Mapping of Benthic Habitats of

Palau

Project Completion Report

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NOAA

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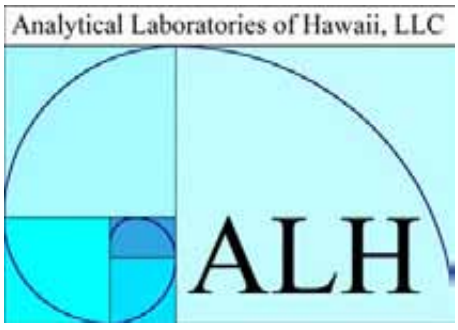


Outline

Figures

Tables

Lookup table for habitat abbreviations from error matrices

Biological Cover	LCoral	Coral 10% - <50%
	MCoral	Coral 50% - <90%
	HCoral	Coral 90% - 100%
	LSeaGr	Seagrass 10%-<50%
	MSeaGr	Seagrass 50%-<90%
	HSeaGr	Seagrass 90%-100%
	LMac	Macroalgae 10% - <50%
	MMac	Macroalgae 50% - <90%
	HMac	Macroalgae 90% - 100%
	LCA	Coralline Algae 10% - <50%
	MCA	Coralline Algae 50% - <90%
	HCA	Coralline Algae 90% - 100%
	LTurf	Turf 10% - <50%
	MTurf	Turf 50% - <90%
	HTurf	Turf 90% - 100%
	Uncol	Uncolonized Hard Bottom
Geomorphologic Structure	AgRf	Aggregate Reef
	AgPtchRf	Aggregated Patch Reef
	IndPtchRf	Individual Patch Reef
	SnG	Spur and Groove
	SCRUS	Scattered Coral and Rock in Unconsolidated Sediment
	Pvnt	Pavement
	Rock/Bldr	Rock/Boulder
	PWSC	Pavement with Sand Channels
	Rub	Rubble

1. Introduction and Background

The National Oceanic and Atmospheric Administration (NOAA) acquired multispectral satellite imagery for the entire archipelago of Palau. The images were used to create maps of the region's marine resources including coral reefs and other important habitats for fisheries, tourism and other 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 LLC (ALH) has been subcontracted to provide mapping and other services to meet the goals of this project.

The primary products of this effort are benthic coral reef habitat maps in geographic information system (GIS) format. The maps are produced by delineating habitat boundaries by visual interpretation from the imagery provided. These maps are generated in GIS format to generate a powerful tool for management of important patterns and trends that are possible only from this intelligent mapping methodology. In all cases, benthic features have been classified using a hierarchical two tiered 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 of the Pacific Island communities. The Coral Reef Habitat Classification Scheme that was developed by NOAA for all islands of the Caribbean and Hawaii was used as a starting point for this work. Subsequent to an intermediate scheme that was developed and used to generate the habitat maps prepared from the NOAA imagery collected during the years 2002 to 2004, comments and suggestions have been incorporated into a new scheme that includes GIS data organized to separate the geolomorphologic substrate structure of the reef system from the biological cover colonizing its surface. For the purpose of this work, habitat is defined by the major and detailed attributes of these two layers.

An integral part of this work includes scientifically sound statistical accuracy estimates of the spatial and thematic content of these coral reef habitat maps. These analyses are presented and conclusions are drawn that can be integrated into long term coral reef mapping objectives.

It has been the goal of this work to map the coral reef habitats of the entire main archipelago of Palau. The work has been completed and is reported on here.

2. Approach

2.1 Development of the Benthic Habitat Classification Scheme for the Pacific

The benthic features depicted in these map products were classified using a hierarchical, two level, Coral Reef Habitat Classification Scheme. In this work, habitats are defined using a two tiered classification scheme consisting of a geomorphologic reef structure and biological cover. 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 original Coral Reef Habitat Classification Scheme that was developed by NOAA for the Caribbean was used as a starting point for this work. This classification scheme was influenced by many factors including but not limited to:

- 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
- Consideration of various minimum mapping units and technological trends toward preparation of living resource map products using digital techniques from remotely sensed imagery including satellite data.

For this work, the imagery was delivered to ALH in two shipments. The entire archipelago was divided into eleven regions. The identification and location of these imagery regions were dictated by dividing the total mapped region into 11 areas as dictated in the SOW and selecting these areas such that the level of effort was approximately equal. While it recognized that acquisition of remotely sensed imagery is challenged by environmental conditions including but not limited to glint, waves, surf, water clarity and cloud cover, nearly all of the area was successfully imaged and delivered to ALH. NOAA provided supplemental satellite imagery that was collected by the Quickbird system and these data were processed at no extra cost to NOAA. All of the GIS products that were those products are reported on here.

The scheme is separated into two levels, the geomorphologic structure of the reef and the biological cover on the substrate. Map classes that were determined to be undetectable from the imagery were not included in the scheme.

Four major structural components for the classification scheme that has been developed for this work include:

- Unconsolidated Sediments
- Coral Reef and Hard Bottom
- Other Delineations
- Unknown

These have been subdivided to include the following detailed coral reef structural classification system:

Unconsolidated Sediments

1. Sand
2. Mud
3. Unclassified
4. Unknown

Coral Reef and Hard Bottom

1. Aggregate Reef
2. Spur and Groove
3. Individual Patch Reef
4. Aggregated Patch Reef
5. Scattered Coral/Rock
6. Pavement
7. Rock/Boulder
8. Pavement with Sand Channels
9. Rubble
10. Unclassified
11. Unknown

Other Delineations

1. Land
2. Artificial
3. Unclassified
4. Unknown

Unknown

1. Unknown

Cover type has been divided into nine classes:

Coral
Seagrass
Macroalgae
Coralline Algae
Turf
Emergent Vegetation
Uncolonized
Unclassified
Unknown

Each of the biological cover types are then subdivided into six density classes:

1. 0%-<10%
2. 10%-<50%
3. 50%-<90%
4. 90%-100%
5. Unclassified
6. Unknown

Fourteen zones have been developed as:

