Atlas of the Shallow-Water Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment
Biogeography Team

February 2005

NOAA Technical Memorandum NOS NCCOS 8

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Citation

NOAA National Centers for Coastal Ocean Science (NCCOS). 2005. Atlas of the Shallow-Water Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. NOAA Technical Memorandum NOS NCCOS 8, Biogeography Team. Silver Spring, MD. 126 pp.

Acknowledgements

This atlas of the Shallow-Water Benthic Habitats of the American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands was developed by NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team, with contributions from various organizations and individuals including:

- NOAA Special Projects Office
- NOAA Coastal Services Center
- NOAA National Geodetic Survey
- NOAA Pacific Island Fisheries Science Center, Coral Reef Ecosystem Division
- NOAA Fagatele Bay National Marine Sanctuary
- National Park Service, War in the Pacific, NHP
- Department of Marine and Wildlife Resources, American Samoa Government
- Coral Reef Advisory Group, American Samoa Department of Commerce
- University of Guam Marine Laboratory
- Division of Aquatic and Wildlife Resources, Guam Department of Agriculture
- Bureau of Statistics and Planning, Guam Government
- Coastal Resource Management, Commonwealth of the Northern Mariana Islands (CNMI)
- Division of Environmental Quality, CNMI
- Division of Fish and Wildlife, CNMI
- Analytical Laboratories of Hawaii
- BAE Systems Spectral Solutions LLC
- Space Imaging

The maps contained in the Atlas of the Shallow-Water Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands have been reviewed by numerous scientists and managers who are familiar with the nearshore environment of the U.S. Pacific Territories. Three review sessions were held, one each on Tutuila, American Samoa; Guam; and Saipan, CNMI; during August 2004.

Related Products

In addition to this Atlas, a CD-ROM is available which contains all the data used to produce the maps portrayed in the Atlas. The CD-ROM contains the digital multispectral IKONOS imagery, accuracy assessment field data, ground validation field data, spatial accuracy field data, benthic habitat GIS files, final reports, and shoreline GIS files. These digital data can be incorporated into a GIS or other software for further use and analysis. The CD-ROM also contains the metadata, the habitat digitizer extension used to generate the benthic habitat delineations, final reports, and a description of mapping methodology and results.

The data on the CD-ROM is also available on the Internet at http://biogeo.nos.noaa.gov/products/us_pac_terr.

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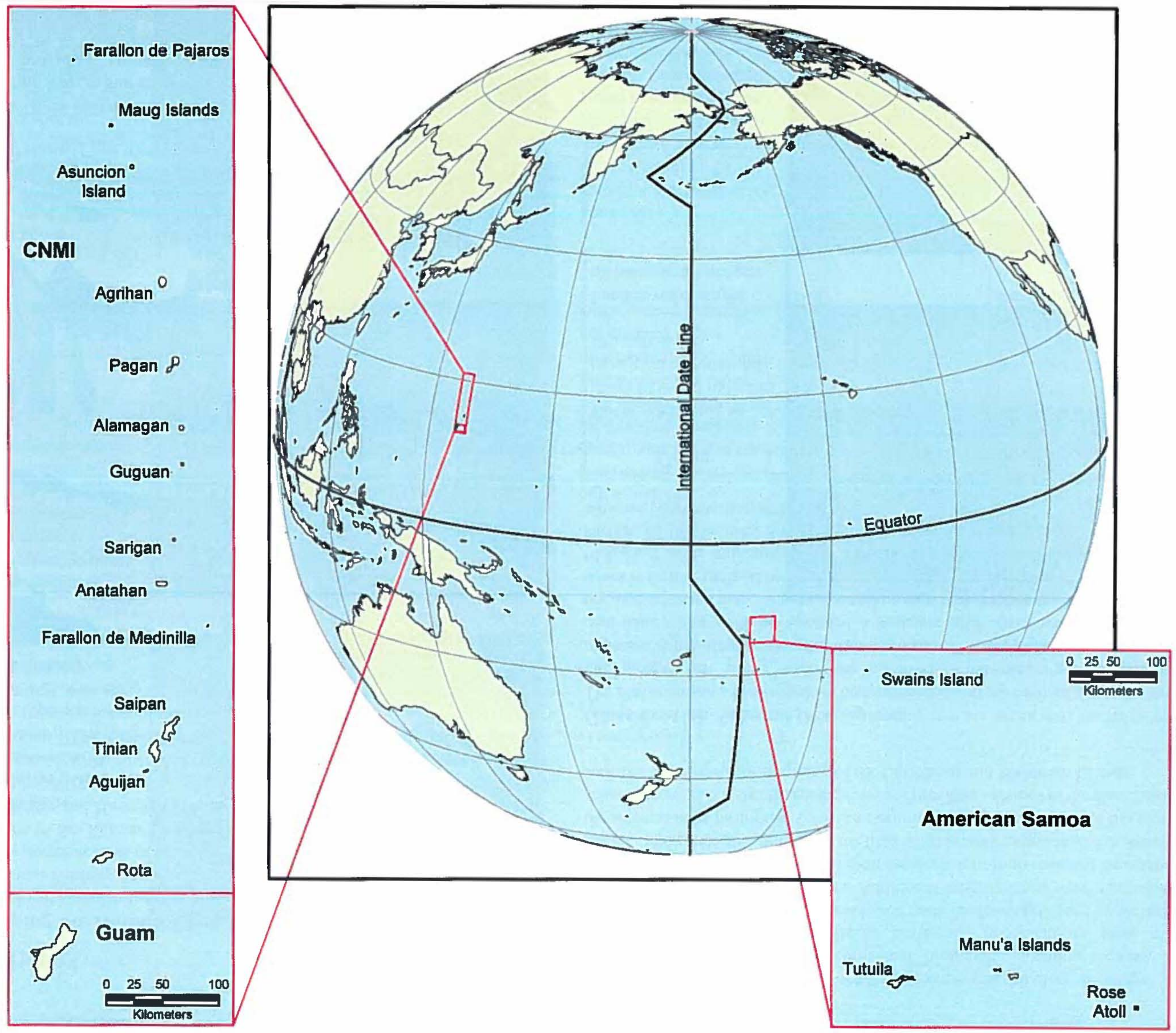
Locator Map



Introduction

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) initiated a coral reef research program in 1999 to map, assess, inventory, and monitor U.S. coral reef ecosystems (Monaco et al. 2001). These activities were implemented in response to requirements outlined in the Mapping Implementation Plan (MIP) developed by the Mapping and Information Synthesis Working Group (MISWG) of the Coral Reef Task Force (CRTF) (MISWG 1999). As part of the MISWG of the CRTF, NOS's Biogeography Team has been charged with the development and implementation of a plan to produce comprehensive digital coral reef ecosystem maps for all U.S. States, Territories, and Commonwealths by 2007. Coordinated activities between Federal agencies is of particular importance so as to effectively map, research, monitor, manage, and restore coral reef ecosystems. In response to the Executive Order 13089 and the Coral Reef Conservation Act of 2000, NOS is conducting research to digitally map biotic resources and coordinate a long-term monitoring program that can detect and predict change in U.S. coral reefs, and their associated habitats and biological communities.

Most U.S. coral reef resources have not been digitally mapped at a scale or resolution sufficient for assessment, monitoring, and/or research to support resource management. Thus, a large portion of NOS's coral reef research activities have focused on mapping of U.S. coral reef ecosystems. The map products will provide the fundamental spatial organizing framework to implement and integrate research programs and provide the capability to effectively communicate information and results to coral reef ecosystem managers. Although the NOS coral program is relatively young, it has had tremendous success in advancing towards the goal to protect, conserve, and enhance the health of U.S. coral reef ecosystems. One objective of the program was to create benthic habitat maps to support coral reef research to the enable development of products that support management needs and questions.

In addition to providing the digital map products called for in the MIP, this project was undertaken in consultation with many scientists and coastal managers in the U.S. Pacific Territories in an effort to meet local management and research needs. The involvement of the Island partners helped shape key aspects of the maps, including the development of an applicable classification scheme and their participation in the collection of critical field data to assess the thematic accuracies of the maps.

The purpose of this Atlas is to provide detailed maps depicting the GIS benthic habitat data produced, and outline the benthic habitat classification scheme and protocols used to map American Samoa, Guam and the Commonwealth of the Northern Mariana Islands.

Thirty-four distinct benthic habitat types (i.e., four major and fourteen detailed geomorphological structure classes; nine major and five detailed biological cover types) within eleven zones were mapped directly into a geographic information system (GIS) using visual interpretation of orthorectified IKONOS satellite imagery benthic features were mapped (see Figure 1) that covered an area of 263 km^2 from the shoreline to water depth of approximately 30 meters. In all, 81 km^2 of unconsolidated sediment, 122 km^2 of submerged vegetation, and 82.3 km^2 of coral reef and colonized hardbottom were mapped.

Methods

Developing the Habitat Classification Scheme

A hierarchical classification scheme was created to define and delineate shallow-water benthic habitats. The classification scheme was influenced by many factors including: requests from the management community, NOS's coral reef mapping experience in the Florida Keys and Caribbean, existing classification schemes for the Pacific and Hawaiian Islands (Holthus and Maragos 1995; Gulko 1998; Allee et al. 2000), other coral reef systems (Kruer 1995; Reid and Kruer 1998; Lindeman et al. 1998; Sheppard et al. 1998; Vierros 1997; Chauvaud et al. 1998; Mumby et al. 1998; Kendall et al. 2001), quantitative habitat data for the U.S. Pacific Territories, the minimum mapping unit (MMU - 1 acre for visual imagery interpretation), and analysis of the spatial and spectral limitations of satellite IKONOS imagery.

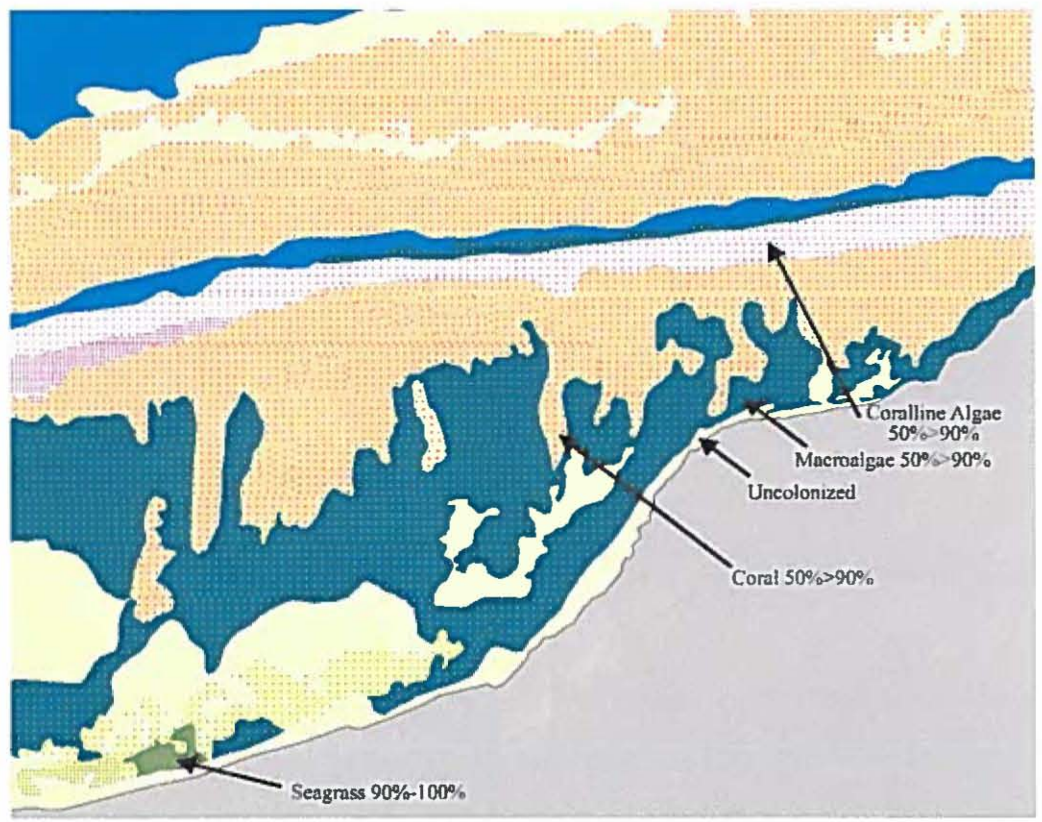


Figure 1. Biological Cover types for Saipan.

