on the draft maps in the GIS. These areas were printed and water proofed in preparation for taking them into the field.
2. In the field, the waypoints were navigated to and occupied using appropriate size boats. The habitat was observed and GPS data collected. The general area was explored and, as needed, additional GPS positions were collected to mark transitions between habitat types of areas mapped at the level of the MMU.
3. The field ground validation data were overlaid on the imagery with the first draft habitat map in the GIS. The habitat polygons were edited to resolve the uncertainties generating a second draft map.
4. Random stratified sampling was developed to conduct accuracy assessment of the second draft map. The detailed habitat polygons were aggregated into the major classes, the random points were generated and the accuracy assessment conducted. In most cases, steps 2 and 4 were conducted at the same time.
5. After completion of the accuracy assessment, an accuracy reported was generated. The map was again edited to correct the erroneously attributed polygons identified during accuracy assessment. The map was delivered to the Government as the final draft. The final edit of the map guarantees that the map was delivered at a higher accuracy than was indicated by the accuracy assessment.

3.3 Ground Control Position Acquisition

Ground control position acquisition requires that suitable features in the scanned aerial photograph are identified and located on the ground. Features with clear intersections with corners that approach 90-degree angles were selected whenever possible. Features such as corners of tennis courts or the intersection in sidewalks were used. In remote areas where man-made features are rare, large boulders or other distinct geophysical features were also used. Formal written requests were occasionally required to occupy features on private property.

Two staff conducted this fieldwork. One drove the vehicle and operated the GPS and digital camera. The second functioned as a navigator, locating features in the imagery on a high-resolution laptop computer operated from an inverter connected to the cigarette lighter and directing the driver to the feature location. In most cases, the feature could be navigated to by car and only a short walk was needed to occupy the position. The horizontal and vertical pixel position on the 500 DPI scanned aerial photograph was identified and all data were recorded on the GPS data logger (Table 1). All data was also hand recorded in field hard copy records.

Data Entry	Description of Data Entry
Operator	Name of person operating GPS
Navigator	Name of person operating the computer
Date	Date data were collected
Time	Time data were collected
Site ID	Unique site ID
Frame	Frame number of aerial photograph
Flight Line	Flight line of aerial photograph
X Pixel	X pixel position of feature in aerial photograph
Y Pixel	Y pixel position of feature in aerial photograph
Location	Area of Island where feature is located
Description	Description of where the feature is located and primary route to relocate it at a later time
Comments	Description of problems experienced during data acquisition
Frame 2	Second Image where feature can be located
X Pixel 2	X pixel position of feature in second aerial photograph
Y Pixel 2	Y pixel position of feature in second aerial photograph

Table 1. Data Collected at each Ground Control Position

Once the GPS was positioned on the feature GPS data logging began. The GPS was kept stationary during the entire logging event. During data logging, three digital photographs were taken of each location. The first was of the GPS on the feature from a distance of about two meters. The second and third photographs were taken from an intermediate and greater distance from the feature. These records will facilitate easy relocation of the feature at a later time. Hand written descriptions were also made of the location of the feature and the route required to relocate it.

Upon completion of the GPS data collection, the data were saved and down loaded to the laptop computer. The horizontal and vertical pixel position of the feature in the digital image was recorded for all overlapping images where the feature was visible. Where flight lines sidelapped, overlapped or intersected with other flightlines of a different heading, as many as six images were used to record a single feature. Photoshop images were generated that show the location of each ground control position identified in each scanned image. The reference pixel was colored red and a red arrow terminated at that pixel. Also included with each arrow was the unique ID for each GCP.

The GPS data was post processed for differential correction using a continually operating reference system (CORS). In the eight Main Hawaiian Islands, there are two CORS. One is located on the Island of Kauai and one on the Island of Hawaii. The least distant station was used to correct each position. All GPS data were provided to the Government.

3.4 Habitat Map Accuracy Assessment

For the purpose of comparison of accuracy between benthic habitat maps produced from visual interpretation of color aerial photography, Aurora hyperspectral imagery and IKONOS satellite imagery and to determine the overall accuracy of the mapped product, four test areas were established (Tables 2, 3, 4 and 5). Each area extends from shore to a depth of approximately 30 meters to the ends of the test areas 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).

Random stratified sampling methods were implemented subsequent to completion of the second draft benthic 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 benthic 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 Geo Explorer 3 GPS data logger (Figures 1, 2, 3 and 4).

	Point A	Point B	Point C	Point D
Latitude	19° 51’ 00”	19° 46’ 12”	19° 59’ 24”	20° 03’ 36”
Longitude	156° 05’ 24”	156° 01’ 12”	155° 46’ 12”	155° 49’ 48”

Table 2. Geographic boundaries of the Kona accuracy assessment area

	Point A	Point B	Point C	Point D
Latitude	21° 33’ 00”	21° 26’ 24”	21° 24’ 00”	21° 30’ 00”
Longitude	157° 49’ 48”	157° 44’ 24”	157° 46’ 48”	157° 52’ 48”

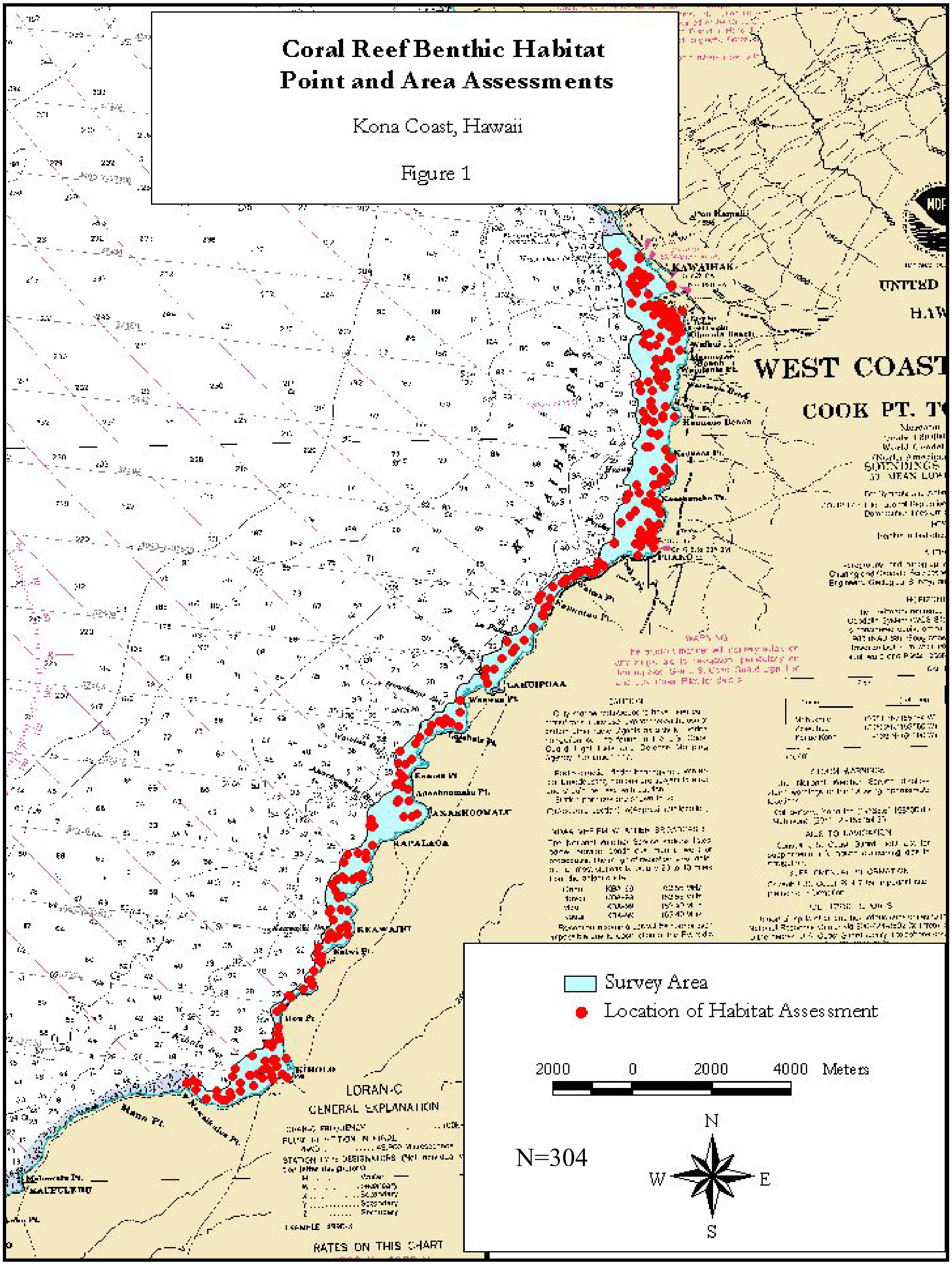
Table 3. Geographic boundaries of the Kaneohe Bay accuracy assessment area

	Point A	Point B	Point C	Point D
Latitude	20° 48’ 36”	20° 37’ 48”	20° 48’ 36”	20° 38’ 24”
Longitude	156° 30’ 36”	156° 28’ 12”	156° 27’ 00”	156° 25’ 48”

