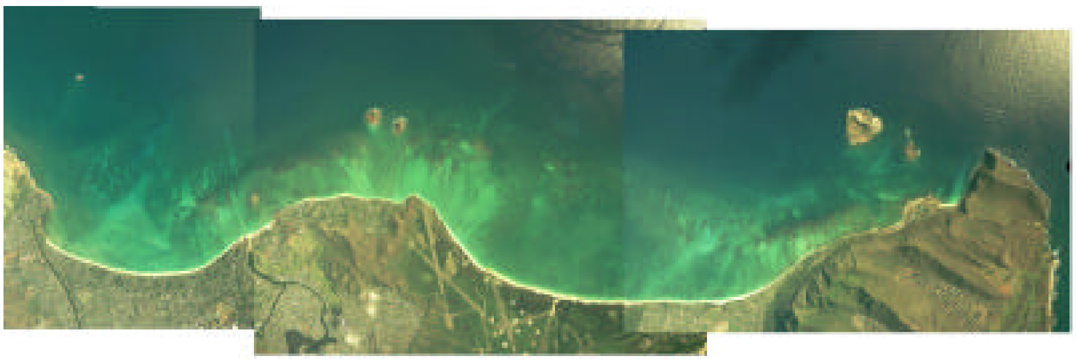
Benthic Habitats of the Hawaiian Islands

A Comparison of Accuracy of Digital Maps Prepared from
Color Aerial Photography and Hyperspectral Imagery

Final Report



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Habitat Abbreviations

AcCr	Aggregate Coral Heads
Artf	Artificial
ColBa	Colonized Basalt and Boulder
ColPv	Colonized Pavement
ColPvSC	Colonized Pavement with Sand Channels
FGDC	Federal Geodetic Data Committee
HCCA	High Density Crustose Coralline Algae (Continuous)
HB	Hard Bottom
HMac	High Density Fleshy Macroalgae (Continuous)
HSeaGr	High Density Seagrass (Continuous)
InCr	Individual Coral Heads
InPtRf	Individual Patch Reef
LCCA	Low Density Crustose Coralline Algae (10% to 50% Cover)
LMac	Low Density Fleshy Macroalgae (10% to 50% Cover)
LSeaGr	Low Density Seagrass (10% to 50% Cover)
MCCA	Medium Density Crustose Coralline Algae (50% to 90% Cover)
MMac	Medium Density Fleshy Macroalgae (50% to 90% Cover)
MSeaGr	Medium Density Seagrass (50% to 90% Cover)
RR	Reef Rubble
SAV	Submerged Aquatic Vegetation
SCRUS	Scattered Coral and Rock in Unconsolidated Sediment
TerR	Terriginous Rubble
UnColBa	Uncolonized Basalt and Boulder
UnColPv	Uncolonized Pavement
UnColPvSC	Uncolonized Pavement with Sand Channels

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 and hyperspectral imagery (HSI) for the near shore waters of the eight Main Hawaiian Islands. The images will be 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 interpreting the remotely collected image data. These benthic habitat maps have been produced by manual delineation of habitats from color aerial photographs and image analysis software applied to color and hyperspectral digital images. In both 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 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. The final scheme that has been adapted for the eight Main Hawaiian Islands was modified only slightly from the parent version developed by NOAA.

The integrated component of the resulting methodology has been developed from a comparative analysis of the accuracy of habitat mapping by color imagery combined with hyperspectral data. These results will be applied in the mapping of the remaining coastlines of the eight Main Hawaiian Islands.

This pilot study includes two areas. The first is 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 and from shore to a depth of 60 feet. The second study area is located in Kaneohe Bay on the island of Oahu. It extends from the Sam Pan Channel on the south end of the bay to Chinaman's Hat on the north end and from shoreline to a depth of 40 feet. Mapping and collection of accuracy validation data have been completed for both study areas and the results of this work are presented here.

II. Approach

A. Development of the Hawaii Benthic Habitat Classification Scheme

A hierarchical classification scheme has been developed to define and delineate coral reef benthic habitats and reef zones. The draft 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

Most important, if a feature (e.g., habitat) cannot be detected or seen in the photographs or hyperspectral imagery or classified by its spectral signature, 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 Colonized Hard Bottom
- Uncolonized Hard Bottom
- Encrusting/Coralline Algae
- Other Delineations

These have been subdivided to include a total of 36 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
        - Spur and Groove
        - Patch Reef (Individual)
        - Patch Reef (Aggregated)
        - Scattered Rock and Coral in Unconsolidated Sediment
        - Coral Head (Individual)
        - Coral Head (Aggregated)
        - Colonized Pavement
        - Colonized Volcanic Rock/Boulder
        - Colonized Pavement with Sand/Surge Channels
        - Colonized Island Vertical Walls

- Uncolonized Hard Bottom
    - Reef Rubble
    - Uncolonized Pavement
    - Uncolonized Volcanic Rock/Boulder
    - Uncolonized Pavement with Sand Channels
    - Uncolonized Island Vertical Wall
- 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
- Mangrove/Hau
- Artificial
- Dredged
- Cultural
- Military
- Terriginous Rubble
- Ship Groundings
- Reef Hole
- Unknown

The Zones have been developed as:

- Island Vertical Wall
- Shoreline Intertidal
- Reef Flat
- Back Reef
- Reef Crest
- Fore Reef
- Shelf
- Shelf Escarpment
- Unknown

B. Habitat Map Accuracy Validation

Recognizing that the purpose of this study is to determine the relative accuracy of maps generated from photointerpretation of color aerial photography and hyperspectral imagery, a photointerpretation accuracy assessment system has been designed and executed to quantify this comparison. For the purpose of validation of the photointerpretation, methods have been applied that have been developed by other researchers (Hudson and Ramm 1987, Congalton, 1991). Rosenfield et al. (1982) have 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 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 applying the Z test wherein the photointerpreter's determination is assigned a probability that it occurred at random.

The assessment of determining the accuracy of photointerpretation of each habitat type is conducted in a similar way. However, this introduces the possibility of comparing the number correct by dividing by the total of the column (producer's accuracy) or dividing by the total of the row (user's accuracy). In this assessment both analysis methods have been employed. It is, however, recognized that the producer's accuracy has been indicative of how well a certain area can be classified (the probability of a reference pixel being correctly classified). Therefore, for the purpose of this analysis, it is suggested that producer's accuracy be considered the most representative of the two methods.

Coral reef benthic habitat field validation assessments have been completed for both the Kona and Kaneohe Bay pilot study areas as ground truth to establish the accuracy of maps produced from color aerial photography and hyperspectral image interpretation. An attempt to collect at least fifty points within the major habitat categories that existed in the study areas was made.

C. 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 lend themselves to distinct advantages. Productivity is higher and by developing an active link between the mapped image and the associated database a GIS is generated. The applications of GIS provide 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 Validation Data Collection

A random geographic referenced point file was created for both the Kona and Kaneohe Bay pilot study areas (Figures 1 and 2). 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. A polygon of the study area was digitized from a georeferenced NOAA navigational chart and a coastline shape file obtained from the Hawaii Department of Aquatic Resources (HDAR) GIS web site. These were projected in the appropriate UTM Zone on WGS 84 datum and MSL altitude. The extent of the Kona study area polygon included the north end of Kawaihae Harbor to the south end of Kiholo Bay and from shore to a depth of 60 feet. The Kaneohe study area was delineated on the north end by Chinaman's Hat and the southern end by the Sam Pan Channel. The area was defined by depth contours from the shoreline to 40 feet.