The hierarchical scheme allows users to expand or collapse the thematic detail of the resulting map to suit their needs. This is an important aspect of the scheme as it will provide a "common language" to compare and contrast digital maps developed from complementary remote sensing platforms. Furthermore, it is encouraged that additional hierarchical categories be added in the resulting geographic information system by users with more detailed knowledge or data for specific areas. For example, habitat polygons smaller than the MMU can be delineated, such as reef holes found in parts of the U.S. Pacific Territories, or habitat polygons delineated as colonized pavement using this scheme could be further attributed with health information (i.e., bleached, percent live cover) or species composition (i.e., Porites, Montipora).

The hierarchical scheme was prepared through consultation, meetings, and workshops that included key coral reef biologists, mapping experts, and professionals throughout the pacific territories. Modifications were made throughout the development process based upon feedback provided by workshop participants and other contributors. Additional modifications were made during the mapping process to ensure that each category definition reflected the intended habitats and zones encountered in the field as accurately as possible. For instance, the separation of biological cover and geomorphological structure in the present scheme represents a significant evolution of previous versions of the classification schemes developed for mapping of the Caribbean and Hawaiian Islands.

Classification Scheme Description

The classification scheme defines benthic habitats on the basis of three attributes: large geographic "zones" which are comprised of the smaller geomorphological structure and biological cover of the reef system. Every polygon on the benthic community map will be assigned a structure and cover within a zone (e.g. uncolonized sand in the lagoon, or coral on aggregate reef on the bank). Biological cover is further defined by five density classes. Zone indicates polygon location, biological cover indicates the predominate biological component colonizing the surface of the feature, and geomorphological structure indicates the physical structural composition of the feature.

Cover	Structure	Zone
Cover refers only to cover type and indicates biological cover on all structure types. Each cover example includes aerial images.	Structure refers only to substrate type and denotes the geomorphological structure of the coral reef. Each structure example includes aerial images.	Zone refers only to the benthic community location and denotes cross-shelf location relative to emergent features. Each zone has a description and includes a schematic diagram. *portrayed on CD-ROM

Biological Cover Types

Twenty-one distinct and non-overlapping biological cover types were identified that could be mapped through visual interpretation of the IKONOS imagery. Habitats or features that cover areas smaller than the MMU were not considered. For example, uncolonized sand halos surrounding coral patch reefs are too small to be mapped independently. Cover type refers only to predominate biological component colonizing the surface of the feature and does not address location (e.g., on the shelf or in the lagoon). The cover types are defined in a collapsible hierarchy ranging from nine major classes (coral, seagrass, macroalgae, coralline algae, turf algae, emergent vegetation, uncolonized, unknown, and unclassified), combined with a density modifier representing the percentage of the predominate cover type (unknown, 0%-<10% bare, 10%-<50% sparse, 50%-<90% patchy, 90%-100% continuous).

Coral: Substrates colonized by live reef building corals and other organisms. Habitats within this category have at least 10% live coral cover.

Seagrass: Habitat with 10 percent or more cover of seagrass. **Representative Species:** *Halophila sp.*

Macroalgae: Substrates with 10 percent or greater coverage of any combination of numerous species of red, green, or brown macroalgae. Usually occurs in shallow back reef and deeper waters on the bank/shelf zone. **Representative Species:** *Caulerpa spp., Dictyota spp., Halimeda spp., Lobophora variegata , Laurencia spp.*

Coralline Algae: An area with 10 percent or greater coverage of any combination of numerous species of encrusting or coralline algae. May occur along reef crest, in shallow back reef, relatively shallow waters on the bank/shelf zone, and at depth. **Representative Species:** *Porolithon gardineri*

Turf Algae: A community of low lying species of marine algae composed of any or a combination of algal divisions dominated by filamentous species lacking upright fleshy macroalgal thali.

Emergent Vegetation: Emergent habitat composed primarily of *Rhizophora mangle* (red mangrove) and *Hibiscus sp* (hau) trees. Generally found in areas sheltered from high-energy waves. This habitat type is usually found in the shoreline intertidal or reef flat zone.

Uncolonized: Substrates not covered with a minimum of 10% of any biological cover types. This habitat is usually on sand or mud structures. Overall uncolonized cover is estimated at 90%-100% of the bottom.

Unknown: Habitat uninterpretable due to turbidity, cloud cover, water depth, or other interference.

Unclassified: Non-benthic areas, such as land, that are delineated are attributed as unclassified.

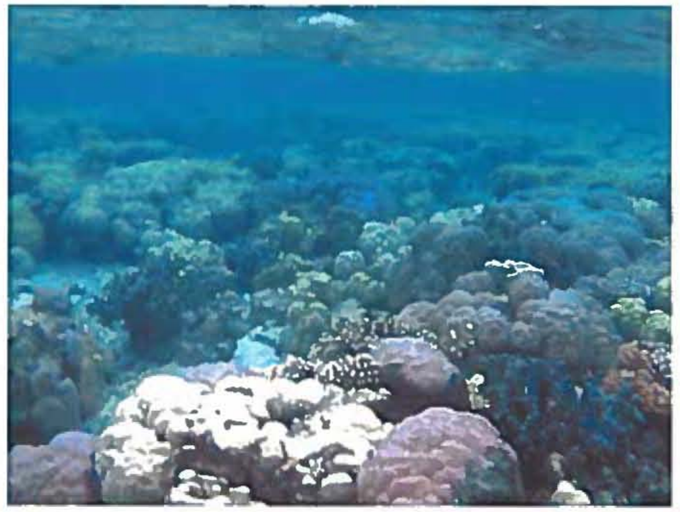
Geomorphological Structure Types

Fifteen distinct and non-overlapping geomorphological structure types were identified that could be mapped through visual interpretation of the IKONOS imagery. Habitats or features that cover areas smaller than the MMU were not considered. For example, sand halos surrounding coral patch reefs are too small to be mapped independently. Structure type refers only to predominate physical structural composition of the feature and does not address location (e.g., on the shelf or in the lagoon). The structure types are defined in a collapsible hierarchy ranging from four major classes (coral reef and hardbottom, unconsolidated sediment, other delineations, and unknown), to thirteen detailed classes (pavement, aggregate reef, spur and groove, individual and aggregated patch reef, scattered coral/rock in unconsolidated sediment, rock/boulder (volcanic and carbonate), pavement with sand channels, reef rubble, mud, sand, artificial, and unknown).

Coral Reef and Hardbottom: Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock or volcanic rock.

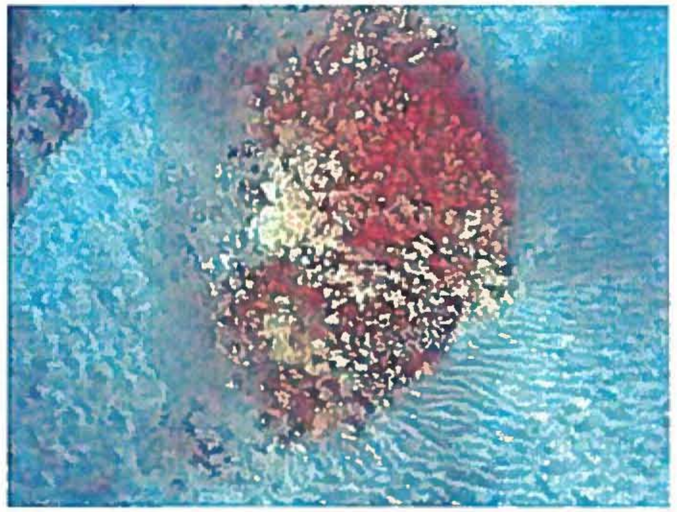
Pavement: Flat, low-relief, solid carbonate rock.

Aggregate Reef: High relief lacking sand channels of spur and groove.



Spur and Groove: Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief relative to pavement with sand channels and are separated from each other by 1-5 meters of sand or hardbottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the fore reef or bank/shelf escarpment zone.

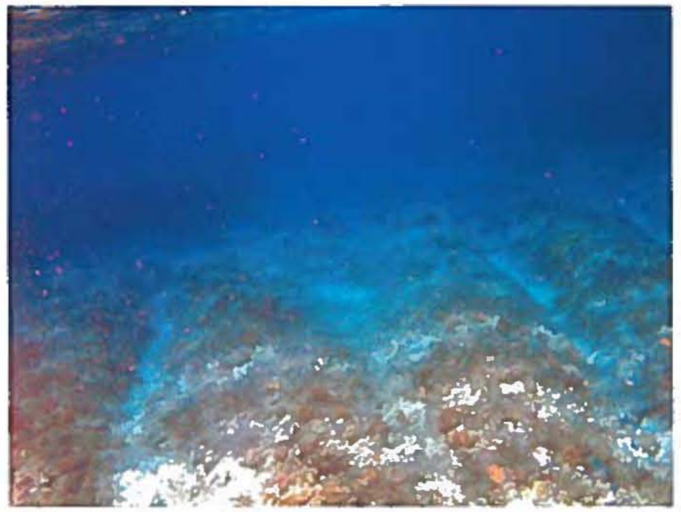
Patch Reef (Individual or Aggregated): Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. Individual patch reefs are distinctive single patches of reef that are larger than or equal to the MMU. Aggregate patch reefs are clustered patches of reef that individually are too small (less than the MMU) or are too close together to map separately.



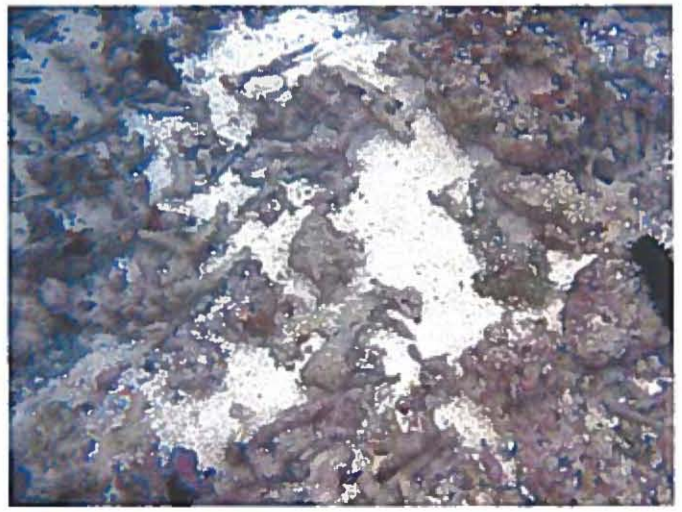
Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e., smaller than individual patch reef).