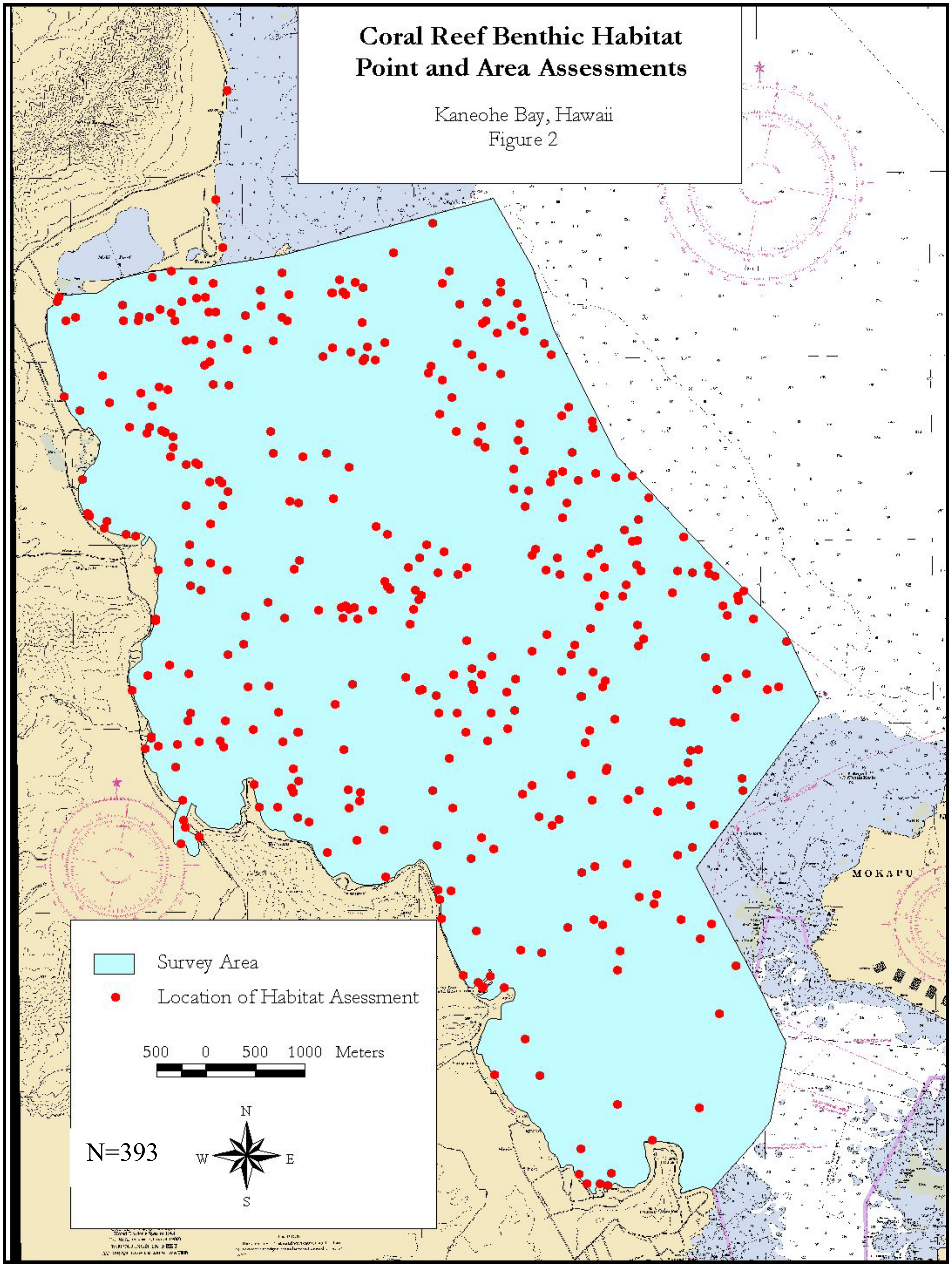
Table 4. Geographic boundaries of the Maui accuracy assessment area

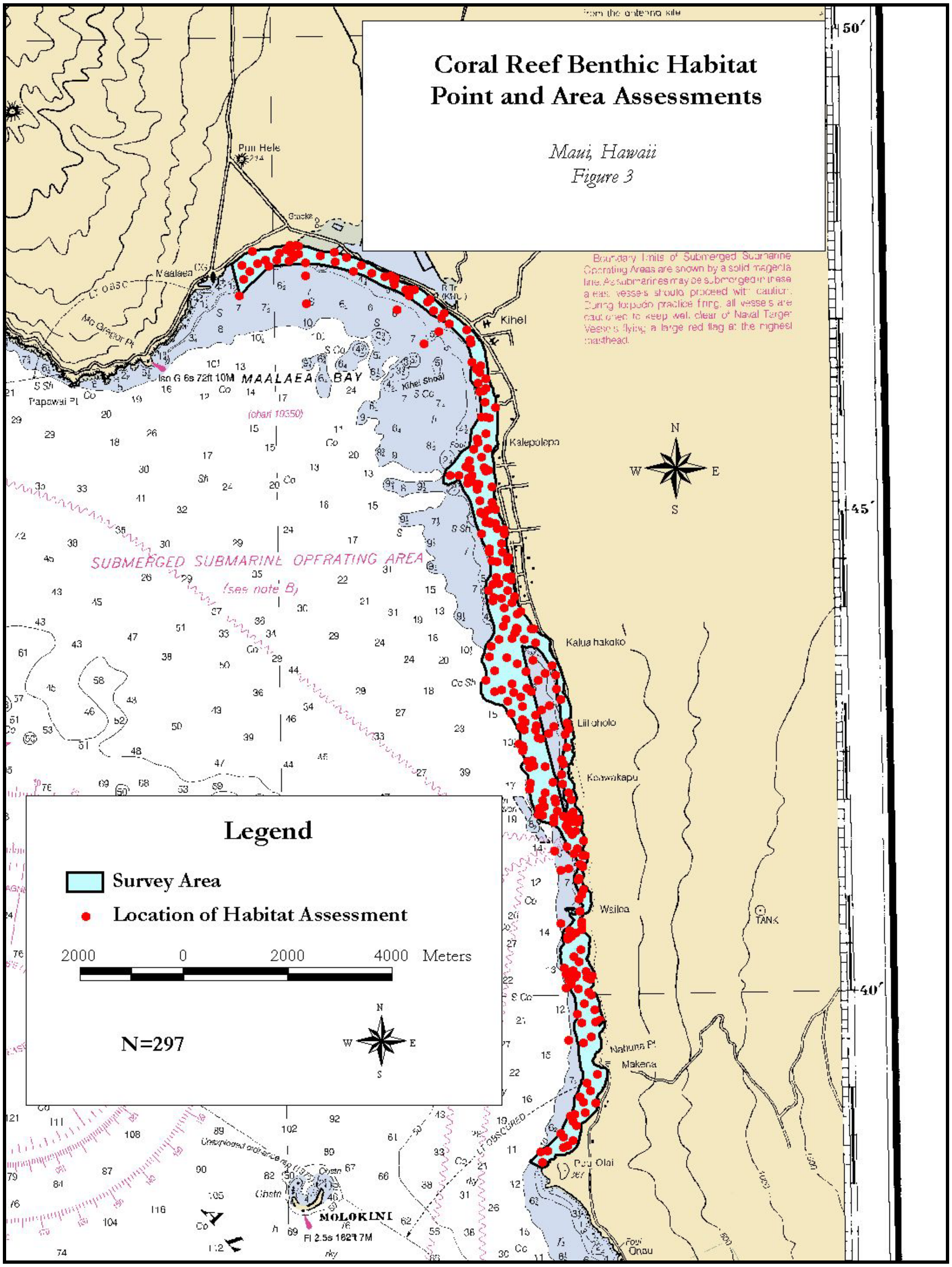
	Point A	Point B	Point C	Point D
Latitude	21° 06’ 36”	21° 03’ 36”	21° 06’ 36”	21° 03’ 36”
Longitude	157° 09’ 00”	157° 09’ 00”	156° 59’ 24”	156° 59’ 24”

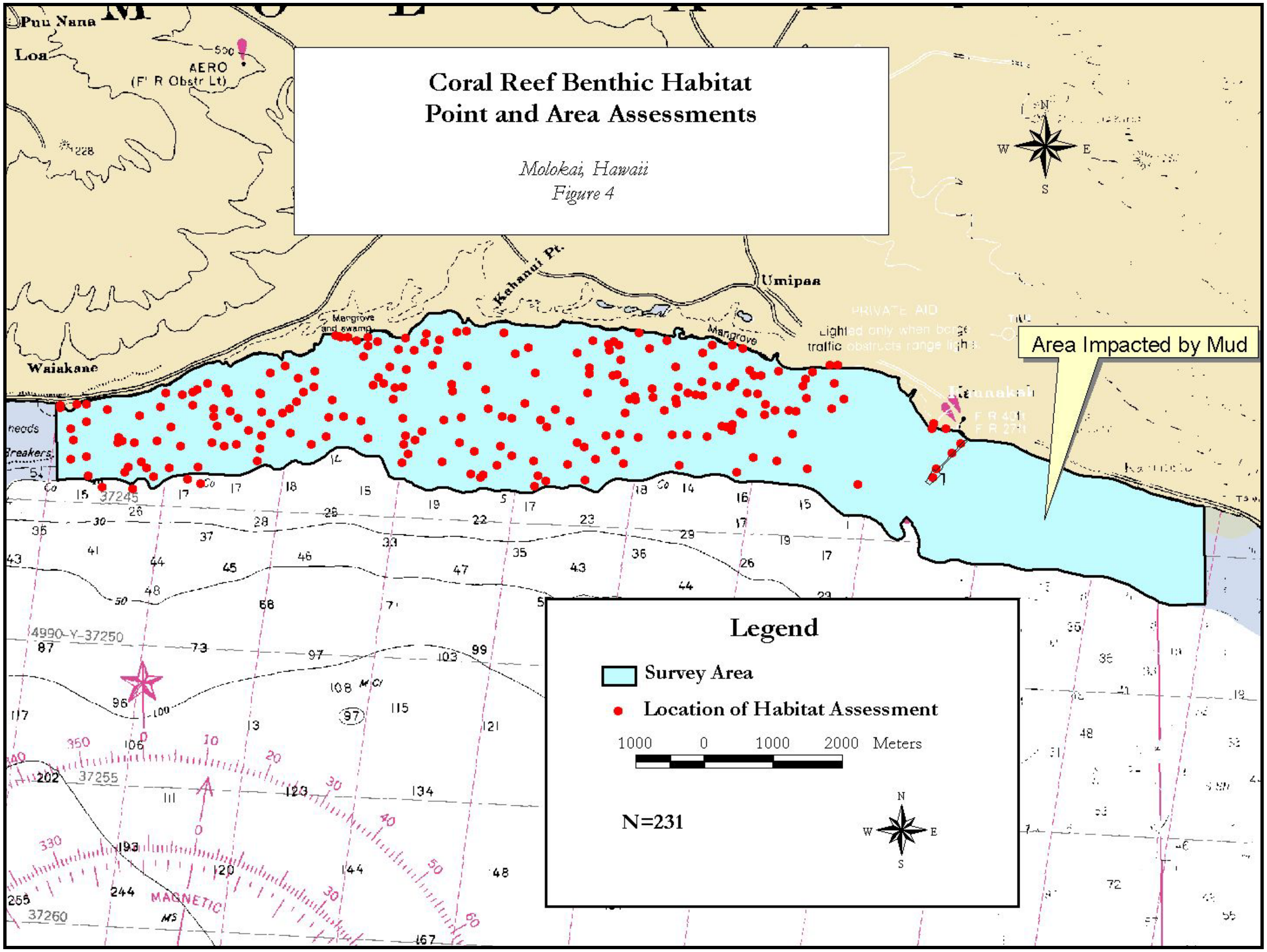
Table 5. Geographic boundaries of the Molokai accuracy assessment area



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


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


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
Keawakapu
Wailea
Makena
MOLOKINI
TANK


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
Puu Nana
Loa
Waiakane
Kahanui Pt.
Umipaa
Mangrove
Kaunakakai

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 6. Data collected at each assessment site during benthic habitat classification surveys

Upon arriving at a waypoint, a weighted meter line was dropped, a buoy fastened and site and habitat specific data collection began (Table 6).