Three sets of random points were generated within the polygon of the Kona study area. The first set contained 200 points and the second and third each contained 100 points. Point and area benthic habitat assessments were conducted at each location in the first set. Upon completion of the first set, the data were examined and habitat types that needed additional surveys were identified. The second and third sets of points were subset to meet these needs and 304 benthic habitat assessments were completed. In Kaneohe Bay, a total of 500 random points were developed and habitat assessments were successfully completed at 393 of these.

Waypoint files were generated and all points that could be safely accessed were navigated to using a Trimble GeoExplorer 3 GPS data logger. 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. The benthic habitat assessment was made using a glass bottom look box, diving or observing from the surface. In areas where waves and sea conditions were prohibitive to using these methods the GPS was placed in a watertight box and swam to the survey point.

All point data were recorded on the GPS data logger using a custom data dictionary designed to meet the specifications of the Coral Reef Habitat Classification Scheme. Area data were entered in waterproof notebooks and transferred to the GIS by hand. Extensive underwater video was collected and video capture was used to create a visual record of habitat types.

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, during the Kona survey, a GPS position was collected at the pier at Kawaihae Harbor 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 data 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.

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 letters to distinguish them from the random point assessments, which were assigned numerical site identifiers.

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 comparison of the ability to photointerpret benthic habitat types from color aerial photography and hyperspectral imagery.

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 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. 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. Optimum band combinations were selected which reveal benthic habitat information and the scenes were converted into RGB composites. The scenes were then georeferenced to UTM Zone 5 on WGS 84 datum and mosaiced using Scene Stitcher, a stand-alone software program produced by Applied Power Technologies, Inc. (APTI). The mosaics were then imported to the ArcView GIS system where manual delineation of habitat boundaries was undertaken based on photointerpretation.

F. Benthic Habitat Map Preparation

The coral reef benthic habitat maps of the study area have been digitized by delineating photointerpreted habitat boundaries from the imagery provided to the contractor by NOAA. As ESRI ArcView GIS software has been 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 maps presented here.

NOAA supplied georeferenced color aerial photography of the Kona survey site to ALH. The georeferenced digital photos were provided as discrete non-mosaiced files. This format allowed the contractor to substitute individual images to take advantage of optimal visibility of reef features and extract the most habitat information. The raw hyperspectral data were processed by the ALH contractor as described above and habitat maps were then produced using the same methods used to generate habitat maps from the color aerial photography.

All delineation of 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 Gulf of Mexico, that little additional information is gained from having the image at a closer 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.

Comparison of the photointerpretation of the two types of remotely sensed data has been conducted. Discrete multivariate analysis has been applied to the results, as have other simple comparisons of correct vs. incorrect calls.

IV. Results

A. Accuracy Validation Data Collection

A total of 304 GPS positions were recorded during the accuracy validation data acquisition of the Kona pilot study area (Figure 1). At the Kaneohe Bay pilot study area, 393 GPS positions were recorded (Figure 2). The total number of detailed and major habitats visited during this tenure for both survey areas is also presented (Table 2). These include the random points, control points and areas of interest. As the details of the habitat data are too extensive to present here, summaries have been made below. An ArcView shape file and Excel spreadsheet containing the details of these data are included on the enclosed CD-ROM. All data were collected as planned.

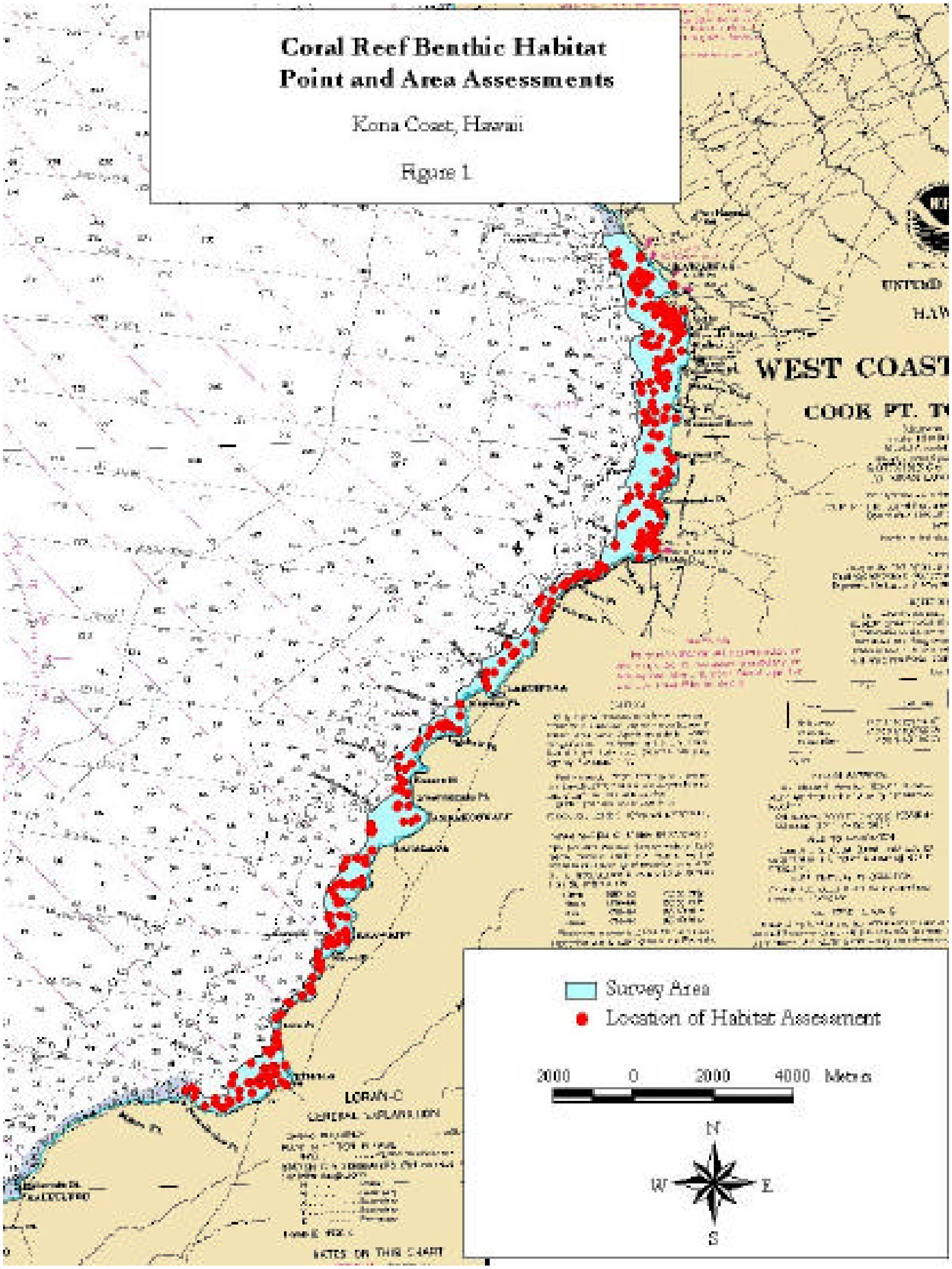
B. Benthic Habitat Map Preparation

Habitat maps were prepared from both color aerial photography and hyperspectral imagery and samples of the habitat maps are presented (Figures 3, 4, 5 and 6). These maps are also included on the enclosed CD-ROM in GIS format. The extent of correct vs. incorrect habitat interpretations is also presented and is organized to illustrate the extent of correctness of photointerpretation of coral reef habitat types for both detailed and major habitat classifications. Validation of photointerpretation of detailed coral reef habitats using color aerial photography and hyperspectral data are presented for Kona and Kaneohe Bay respectively (Tables 3, 4, 8 and 9). Validation of photointerpretation of major coral reef habitats using color aerial photography and hyperspectral imagery are also presented for Kona and Kaneohe Bay respectively (Tables 5, 6, 10, and 11).