Rock/Boulder: Solid carbonate blocks and/or boulders or volcanic rock.

Pavement with Sand Channels: Habitats of pavement with alternating sand/surge channel formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand/ surge channels of this feature have low vertical relief relative to spur and groove formations and are typically erosional in origin. This habitat type occurs in areas exposed to moderate wave surge such as the bank/shelf zone.

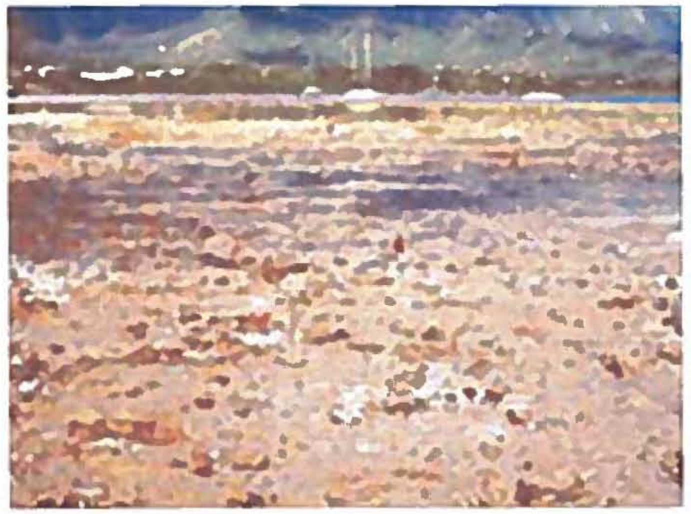


Reef Rubble: Dead, unstable coral rubble often colonized with coralline algae and filamentous or other macroalgae. This habitat often occurs landward of well developed reef formations in the reef crest or back reef zone.



Unconsolidated Sediment: Unconsolidated sediment with less than 10 percent of any hardbottom structure type.

Mud: Fine sediment often associated with river discharge and buildup of organic material in areas sheltered from high-energy waves and currents.



Sand: Coarse sediment typically found in areas exposed to currents or wave energy.

Other Delineations:
Artificial: Man-made habitats such as submerged wrecks, large piers, and submerged portions of rip-rap jetties, and the shoreline of islands created from dredged spoil.

Unknown: Habitat uninterpretable due to turbidity, cloud cover, water depth, or other interference.

Creating and Interpreting Digital Satellite Imagery

Satellite imagery is a valuable tool for natural resource managers and researchers since they provide an excellent record of the location and extent of habitats. Habitat maps of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands were created through visual interpretation of multispectral IKONOS imagery using the NOAA Habitat Digitizer extension. Habitat boundaries were delineated around signatures (e.g., areas with specific color and texture patterns) in the orthorectified imagery mosaic corresponding to habitat types in the Classification Scheme. The custom Habitat Digitizer extension was used, digitizing at a scale of 1:6,000 with a 1-acre minimum mapping unit. Generally, feature detection of seafloor habitats was possible from the shoreline to water depths of approximately 30 meters, depending on water clarity. In order to optimize the satellite imagery for visual interpretation, a number of processing steps were implemented to enhance the geopositioning and clarity of the imagery. These steps include: orthorectification to remove spatial distortions in the imagery due to relief displacement; pansharpening; deglinting; and generating normalized reflectance values.

Satellite Imagery
The IKONOS™ satellite, owned and operated by Space Imaging Incorporated, LLC, provides commercially available panchromatic (black and white) and multispectral (blue/green/red/near-infrared) imagery. The panchromatic imagery has a 1 m pixel dimension (meaning features larger then 1 m^2 can be detected in the imagery). The multispectral imagery has a 4 m pixel dimension (meaning features larger then 16 m^2 can be seen in the imagery). The IKONOS imagery is purchased in 11 km wide swaths that are mosaicked together to produce complete images of locales. IKONOS satellite imagery provides precise and robust data with spectral and spatial resolution suitable for shallow water benthic mapping. Furthermore, satellite imagery provides efficient and effective global coverage for repeated imaging of remote islands that are often obscured by cloud cover.

All of the IKONOS imagery was purchased in National Imagery Transmission Format (NITF) with the associated Rational Polynomial Coefficients (RPCs or satellite ephemeris data). When using image analysis software capable of reading NITF files with associated RPCs, the initial horizontal positioning error never exceeded 15 m (for locations where there is little or no vertical relief to affect image pixel displacement).

Mosaicking the Imagery
Georeferencing/mosaicking of the imagery was performed using PCI OrthoEngine, and Erdas OrthoBase. The NITF IKONOS imagery was orthorectified using the Rational Functions extracted from the NITF, then further supplemented with ground control and corrected for terrain displacement using the DEM's where available. When multiple scenes were available for a given island, these were collectively incorporated into the orthomosaic project through bundle adjustment. Each scene was exported as a separate orthorectified file for further image processing. In addition, the best segments of each scene were selected for creation of the final mosaic. Segments of each scene were selected to minimize sun glint, cloud interference, turbidity, etc. in the final mosaic. Where possible, parts of images obscured by sun glint or clouds were replaced with cloud/glint free parts of overlapping images. As a result, most mosaics have few or no clouds or sun glint obscuring bottom features. However, in some cases, clouds, sun glint, or turbid areas could not be replaced with overlapping imagery. In these areas, such obstructions were minimized but could not be eliminated completely.

Ground Control Points (GCPs) for Georeferencing
Fixed ground features visible in the IKONOS imagery were selected for ground control points (GCPs) which were then used to georeference the imagery (i.e., link the image pixels to a real world coordinate system such as Universal Transverse Mercator). NOAA's National Geodetic Survey (NGS) gathered ground control data (horizontally accurate to within 5 cm of its location on the earth) on seventeen of the twenty-one islands mapped in the U.S. Pacific Territories (see Figure 2). GCPs were measured and then differentially corrected to the closest Continuously Operating Reference System (CORS). We obtained points with a wide distribution throughout the imagery whenever possible since this results in the most accurate registration throughout each image. Only ground control points for terrestrial features were collected due to the difficulty of obtaining precise positions for submerged features.

Figure 2. GPS occupying Geodetic benchmark on Maug, CNMI.

Image to Image Tie-Points
Image to image tie-points (distinct features visible in overlap areas of each frame such as street intersections, piers, coral heads, reef edges, and bridges) were then used to further co-register the imagery, especially for photos taken over open water where ground control points were not available (see Figure 3). Softcopy photogrammetry software has the ability to automatically find such features common to overlapping imagery but this automated function has mixed results for submerged features.

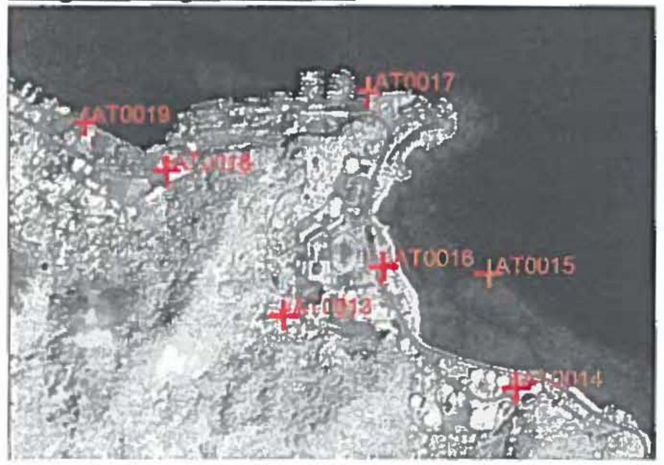


Figure 3. Tie-points collected for Pago Pago Harbor.

Digital Elevation Models (DEM)
Pre-existing U.S. Geological Survey (USGS) 10 m^2 resolution digital elevation models (elevation contour intervals 1 m) were available for eight of the twenty-one islands and used to correct for relief displacement (see Figure 4). Once a draft orthorectified mosaic was produced, a set of independent ground control points (i.e. check points) were used to measure the quality of each mosaic's rectification and ensure that it required horizontal and vertical spatial accuracy limits. If the spatial accuracy was not acceptable based on this comparison, additional modifications were made to the GCPs, tie-points, etc., until a satisfactory mosaic was created for each island. In general, mosaics were georeferenced such that pixels are positioned within one pixel width of their correct location.

Figure 4. Example DEM.

Image Analysis
Several intermediate, derived products were produced as the satellite imagery was processed for use in producing the benthic habitat maps. First, the raw satellite images were converted from Digital Numbers (DNs) to normalized reflectance. Normalized reflectance (or at-satellite reflectance) converts DNs into standardized, satellite-independent, comparable values. First developed for Landsat satellite imagery, the algorithm used to perform this conversion was modified for IKONOS image processing. As part of the conversion from DNs to at-satellite reflectance, the following equation is used (Green et al. 2000):

R = pi * L/ (Eo cos(theta0) 1/r^2)

L = radiance (from calibration provided by Space Imaging).
theta0 = the solar zenith angle.
r = earth-sun distance in Astronomical Units.
Eo = the mean solar exo-atmospheric irradiance in each band. (A convolution of the spectral response and solar radiation from Neckel and Labs (1984) was used to get Eo.)

The acquisition angles (ephemeris data) of the satellite relative to the ground at the time of image acquisition were also used. Calibration coefficients for the satellite, provided by Space Imaging, were used to calculate at-satellite radiance, which was then transformed to reflectance. The normalized reflectance imagery was then transformed into water reflectance (or the signal < 10 cm above the water surface). Water reflectance uses the near-infrared band to remove radiance attributed to atmospheric and surface effects (Stumpf et al. 2003). Water reflectance estimates how the signal (photons) received by the satellite is diminished as it passes through the atmosphere on the way down to the water-atmosphere boundary and on the way back up to the satellite after the signal leaves the water-atmosphere boundary. Water reflectance also estimates how the signal at the satellite is diminished by water vapor, clouds, specular effects at the water surface (wave surface glint), and other signal-absorbing and diffusing materials.

Finalizing the Process
Final mosaics were created in "img" file format (georeferenced image file) with the following projection parameters Universal Transverse Mercator (UTM) Zone 55 North for Guam and the Commonwealth of the Northern Mariana Islands, UTM Zone 2 South for American Samoa , North American Datum 83.

These files are available on the Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands CD-ROM and at the NOAA's Biogeography Team Web site (http://biogeo.nos.noaa.gov/products/us_pac_terr). These mosaics were color-balanced in order to provide the most seamless, cloud-free product available for use (see Figure 5).