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

2.2 Remotely Sensed Imagery

NOAA provided ALH with multispectral IKONOS and Quickbird satellite imagery to complete the objectives of this project. This high spatial resolution processed imagery proves suitable for visual extraction of the habitat classes mapped here. Furthermore, acquiring imagery by satellite facilitates convenient imaging in areas that are too remote to economically acquire the imagery by fixed wing or other platform. For this work, all imagery was provided by NOAA completely processed to ALH. NOAA processing included atmosphere correction, deglinting, color balancing, orthorectification, correction for water column effects and pan sharpening. Collection constraints were set to control environmental effects such as glare, glint and other interferences that would limit visualization of benthic features. Multiple collects were conducted to mosaic multiple scenes to a maximum of 20% cloud cover. These images were used to manually interpret and delineate geomorphologic features, zones and cover type. This task was accomplished using on screen digitizing in ArcView GIS format facilitated by the Coral Reef Digitizer Extension developed by NOS and published on the NOAA web site (http://biogeo.nos.noaa.gov/products/apps/digitizer/).

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. GPS data was acquired for accuracy assessment of the habitat maps. It was also collected

for ground validation information that was used to investigate uncertainties on the photointerpreter's behalf during the decision making process of the manual delineation of zone, structure and biological cover. The accuracy assessment data was generated on a random stratified point basis. Ground validation data was generated by selecting specific targets in areas where habitat type was not certain during photointerpretation 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 photo interpreted habitat classes have been nearly completely 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 superior and desired. 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.

All benthic habitats were mapped from the shoreline to a depth of 30 meters.

2.5 Habitat Map Accuracy Assessment

To determine the overall accuracy of the mapped product, conventional assessment of the accuracy of resource maps prepared from remotely sensed data was completed. It was proposed that specific areas being mapped be used as test areas for this work. A statistically robust data set composed of random field habitat observations were made to assess the accuracy of the mapped product. These areas were chosen based on input from the local marine biologists and coral reef managers. These groups provided advice on the location of the most diverse benthic communities and also areas of particular importance based on management strategies and marine protected areas. Thus, it was the goal of this team to collect accuracy assessment field data representing as many of the habitats that occur in these regions as possible.

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 specified in the scope of work and needed to complete the task. Less than 5 meter RMS horizontal error was required for the accuracy assessment and benthic habitat characterization positions and vertical data were all set to sea level as all data was collected there. While the requirements for positional accuracy of the ground validation data were the same as the accuracy assessment field data, the descriptive information in the ground validation data was more general. 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.

3.1.1 Reference Systems

ALH has provided all geospatial deliverable products referenced to the North American Datum of WGS84 on geoid model 99. All such coordinates in this datum are affixed to the Pacific Plate. All spatial data was projected in Universal Transverse Mercator (UTM) Zone 53 for the entire map.

3.1.2 Acquisition of GPS and Habitat Characterization Data

A Trimble Geo Explorer 3 hand held GPS unit was used to collect the GPS data and Trimble Pathfinder Office Software was used for all post processing and differential correction of the raw GPS data to the geographically closest Continually Operating Reference System (CORS). Habitat 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 Pacific (Section 2.1).

3.2 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. Waypoints were generated using a stratified random sampling regime or were selected to explore specific features in the imagery. Each waypoint that could be safely occupied was navigated to using a suitable sized boat to accommodate the sea conditions. After arrival at the way point, 100 GPS positions were collected at one-second intervals and were averaged to generate a single position. After GIS data collection was complete the habitat characterization was conducted in a circular area of 7.5 meter radius centered on the way point. Each feature was populated with site-specific data using a custom designed data dictionary and processed using Trimble Pathfinder Software (Table 1).

Table 1. Data collected using Trimble Geo Explorer 3 GPS data logger at each benthic habitat characterization site during field habitat surveys

Site Data	Habitat Data
Study Area	Point Habitat Type (0.5 meter radius)
UTM Zone	Area 1 Habitat Type (7 meter radius)
Site ID	Major Structure and Detailed Structure
GP Date	Hierarchical Biological Cover and Modifier
GPS Time	Estimated Coral Cover
GPS Position	Estimated Macroalgae Cover
GPS Statistics	Estimated Coralline Algae Cover
Depth	Estimated Turf Cover
Photo Information	Estimated Emergent Vegetation Cover
	Estimated Uncolonized Bottom

Two benthic habitat assessments were undertaken at each field site. A point assessment was conducted by surveying the one square meter area around the point where the weight dropped and an assessment was conducted in an area of a 7.5 meter radius around the weight. The geomorphologic structure was determined and estimates of each of the biological cover types in the classification scheme were made. The depth of the site was recorded using a hand held depth sounder. The benthic habitat assessments were made using a glass bottom look box, free diving, video drop camera 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 access the waypoint by boat, the GPS was placed in a watertight box and swam to the survey point.

All observations at each position were recorded on the GPS data logger using a custom data dictionary designed to meet the specifications of the Coral Reef Habitat Classification Scheme.

At the end of each field day, the data was downloaded from the GPS data logger and differentially corrected to the closest CORS. The Trimble GPS file was then converted to an ArcView GIS shape file and the data was compared with the handwritten field notes. All data were processed at the end of each field day.

Observer Objectivity

During the field habitat surveys, ALH mapping personnel made field observations for ground validation and accuracy assessment purposes. Ground validation data were used to elucidate the habitat types where uncertainty existed on the part of the photo interpreter during map preparation and to enhance reef habitat and zone interpretation. The field accuracy data collection team independently conducted benthic habitat characterizations and conducted the assessment of the extent to which the photointerpretation met the field assessment determinations. These accuracy assessment field data were not made available to the photo interpreter during manual delineation of habitat boundaries.

3.3 Habitat Delineation, Identification and Mapping Methodologies

The coral reef benthic habitat maps were prepared in a five step process.

1) A first draft coral reef habitat map was produced by delineating all features that could be identified by visual inspection of the satellite imagery. This first draft map includes all zones, geomorphologic structure and biological cover types as well as shoreline and unknown areas. It was generated by heads up "on screen" manual photo interpretation and delineation in ArcView GIS format. NOAA staff has published 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. It also provides the option of setting the area of minimum mapping unit (MMU). 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.