C. Comparison of Results

These tables have been summarized along with the Kappa and Tau Statistic for the major habitat types for each pilot study area providing a simple overview of the estimated accuracy of the two methods (Tables 7 and 12). From Table 7 it can be seen that the overall accuracy of photointerpretation of detailed coral reef habitats from color aerial photography and hyperspectral imagery is 83.5% and 81.4% respectively at the Kona pilot study area. It can also be seen that the overall accuracy of photointerpretation of major coral reef habitats from color aerial photography and hyperspectral imagery is 93.9% and 92.4% respectively in the same area. From Table 12 it can be seen that in Kaneohe Bay the overall accuracy of photointerpretation of detailed coral reef habitats from color aerial photography and hyperspectral imagery is 72.9% and 75.8% and the overall accuracy of photointerpretation of major coral reef habitats from color aerial photography and hyperspectral imagery is 86.0% and 87.0% respectively in that area.

The result of Z analysis, a probability representing the confidence that there is no difference between the accuracy of the maps from photointerpretation of color aerial photography and hyperspectral imagery, is also included in Table 7 and 12. For both pilot study areas, the result of the comparison yields a Z value of less than 1.96, the value below which no statistical difference exists within a 95% confidence interval.


Coral Reef Benthic Habitat
Point and Area Assessments
Kona Coast, Hawaii
Figure 1
WEST COAST
COOK PT. T
Survey Area
Location of Habitat Assessment
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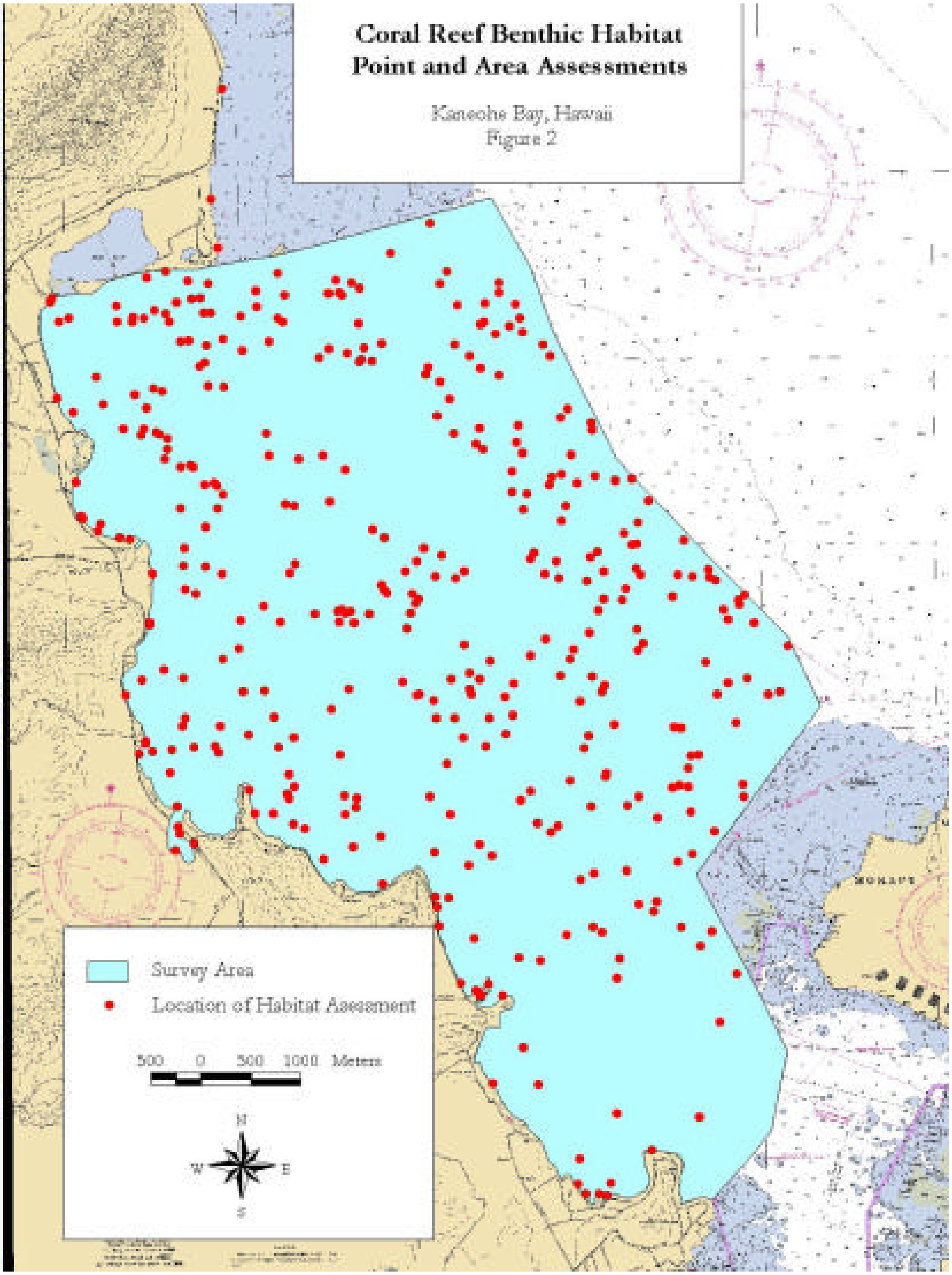
Coral Reef Benthic Habitat
Point and Area Assessments
Kaneohe Bay, Hawaii
Figure 2
Survey Area
Location of Habitat Assessment
500 0 500 1000 Meters
N
W
E
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Table 1. Data collected at each random site during benthic habitat classification surveys

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 Kona and Kaneohe Bay

Habitat Type (Major Habitats in Bold Face Type)	Survey Area Kona	Survey Area KBay	Total (Major Habitat)	Total (Detailed Habitat)
Unconsolidated Sediment	**99**	**95**	**194**	
Sand	98	45		143
Mud	1	50		51
Submerged Aquatic Vegetation	**4**	**81**	**85**	
Seagrass (10%-50%)	3	4		7
Seagrass (50%-90%)	1	0		1
Seagrass (Continuous)	0	0		0
Macroalgae (10%-50%)	0	65		65
Macroalgae (50%-90%)	0	9		9
Macroalgae (Continuous)	0	3		3
Coral Reef and Col. HB	**144**	**100**	**244**	
Linear Reef	0	0		0
Spur and Groove	4	0		4
Patch Reef (Individual)	0	6		6
Patch Reef (Aggregated)	0	0		0
Scattered C/R in Unconsol. Sed.	0	0		0
Coral Head (Individual)	5	11		16
Coral Head (Aggregated)	68	15		83
Colonized Pavement	11	29		40
Col. Volcanic Rock/Boulder	55	0		55
Col. Pav. With Sand Surge Chan.	1	39		40
Col. Island Vertical Walls	0	0		0
Uncolon. Hardbottom	**21**	**68**	**89**	
Reef Rubble	5	10		15
Uncol. Pavement	0	55		55
Uncol. Volcanic Rock/Boulder	16	0		16
Uncol. Pavement w/Sand Chan.	0	3		3
Uncol. Island Vertical Wall	0	0		0
Encrust. Coralline Algae	**17**	**13**	**30**	
Coralline Algae (10%-50%)	7	13		20
Coralline Algae (50%-90%)	8	0		8
Coralline Algae (Continuous)	2	0		2