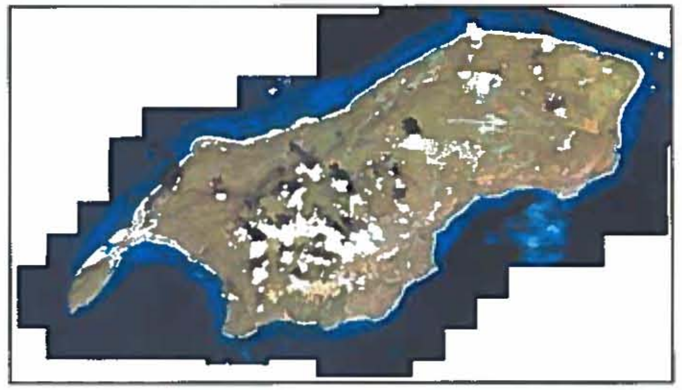


Figure 5. Seamless color-balanced mosaic for Tinian, CNMI.

Evaluating Thematic Accuracy
The quality of the habitat information derived from remotely sensed data is determined by the quantitative process of accuracy assessment. The purpose of accuracy assessment is to identify and quantify errors in the maps by comparing the attributes of the map versus reference data at various sites. It is important that the mapmaker know the reliably of a given classified habitat. This parameter is called "producers accuracy". The users of a map product also want to know what percentage of the polygons of a particular class are correctly attributed. This parameter is called "users accuracy". Furthermore, remotely sensed imagery that may be suitable for mapping coral reef habitats can be acquired from a wide variety of platforms and imaging systems, each having it's own strengths and limitations. It is important to identify the technical merits of each, one measure of which is the thematic accuracy of the map products.

To determine the overall accuracy of the mapped product, GIS data prepared by visually interpreting IKONOS satellite imagery was assessed for accuracy using conventional methodologies. 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 collected within the test areas 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.

The thematic accuracy of all mapped products was determined at the most general and detailed levels of the classification scheme including both the biological cover type and geomorphological structure. Sixteen coral reef test areas were selected based on the diversity of the habitat types and to assure that all benthic habitats throughout the U.S. Pacific Territories were represented. The accuracy of all maps is, therefore, considered a conservative representation of the thematic accuracy of the habitat maps prepared using the same methods for imagery collected throughout the remainder of the U.S. Pacific Territories.

Thematic Accuracy in the American Samoa, Guam, and the Commonwealth of the Northern Marianas Islands
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, 20 to 30 field habitat observations were completed per detailed structure as well as detailed biological cover type (see Figure 6). 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.

Five test areas for American Samoa and eleven test areas for the Marianas Archipelago were established to determine the thematic accuracy of the benthic habitat maps prepared from IKONOS satellite imagery. The test areas for American Samoa included Pala Lagoon, Fagatele Bay, Fagaitua Bay, the Manu'a Islands and Tafeu. The test areas for the Marianas Archipelago included Piti Bay and Cocos Lagoon, Guam; Saipan Lagoon and Lau Lau Bay, Saipan; South Beach, Tinian; west and southeast sides of Rota; the west side of Sarigan; and the entire islands of Pagan, Agrihan, and Maug.

Figure 6. Accuracy Assessment Points for Cocos Lagoon, Guam.

Benthic habitat maps from these areas were generated from IKONOS satellite imagery collected at 4 meter resolution and pansharpened to 1 meter resolution. All image interpretation and digitizing was conducted by a single NOAA contractor. The field habitat characterization data collection methods for thematic accuracy assessment differed little from the data collected for ground validation. The primary distinction between the two data sets was the method of selection of the field points. Where as the assessment sites for ground validation were selected to specifically investigate habitat types and gradients of spectral signatures in the imagery, a random stratified sampling method was implemented to select field sites to test map accuracy (Congalton 1991).

Subsequent to completion of the second draft coral reef habitat maps, waypoints were generated using a stratified random sampling scheme. Twenty to thirty accuracy assessment waypoints were collected per test area for each detailed structure and detailed cover class encountered. Waypoint files were generated from these points and all waypoints that could be safely accessed were navigated to using a Trimble Geo Explorer 3 GPS data logger (see Figure 7). Upon arriving at the waypoint, a weighted meter line was dropped, a buoy fastened and site and habitat specific data collection was undertaken. After deployment of the buoy, 100 GPS positions were collected at one-second intervals and were averaged to generate a single position.

Three benthic habitat assessments were conducted. A point assessment was conducted by surveying the one square meter area around the point where the weight dropped. Two area assessments were conducted in an area of a seven-meter radius around the weight. The first assessment identified the most common habitat type within the area and the second identified the second most common habitat type with in the area. The depth of the site was recorded using a hand held depth sounder. Benthic habitat assessments were made using a glass bottom look box, free diving or observing from the surface. All diving was conducted by breath holding or snorkeling on the surface. In areas where waves and sea conditions were prohibitive to safely accessing the waypoint by boat the GPS was placed in a watertight box and swam to the survey point.

Figure 7. Entering accuracy assessment data into the GPS data logger.

Data including but not limited to site ID, depth, most common habitat, zone and assessment method were recorded using the GPS data logger equipped with 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 were downloaded, differentially corrected to the closest CORS station and seamlessly converted to ArcView GIS format. All hand written descriptions were entered in waterproof notebooks and transferred to the GIS by hand. A total of 1,720 benthic habitat characterizations were completed in all sixteen test areas combined, 613 characterization points for American Samoa and 1107 points for the Marianas Archipelago.

To maintain objectivity in the analysis of accuracy, an independent team conducted this work. The Coral Reef Assessment and Monitoring Program (CRAMP) biologists from the Hawaii Institute of Marine Biology from the University of Hawaii at Manoa made the official judgments. The accuracy assessment point theme and the benthic habitat polygon themes were overlaid on the imagery in the GIS. The GIS was queried to select all points within the polygons that matched the polygon habitat type. These were set aside as correct calls. The mismatched pairs were closely examined.

The classification errors that occurred between the MMU and size of accuracy assessment areas were accounted for in this analysis. A map classification was not considered incorrect in a case where a seven meter radius field assessment fell on a habitat feature in the field that was smaller than 1 acre. For example, if a field assessment fell on a small patch reef surrounded by sand that was less than the MMU and thus was not mapped, the point was excluded from the accuracy assessment report. Points that fell close to polygon boundaries were all included as it was assumed that the probability of error contributing to false negatives would be equal to that for false positives. The habitat type for the portions of the test area that were not interpretable due to cloud cover, glint or water quality were classified as "unknown". The accuracy assessment points that fell within polygons with the habitat type of "unknown" were not included in the accuracy analysis.

Results of Overall Accuracy Assessment of Benthic Habitat Map Products

Thematic accuracy of the benthic habitat maps was determined using the aforementioned methods. The mapped habitat type was compared with that of the actual habitat type from field observation. The data is organized into columns representing the field habitat assessment and the rows organized into mapped habitat type. The correct class for each of the incorrect attributes was recorded and included in a comprehensive matrix at the most detailed level of the classification scheme. Four of these detailed matrices were generated, one each for biological cover and geomorphological structure in American Samoa and the Marianas Archipelago. Error matrices were prepared at the detailed and general levels to identify patterns of confusion in the interpretation of the signatures in the imagery. This information was incorporated into ongoing work to improve the accuracy of mapped product. A complete description of these results can be found in the final project report, *Project Completion Report: Mapping of Benthic Habitats for U.S. Pacific Territories*.

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 whereas the Tau analysis indirectly incorporates the off-diagonal elements as a product of the row and column marginals. Furthermore, the Tau analysis compensates for unequal probabilities of groups or for differences in numbers of groups (Ma and Redmond 1995). This assessment lends itself to statistical analysis wherein the photointerpreter's determination is assigned a probability that it occurred at random (Tables 1 and 2).

Table 1. Summary of benthic habitat map thematic accuracy of American Samoa.

American Samoa		
Map Category	**Overall Accuracy**	**Tau**
Major Structure	98.0 %	0.97
Detailed Structure	84.0 %	0.83
Major Cover	87.6 %	0.86
Detailed Cover	77.3 %	0.76

Table 2. Summary of benthic habitat map thematic accuracy of the Mariana Archipelago.

Marianas Archipelago		
Map Category	**Overall Accuracy**	**Tau**
Major Structure	98.7 %	0.98
Detailed Structure	92.6 %	0.92
Major Cover	87.8 %	0.86
Detailed Cover	80.9 %	0.80

Map Uses

Maps included in this atlas and the *Shallow-water Benthic Habitats of the American Samoa, Guam, and CNMI* (CD-ROM) are tools with a wide variety of uses. One purpose of the maps was to provide a baseline inventory of the tropical shallow-water marine ecosystems of the U.S., specifically habitats that support coral reefs or are functionally connected to them, however, the resulting maps have applications beyond a baseline inventory.

As a stand-alone product, the maps themselves provide a wealth of information about the seascapes depicted in them. Attributes contained in the GIS shapefiles provide access to a broad range of spatial metrics and statistics. A few examples include: determining the spatial extent of each habitat (e.g., total area of dense macroalgae), determining the spatial extent of major classes (e.g., area of soft bottom habitats), and performing proximity analyses (e.g., finding sand within 20m of a reef). They also provide a visual guide to the relative scarcity or abundance of particular habitat types. When used in conjunction with other data sets, the possibilities become much greater. Some potential applications are described below:

Scientific Applications

Maps and derived seascape metrics have been used extensively as a tool for

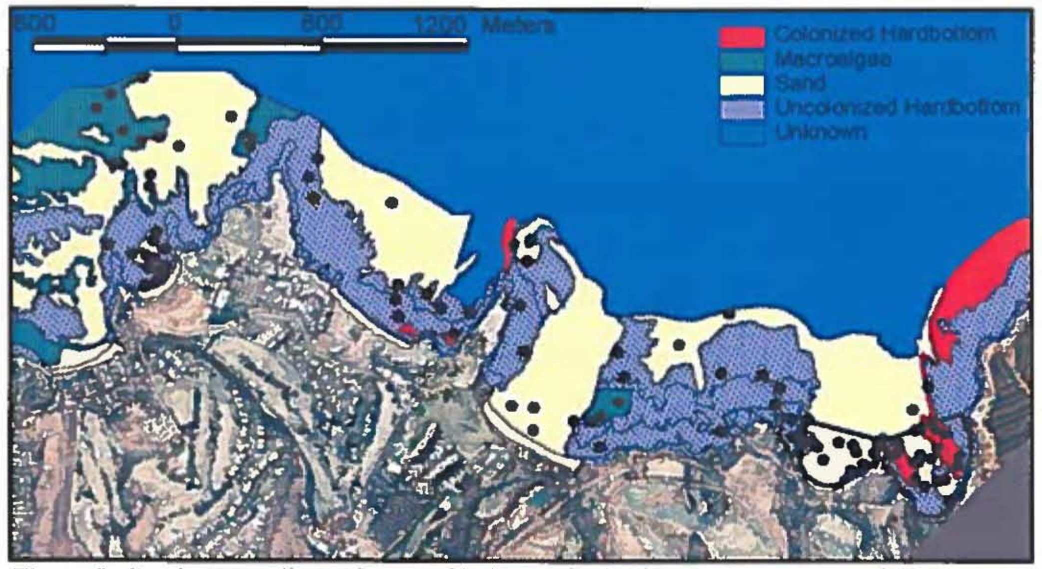


Figure 8. Random sampling points stratified by major habitat class and location inside/outside the Honolua-Mokuleia Marine Life Conservation District boundaries that were used by scientists for monitoring fish and benthic communities on the island of Maui in July and August 2002.