NOAA supplied orthorectified imagery to ALH. Manual delineation process was conducted with the image scale at 1:6,000 or less with the MMU set to one acre.

All manual delineation was conducted based on the color and texture of the features in the imagery as well as the subcontractor's extensive knowledge of the coral reef systems and field observations.

2) Areas that were difficult to interpret or where the photo interpreter needed additional field information were identified and labeled as ground validation positions. These locations were explored in the field to enhance map accuracy. These surveys were completed and the maps were edited based on the ground validation information to generate a second draft map product. During this edit, the accuracy assessment data was withheld from the photo interpreter.

A second set of field survey positions were created and used for accuracy assessment of the map products. This second set of points was generated by stratifying each habitat and structure type and generating randomly distributed field positions. This process step is completely described in Section 3.4.

3) The accuracy of the second draft map was determined based on the field accuracy assessment data. If the accuracy met NOAA standards, the process proceeded to step 4. If it did not, it was returned to the photo interpreter to be further refined. If additional ground validation observations were needed to improve accuracy, they were collected at this time.

4) After completely demonstrating that the map products meet the NOAA accuracy standards, these map products were reviewed by local marine biologists, coral reef scientists and marine recourse managers. Comments were integrated into the map products to generate a third draft map.

5) Content Standard for Digital Geospatial Metadata (CSDGM) compliant metadata summaries were prepared for all point and polygon GIS data generated during this tenure. These GIS data and metadata summaries were provided to be reviewed by NOAA and prepared for publication.

3.4 Habitat Map Accuracy Assessment

An accuracy assessment system was designed and executed to quantify the thematic accuracy of the maps generated at all levels of the classification scheme. Statistical analysis methods have been applied that have been developed by other researchers (Hudson and Ramm 1987, Congalton 1991, Rosenfield et al. 1982). In this work, a minimum of 25 field habitat observations have been completed per detailed structure as well as detailed biological cover type. The accuracy assessment is prepared from a matrix that compares the attribute 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).

For this work, a total of four accuracy assessment test areas were selected for Palau. (Table 2). Consideration was taken to select areas that constituted as comprehensive representation of the habitats and exposure regimes in this scheme as possible. Furthermore, the accuracy assessment test areas were chosen such that areas that had been used to test the thematic accuracy of products generated previously were not included.

Table 2. Accuracy assessment test areas surveyed during this work

Test Area ID	Test Area Name
Test Area 1	Ebiil Pass
Test Area 2	Toach Ngerdorch Mangroves
Test Area 3	Ngemelachel Ngederrak Seagrass Beds
Test Area 4	Ngerumekaol Spawning Area

3.5 Ground Validation

The purpose of this survey is to investigate areas of imagery where uncertainties exist on the photo interpreter's behalf during the decision making process of determining 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 are typically gradients through a transition of two or more habitat types or general areas where the habitat type is uncertain. These positions are then converted to GPS waypoints and occupied in the field.

3.6 Geodetic Control, Accuracy and Verification

Quality control was established by implementation of four steps. These assured a final product meeting the specification of spatial accuracy of GPS data not exceeding 5 meters at a 95% sigma RMS error from their true geographic location. This plan ensured the reliability and accuracy of the field data collected for benthic habitat accuracy assessment and the final GIS map output.

3.6.1 Spatial Accuracy and Precision

Data are collected to determine the spatial accuracy of the GPS positions acquired during this work. GPS data was collected on registered and recently recovered survey markers in the area of each survey (Figure 1). The variability in this GPS data quantifies spatial precision without error due to navigation. The field team also navigated to a waypoint in the field at least 20 times and circular error was calculated for that data. This quantifies the spatial error in reoccupying field positions and incorporates error due to navigation. The difference between these two positions gives the error due to station drift in the survey vessel.

Figure 1. Sample of a GPS spatial control site; PA25 at Oketol on Babledaob, Palau

3.6.2 GIS Quality Control

All GIS map products generated during this work were closely examined (Table 3). 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. As an additional step in quality control, 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 have been corrected. GIS data from this work were delivered to NOAA free of errors and a final review by ALH confirmed this.

Table 3. Quality control of GIS data delivered in this work

Topology – All GIS data is topologically cleaned
Void polygons – Data are free of void polygons
Adjacent polygons with the same zone or habitat do not exist in the data
Multipart polygons do not exist in the data
Overlapping polygons do not exist in the data
Sliver polygons do not exist in the data
All polygons attributed consistent with the classification scheme
All fields in the GIS data base are populated
All “unknown” zones have unknown habitats

3.6.3 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 handwritten records were collected. Chain of custody records were not needed as all data were maintained in secure custody of ALH at all times.

3.6.4 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 possible introduction 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 handwritten 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.

3.7 Records and Metadata Summaries

All physical records, with the exception of accuracy assessment field data, were kept in secure archives at the ALH facilities. Accuracy assessment field data was stored with the field assessment team outside of ALH facilities as this information was not privileged to ALH until map attribute accuracy had been shown to meet NOAA standards. Metadata summaries are prepared in CSDGM compliant format for all GIS point and polygon data are included in with this delivery. Original field notes were included with the delivery of each draft map package for each bundle.

4. Results

This Task Order had been organized into eleven image bundles. Four accuracy assessment survey areas were selected and populated with GPS surveys based on stratified random sampling methods.

4.1 Acquisition of Accuracy Assessment GPS Data

Six hundred and twenty three (623) waypoints that were stratified within each detailed habitat type were visited and habitat characterizations conducted during this work. Each position is delivered in ArcView GIS format and all contain the full complement of data described in Section 3.1.2.

4.2 Accuracy Assessment Data

It was the objective of this work to collect at least 25 field assessments for each of the detailed structure and detailed cover classes that were encountered in the Palau test areas. The GIS was queried and the number of positions where each was encountered was tallied (Tables 4 and 5). It will be noted that the number of detailed structure and cover positions occupied during this work differ. This is due to the "Artificial" structure class lacking a cover class. Hence the structure classes contain twenty six more points than the cover class.