Figure 3. North End of Kona Coral Reef Benthic Habitat Map Prepared from Photointerpretation of Color Aerial Photography

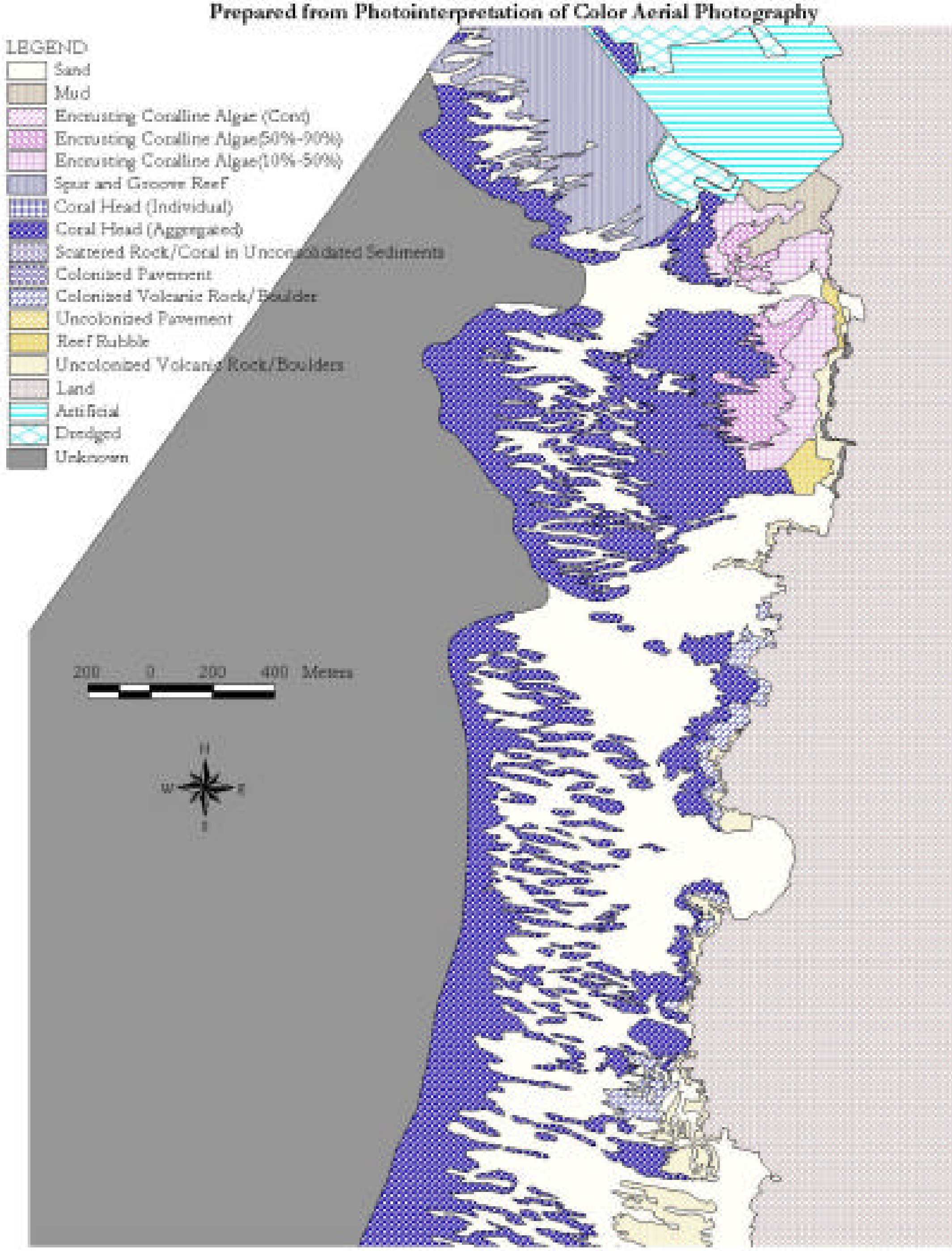

Figure 4. North End of Kona Coral Reef Benthic Habitat Map Prepared from Photointerpretation of Hyperspectral Imagery