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 Benthic Habitat Classification Scheme. The second most common habitat and general area descriptions as well as the point habitat were entered in waterproof notebooks and transferred to the GIS by hand.

In each field survey, the boats that were used were selected to be compatible with the sea conditions at the site. During the inter-island voyage between Kauai and Niihau, a 36-foot Radon was used. Where coastal areas were surveyed that were vulnerable to wind and waves, boats were used that met these conditions and were of a length of about 25 feet. In sheltered areas that were not reef flat zone, 17 foot Boston Whalers were used and during windless conditions, a 14-foot inflatable boat was used. One of the most useful boats used during these field surveys was a plastic sea kayak. This tool proved extremely useful in the extensive reef flat areas where the water is very shallow and much of the area is intermittently emergent at low tide. The team placed the kayak on a rented SUV, drove to the survey area and occupied the waypoints by paddling with the GPS sealed in a waterproof transparent boot albeit at the expense of considerable exercise.

3.5 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.

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 Kaunakakai at the Molokai test area, Port Allen on Kauai and at the lighthouse at Maalaea at the Maui test site.

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.

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.

3.6 Ground Validation

The purpose of this survey is to investigate areas of imagery where uncertainties exist on the photointerpreter's behalf during the decision making process of benthic habitat type. The GPS data acquisition methods used in this investigation are the same as those used for acquiring habitat data for accuracy assessment. Selection of waypoints and summary of data are significantly modified. Waypoints were selected by manually identifying the areas in the imagery where uncertainty existed in interpretation of benthic habitat. These areas were typically gradients through a transition of two or more habitat types or general areas where the habitat type was uncertain. Waypoints were selected to investigate these areas and subsequent to the completion of these observations, the data were included as a layer in the GIS. The GIS layer was examined by the photointerpreter to resolve the uncertainty of interpretation.

3.7 Geodetic Control, Accuracy and Verification

Quality control was established by implementation of four steps. These assured a final product meeting the specification of both horizontal and vertical accuracy of ground control not exceeding 1 and 2 meters at a 95% sigma RMS error from their true geographic location respectively. This plan also ensured the reliability and accuracy of the field data collected for benthic habitat accuracy assessment and the final GIS map output.

3.7.1 Spatial Accuracy and Precision

At each field location, a registered U.S. Geological Survey (USGS) or Hawaii State Department of Transportation (DOT) monument was occupied and GPS positions were collected using the same protocols that were used to collect field data. As the true position of the monument is known, the accuracy and precision of the GPS data acquired for this work was established.

Replicate GPS positions were collected at habitat assessment sites and compared to the mean position. Also, a waypoint was repeatedly navigated to and occupied to establish the spatial variability due to navigation.

The GPS data generated from this contract was subsequently used by a separate NOAA contractor, Greenhorn and O'Mara, Inc. (G&O) to orthorectify the color aerial photography. Positional accuracy of the raster product was determined by solution of Softplotter and the model generated an RMS value. These products met the NOAA standards of the contract with G&O.

3.7.2 GIS Quality Control

All GIS map products generated during this work were closely examined. Errors such as multipart, overlapping, sliver and void polygons were identified and corrected using an ArcView GIS Quality Control extension downloaded from the ESRI web site. The extension was also used to topologically clean the GIS data. Polygons that are adjacent and have the same zone and habitat attributes are identified using an ArcView script and all errors are corrected. Attribution of GIS polygons was conducted seamlessly using the NOAA habitat digitizing extension software thus errors are not expected. A tool within this extension searches the GIS database and identifies all polygons where mismatches occur between the polygon attributes and the habitat classification scheme and all errors corrected. GIS data from this work were delivered to NOAA free of errors and an independent review by NOAA confirmed this.

3.7.3 Data Security

All digital and hard copy records were kept in secure locations and daily backups were made of field data. The field data acquired each day were archived on CD ROM and hand written records were collected. Chain of custody records were not needed as all data were maintained in secure custody of ALH at all times.

3.7.4 Tabular Data Quality Control

ALH made a paramount effort to include seamless software processing of all tabular data. Manual entry of data was minimized to limit the possibility of human error. However, in some cases, manual entry of information was unavoidable. These steps were identified and particular attention was given to control these processes. An original hand written record was made for all data where manual entry was required. This record was securely archived and two independent reviews were conducted of the data subsequent to the transfer of the data to the GIS database.

4. Results

All goals set forward in the SOW for this contract have been completed. The work has resulted in:

- Acquisition of 350 ground control positions
- Acquisition of 566 ground validation points
- Acquisition of 1,225 benthic characterization field accuracy assessments
- Completion of twelve test benthic habitat maps for accuracy assessment
- Completion of eight production benthic habitat maps covering all remotely sensed imagery collected by NOAA during the year 2000
- Completion of comparisons of accuracy between test areas and imagery types
- Delivery of all products including reports
- Reporting on all work completed in a timely manner

4.1 Acquisition of GPS Data

Acquisition of GPS data was completed for all areas mapped as described in the SOW. The GPS data collected on the Island of Oahu has been illustrated as a sample of this work (Figure 5).

4.1.1 Ground Control Positions

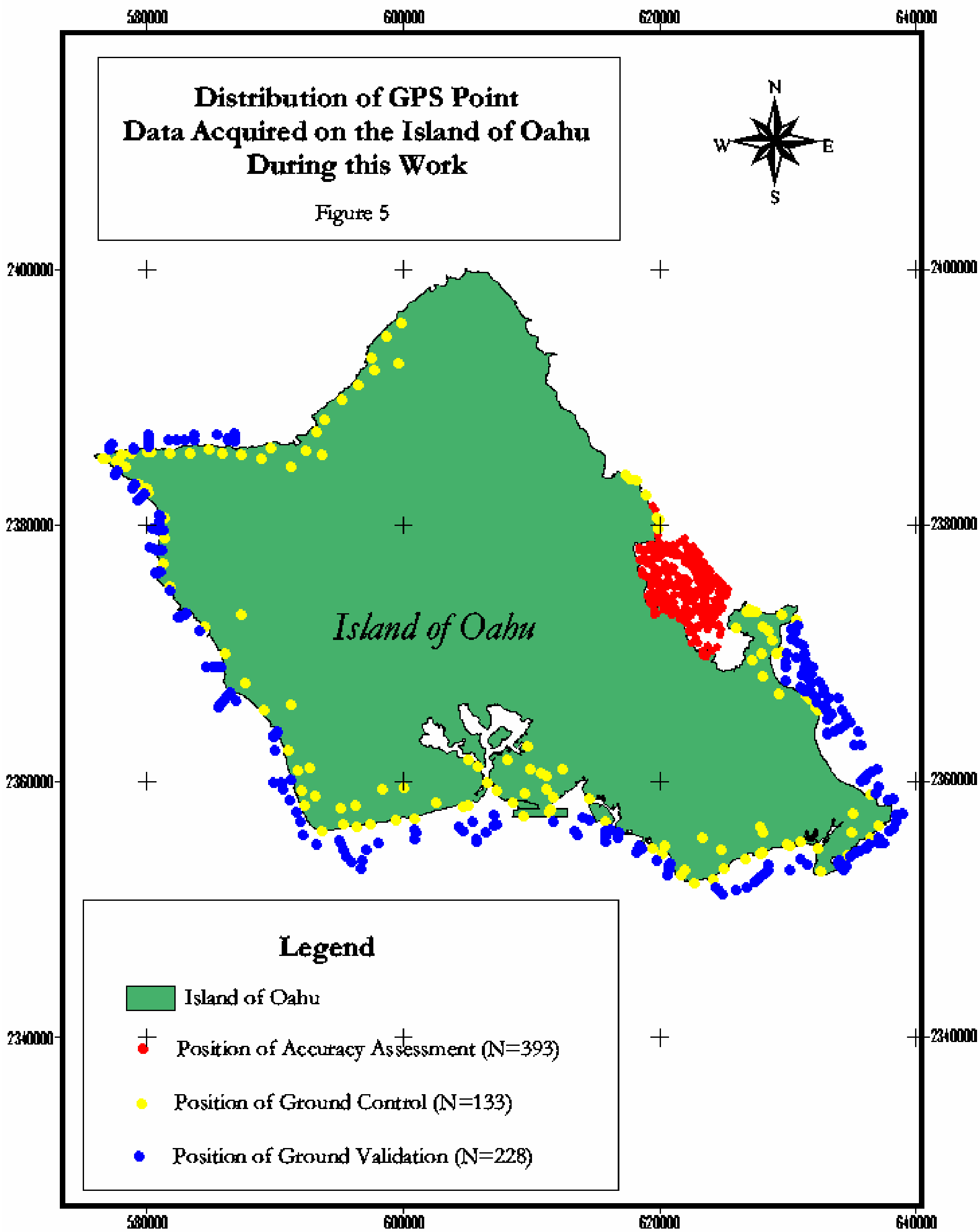
A total of 327 GCPs were collected on the islands within UTM zone 4 and 23 were collected on the Island of Hawaii in UTM zone 5. All positions on the Island of Hawaii were accessible and a minimum of 10 minutes of carrier signal was acquired by stationary GPS and post processed for differential correction. Five areas were inaccessible in UTM zone 4 and DOQs were used to obtain geographic positions in these. Three of these were military bases and included Pearl Harbor and Kaneohe Marine Corps Base on Oahu and the Pacific Missile Range Facility at Barking Sands on Kauai. The area north of Barking Sands on the northwest side of Kauai was inaccessible due to remoteness. The east side of Lanai was inaccessible as all roads into the area were impassable due to the flash flooding resulting from the heavy rains during the winter months of this year. All other areas were accessed and GPS data were collected. These data have been delivered to and accepted by the Government.

Subsequent to the delivery of these data, the government provided this product to another NOAA contractor, G&O, who used these positions to orthorectify the color aerial photography acquired by NOAA in the year 2000. These orthorectified images were provided to ALH to proceed with benthic habitat maps. All work was completed on time.

4.1.2 Accuracy Assessment Data

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 these 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 east 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 east end of the Molokai test area are very similar to those on the west end of the test area, the density of accuracy assessment points was increased on the west end to compensate for the reduced density on the east 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.