During this work, four biological cover types were not encountered and were therefore not sampled. These were:

- Medium Emergent Vegetation
- High Vegetation
- High Coralline Algae
- High Turf

Table 4. Summary of major and detailed reef structure classes encountered during field accuracy assessment surveys

Major Structure	Count	Detailed Structure	Count
Coral Reef and Hard Bottom	488	Aggregated Patch Reef	36
		Aggregate Reef	33
		Pavement	236
		Rubble	27
		Individual Patch Reef	32
		SCRUS	44
		Spur and Groove	26
		Rock and Boulder	27
		Pavement w/Sand Channels	27
Unconsolidated Sediment	109	Sand	70
		Mud	39
Other	26	Artificial	26
Total	**623**	**Total**	**623**

A similar tally was generated for primary and detailed biological cover type. Continuous cover of coralline algae occurs only in areas where the minimum mapping unit requirement was not met and thus no polygons were mapped or tested. Further more, medium and low cover of emergent vegetation was not encountered in the test areas and was there fore not included in the stratified random point generation and thus was not tested in the assessment of thematic accuracy.

Table 5. Summary of major and detailed biological cover classes encountered during field accuracy assessment surveys

Major Cover	Count	Modifier	Count
Live Coral	185	10%-<50% (Low)	113
		50%-<90% (Medium)	41
		90%-100% (High)	31
Macroalgae	115	10%-<50% (Low)	47
		50%-<90% (Medium)	33
		90%-100% (High)	35
Seagrass	94	10%-<50% (Low)	39
		50%-<90% (Medium)	24
		90%-100% (High)	31
Coralline Algae	75	10%-<50% (Low)	29
		50%-<90% (Medium)	46
Turf	66	10%-<50% (Low)	29
		50%-<90% (Medium)	37
Emergent Vegetation	29	90%-100% (High)	29
Uncolonized	33	90%-100% (High)	33
Total	**597**	**Total**	**597**

4.3 Ground Validation Data

In this work, 1,140 ground validation positions were occupied throughout all of the benthic habitats of Palau between the depths of 0 and 30 meters. These data are delivered with this final shipment of GIS products and are accompanied with valid projection and FGDC CSDGM compliant metadata.

4.4 GIS Products, Quality Control Performed and Spatial Accuracy

4.4.1 GPS Data and Field Data Collection

Both point and polygon GIS data were generated in this work. Six hundred and twenty three (623) GPS positions were created using the random stratified method, converted to waypoints and navigated to in the accuracy assessment test areas. One thousand one hundred forty (1,140) GPS positions were occupied for the purpose of ground validation. One hundred ninety one positions were collected on registered survey benchmarks to generate a robust statistical estimate of GPS accuracy and precision. These data have been controlled by executing all quality control measures compliant with the proposed methods. CSDGM metadata summaries have been provided for all of these data and 95% sigma RMS error has been calculated for GPS positions as well as on-screen digitizing accuracy (Table 6). These results meet contractual requirements.

All GPS raw data has been delivered to the contractor along with the correction files obtained from the CORS, text files generated during GPS data processing. All the files needed to recreate the project have been delivered.

Table 6. Results of spatial accuracy generated from empirical measurements of GPS field positions and on-screen digitizing

Type of Replicate	N	Contract Standard	Circular RMS (M)
Accuracy generated from replicates on survey benchmark	191	< 5m	0.97
Precision generated from replicates on ground condition	191	<5m	0.84
On-screen digitizing accuracy at 1:6,000 scale	20	<1m	0.94

4.4.2 GIS Polygon Map Products

All polygon habitat map products generated in this work and are included in this delivery as a single ArcView GIS shape file. The products from the 18 image bundles were merged in the GIS software to generate a single file for the entire archipelago of Palau. Each product includes a projection file and CSDGM metadata summary.

4.5 Coral Reef Habitat Map Thematic Accuracy

A comprehensive thematic accuracy assessment has been conducted of the coral reef habitat map product for the four test areas of Palau. Six twenty three (623) benthic habitat characterizations were conducted for this purpose. These data were overlaid on the second draft maps generated from visual interpretation of the IKONOS imagery and error matrixes developed. In this summary, the overall accuracy, user and producer accuracy as well as incorrect classifications are presented. The Tau coefficient was also calculated. It will be noted that the detailed cover error matrix is not tabulated due to the large number of classes at the detailed level. The resulting table is too large to display. However, the results of these error calculations are presented in the overall summaries (Tables 7, 8, 9 and 10). It can be seen from these data that the coral reef habitat maps prepared for Palau meet contractual standards of 0.75 and 0.85 Tau for the detailed and major levels of the classification scheme respectively.

Table 7. Coral reef habitat map thematic accuracy of major reef structure classes

		Truth Based on Field Observation				
		Coral Reef and Hard Bottom	Unconsolidated Sediment	Other	Total	UA
Polygon Attribute	Coral Reef and Hard Bottom	480	8	0	488	98%
	Unconsolidated Sediment	9	100	0	130	92%
	Other	0	0	26	26	100%
	Total	489	108	26	Diagonal Sum: 606	
	PA	98%	93%	100%	Total Observations: 623	
					Overall Accuracy	**97.3%**

Table 8. Coral reef habitat map thematic accuracy of detailed reef structure classes

	Truth Based on Field Observations														
Polygon Attributes		AgRf	AgPR	IndPR	SnG	SCRUS	Pvnt	Pvmtw/SC	Rock/Bldr	Rubble	Sand	Mud	Artificial	Total	UA
	AgRf	**30**	1				2							33	91%
	AgPR	1	**31**				1	1		1	1			36	86%
	IndPR			**31**			1							32	97%
	SnG				**26**									26	100%
	SCRUS		2			**36**	5				1			44	82%
	Pvnt	2	2		6	6	**212**			2	6			236	90%
	PvmtW/SC		2				2	**23**						27	85%
	Rock/Bldr								**27**					27	100%
	Rubble						3			**24**				27	89%
	Sand	1					4			1	**60**	4		70	86%
	Mud	1					2				1	**35**		39	90%
	Artificial												**26**	26	100%
	Total	35	38	31	32	42	232	24	27	28	69	39	26	Diag. Sum 561	
	PA	86%	82%	199%	81%	86%	91%	96%	100%	86%	87%	90%	100%	Total Obs. 623	
	Overall Accuracy														**90.0%**