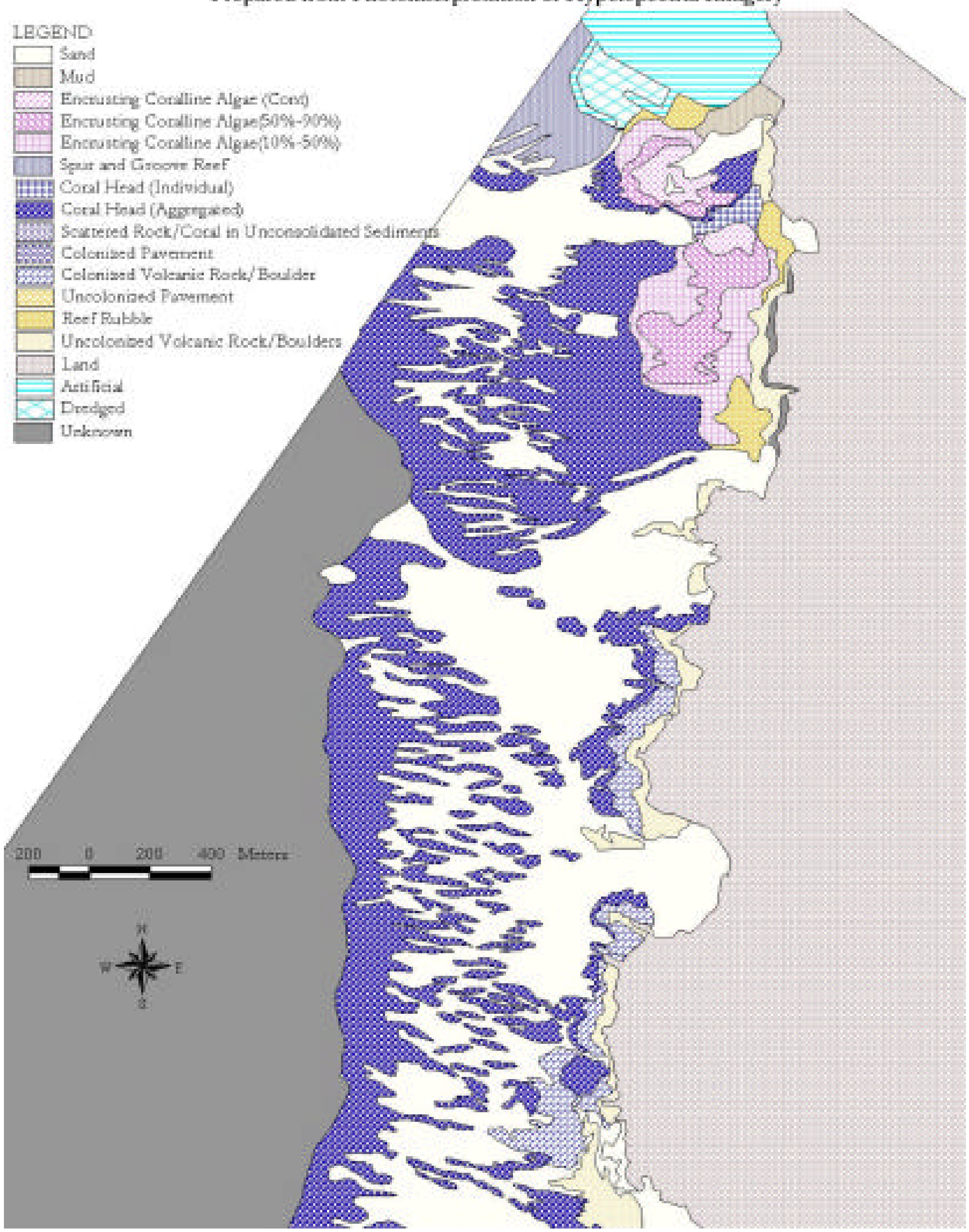

Figure 5. Coral Reef Benthic Habitat Map of Kaneohe Bay Prepared from Photointerpretation of Color Aerial Photography

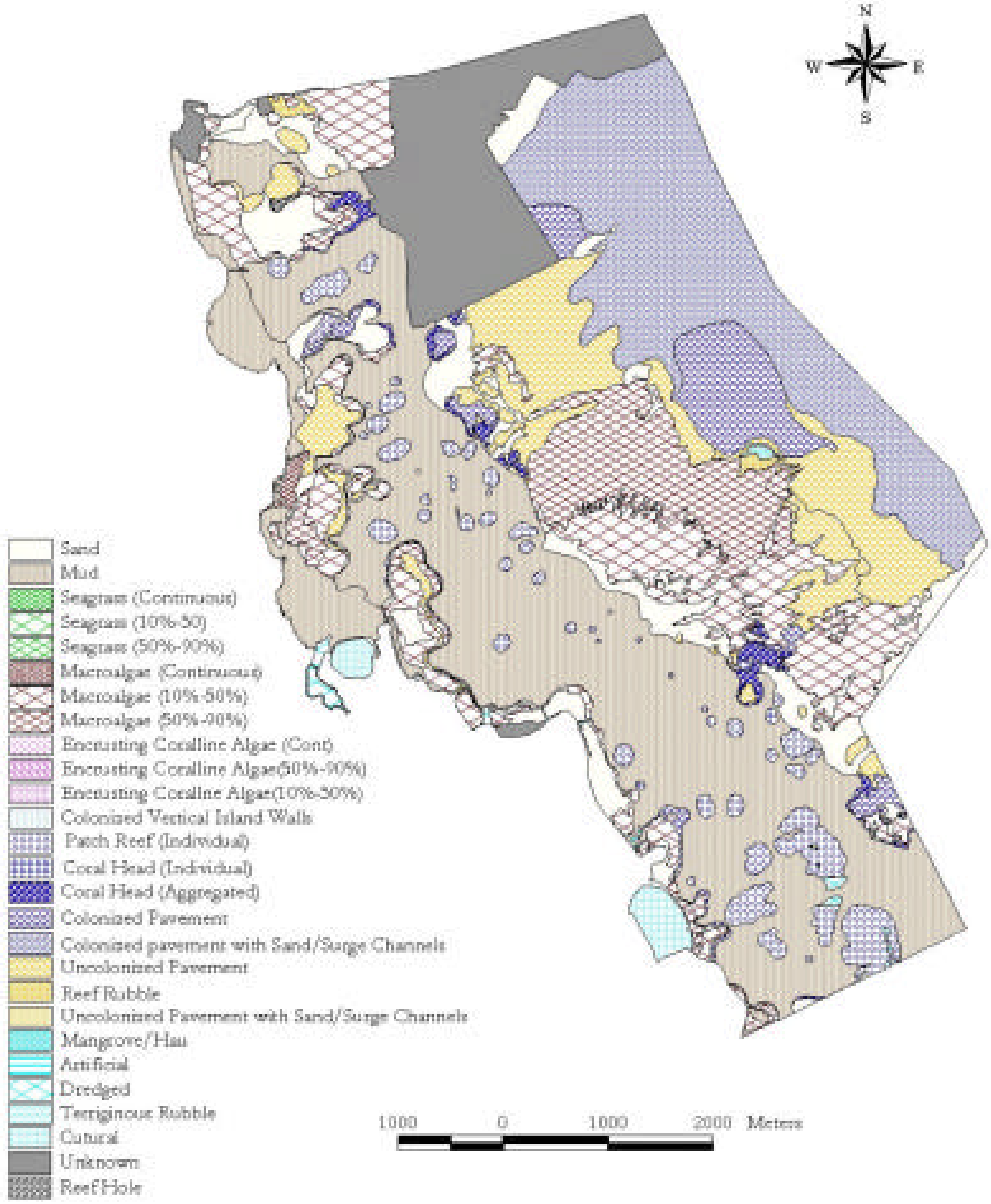

Figure 6. Coral Reef Benthic Habitat Map of Kaneohe Bay Prepared from Photointerpretation of Hyperspectral Imagery