580000
600000
620000
640000
Distribution of GPS Point
Data Acquired on the Island of Oahu
During this Work
Figure 5
N
W
E
S
2400000
2380000
2360000
2340000
Island of Oahu
Legend
Island of Oahu
Position of Accuracy Assessment (N=393)
Position of Ground Control (N=133)
Position of Ground Validation (N=228)

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 accuracy assessment habitat characterizations conducted 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. These have been aggregated into shape files for UTM zone 4 and UTM zone 5 data. Summaries of the major and detailed habitat types encountered during field surveys at each test area have been presented here (Table 7). The results show that an adequate sample size was collected for each major habitat at each test area with the exception of the "Submerged Aquatic Vegetation" category in Kona. The area is composed of young unweathered volcanic rock prolific with live coral. The areas that lack coral are shallow and both grazing and abrasion from water motion keep macro algae sparse throughout the entire test area.

4.1.3 Ground Validation Data

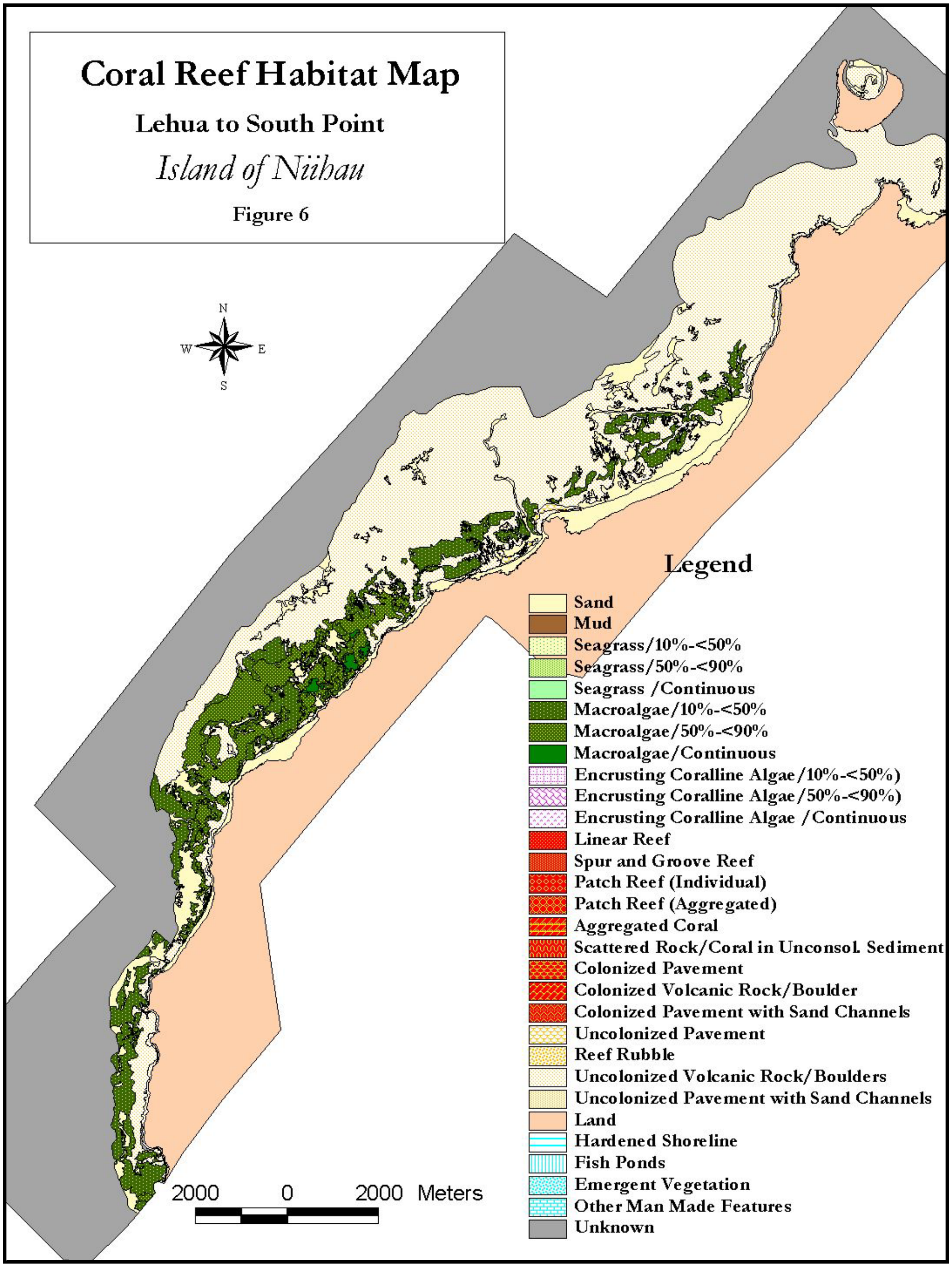
Five hundred sixty six field positions were occupied and habitat characterization conducted for ground validation during this work. These data were included as a layer in the GIS and the first draft map was edited based on this ground truth. All areas where uncertainty existed on the part of the photointerpreter during habitat delineation were investigated in the field. The ground validation data have been included as an ArcView shape file and provided to the government with the individual contract line item deliverables. All data were collected and integrated into the mapped products as planned.

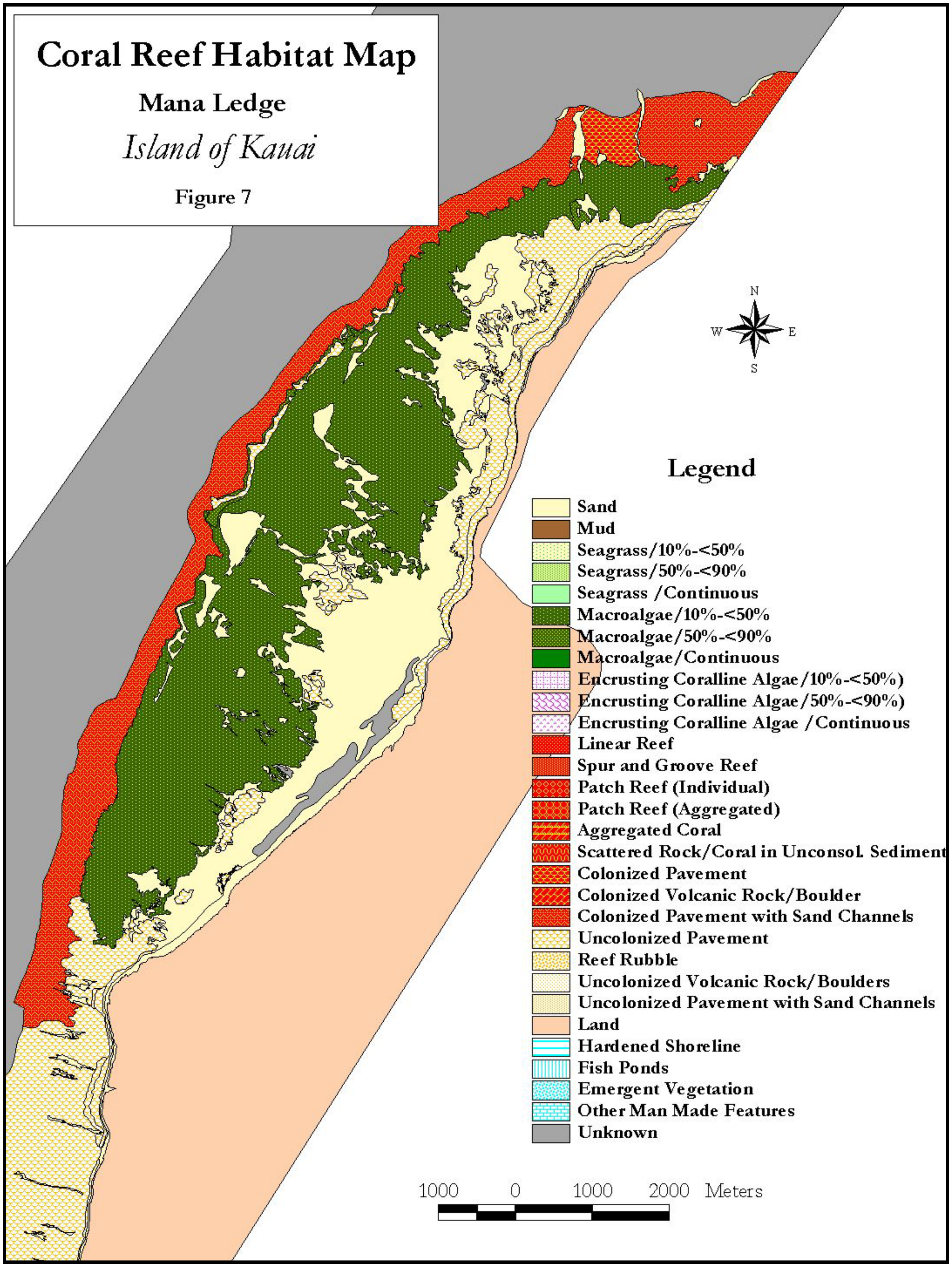
4.2 Benthic Habitat Maps and Thematic Content Summary