Table 9. Coral reef habitat map thematic accuracy of major biological cover classes

	Truth Based on Field Observations									
Polygon Attributes		Coral	Coralline Algae	Macroalgae	Turf	Seagrass	Emergent Vegetation	Uncol.	Total	UA
	Coral	**172**	6		2	2		3	185	93%
	Coralline Algae	20	**54**	1					75	72%
	Macroalgae	3	1	**96**	11	4			115	83%
	Turf	1	1	7	**57**				66	86%
	Seagrass	1		2		**91**			94	97
	Emergent Vegetation						**29**		29	100%
	Uncolonized	2		1	1			**29**	33	88%
	Total	199	62	107	71	97	29	32	Diag. Sum: 528	
	PA	86%	87%	90%	80%	94%	100%	91%	Total Obs: 597	
	Overall Accuracy									**88.4%**

Table 10. Summary of thematic accuracy of the Palau benthic habitat map products

Map Category	Overall Accuracy	Tau
Major Structure	97.3%	0.959
Detailed Structure	90.0%	0.891
Major Cover	88.4%	0.865
Detailed Cover	79.9%	0.788

4.6 Expert Review

The final step in map production is to provide hard copy map products for the expert coral reef researchers and managers in Palau for their review and comments. NOAA produced E sheet size hard copies of the entire mapped area for this review. A total of 88 maps were generated. A presentation was held at the Palau International Coral Reef Center and comments were taken on the observations made by the attendees.

Of the 10,038 habitat polygons delineated in this work, expert reviewers recommended editing 7. All seven polygons were edited based on the experts comments.

4.7 Coral Reef Habitat Maps and Thematic Content Summary

A GIS summary has been prepared that presents the areas of each of the major and detailed structure cover classes encountered in Palau (Tables 11 and 12). The information is presented in absolute areas (km^2). Of the 2,450 km^2 that have been mapped, 43.8% ot the benthic habitat is coral reef and hard bottom and 28.74% is composed of unconsolidated sediment. Thirty two and three tenths percent (32.3%) of the benthic habitat mapped is colonized by at least 10% live coral cover.

Table 11. Coral reef habitat thematic content summary of the major and detailed structure classes of Palau

Coral Reef Structure Type	Major and Detailed Habitat Structural Spatial Statistics			
	Number of Polygons	Area (km^2)	Perimeter (km)	% of total Benthic Habitats
Pavement	1397	106	4005	5.21%
Spur and Groove	254	299	2098	14.69%
Individual Patch Reef	2525	44	1289	2.18%
Aggregated Patch Reef	2467	310	6880	15.20%
Aggregated Reef	40	24	177	1.16%
Rock/Boulder	4	0	11	0.01%
Pavement with Sand Channels	347	39	939	1.93%
Rubble	287	47	803	2.29%
Scattered Coral/Rock	96	23	536	1.13%
Total Coral Reef and Hard Bottom	**7421**	**892.15**	**16738.14**	**43.80%**
Sand	335	68	1034	3.34%
Mud	1474	517	4846	25.40%
Total Unconsolidated Sediment	**1809**	**585.362**	**5879.951**	**28.74%**
Artificial	64	1	69	0.05%
Land	617	413	1022	n/a
Total Other Delineations	**681**	**413.999**	**1091.241**	**n/a**
Unknown	**131**	**558**	**1658**	**27.40%**
Total (including land)	10038	2450	25367	**n/a**

Table 12. Coral reef habitat thematic content summary of the major and detailed biological cover classes of Palau

Biological Cover Type	Major and Detailed Habitat Biological Cover Spatial Statistics			
	Number of Polygons	Area (km^2)	Perimeter (km)	% of total Benthic Habitats
Coral (Major Cover)	**3422**	**386**	**6777**	**33.86%**
10%-<50% (Detailed Cover)	294	18	620	1.47%
50%-<90% (Detailed Cover)	11	1	28	0.11%
90%-100% (Detailed Cover)	3423	386	6777	32.29%
Macroalgae (Major Cover)	**1242**	**326**	**4226**	**27.28%**
10%-<50% (Detailed Cover)	745	119	2274	9.92%
50%-<90% (Detailed Cover)	353	149	1447	12.46%
90%-100% (Detailed Cover)	144	59	505	4.89%
Coralline Alg. (Major Cover)	**276**	**63**	**1518**	**5.31%**
10%-<50% (Detailed Cover)	65	18	442	1.49%
50%-<90% (Detailed Cover)	207	45	1062	3.78%
90%-100% (Detailed Cover)	4	0	14	0.03%
Seagrass (Major Cover)	**441**	**80**	**1344**	**6.68%**
50%-<90% (Detailed Cover)	176	27	529	2.22%
90%-100% (Detailed Cover)	161	21	404	1.76%
10%-<50% (Detailed Cover)	104	32	411	2.71%
Turf (Major Cover)	2104	196	3696	16.38%
10%-<50% (Detailed Cover)	1039	87	1612	7.24%
50%-<90% (Detailed Cover)	886	98	1770	8.18%
90%-100% (Detailed Cover)	178	11	314	0.95%
Emergent Veg. (Major Cover)	**174**	**44**	**532**	**3.68%**
10%-<50% (Detailed Cover)	12	0	19	0.04%
50%-<90% (Detailed Cover)	10	1	22	0.10%
90%-100% (Detailed Cover)	152	43	492	3.55%
Uncolonized (Major Cover)	**1265**	**362**	**3877**	**16.38%**
Unknown	**130**	**558**	**1656**	**n/a**
Unclassified	**681**	**414**	**1091**	**n/a**
Total (including land)	**10038**	**2450**	**25367**	**n/a**

Sample maps have been provided of the zones (Figure 2), detailed structure (Figure 3) and detailed biological cover (Figure 4) using the Ebiil Pass test area.