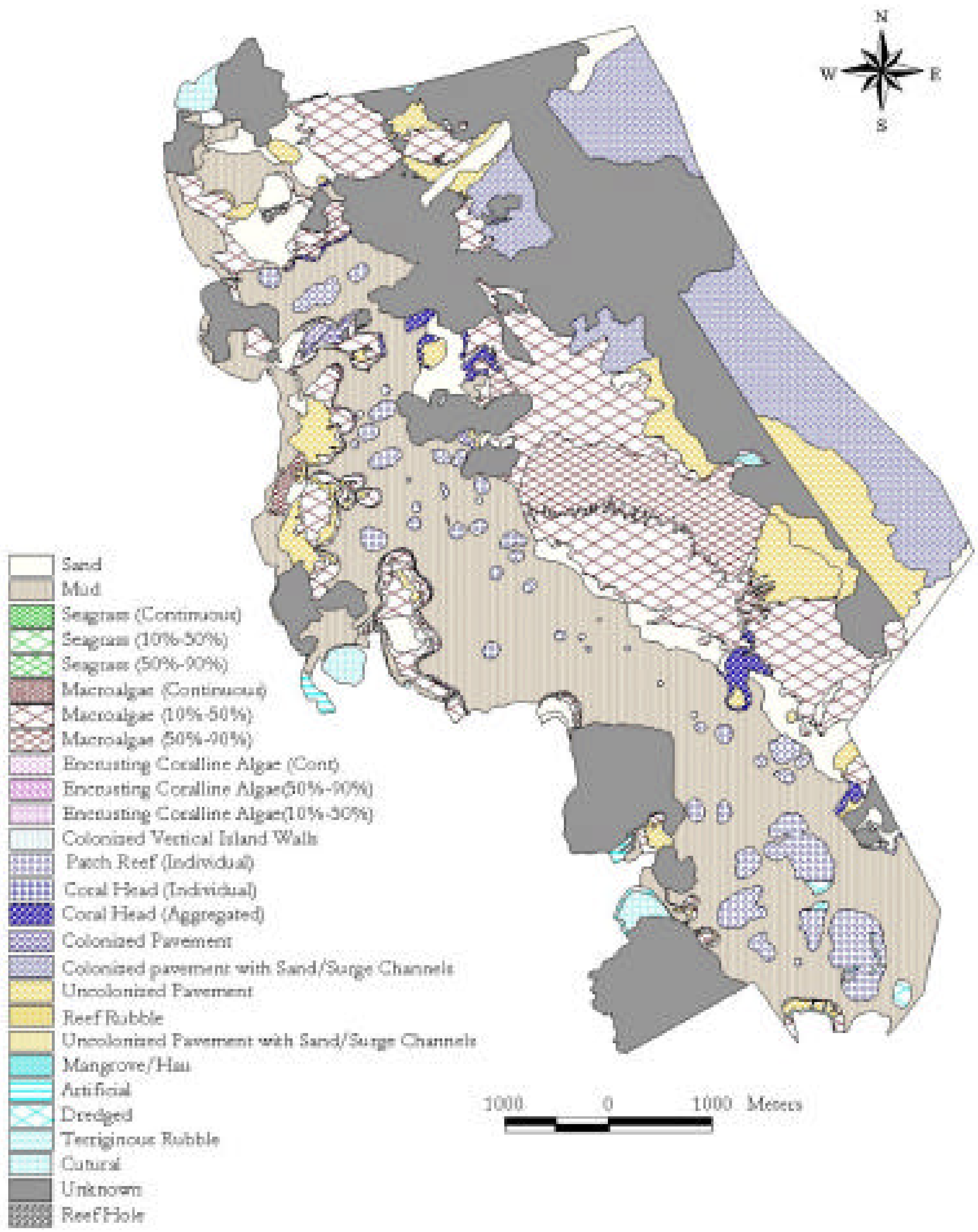

Table 3. Validation of photointerpretation of detailed coral reef habitats using color aerial photography of the Kona survey site

	Ground Truth Detailed Habitats for Kona Site														**Row Totals**	**User's Accuracy**
	Sand	Mud	SandG	InCr	AgCr	ColPv	ColBa	ColPvSC	UnColBa	LCCA	MCCA	HCCA	Artf	Dredged		
Sand	**51**	0	0	0	1	0	0	0	0	0	0	0	0	0	**52**	98%
Mud	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	100%
SandG	0	0	**11**	0	0	0	0	0	0	0	0	0	0	0	**11**	100%
InCr	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	**0**	NA
AgCr	4	0	0	0	**82**	4	16	0	0	0	1	0	0	0	**107**	77%
ColPv	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	**0**	NA
ColBa	3	0	0	2	2	0	**50**	0	2	0	0	0	0	0	**59**	85%
ColPvSC	0	0	0	0	1	0	0	**1**	0	0	0	0	0	0	**2**	50%
UnColBa	1	0	0	0	0	0	4	0	**21**	0	0	0	0	0	**26**	84%
LCCA	0	0	0	0	1	0	0	0	0	**1**	1	0	0	0	**3**	33%
MCCA	0	0	0	0	0	0	0	0	0	1	**5**	2	0	0	**8**	63%
HCCA	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	**0**	NA
Artf	0	0	0	0	0	0	0	0	0	0	0	0	**7**	0	**7**	100%
Dredged	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**	**3**	100%
Column Totals	**59**	**1**	**11**	**2**	**87**	**4**	**70**	**1**	**23**	**2**	**7**	**2**	**7**	**3**	**279**	
Producer's Accuracy	88%	100%	100%	NA	94%	NA	71%	100%	91%	50%	71%	NA	100%	100%		

Overall Accuracy: 83.3%

Table 4. Validation of photointerpretation of detailed coral reef habitats using hyperspectral imagery of the Kona survey site

	Ground Truth Detailed Habitats for Kona Site														Row Totals	User's Accuracy
	Sand	Mud	SandG	InCr	AgCr	ColPv	ColBa	ColPvSC	UnColBa	LCCA	MCCA	HCCA	Artf	Dredged		
Sand	**49**	0	0	0	0	0	0	0	0	0	0	0	0	0	**49**	100%
Mud	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	100%
SandG	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	**1**	100%
InCr	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	**0**	NA
AgCr	4	0	0	2	**72**	4	8	0	0	1	1	0	0	0	**92**	78%
ColPv	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	**0**	NA
ColBa	4	0	0	0	6	0	**59**	0	2	0	0	0	0	0	**71**	83%
ColPvSC	1	0	0	0	1	0	0	**1**	0	0	0	0	0	0	**3**	33%
UnColBa	1	0	0	0	1	0	4	0	**21**	0	0	0	0	0	**27**	75%
LCCA	0	0	0	0	1	0	0	0	0	**1**	2	0	0	0	**4**	25%
MCCA	0	0	0	0	0	0	0	0	0	1	**1**	3	0	0	**5**	17%
HCCA	0	0	0	0	0	0	0	0	0	0	2	**0**	0	0	**2**	NA
Artf	0	0	0	0	0	0	0	0	0	0	0	0	**7**	0	**7**	100%
Dredged	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	100%
Column Totals	**59**	**1**	**1**	**2**	**81**	**4**	**71**	**1**	**23**	**3**	**6**	**3**	**7**	**1**	**263**	
Producer's Accuracy	82%	100%	100%	NA	88%	NA	83%	100%	91%	33%	17%	NA	100%	100%		

Overall Accuracy: 81.4%

Table 5. Validation of photointerpretation of major coral reef habitats using color aerial photography of the Kona survey site

Color Aerial Photo Interpretation Major Habitats	**Ground Truth Major Habitats**						**Total Classified**	**User's Accuracy**
	Unconsol. Sed.	Submerged Aquat. Veg.	Coral Reef & Col HB	Uncol. Hard-bottom	Encrust. Coralline Algae	Other Delineations		
Unconsolidated Sediments	**52**	0	1	0	0	0	53	**93%**
Submerged Aquatic Vegetation	0	**0**	0	0	0	0	0	**NA**
Coral Reef & Col. HB	7	0	**169**	2	1	0	179	**94%**
Uncolonized Hardbottom	1	0	4	**21**	0	0	26	**75%**
Encrust. Coralline Algae	0	0	1	0	**10**	0	11	**91%**
Other Delineations	0	0	0	0	0	**10**	10	**100%**
Total Ground Truth Points	60	0	175	23	11	10	**279**	**NA**
Producer's Accuracy	**84%**	**0%**	**96%**	**96%**	**91%**	**100%**	**NA**	

Overall Accuracy: 93.9%

Table 6. Validation of photointerpretation of major coral reef habitats using hyperspectral imagery of the Kona survey site