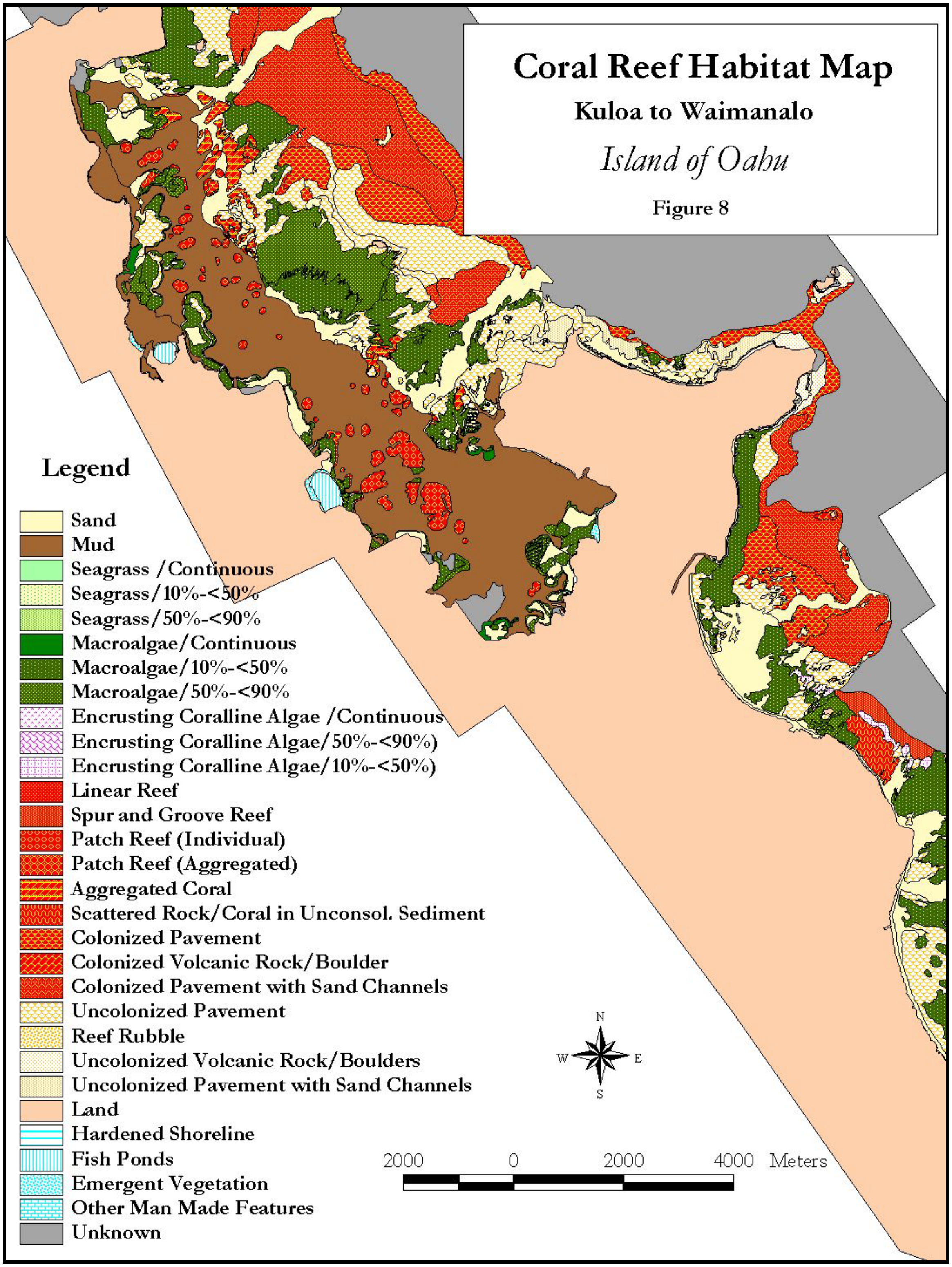
All thematic GIS map data that were specified in the SOW have been completed. A total of 12 test habitat maps and 8 production maps were generated and an *.prj file created for each. A sample map of an area from each Island is presented (Figures 6 thru 12).

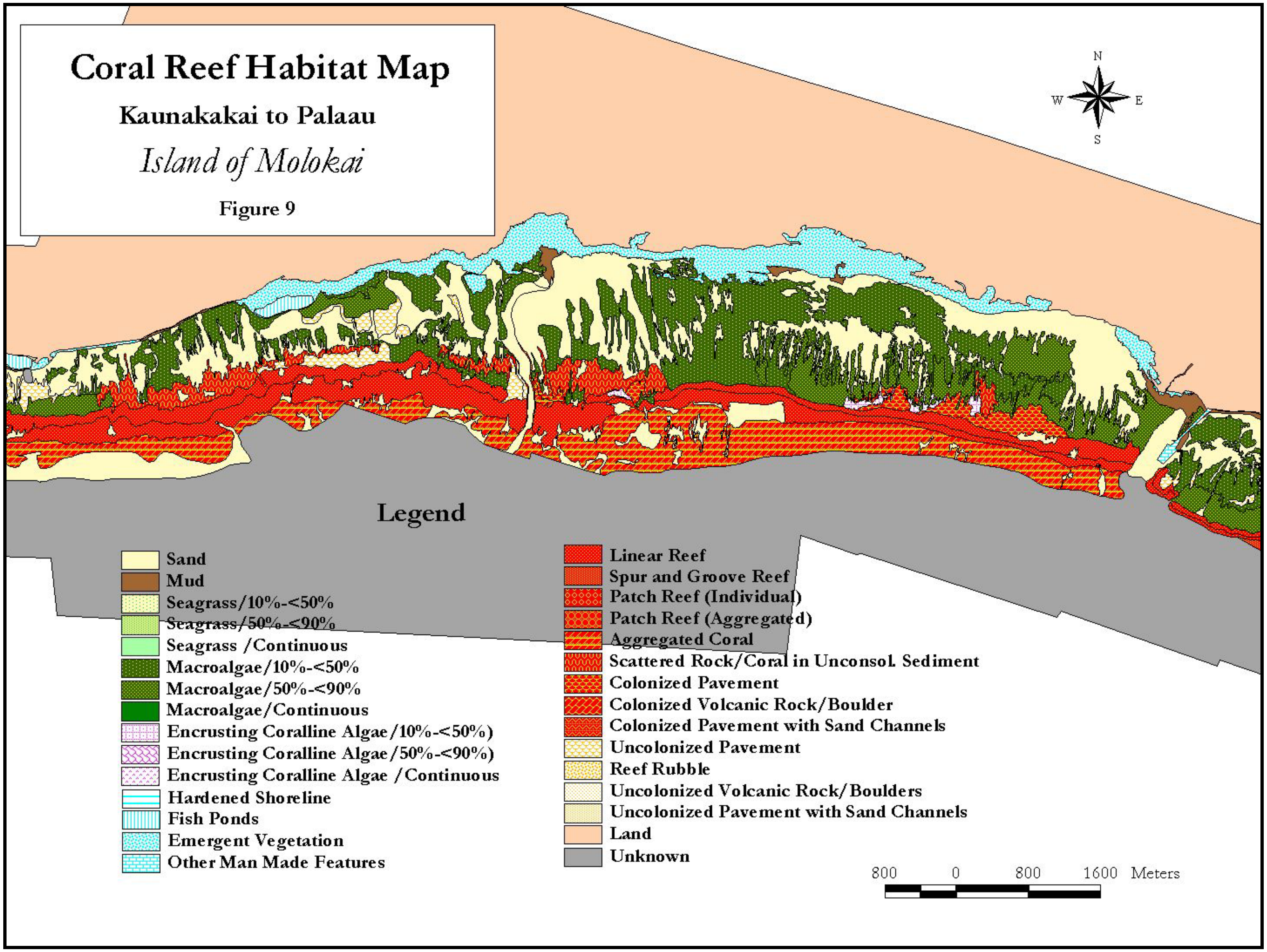
Table 7. Summary of major and detailed habitat types encountered during field surveys at each test area

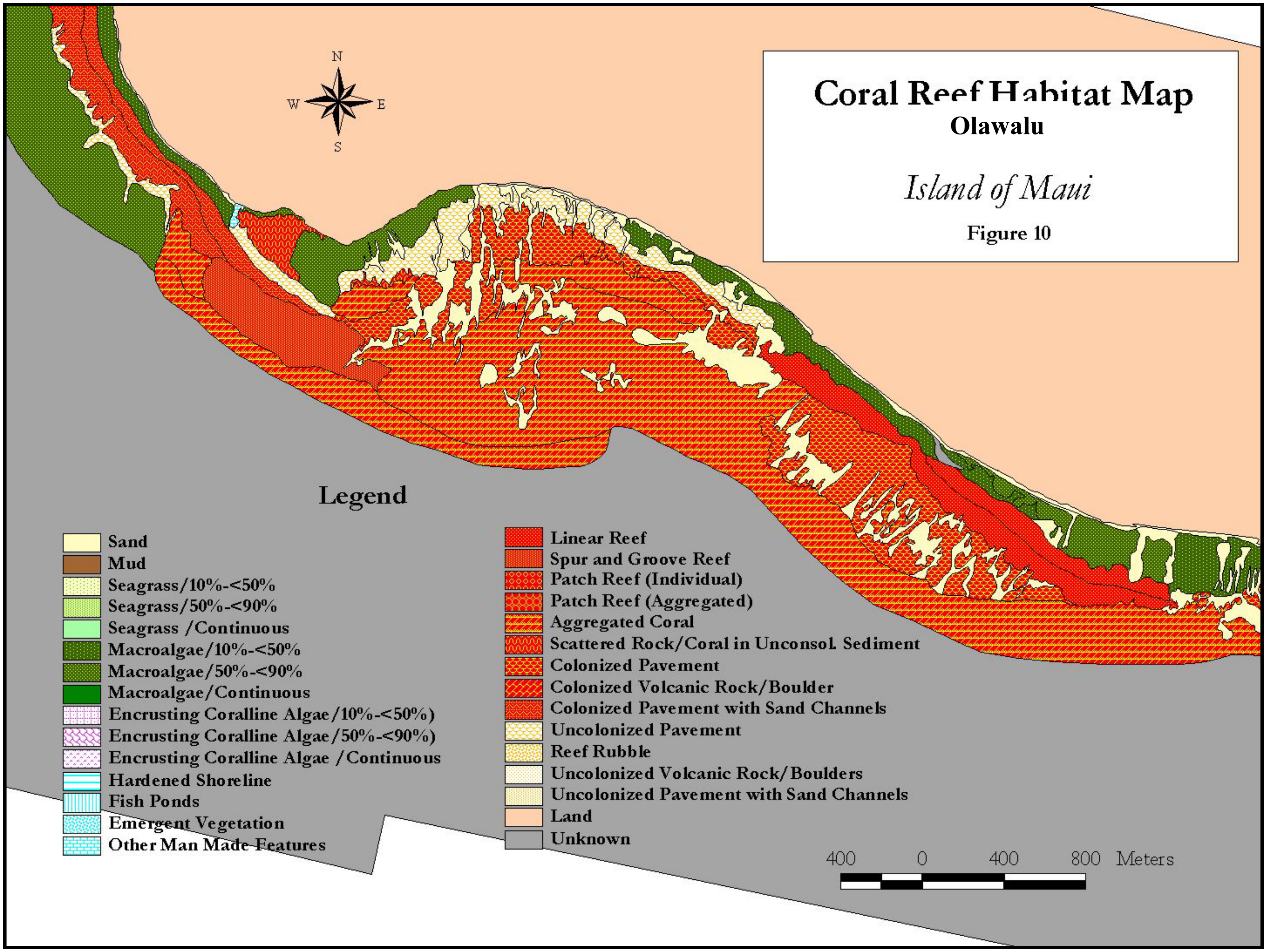
Habitat Type (Major Habitats in Bold Face Type)	Survey Area			
	Kona	KBay	Maui	Molokai
Unconsolidated Sediment	**102**	**97**	**136**	**54**
Sand	99	45	136	51
Mud	3	52		3
Submerged Aquatic Vegetation	**4**	**81**	**55**	**52**
Continuous Seagrass (90%-100%)				
Patchy Seagrass (50%-<90%)	1			
Patchy Seagrass (10%-<50%)	3	4		
Continuous Macroalgae (90%-100%)		3	2	
Patchy Macroalgae (50%-<90%)		9	18	9
Patchy Macroalgae (10%-<50%)		65	35	43
Coral Reef and Hardbottom	**181**	**191**	**106**	**99**
Linear Reef				
Spur and Groove	4			1
Patch Reef (Individual)		1		
Patch Reef (Aggregated)				
Scattered C/R in Unconsol. Sed.	5	11		12
Aggregated Coral	68	17	49	48
Colonized Pavement	11	30	12	12
Col. Volcanic Rock/Boulder	56		20	
Col. Pav. With Sand Chan.	1	39		
Reef Rubble	5	10	1	3
Uncol. Pavement		62	18	19
Uncol. Volcanic Rock/Boulder	14	5	6	
Uncol. Pavement w/Sand Chan.		3		
Patchy Coralline Algae (10%-<50%)	7	13		4
Patchy Coralline Algae (50%-<90%)	8			
Continuous Coralline Algae (90%-100%)	2			
Other Delineations	**14**	**25**	**0**	**28**
Emergent Vegetation		8		22
Artificial	14	17		6