monitoring tropical shallow-water marine ecosystems and the biological communities that exist there. The GIS maps enable researchers to design sampling strategies that support field operations (Figure 8; Friedlander and Brown 2003, Kendall et al. 2003). When combined with monitoring data such as fish censuses or water quality measurements, the maps allow for sophisticated spatially-explicit analyses (Monaco et al. 2001). Analysis of habitat maps in conjunction with information about biological community structure (derived from monitoring efforts) allows scientists to model and predict areas of biological importance (Figure 9; Christensen et al. 2003, Kendall et al. 2003). Some scientists use the habitat maps as proxies in defining the distribution of species or groups that have specific habitat requirements. When used in combination with time-series

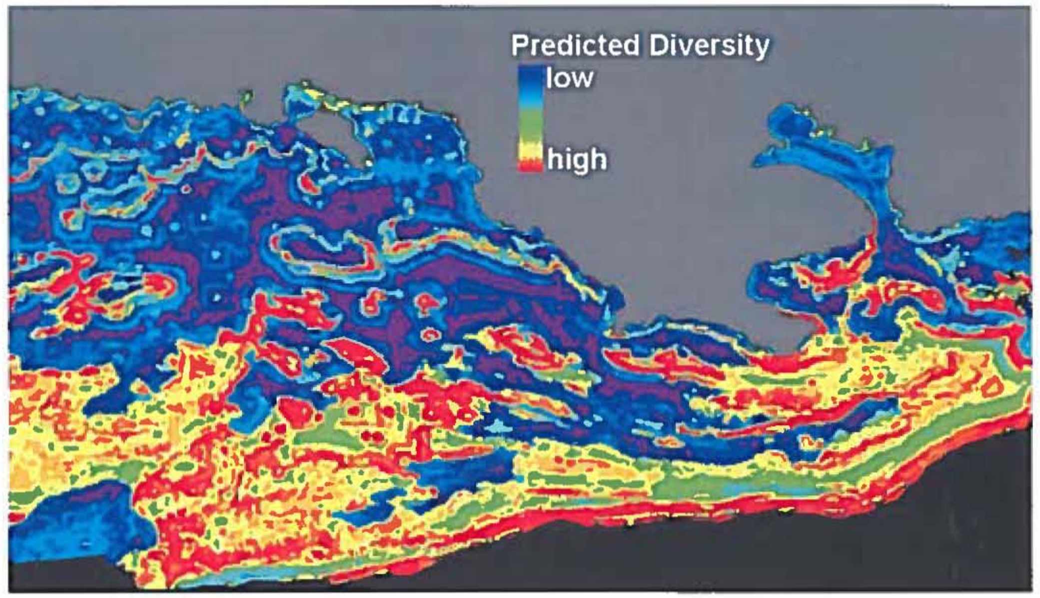


Figure 9. A map of the predicted diversity of fish species in Southwestern Puerto Rico, based on the habitat map developed for the area and fish census data collected by NOAA/ NOS scientists between 2000-2002.

data, the maps provide a mechanism for change detection. If habitat maps are combined with other environmental data layers and known species affinities, they can be instrumental in Habitat Suitability Modeling.

Planning and Management Applications

Coastal zone managers are often required to balance multiple and conflicting uses of the nearshore environment. Habitat maps can help managers identify areas that may be especially susceptible to damage from spills, vessel groundings, and other accidents. The maps also can be used in response planning and evaluating restoration activities in the event that marine resources are damaged, and can contribute to natural resource damage assessment activities. Managers may also use the maps to identify areas of special concern, such as in the case of habitats that sustain rare or threatened species. When used in conjunction with other biological and environmental data, such map products can help determine optimal locations for establishing networks of marine protected areas. The maps and associated data help ensure that the selected sites encompass areas of high biological importance and are representative of biological conditions. With the inclusion of oceanographic information, managers can identify sites that are effectively linked by prevailing currents, thereby preserving important ecological linkages. Habitat maps can help identify areas that are more or less suitable for a particular purpose. For example, similar benthic habitat maps in the Northwestern Hawaiian Islands are being used to support discussions on marine zoning throughout the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (Figure 10). They are also helpful in evaluating permit applications and identifying alternate locations for proposed marinas, dredging activities, sand mining and beach nourishment operations, and coastal access points. The maps may also contribute important contextual information about effects in the nearshore environment that stem from land use in adjacent coastal and upstream areas.

Other Applications

Members of the public have found the maps useful in a variety of ways as well. Recreational fishers benefit from knowing where particular habitat areas are located, especially if the target species has a particular habitat affinity. Commercial interests have used the habitat maps for siting aquaculture facilities in order to protect their equipment from damage and minimize the potential negative impacts associated with those operations. Other commercial ventures use habitat maps in conjunction with geologic maps to assess potential risk to proposed undersea cables or structures. Academics have used the CD-ROM map products in classes to teach students about the capabilities of Geographic Information Systems. Several graduate students have pursued projects or Ph.D. dissertations in the fields of fish biology or landscape ecology that utilize digital habitat maps developed by NOAA. One student project refined the habitat maps for marine protected areas along Hawaii's west coast to provide finer scale habitat information to managers.

It is important to note that these maps represent the best efforts of scientists, who are working within budget and time constraints, to communicate habitat information at a scale relevant to management. As such, we encourage map users to consider the current maps as a springboard for further development. We have provided all the necessary tools (IKONOS imagery, mosaics, the habitat digitizing extension to ArcView, a hierarchical classification scheme, shapefiles and legends that define areas by geomorphologic zone and habitat, etc.) to enable users to further refine the map products, such as by re-digitizing polygons from aerial photos viewed at a finer scale or by decreasing the size of the minimum mapping unit to capture even more detailed features. This has been accomplished by scientists working within National Park boundaries in the Caribbean and in Marine Life Conservation Districts in Hawaii, and resource managers in the U.S. Pacific Territories.

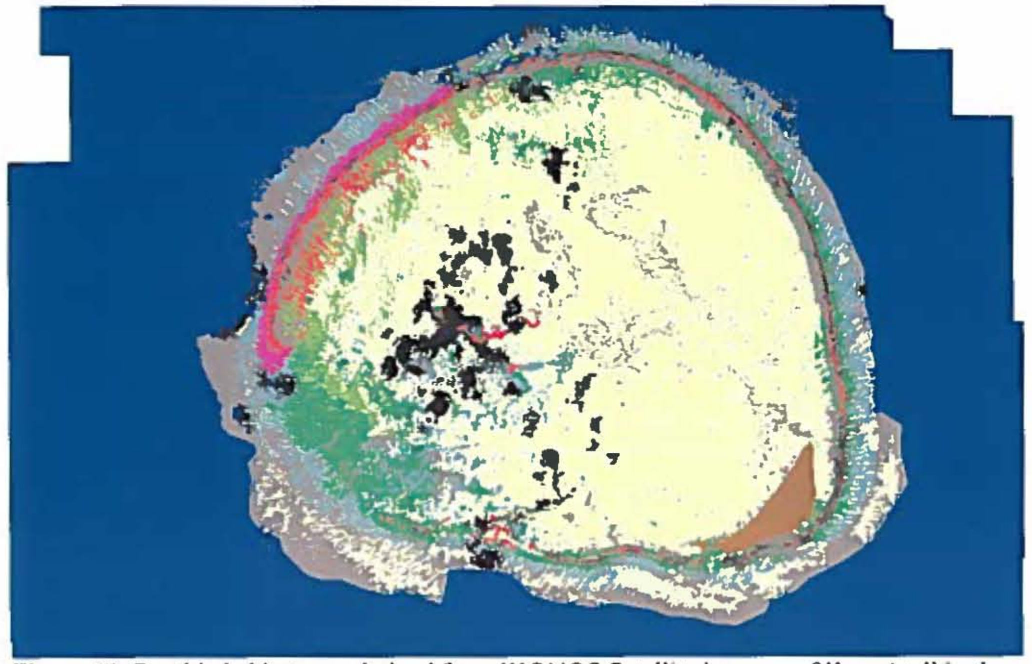


Figure 10. Benthic habitat map derived from IKONOS Satellite imagery of Kure Atoll in the Northwestern Hawaiian Islands.

A GIS summary has been prepared that presents the areas of each of the detailed structure classes and major cover classes encountered in the American Samoa and Mariana Archipelago Regions. The information is presented in absolute areas (km²) and percentage of the total coral reef area mapped. From the American Samoa data it can be seen that of the 71.5 km² mapped, approximately 85.3% is coral reef and hard bottom and approximately 14.7% is composed of unconsolidated sediment. Of the total area mapped in American Samoa approximately 53% is colonized by at least 10% live coral cover (Tables 3 and 4). From the Mariana Archipelago data it can be seen that of the 263.2 km² mapped, approximately 69.2% is coral reef and hard bottom and approximately 30.8% is composed of unconsolidated sediment. Of the total area mapped in the Mariana Archipelago 27.8% is colonized by at least 10% live coral cover (Tables 5 and 6).

Table 3. Coral reef habitat thematic content summary of biological cover classes in American Samoa.

Coral Reef Biological Cover Type	Area (km²)	% of Area
Coral	38.3	53.0
Macroalgae	2.6	3.6
Coralline Algae	14.9	20.8
Turf	4.9	6.9
Emergent Vegetation	0.3	0.4
Uncolonized	10.5	14.7
Total Coral Reef Area	**71.5**	**100**

Table 4. Coral reef habitat thematic content summary of geomorphological structure classes of American Samoa.

Coral Reef Structure Type	Area (km²)	% of Total Reef Area
Pavement	29.9	41.4
Spur and Groove	8.8	12.4
Individual Patch Reef	0.3	0.4
Aggregate Patch Reef	0.7	1.0
Aggregated Reef	9.4	13.2
Rock/Boulder	1.9	2.7
Rubble	8.4	1.8
Scattered Coral and Rock in Unconsolidated Sediment	1.6	2.3
Total Coral Reef and Hard Bottom	**60.9**	**85.3**
Sand	8.9	12.4
Mud	1.7	2.4
Total Unconsolidated Sediment	**10.5**	**14.7**
Total Coral Reef Area	**71.5**	**100**

Table 5. Coral reef habitat thematic content summary of biological cover classes in Mariana Archipelago.

Coral Reef Biological Cover Type	Area (km²)	% of Area
Coral	73.1	27.8
Seagrass	10.4	4.0
Macroalgae	35.3	13.4
Coralline Algae	26.0	9.9
Turf	50.0	19.0
Emergent Vegetation	0.2	0.1
Uncolonized	68.1	25.9
Total Coral Reef Area	**263.1**	**100**

Table 6. Coral reef habitat thematic content summary of geomorphological structure classes of Mariana Archipelago.