Hyperspectral Image Interpretation Major Habitats	**Ground Truth Major Habitats**						**Total Classified**	**User's Accuracy**
	Unconsol Sed	Submerg Aquat Veg	Coral Reef & Col HB	Uncol Hard-bottom	Encrust. Coralline Algae	Other Delineations		
Unconsolidated Sediments	**50**	0	0	0	0	0	50	**94%**
Submerged Aquatic Vegetation	0	**0**	0	0	0	0	0	**NA**
Coral Reef & Col. HB	9	0	**154**	2	2	0	167	**92%**
Uncolonized Hardbottom	1	0	4	**21**	0	0	26	**75%**
Encrust. Coralline Algae	0	0	2	0	**10**	0	12	**83%**
Other Delineations	0	0	0	0	0	**8**	8	**100%**
Total Ground Truth Points	60	0	160	23	12	8	**263**	**NA**
Producer's Accuracy	**81%**	**0%**	**96%**	**91%**	**83%**	**100%**	**NA**	

Overall Accuracy: 92.4%

Table 7. Summary of accuracy of photointerpretation of detailed and major coral reef habitats at the Kona Survey site

Statistic	Color	Hyperspectral
Overall Accuracy Detailed Habitat Types	83.5%	81.4%
Overall Accuracy Major Habitat Types	93.9%	92.4%
Kappa Statistic	0.89	0.86
Tau Statistic	0.89	0.87
Z Analysis = 0.81	Probability that photointerpretation of coral reef habitat from Color and HSI data are equivalent: P = 0.05 or less	

A similar examination has been conducted that yields these statistics comparing the accuracy of habitat maps prepared from photointerpretation of color aerial photography and hyperspectral imagery for the two study sites combined (Table 13). It can be seen that the overall accuracy of photointerpretation of detailed coral reef habitat maps prepared from color aerial photography and hyperspectral imagery is 77.6% and 78.6% respectively and that for the major coral reef habitat maps it is 89.6% and 89.7% respectively.

The result of Z analysis for the combined data sets yields a value of 0.149. This value is considerably less than 1.96 below which no statistical difference exists within a 95% confidence interval.

Table 8. Validation of photointerpretation of detailed coral reef habitats using color aerial photography of the Kaneohe Bay survey site

	Ground Truth Detailed Habitats for Kaneohe Bay Site																**Row Totals**	**User's Accuracy**
	AgCr	Artf	ColPv	ColPvSC	Dredged	HMac	InPtRf	LCCA	LMac	LSeaGr	MMac	Mud	RR	SAND	UnColPv	UnColPvSC		
AgCr	**5**																**5**	100%
Artf		**4**			5												**9**	44%
ColPv			**11**								1				8		**20**	55%
ColPvSC			13	**51**											1	3	**68**	75%
Dredged					**0**												**0**	NA
HMac						**1**											**1**	100%
InPtRf							**14**										**14**	100%
LCCA								**5**									**5**	100%
LMac									**37**		1			1	10		**49**	76%
LSeaGr										**0**							**0**	NA
MMac						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**	**5**	**24**	**52**	**5**	**3**	**14**	**7**	**62**	**3**	**8**	**63**	**1**	**27**	**41**	**5**	**329**	
Producer's Accuracy	56%	80%	46%	98%	NA	33%	100%		60%	0%	75%	98%	0%	89%	44%	40%		

Overall Accuracy: 72.9%

Table 9. Validation of photointerpretation of detailed coral reef habitats using hyperspectral imagery of the Kaneohe Bay survey site

	Ground Truth Detailed Habitats for Kaneohe Bay Site																Row Totals	User's Accuracy
	AgCr	Artf	ColPv	ColPvSC	Dredged	HMac	InPtRf	LCCA	LMac	LSeaGr	MMac	Mud	SAND	TerR	UnColPv	UnColPvSC		
AgCr	**4**								1		1						**6**	67%
Artf		**7**			1												**8**	88%
ColPv			**4**														**4**	100%
ColPvSC			14	**30**											1		**45**	67%
Dredged					**1**												**1**	100%
HMac						**1**											**1**	100%
InPtRf							**14**										**14**	100%
LCCA								**6**									**6**	100%
LMac			1						**45**	1	1		3		16		**67**	67%
LSeaGr										**0**							**0**	NA
MMac									13		**4**				1		**18**	22%
Mud								1				**57**	1				**59**	97%
SAND										1			**17**		1		**19**	89%
TerR														**1**			**1**	100%
UnColPv			1	1					4		1				**10**		**17**	59%
UnColPvSC																**3**	**3**	100%
Column Totals	**4**	**7**	**20**	**31**	**2**	**1**	**14**	**7**	**63**	**2**	**7**	**57**	**21**	**1**	**29**	**3**	**269**	
Producer's Accuracy	100%	100%	20%	97%	50%	100%	100%	86%	71%	0%	57%	100%	81%	100%	34%	100%		

Overall Accuracy: 75.8%

Table 10. Validation of photointerpretation of major coral reef habitats using color aerial photography of the Kaneohe Bay survey site

Color Aerial Photo Interpretation of Major Habitats	**Ground Truth Major Habitats**						**Total classified**	**User's Accuracy**
	Unconsol. Sediments	Submerged Aquat. Veg.	Coral Reef & Col. HB	Uncolon. Hardbottom	Encrust. Coralline Algae	Other Delineations		
Unconsolidated Sediments	**88**	5	1	1	2	1	98	**90%**
Submerged Aquatic Vegetation	1	**66**	0	13	0	0	80	**83%**
Coral Reef & Col. HB	0	0	**94**	12	0	0	106	**89%**
Uncolonized Hardbottom	1	5	4	**21**	0	0	31	**68%**
Encrust. Coralline Algae	0	0	0	0	**5**	0	5	**100%**
Other Delineations	0	0	0	0	0	**9**	9	**100%**
Total Ground Truth Points	90	76	99	47	7	10	**329**	**NA**
Producers Accuracy	**98%**	**87%**	**95%**	**45%**	**71%**	**90%**	**NA**	

Overall Accuracy 86.0%

Table 11. Validation of photointerpretation of major coral reef habitats using hyperspectral imagery of the Kaneohe Bay survey site

Hyperspectral Imagery Interpretation of Major Habitats	**Ground Truth Major Habitats**						**Total classified**	**User's Accuracy**
	Unconsol. Sediments	Submerged Aquat. Veg.	Coral Reef & Col. HB	Uncolon. Hardbottom	Encrust. Coralline Algae	Other Delineations		
Unconsolidated Sediments	**66**	0	0	2	2	0	**70**	**94%**
Submerged Aquatic Vegetation	0	**6**	0	0	0	0	**6**	**100%**
Coral Reef & Col. HB	0	0	**10**	0	0	0	**10**	**100%**
Uncolonized Hardbottom	1	0	0	**65**	17	3	**86**	**76%**
Encrust. Coralline Algae	2	0	0	5	**12**	0	**19**	**63%**
Other Delineations	0	1	0	1	1	**75**	**78**	**104%**
Total Ground Truth Points	**69**	**7**	**10**	**73**	**32**	**78**	**269**	**NA**
Producers Accuracy	**96%**	**86%**	**100%**	**89%**	**38%**	**96%**	**NA**	

Overall Accuracy: 87.0%

Table 12. Summary of accuracy of photointerpretation of detailed and major coral reef habitats at the Kaneohe Bay survey site

Statistic	Color	Hyperspectral
Overall Accuracy Detailed Habitat Types	72.9%	75.8%
Overall Accuracy Major Habitat Types	86.0%	87.0%
Kappa Statistic	0.81	0.83
Tau Statistic	0.82	0.83
Z Analysis = 0.40	Probability that photointerpretation of coral reef habitat from Color and HSI data are equivalent: P = 0.05 or less	