Figure 2. Sample coral reef habitat map of zones of the Ehiil Pass conservation area

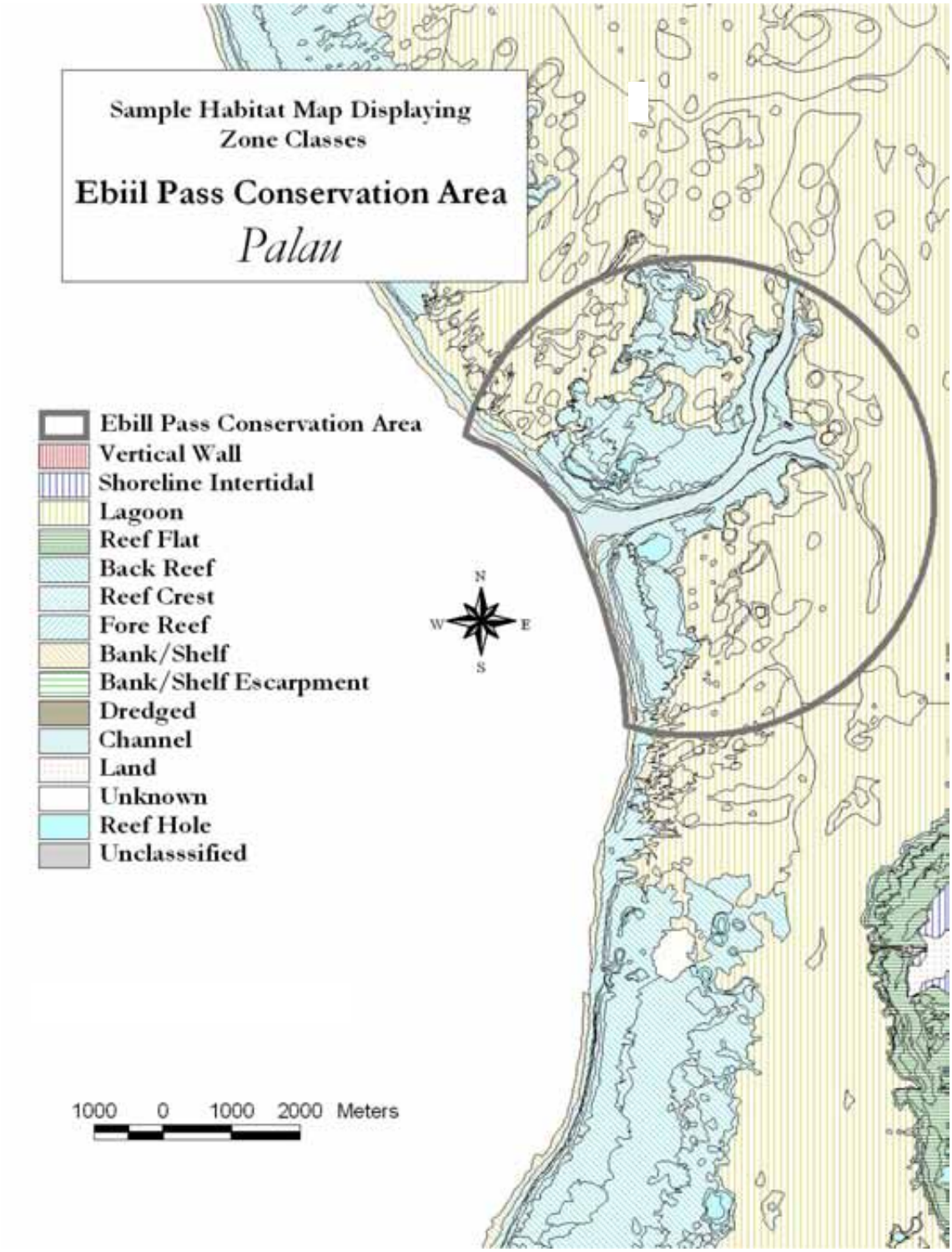


Figure 3. Sample of coral reef habitat map of detailed structure classes of the Ebiil Pass conservation area