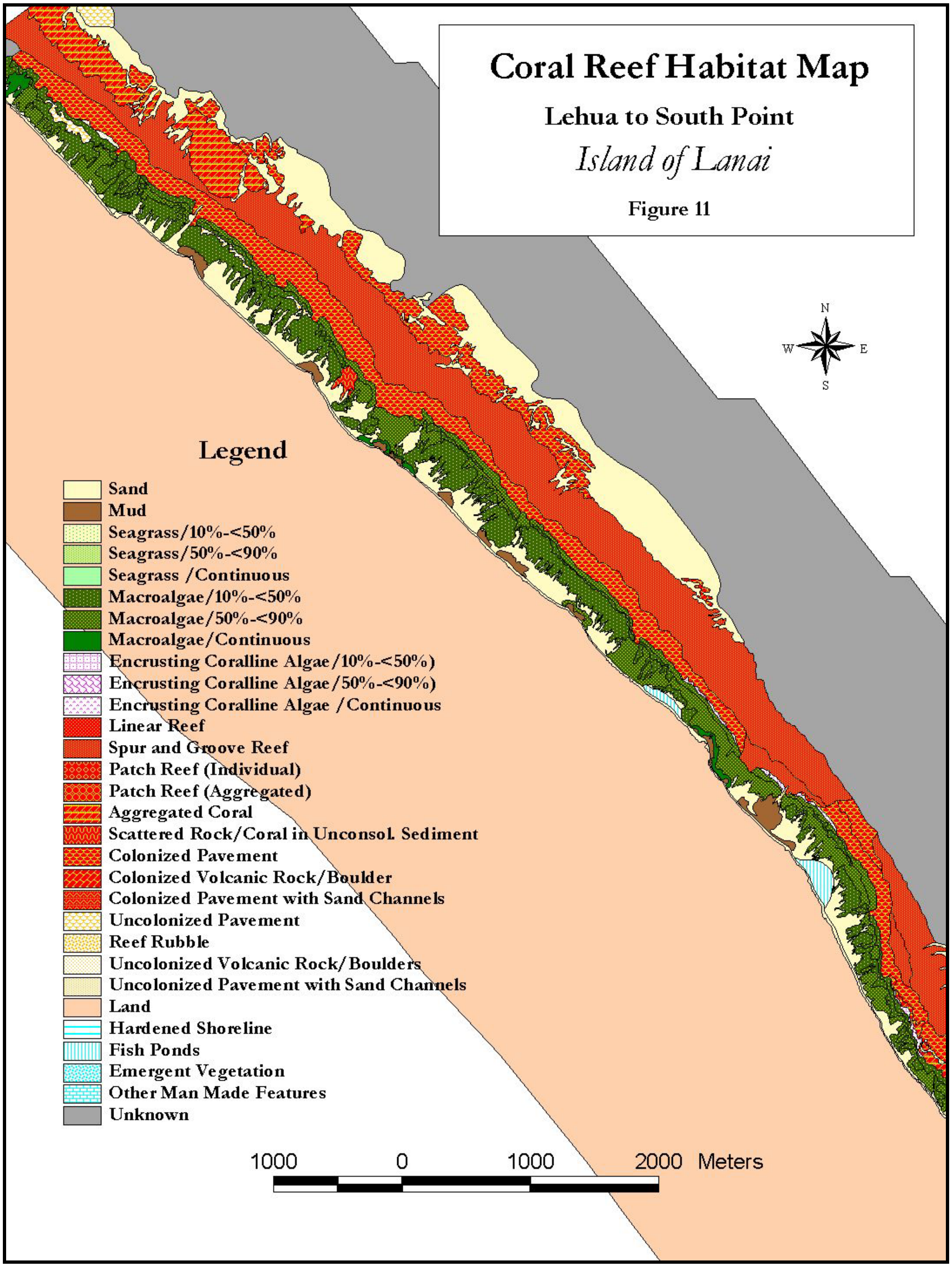

Coral Reef Habitat Map
Lehua to South Point
Island of Niihau
Figure 6
N
W
E
S
Legend
Sand
Mud
Seagrass/10%-<50%
Seagrass/50%-<90%
Seagrass /Continuous
Macroalgae/10%-<50%
Macroalgae/50%-<90%
Macroalgae/Continuous
Encrusting Coralline Algae/10%-<50%)
Encrusting Coralline Algae/50%-<90%)
Encrusting Coralline Algae /Continuous
Linear Reef
Spur and Groove Reef
Patch Reef (Individual)
Patch Reef (Aggregated)
Aggregated Coral
Scattered Rock/Coral in Unconsol. Sediment
Colonized Pavement
Colonized Volcanic Rock/Boulder
Colonized Pavement with Sand Channels
Uncolonized Pavement
Reef Rubble
Uncolonized Volcanic Rock/Boulders
Uncolonized Pavement with Sand Channels
Land
Hardened Shoreline
Fish Ponds
Emergent Vegetation
Other Man Made Features
Unknown
2000 0 2000 Meters

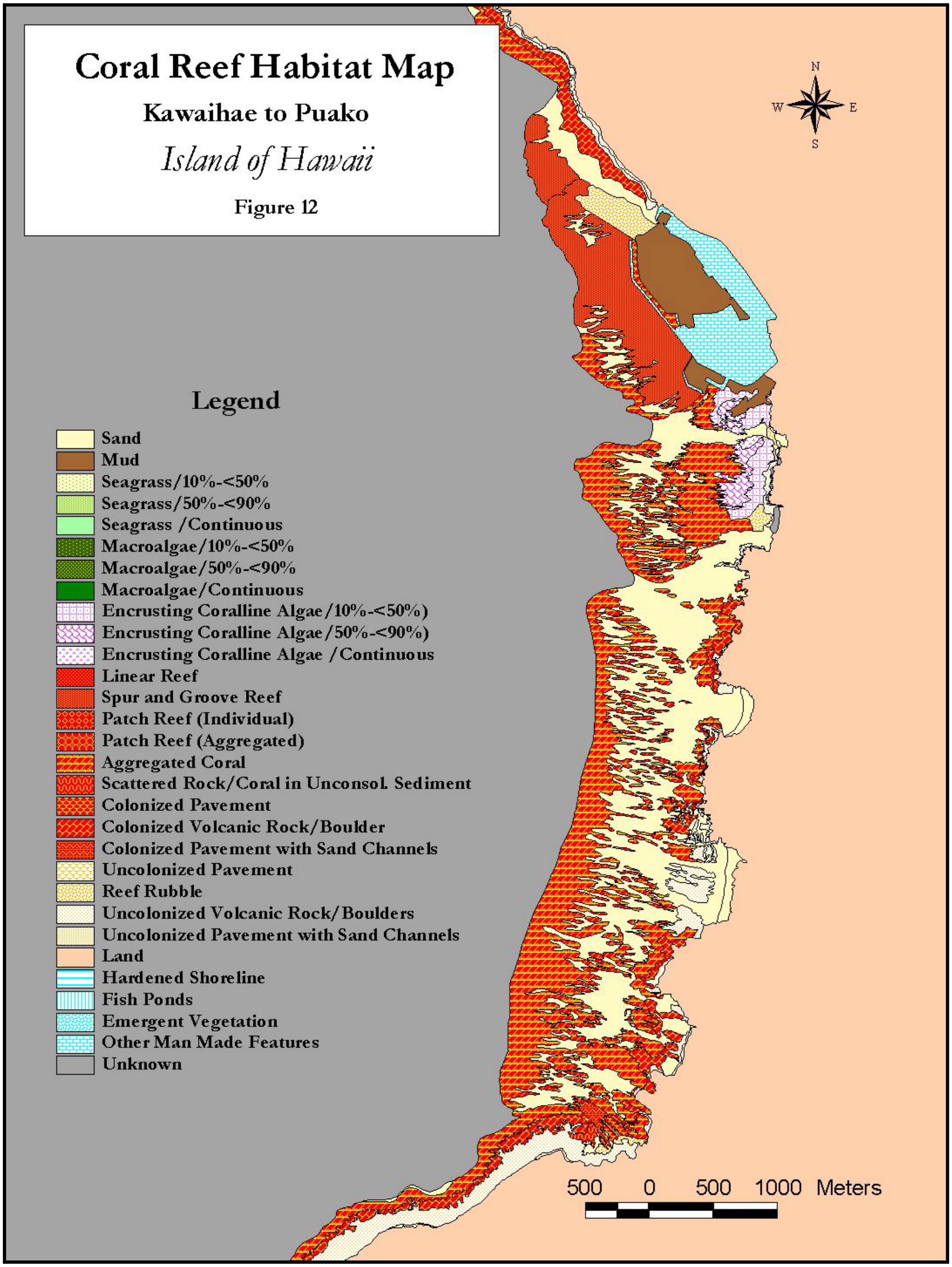

Coral Reef Habitat Map
Mana Ledge
Island of Kauai
Figure 7
N
W
E
S
Legend
Sand
Mud
Seagrass/10%-<50%
Seagrass/50%-<90%
Seagrass /Continuous
Macroalgae/10%-<50%
Macroalgae/50%-<90%
Macroalgae/Continuous
Encrusting Coralline Algae/10%-<50%)
Encrusting Coralline Algae/50%-<90%)
Encrusting Coralline Algae /Continuous
Linear Reef
Spur and Groove Reef
Patch Reef (Individual)
Patch Reef (Aggregated)
Aggregated Coral
Scattered Rock/Coral in Unconsol. Sediment
Colonized Pavement
Colonized Volcanic Rock/Boulder
Colonized Pavement with Sand Channels
Uncolonized Pavement
Reef Rubble
Uncolonized Volcanic Rock/Boulders
Uncolonized Pavement with Sand Channels
Land
Hardened Shoreline
Fish Ponds
Emergent Vegetation
Other Man Made Features
Unknown
1000 0 1000 2000 Meters