Table 13. Summary of accuracy of photointerpretation of detailed and major coral reef habitats for both the Kona and Kaneohe Bay survey sites combined

Statistic	Color	Hyperspectral
Overall Accuracy Detailed Habitat Types	77.6%	78.6%
Overall Accuracy Major Habitat Types	89.6%	89.7%
Kappa Statistic	0.85	0.85
Tau Statistic	0.86	0.86
Z Analysis = 0.149	Probability that photointerpretation of coral reef habitat from Color and HSI data are equivalent: P = 0.05 or less	

V. Discussion

Remotely sensed data have been used in developing management strategies for natural resources in terrestrial ecosystems for many years. These same tools are now being applied to mapping and monitoring of living marine resources. Much of this interest is fostered by the escalation of concern of depletion of marine resources on a global scale. As coral reefs are among the most productive of these resources and are integrated into nearly every aspect of the reproduction, feeding and growth to maturity within the entire ecosystem, remote sensing has been demonstrated to be an invaluable management tool. The methods yield vast amounts of habitat related information over large geographic areas. New technology is being developed in ongoing research and development programs that resolve the difficulties encountered when these traditionally terrestrial methods were first applied to marine systems. In recent years the utility of advanced spectral processing of imagery has been closely examined. When extracting marine habitat information from traditional color photography, the methods have been primarily limited to photointerpretation. However, with the development of techniques that include a large number of spectral bands from which to choose, the potential to select spectral data that are upwelled from specific habitat types is being realized. Significant progress is being made in reducing the water column effects that have previously interfered with these determinations.

With automated classification of habitat maps from algorithmic processing using spectral libraries being developed, we are still obligated to remain conservative. It is recognized that in a worst case scenario, the least sophisticated method of extracting habitat information from remotely sensed data must be retained until it has been demonstrated to be completely obsolete. Photointerpretation of “0” level processed data must therefore be retained as an option as the more sophisticated methods are being refined. This study addresses the accuracy with which a photointerpreter delineates coral reef habitat using color aerial photography and RGB composites of 72 band hyperspectral imagery.

Both remotely sensed data sets collected by NOAA for the Kona study site are excellent. Environmental conditions were ideal at the time the data were collected. Wind was light, the sky cloudless, swell size very small and water clarity good. All conditions considered this was an excellent opportunity to conduct this work with minimal variables. Furthermore, as the color aerial photography and hyperspectral imagery were collected simultaneously from the same aircraft, many other variables were controlled that would have otherwise introduced uncertainties.

Several logistic factors resulted in the color aerial photography and hyperspectral imagery being collected in separate missions for the Kaneohe Bay survey area. Conditions were less favorable when the hyperspectral data were collected with more cloud cover, obscuring portions of the coral reef habitat that was visible in the color photographs. While this resulted in an increase in the area designated as “unknown” on the map, the statistical difference in accuracy assessment was not significantly affected.

Acquisition of field accuracy assessment data proceeded flawlessly. 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 habitat assessments. During the field survey, the contractor conducted general observations correlating habitat type with information in the images and managed navigational data quality and data base management.

Both data sets were adequately georeferenced and the mosaic software supplied by APTI stitched the hyperspectral imagery data into seamless backdrops with specific bands selected to enhance deep-water features and a separate set of bands to enhance shallow water features. Production of GIS maps of benthic coral reef habitat was considerably streamlined by the NOAA ArcView Habitat Digitizing Extension. Throughout the project, the extension was refined and the final version is user friendly and easily modified to meet the demanding requirements of the needs of particular projects.

The CRAMP team conducted validation of the maps based on determination of the correctness of each polygon class judged by the field accuracy assessment data. Several instances occurred where it was apparent that the minimum mapping unit of one acre resulted in false negative determinations. This occurs when a random field assessment falls on a habitat area that qualifies for the field assessment of seven-meter diameter but does not qualify for delineation of a GIS polygon, as it is less than the MMU. In these cases, though the data were not deleted from the database, the assessment was not included in the determination of accuracy.

It will also be noted that the number of points, which were used in the final assessment of accuracy, was 279 for the color aerial photography and 263 for the hyperspectral imagery data for the Kona site and 329 for color aerial photography and 269 for the hyperspectral imagery for the Kaneohe Bay site. The slightly reduced number of points for the hyperspectral imagery accuracy data set results as the extent of the boundary of the hyperspectral imagery data does not include an area of the color photography on the north end of the study area for Kona and due to cloud cover in the hyperspectral imagery of Kaneohe Bay. The statistical analysis was not corrupted by this difference.

Of particular interest is that the hyperspectral imagery data, even at level “0” processing, resolves reef features in deeper water than color photography. This observation was made at the Kona survey site as the remote sensing data for the Kaneohe Bay site was all in water with depth less than 40 feet and was therefore not suitable for this examination. Also, the benthic habitat assessment field survey that was conducted at the Kona site was restricted to a maximum of 60 feet for diving safety purposes. As a result, the deep reef features visible in hyperspectral data were not surveyed for benthic habitat type. Based on the bathymetry from NOAA navigational charts for that coastline, it was estimated that the depth of benthic habitat detection using hyperspectral data was 100 feet or more and that the color aerial photography limit for these conditions was approximately 60 feet. Using the spatial analysis capabilities the ArcView GIS format habitat maps produced during this tenure, it was shown that the coral reef habitat that was mapped was 25% greater for hyperspectral data than color aerial photography at the Kona survey site.

VI. Conclusion

A comparison of accuracy of coral reef benthic habitat maps generated from photointerpretation of color aerial photography and AURORA HSI collected for two pilot study areas in the Main Hawaiian Islands has been completed. The results of the comparison show that for both study sites independently, as well as combined, there is no statistical difference in the accuracy of the mapping products.

VII. Products Delivered

The GIS maps and accuracy assessment data prepared in this effort have been provided as hard copy output in this report and also as digital data on the enclosed CD-ROM.

ArcView GIS data are located in the "GIS Data" directory. These files include the *.prj file for the convenience of other users of these data. The files include:

1. ArcView shape file of the benthic habitat map generated from photointerpretation of color aerial photography of the Kona Coast
2. ArcView shape file of the benthic habitat map generated from photointerpretation of hyperspectral imagery of the Kona Coast
3. Accuracy assessment database for the Kona Coast
4. ArcView shape file of the benthic habitat map generated from photointerpretation of color aerial photography of Kaneohe Bay
5. ArcView shape file of the benthic habitat map generated from photointerpretation of hyperspectral imagery of Kaneohe Bay
6. Accuracy assessment database for Kaneohe Bay

Also on the CD-ROM is a directory of selected underwater photographs that were taken of representative habitat types within the study areas. Each photograph includes the unique site ID and habitat type and thus can be referenced to its geographic location in the GIS. These have been stored in the CD-ROM in the "UW Photos" directory.

Other important files needed to view the maps in ArcView GIS software have been included in the "Digitizer Extension Files" directory. They include:

1. Habitat classification scheme prepared in the habitat map digitizing extension
2. Blank habitat legend file
3. Filled habitat legend file
4. Blank zone legend file
5. Filled zone legend file

The details of the error assessment for each study site and for the sites combined are provided in the "Error Assessment Files" directory.

A metadata file has been provided for each of the line files produced during this tenure. These are in FGDC format and are located in the Metadata file directory on the CD-ROM.

VIII. References

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