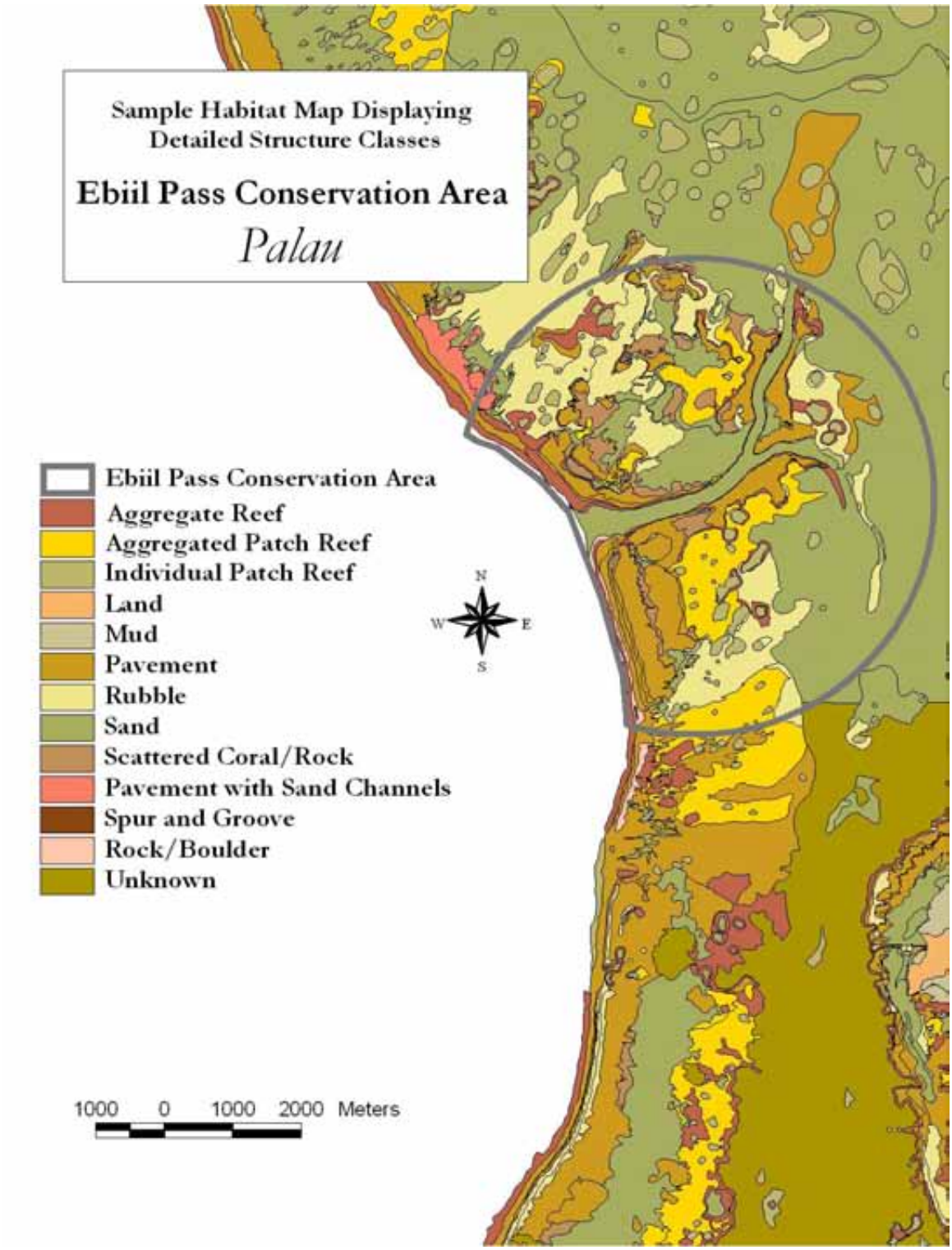
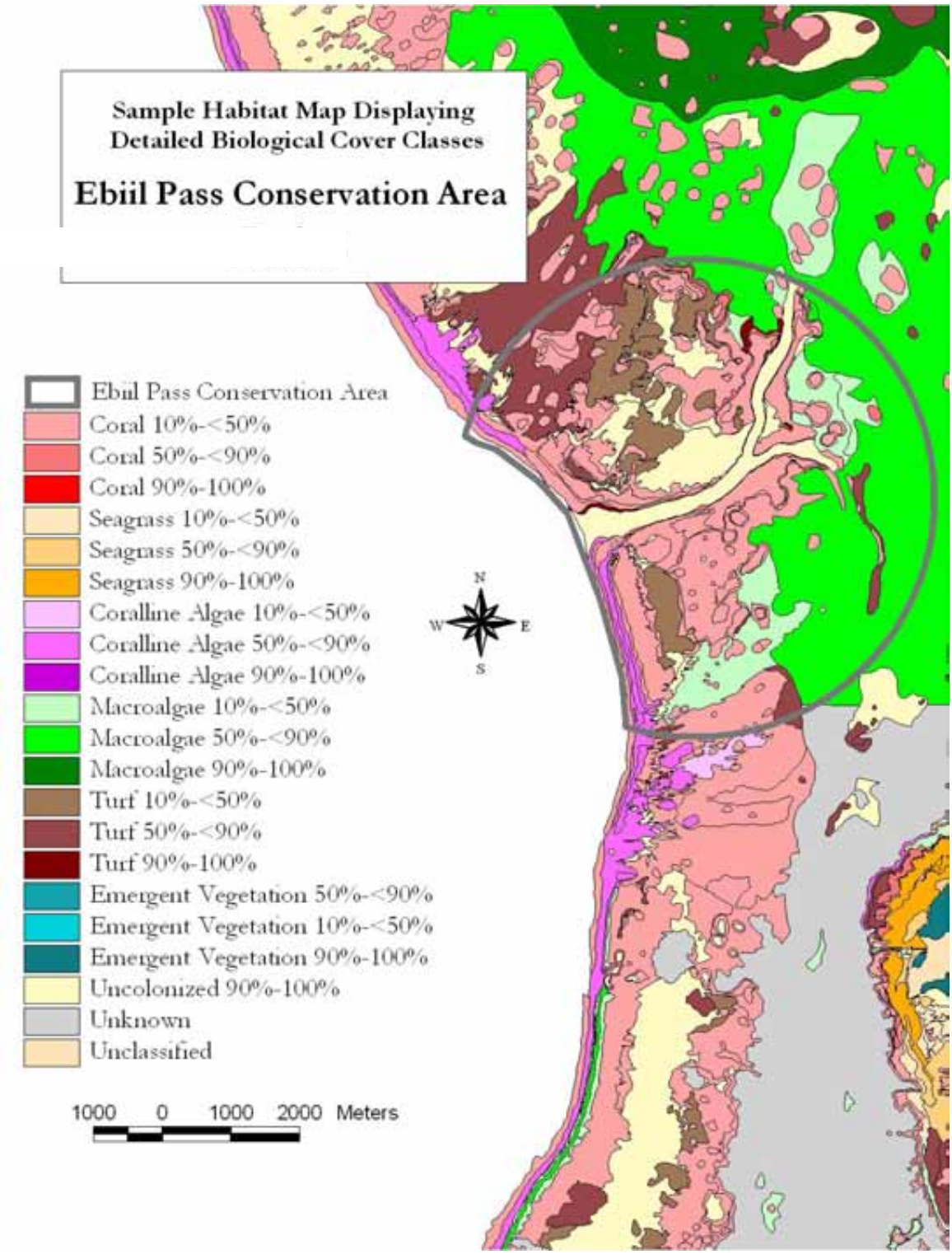


Figure 4. Sample coral reef habitat map of detailed biological cover classes of the Ebiil Pass conservation area



5. Discussion

Four points that were collected in the field were not used in the AA analysis. These points were numbers 186, 217, 64 and 84. Point 186 fell two meters into a cloud unknown. Points 217, 64 and 84 all fell 8 to 12 meters outside the study area. These points were not used in the accuracy assessment error matrix or accuracy statistics.