Coral Reef Structure Type	Area (km²)	% of Total Reef Area
Pavement	100.0	38.0
Spur and Groove	20.7	7.9
Individual Patch Reef	0.6	0.2
Aggregate Patch Reef	14.9	5.7
Aggregated Reef	25.3	9.6
Rock/Boulder	0.9	0.3
Rubble	2.8	1.1
Scattered Coral and Rock in Unconsolidated Sediment	1.7	0.6
Pavement with Sand Channels	15.3	5.8
Total Coral Reef and Hard Bottom	**182.2**	**69.2**
Sand	80.4	30.5
Mud	0.62	0.2
Total Unconsolidated Sediment	**81.0**	**30.8**
Total Coral Reef Area	**263.2**	**73.0**

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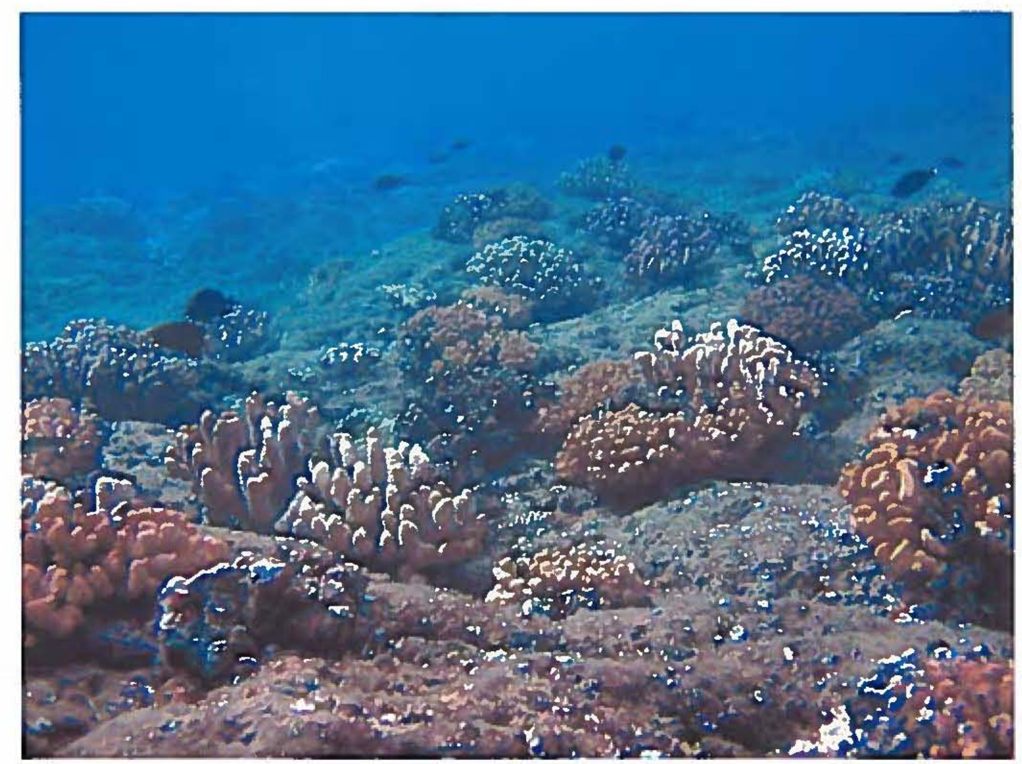
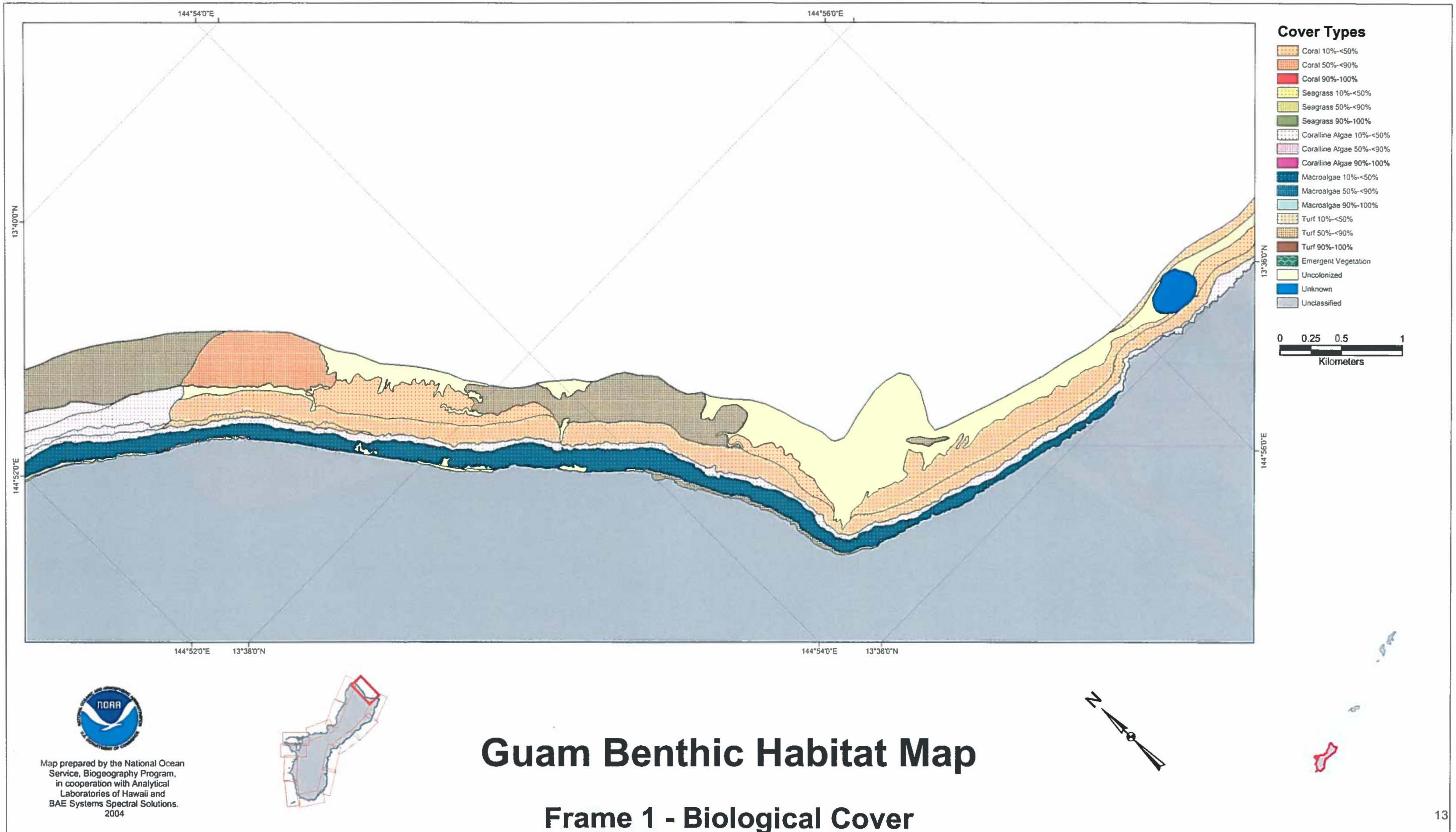
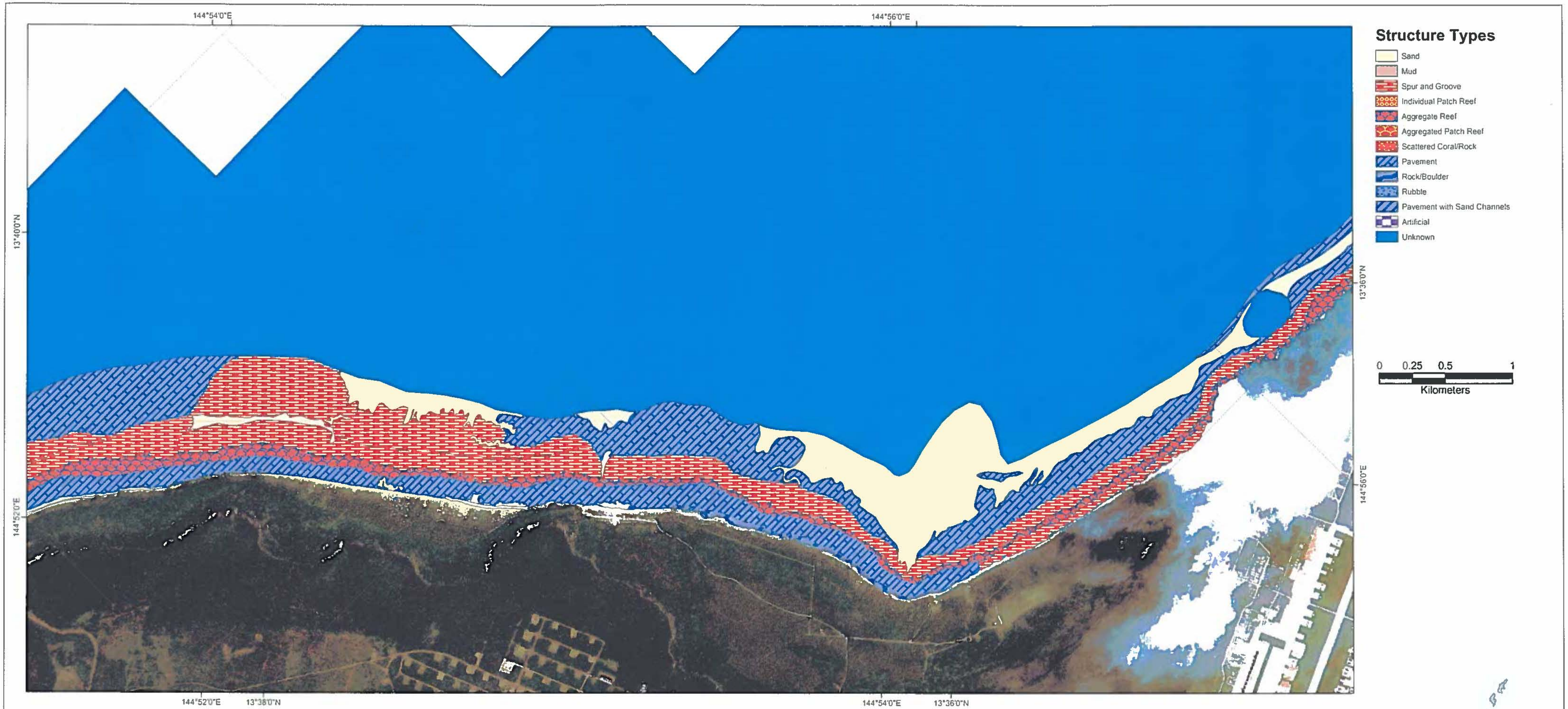




Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

Frame 1 - Biological Cover



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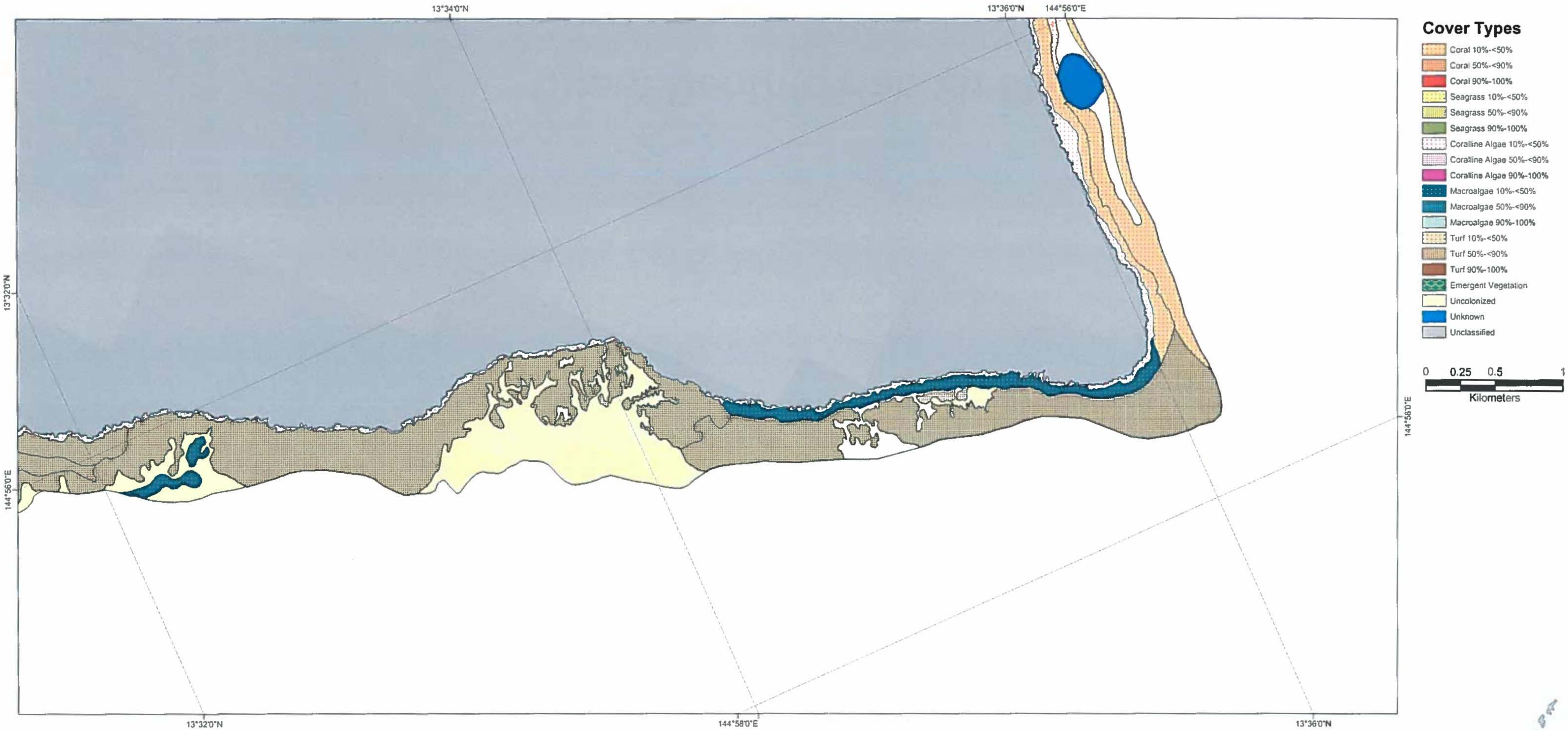
Guam Benthic Habitat Map

Frame 1 - Geomorphological Structure



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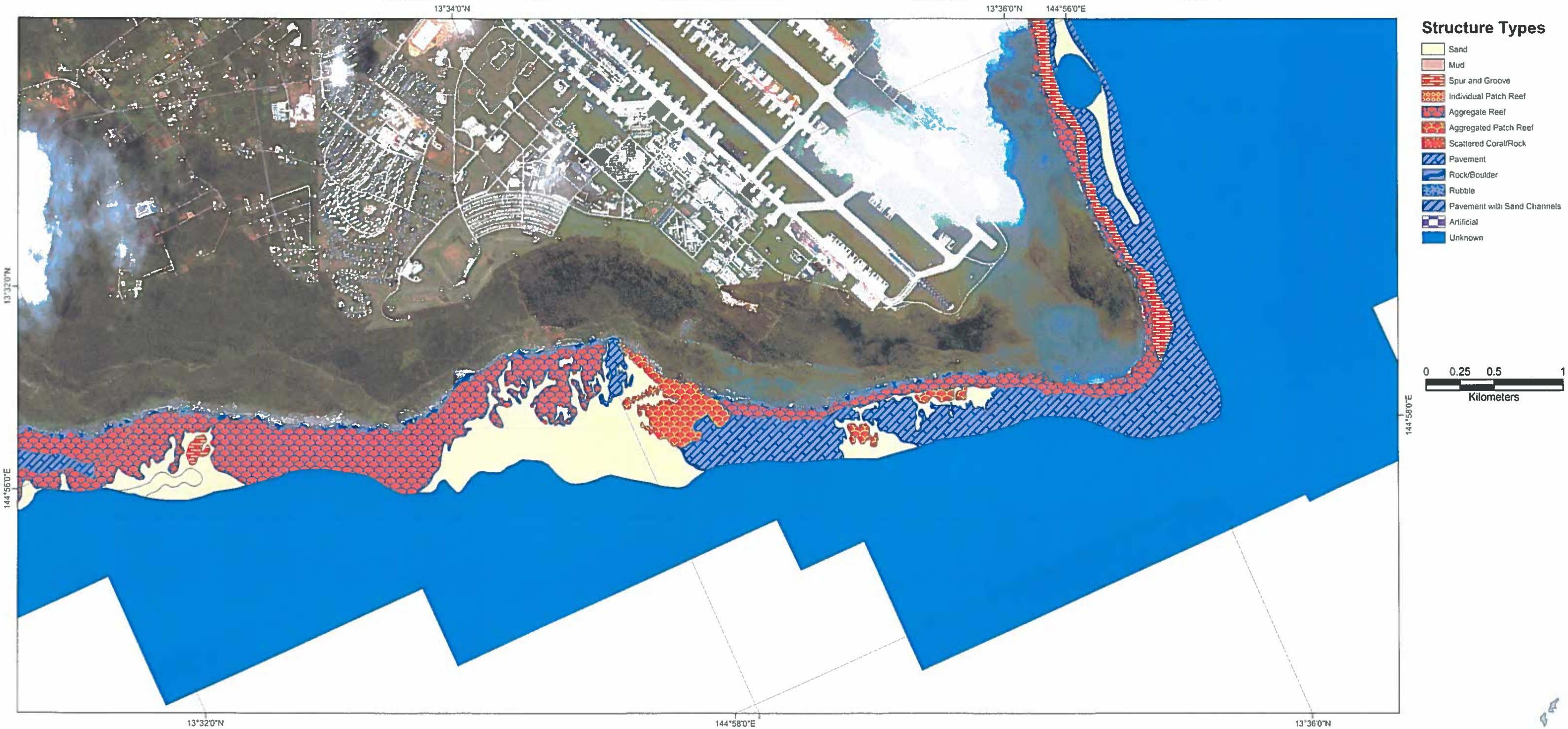
Guam Benthic Habitat Map

Frame 2 - Biological Cover



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Guam Benthic Habitat Map

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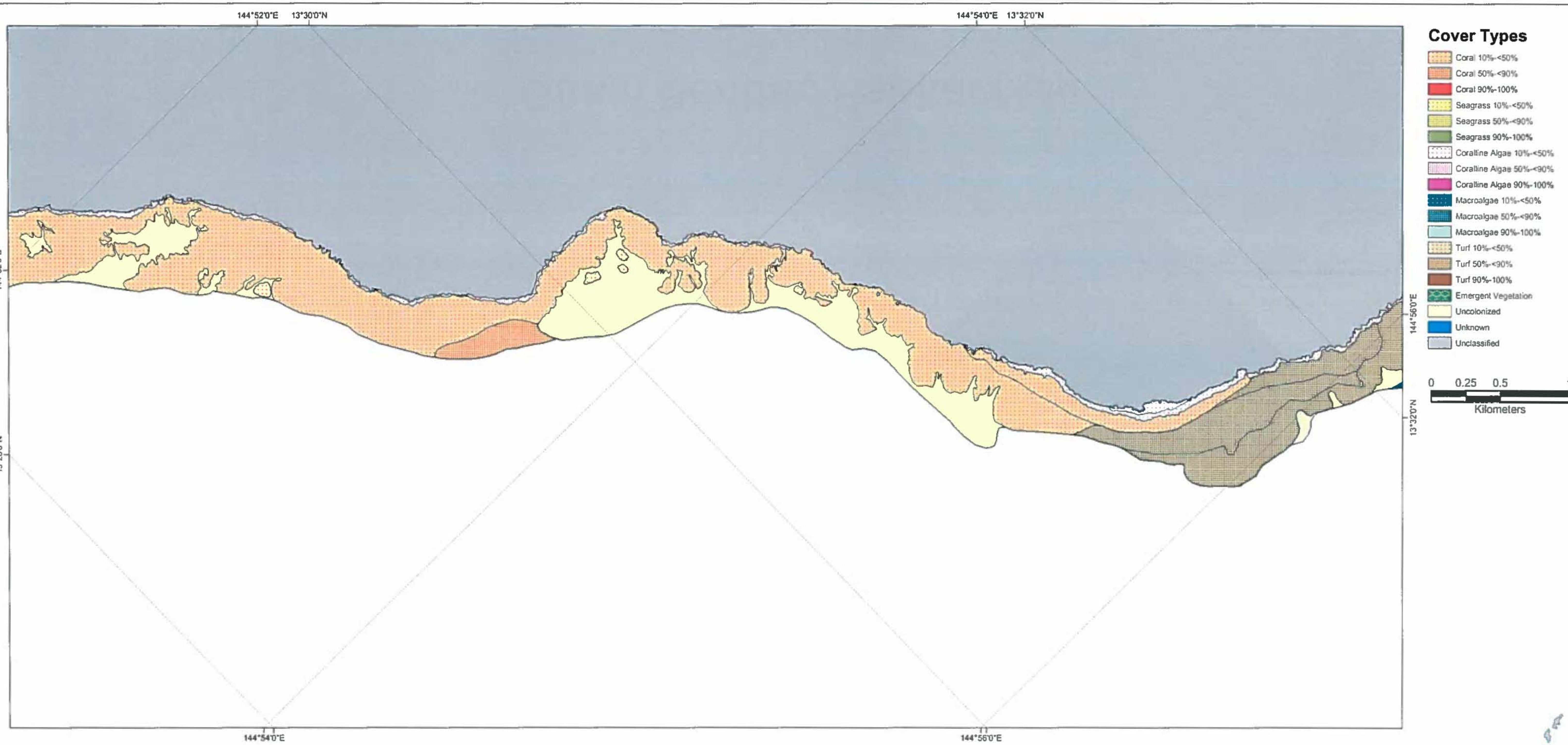