Coral Reef Habitat Map
Kuloa to Waimanalo
Island of Oahu
Figure 8
Legend
Sand
Mud
Seagrass /Continuous
Seagrass/10%-<50%
Seagrass/50%-<90%
Macroalgae/Continuous
Macroalgae/10%-<50%
Macroalgae/50%-<90%
Encrusting Coralline Algae /Continuous
Encrusting Coralline Algae/50%-<90%)
Encrusting Coralline Algae/10%-<50%)
Linear Reef
Spur and Groove Reef
Patch Reef (Individual)
Patch Reef (Aggregated)
Aggregated Coral
Scattered Rock/Coral in Unconsol. Sediment
Colonized Pavement
Colonized Volcanic Rock/Boulder
Colonized Pavement with Sand Channels
Uncolonized Pavement
Reef Rubble
Uncolonized Volcanic Rock/Boulders
Uncolonized Pavement with Sand Channels
Land
Hardened Shoreline
Fish Ponds
Emergent Vegetation
Other Man Made Features
Unknown
N
W
E
S
2000
0
2000
4000
Meters


Coral Reef Habitat Map
Kaunakakai to Palaau
Island of Molokai
Figure 9
N
W
E
S
Legend
Sand
Mud
Seagrass/10%-<50%
Seagrass/50%-<90%
Seagrass /Continuous
Macroalgae/10%-<50%
Macroalgae/50%-<90%
Macroalgae/Continuous
Encrusting Coralline Algae/10%-<50%)
Encrusting Coralline Algae/50%-<90%)
Encrusting Coralline Algae /Continuous
Hardened Shoreline
Fish Ponds
Emergent Vegetation
Other Man Made Features
Linear Reef
Spur and Groove Reef
Patch Reef (Individual)
Patch Reef (Aggregated)
Aggregated Coral
Scattered Rock/Coral in Unconsol. Sediment
Colonized Pavement
Colonized Volcanic Rock/Boulder
Colonized Pavement with Sand Channels
Uncolonized Pavement
Reef Rubble
Uncolonized Volcanic Rock/Boulders
Uncolonized Pavement with Sand Channels
Land
Unknown
800 0 800 1600 Meters


Coral Reef Habitat Map
Olawalu
Island of Maui
Figure 10
N
W
E
S
Legend
Sand
Mud
Seagrass/10%-<50%
Seagrass/50%-<90%
Seagrass /Continuous
Macroalgae/10%-<50%
Macroalgae/50%-<90%
Macroalgae/Continuous
Encrusting Coralline Algae/10%-<50%)
Encrusting Coralline Algae/50%-<90%)
Encrusting Coralline Algae /Continuous
Hardened Shoreline
Fish Ponds
Emergent Vegetation
Other Man Made Features
Linear Reef
Spur and Groove Reef
Patch Reef (Individual)
Patch Reef (Aggregated)
Aggregated Coral
Scattered Rock/Coral in Unconsol. Sediment
Colonized Pavement
Colonized Volcanic Rock/Boulder
Colonized Pavement with Sand Channels
Uncolonized Pavement
Reef Rubble
Uncolonized Volcanic Rock/Boulders
Uncolonized Pavement with Sand Channels
Land
Unknown
400 0 400 800 Meters


Coral Reef Habitat Map
Lehua to South Point
Island of Lanai
Figure 11
N
W
E
S
Legend
Sand
Mud
Seagrass/10%-<50%
Seagrass/50%-<90%
Seagrass /Continuous
Macroalgae/10%-<50%
Macroalgae/50%-<90%
Macroalgae/Continuous
Encrusting Coralline Algae/10%-<50%)
Encrusting Coralline Algae/50%-<90%)
Encrusting Coralline Algae /Continuous
Linear Reef
Spur and Groove Reef
Patch Reef (Individual)
Patch Reef (Aggregated)
Aggregated Coral
Scattered Rock/Coral in Unconsol. Sediment
Colonized Pavement
Colonized Volcanic Rock/Boulder
Colonized Pavement with Sand Channels
Uncolonized Pavement
Reef Rubble
Uncolonized Volcanic Rock/Boulders
Uncolonized Pavement with Sand Channels
Land
Hardened Shoreline
Fish Ponds
Emergent Vegetation
Other Man Made Features
Unknown
1000 0 1000 2000 Meters



Coral Reef Habitat Map
Kawaihae to Puako
Island of Hawaii
Figure 12
N
W
E
S
Legend
Sand
Mud
Seagrass/10%-<50%
Seagrass/50%-<90%
Seagrass /Continuous
Macroalgae/10%-<50%
Macroalgae/50%-<90%
Macroalgae/Continuous
Encrusting Coralline Algae/10%-<50%)
Encrusting Coralline Algae/50%-<90%)
Encrusting Coralline Algae /Continuous
Linear Reef
Spur and Groove Reef
Patch Reef (Individual)
Patch Reef (Aggregated)
Aggregated Coral
Scattered Rock/Coral in Unconsol. Sediment
Colonized Pavement
Colonized Volcanic Rock/Boulder
Colonized Pavement with Sand Channels
Uncolonized Pavement
Reef Rubble
Uncolonized Volcanic Rock/Boulders
Uncolonized Pavement with Sand Channels
Land
Hardened Shoreline
Fish Ponds
Emergent Vegetation
Other Man Made Features
Unknown
500 0 500 1000 Meters

The total number of polygons and the total area of each map are presented. These have been summarized for both the test areas (Table 8) and production maps (Table 9). These data have been queried directly from the GIS and polygons representing unknown areas and land have been excluded from this summary.

	ArcView GIS Map Name	Number of Polygons	Total Area Mapped Sq. Km
Test Maps	Kbay_color_test_area	314	53.58
	Kbay_hsi_test_area	226	32.11
	Kbay_ikonos_test_area	393	52.22
	Kona_color_test_area	278	20.43
	Kona_hsi_test_area	250	25.00
	Kona_ikonos_test_area	241	19.75
	Maui_color_test_area	200	15.52
	Maui_hsi_test_area	194	13.90
	Maui_ikonos_test_area	140	11.58
	Molokai_color_test_area	228	29.66
	Molokai_hsi_test_area	182	27.60
	Molokai_ikonos_test_area	188	28.80
	Total from Test Areas	**2,834**	**330.15**

Table 8. Summary showing the number of polygons and total area of each habitat map prepared for each test area.

	ArcView GIS Map Name	Number of Polygons	Total Area Mapped Sq. Km
Production Maps	Niihau_production	219	64.62
	Kauai_production	571	125.30
	Oahu_section_1	620	111.90
	Oahu_section_2	1061	248.60
	Molokai_production	954	116.20
	Maui_production	633	56.82
	Lanai_production	213	19.65
	Hawaii_production	583	63.78
	Total from Production	**4854**	**806.87**

Table 9. Summary showing the number of polygons and total area of each habitat map prepared for each production area.

Map Type	ArcView GIS Map Name	Coral Reef and Hard Bottom	Submerged Aquatic Vegetation	Unconsolidated Sediment	Total Area per Map
TEST AREA MAPS	Kbay_color_test_area	19.46	9.50	24.09	53.05
	Kbay_hsi_test_area	9.25	8.29	14.12	31.66
	Kbay_Ikonos_test_area	13.62	13.23	24.71	51.56
	Total Class Area for Kbay	42.33	31.02	62.92	**136.27**
	Kona_color_test_area	13.24	6.66	0.00	19.90
	Kona_hsi_test_area	17.60	7.11	0.00	24.71
	Kona_Ikonos_test_area	12.85	6.55	0.00	19.40
	Total Class Area for Kona	43.69	20.32	0.00	**64.01**
	Maui_color_test_area	4.69	1.70	9.07	15.46
	Maui_hsi_test_area	5.68	1.92	6.24	13.84
	Maui_ikonos	4.45	1.59	5.05	11.09
	Total Class Area for Maui	14.82	5.21	20.36	**40.39**
	Molokai_color	10.33	9.05	7.71	27.09
	Molokai_hsi_test_area	9.30	9.07	7.73	26.10
	Molokai_ikonos	10.22	8.72	7.22	26.16
	Total Class Area for Molokai	29.85	26.84	22.66	**79.35**
	Total Mapped in Test Areas	**130.69**	**83.39**	**105.94**	
PRODUCTION MAPS	Niihau_production	40.70	14.04	9.88	64.62
	Kauai_production	71.76	17.68	35.81	125.25
	Oahu_section_1	50.46	24.28	36.51	111.25
	Oahu_section_2	102.47	67.76	68.08	238.31
	Molokai_production	65.17	19.60	27.45	112.22
	Maui_production	24.87	9.43	22.42	56.72
	Lanai_production	12.35	2.53	4.10	18.98
	Hawaii_production	47.76	15.72	0.00	63.48
	Total Mapped in Production	**415.54**	**171.04**	**204.25**	

Table 10. Areas of major habitat classes mapped from NOAA 2000 remotely sensed imagery (sq km).

It can be seen from table 8 that 2,834 polygons were delineated in the test maps and 4,854 were delineated in the production maps. From table 9 it can be seen that 330.15 square kilometers of reef area were delineated in the test maps and 806.87 were delineated in the production maps. It is important to recognize that the test areas are a subset of the production areas and therefore the total benthic habitat mapped during this work is 806.87 km^2.

The spatial data in the GIS have been queried to summarize the areas of the major habitats (Table 10). The data have been aggregated to show the major habitat area totals for each of the maps prepared for the test areas as well as the maps generated from routine production. From these data it is calculated that 52.6% of the mapped area is coral reef and hard bottom, 21.6% is submerged vegetation and 25.8% is composed of unconsolidated sediment.

4.3 Benthic Habitat Map Thematic Accuracy

Assessment of the accuracy of the maps generated in this work and a comparative analysis between accuracy of maps prepared from color aerial photography, AURORA HSI and IKONOS satellite imagery has been completed and provided to the government (Appendix B). For greater detail, this report should be consulted.