It should also be noted that the number of points used to generate the structure and cover error matrices differ by 26. This difference is due to the fact that the detailed structure class of "Artificial" lacks a cover class. As a result, 26 fewer points were available to use in the cover error matrix than were used in the structure error matrix.

6. List of Products Delivered

Nineteen (19) contract line items (CLIN) were agreed on for this work (Table 13). The entire mapped area of Palau was divided into eleven regions of which each constituted a deliverable product. Thus, of the 19 deliverable products, eleven were polygon GIS map products. The eleven mapped products were combined into a single seamless product that was delivered as part of the requirements of this final delivery. The project was designed such that NOAA would deliver all of the imagery at the start of the project and ALH processing could proceed without limitation of imagery delivery. These map products, as well as the GPS point data required for Ground validation, Accuracy assessment and spatial control and all of the ancillary GPS data needed to recreate the project are included here along with CSDGM compliant metadata. All original field notes were provided with the original delivery of each CLIN.

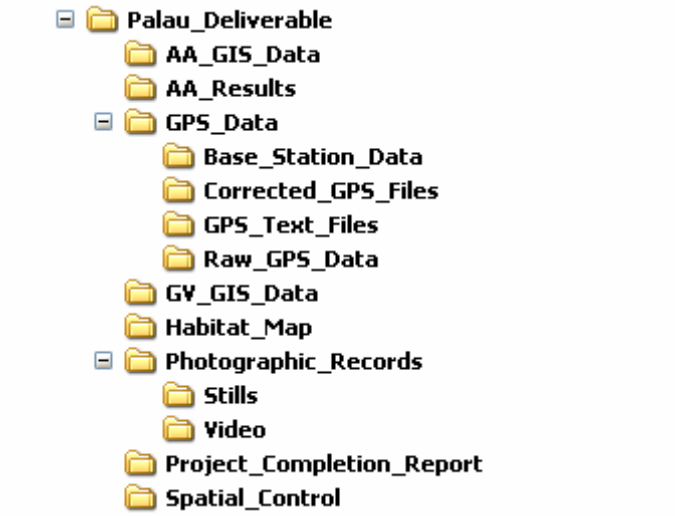
An important data set that has been delivered with this product includes the photographic records made during field surveys. During this tenure ALH recorded 278 georeferenced still and 1,063 video captures. Each of these files includes the site number in the naming convention. For the convenience of linking these photographic records to the GIS ground validation and accuracy assessment point data they have been combined into a single directory for the still photos and a single directory for the video captures. This format was at the request of the NOAA Contract Officer's Technical Representative.

This final delivery includes all components requested in the scope of work for this contract. The digital data included with this package are listed (Figure 5).

Table 13. Nineteen contract line items that have been delivered during this tenure

Contract Line Item Number	Status
Original Kick-off Meeting	Complete
GV Field Trip 1 including all ancillary data	Complete
Region 1 Draft Benthic Habitat Map	Complete
Region 2 Draft Benthic Habitat Map	Complete
Region 3 Draft Benthic Habitat Map	Complete
Region 4 Draft Benthic Habitat Map	Complete
Region 5 Draft Benthic Habitat Map	Complete
Region 6 Draft Benthic Habitat Map	Complete
Region 7 Draft Benthic Habitat Map	Complete
GV Field Trip 2 including all ancillary data	Complete
AA Field Trip and Tech Transfer Meetings	Complete
Final AA and GV Field Trip including all ancillary data	Complete
Thematic Accuracy Assessment	Complete
Region 8 Draft Benthic Habitat Map	Complete
Region 9 Draft Benthic Habitat Map	Complete
Region 10 Draft Benthic Habitat Map	Complete
Region 11 Draft Benthic Habitat Map	Complete
Peer Review	Complete
Final Products	Complete

Figure 5. File structure of this deliverable product



7. Deviations from Contract Requirements

ALH began this work by developing a matrix of goals that would be completed prior to delivery of the final product (Table 14). This matrix has been used as a check list throughout the project.

All objectives were met with the exception of the MMU restriction. Three cases were allowed for delineation of benthic habitats below the MMU of one acre.

1) The MMU restriction was removed for shoreline features.

2) The MMU restriction was removed in the event that a similar benthic feature was delineated near a below MMU polygon such as the patch reefs in the Northern Palau Lagoon. This allowance was to remove what would have otherwise been an apparent oversight.

No other deviations have been made from contract requirements.

Table 14. Matrix of goals completed prior to delivery of final product

All GIS polygon data is free of overlapping polygons
All GIS polygon data is free of multipart polygons
All GIS polygon data is built and cleaned
All GIS polygon data is free of adjacency
Minimum mapping restrictions have been met
All GIS polygon data is attributed consistent with the classification scheme
All GIS polygon data has matching unique ids and habitat attributes
All GIS polygon deliverables have valid *.prj files
All GIS polygon deliverables have CSDGM compliant metadata files
All GIS polygon deliverables have consistent fields
All GIS polygon deliverables are checked through QA/QC procedures
All GIS point deliverables have valid *.prj files
All GIS point deliverables have CSDGM compliant metadata files
All GIS point deliverables have consistent fields
All GIS point deliverables are checked through QA/QC procedures
All GPS data is spatially controlled for accuracy and precision
All GPS files needed to recreate the project are provided
All GPS geodetic standards are met including • Horizontal Reference Systems • Vertical Reference Systems • Geoid Model • Projection Time • Minimum mapping units
All Review meetings have been attended
Digitizing has been controlled
Minimum of 25 points have been collected per detailed structure and cover class
All AA test areas have been occupied
Observer objectivity has been maintained
Thematic accuracy meets contractual standard
All original field notes have been delivered
Monthly reports have been provided on time

8. References

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