The CRAMP team has completed the determination of the extent of correct vs. incorrect habitat interpretation. Accuracy of photointerpretation of major benthic habitats for each of the image types and for each of the test areas are presented here (Tables 11, 12, 13, and 14) and the results of the accuracy assessments for the four test areas have been combined (Table 15). In these tables, producer's accuracy is calculated by dividing the total number of correct determinations by the total number of determinations in a class (column total). This value indicates the probability that a polygon is correctly classified and thus informs the producer how well a certain class can be interpreted. User's accuracy is derived by dividing the total number of correctly classified assessments by the number of field assessments in a particular class (row total). This value indicates the probability that the classification of a polygon on the map accurately represents the habitat on the reef.

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 15 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 ($p<0.05$) that there is no difference between the accuracy of the maps in the contrast, are also presented (Table 16). 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.

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 11. Users and producers accuracy of benthic habitat map products generated from photointerpretation of major benthic habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Kona 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 12. Users and producers accuracy of benthic habitat map products generated from photointerpretation of major benthic habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Kaneohe Bay 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 13. Users and producers accuracy of benthic habitat map products generated from photointerpretation of major benthic habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Maui 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 14. Users and producers accuracy of benthic habitat map products generated from photointerpretation of major benthic habitats using color aerial photography, AURORA hyperspectral and IKONOS satellite imagery for the Molokai test area

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

	Image Type	Color	IKONOS	HSI
MAUI	**Color**		0.9990	-0.6166
	IKONOS			-0.0824
	HSI			
MOLOKAI	**Color**		2.6216	-2.3735
	IKONOS			-0.2922
	HSI			
OAHU	**Color**		1.5673	-0.3975
	IKONOS			-1.8923
	HSI			
HAWAII	**Color**		2.0126	0.8084
	IKONOS			-1.1730
	HSI			
OVERALL	**COLOR**		-3.0709	1.4236
	IKONOS			-1.5961
	HSI			

Difference Significant, p<0.05

Table 16. Summary of the probability that photointerpretation of benthic habitat from color aerial photography, hyperspectral and IKONOS Satellite imagery are equivalent: P = 0.05 or less with significant difference highlighted

4.4 Quality Control Performed

During the execution of quality control in this work, 136 field positions were occupied (Table 17). RMS distance was calculated for five quality control parameters and is reported here.

RMS Parameter	RMS Value (meters)	N
Digitizing RMS	0.86	32
Benchmarks Vertical RMS	1.67	30
Benchmarks Horizontal RMS	0.66	30
Occupation of a Waypoint From a Boat	2.1	10
Occupation of a Waypoint on Land	3.4	34

Table 17. Summary of spatial accuracy of GPS and "on screen" digitizing processes.

GPS positions collected for ground control show horizontal and vertical RMS was less than one and two meters respectively, meeting the contract specifications.

All GIS map products generated during this work were delivered free of errors such as multipart, overlapping, sliver and void polygons and were topologically clean. Polygons that were adjacent and had the same zone and habitat attributes were identified and all errors were corrected. Attribution of GIS polygons was conducted seamlessly using the NOAA habitat digitizing extension software thus errors are not expected. GIS data from this work were delivered to NOAA free of errors and an independent review by NOAA confirmed this.

4.5 Records and Metadata

All digital and hard copy records were kept in secure locations and electronic field data were backed up daily to CD ROM. All hand written records were collected daily from subcontractors and other support personnel. Chain of custody records were not needed as all data were maintained in secure custody of ALH at all times.

Where manual entry of information was unavoidable, particular attention was given to control these processes. A hard copy was made of all manual entry and this record was securely archived. Two independent reviews were conducted subsequent to the transfer of the data to the GIS database.

Content Standard Digital Geospatial Metadata (CSDGM) compliant metadata summaries were completed for each GIS shape file. The MetaData Collection Tool V2.0 downloaded from the ESRI web was used to prepare these documents. The metadata records were delivered free of errors in both content and format as determined by the metadata parser (mp) program developed by Peter Schweitzer of the USGS.

All original hand recorded field data have been delivered to the government.

5. Deviations from Contract Requirements

Three priorities were established to complete this work in a timely fashion.

- The collection of GCPs was placed as the first priority as to allow processing of the imagery needed to complete the habitat maps. These data were provided to NOAA and its contractor, G&O, expediently as to minimize the risk of this processing step interfering with map production.

- The second general priority was placed on collection of accuracy assessment habitat characterization data as the weather windows in which this work could be effectively completed were significantly more likely to occur during the late fall and early winter months.

- The third priority was placed on generating the benthic habitat maps from remotely sensed imagery. Accuracy assessment maps were generated first and routine production maps were generated subsequent to those.

In this work all priorities were followed and the 15 contract line item products that were specified in the contract were delivered to the government. Two procedural changes to the original plan were needed but both were minor and did not require contract modification. Neither of these changes resulted in compromise to data quality that was generated in this work.

The first change resulted from unusually severe winter storms that occurred in the Hawaiian Islands during the winter of 2001-2002 after an extended drought period in Hawaii that resulted in difficulties accessing the survey sites. The distribution of the random stratified points of the Molokai accuracy assessment area were adjusted to increase the density on the west end of the study area to compensate for the inaccessibility on the east end due to mud inundation. It was recognized that the habitat type and diversity varies little throughout the test area and this change would not affect the results of the accuracy assessment.

The second change resulted from both the winter storm season and inaccessibility to military bases due to the increased security subsequent to the terrorist attack on the World Trade Center on September 11, 2002 and in one case, an area was not accessible due to remoteness. In these areas it was necessary to extract geographic positions from DOQs instead of field surveys. Contract modification was not needed for this change and the data generated were not compromised. The areas where DOQs were substituted included:

- The southwest side of the Island of Lanai where access was not available due to mudslides and eroded roads that resulted from flash flooding during the winter storms.
- Pearl Harbor and Kaneohe Marine Corp Base on Oahu and the Pacific Missile Range Facility on Kauai due to heightened military security.

- The coastal area northeast of the end of the road at Barking Sands Kauai as it is composed of cliffs over 1,000 feet high that fall precipitously to the ocean. There are no roads into the area.

The GCPs collected by ALH were delivered to G&O and were used to orthorectify the color aerial photography collected by NOAA during the year 2000 Hawaii Mission. The spatial solution obtained by G&O met the NOAA specifications for that work lending further evidence to the acceptable quality of the accuracy of the GCPs generated during this work including those obtained from DOQs.

Though all fieldwork was completed, significant time was lost due to failed attempts. As a result, a contract modification for a no-cost one month extension was requested by ALH and granted by the government

No other difficulties were experienced during this work.

6. Products Delivered

Fifteen contract line item number (CLIN) deliverables were completed, accepted by the government and delivered to complete this contract (Table 18).

CLIN 0001

The kick-off meeting was held at the ALH office on October 2, 2002.

CLIN 0002

All GCPs were collected on time. As the acquisition of GCPs for each Island was completed, it was delivered to the government. This facilitated the orthorectification of the color aerial photography in preparation for benthic habitat map production.

This product included:

- All hand written field data
- Raw GPS Observation Files
    1) Original raw data files from the receiver
    2) Broadcast ephemeris file from the receiver
    3) Message file from the receiver
- Final processed data files
    1) Vector reduction and adjustment was not performed
    2) Verification of positional accuracy
    3) Post processing differential correction files
    4) All files necessary to recreate the project
- Digital files depicting GCP pixel location
    1) Adobe Photoshop (.PSD) for each GCP
    2) Separate annotation layer for each file

Contract Line Item Number	CLIN Description
CLIN 0001	Kick-off meeting (No deliverable required)
CLIN 0002	GPS/GCP Data
CLIN 0003	IKONOS Interpretive Rulemaking Report
CLIN 0004	Test Area Statistical Report
CLIN 0005	Draft Benthic Habitat Map, GIS Data and Accuracy Assessment Points for Niihau
CLIN 0006	Draft Benthic Habitat Map, GIS Data and Accuracy Assessment Points for Kauai
CLIN 0007	Draft Benthic Habitat Map, GIS Data and Accuracy Assessment Points for Lanai and Hawaii
CLIN 0008	Draft Benthic Habitat Map, GIS Data and Accuracy Assessment Points for Oahu
CLIN 0009	Draft Benthic Habitat Map, GIS Data and Accuracy Assessment Points for Molokai
CLIN 0010	Draft Benthic Habitat Map, GIS Data and Accuracy Assessment Points for Maui
CLIN 0011	Final GIS Data (Including Accuracy Assessment Points)
CLIN 0012	METADATA
CLIN 0013	Project Completion Report and Presentation
CLIN 0014	Transmittal Letter
CLIN 0015	Monthly Progress Reports

Table 18. Contract line items delivered during this work

CLIN 0003

The IKONOS Interpretive Rulemaking Report was completed and provided to the government (Appendix A)

CLIN 0004

The Accuracy Assessment Statistical Report was completed and provided to the government (Appendix B)

CLIN 0005 thru 10

Complete draft benthic habitat map products were delivered including:

- ArcView GIS polygon shape file of habitat maps including *.prj file. These included production maps of all data mapped for that island from the NOAA 2000 remote sensing data acquisition mission and accuracy assessment maps for each of the three imagery types for the test areas.
- ArcView GIS accuracy assessment point shape file including *.prj file
- ArcView GIS accuracy assessment point shape file including *.prj file
- Read me file describing the contents of the delivery

CLIN 0011

All GIS data was combined into a single delivery. The CSDGM metadata file was imbedded in each shape file suite. The shipment included:

- Accuracy Assessment GIS data including the files:

  Point themes

  utm zone 4 aa
  utm zone 5 aa

  Polygon themes

  Kbay_color_test_area
  Kbay_HSI_test_area
  Kbay_IKONOS_test_area
  Kona_color_test_area
  Kona_HSI_test_area
  Kona_IKONOS_test_area
  Maui_color_test_area
  Maui_HSI_test_area
  Maui_IKONOS_test_area
  Molokai_color_test_area
  Moloka_HSI_test_area
  Moloka_IKONOS_test_area

- Ground Validation GIS data

  utm_zone_4_gv

- GCP GIS Data

  utm_4_gcps
  utm_5_gcps

- Production Maps

  Niihau_production
  Kauai_production
  Oahu_section_1_production
  Oahu_section_2_production
  Molokai_production
  Maui_production
  Lanai_production
  Hawaii_production

CLIN 0012

CSDGM compliant metadata summaries were prepared for each of these GIS products. Twenty polygon theme summaries were prepared, one each for the polygon themes, and five point theme summaries were prepared, one each for the point themes.

CLIN 0013

This Project Completion Report was completed and accepted by the government. On July 29, 2002 these data were presented to the NOAA NOS Biogeography team at the Silver Spring Maryland NOAA headquarters.

CLIN 0014

A letter of transmittal has been provided with these products.

CLIN 0015

All monthly reports have been prepared by ALH and provided to the government.

7. References

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