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Guam Benthic Habitat Map

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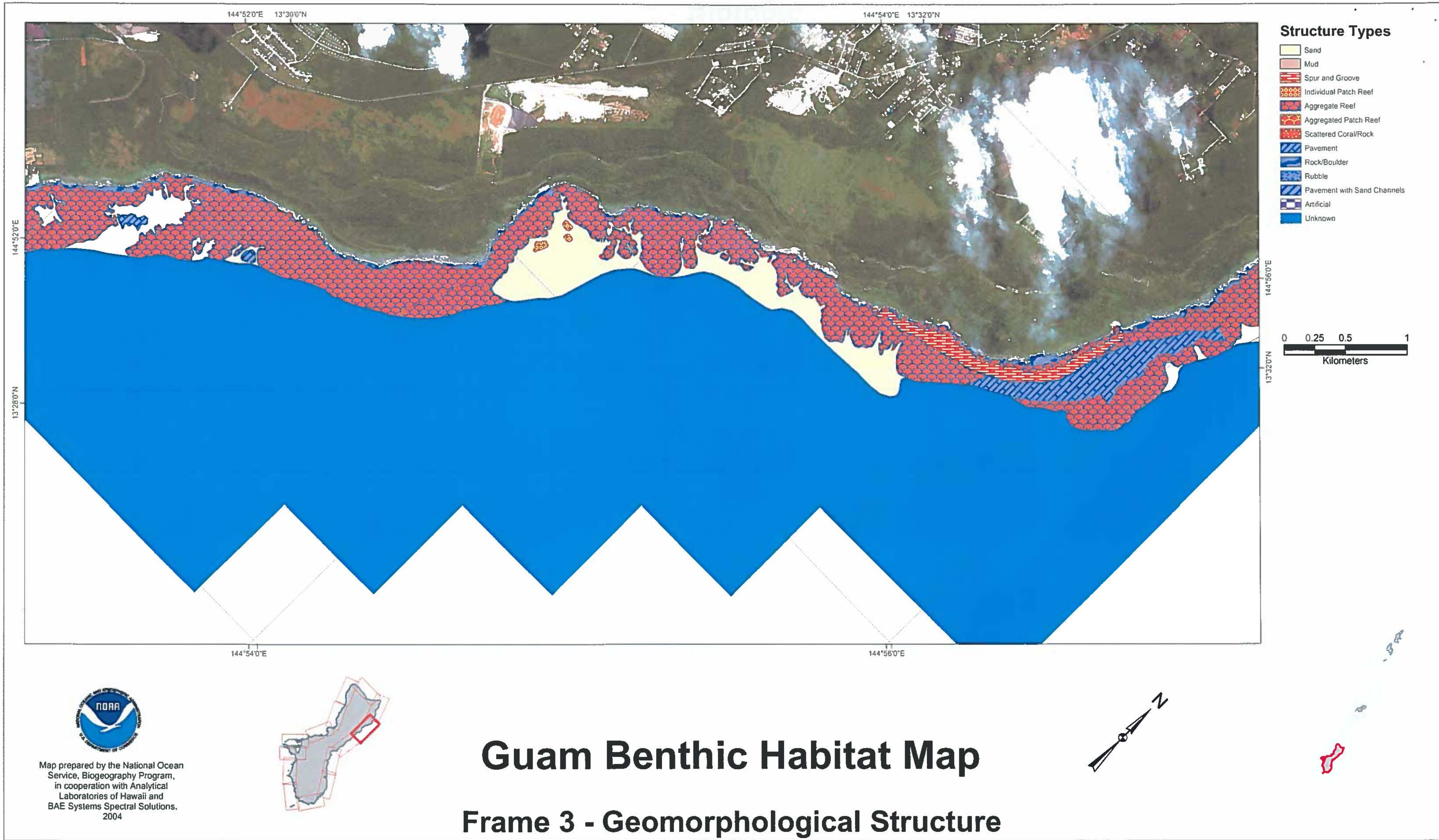
Frame 3 - Biological Cover



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Guam Benthic Habitat Map

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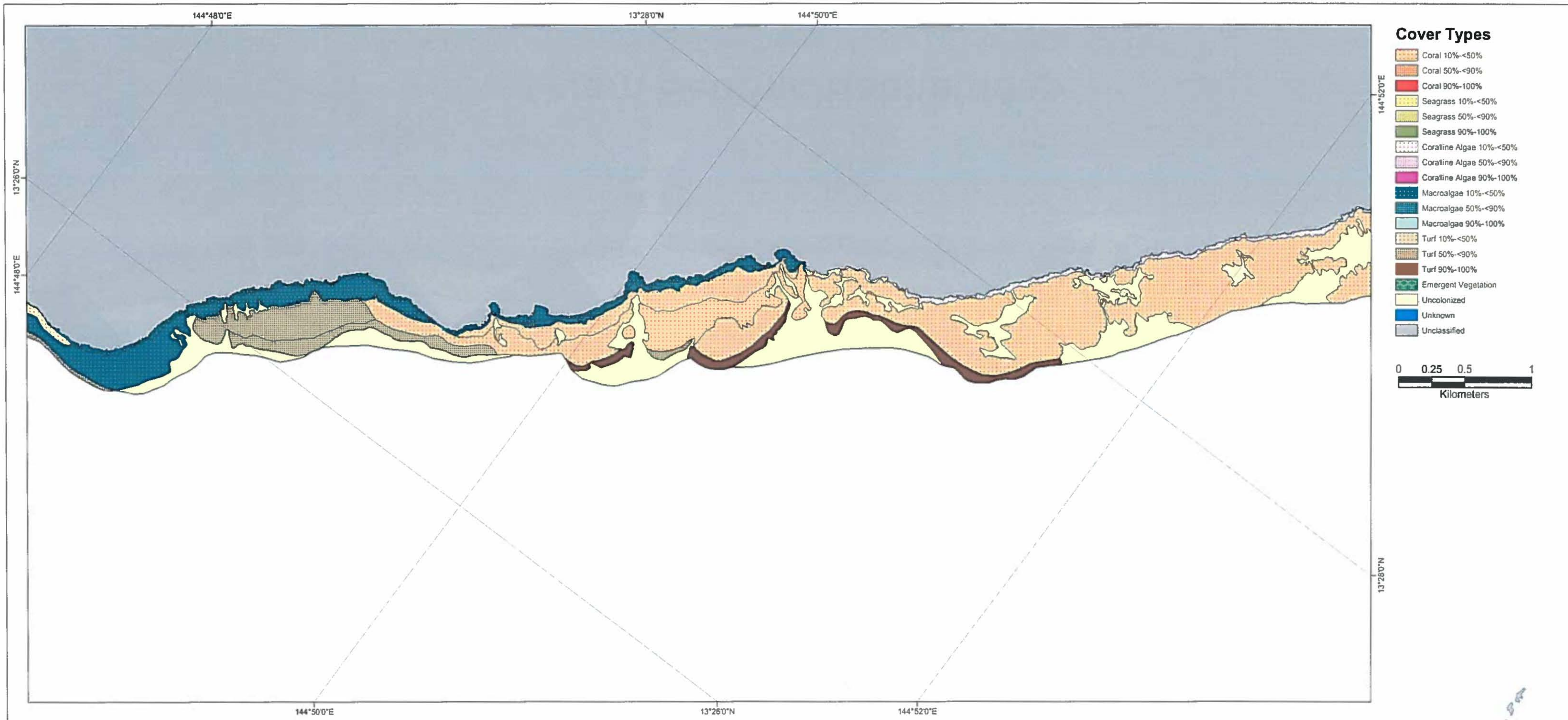

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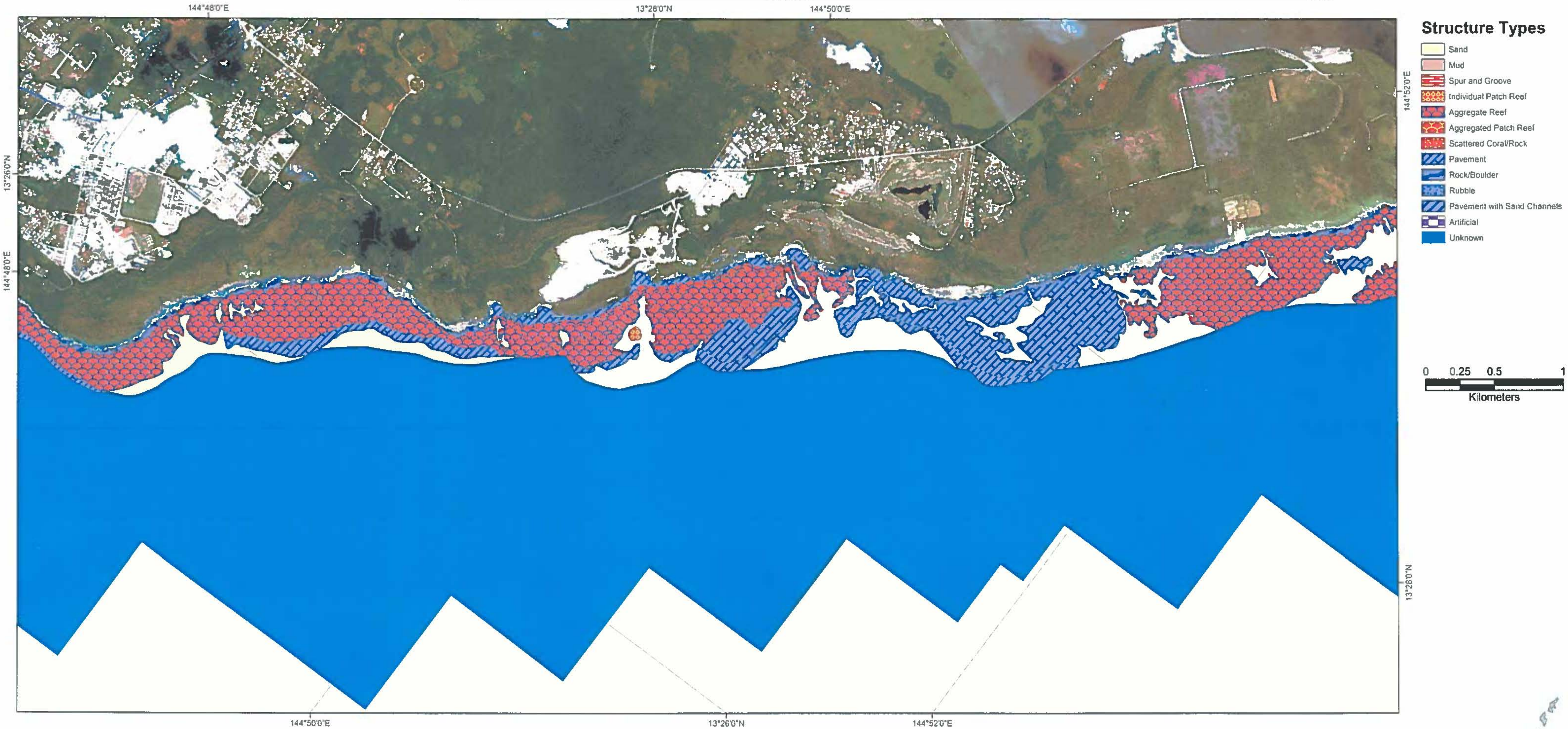
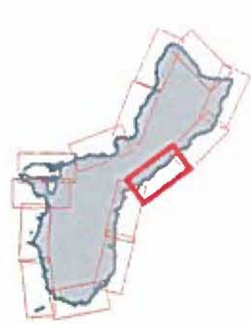
Guam Benthic Habitat Map

Frame 4 - Biological Cover





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Guam Benthic Habitat Map

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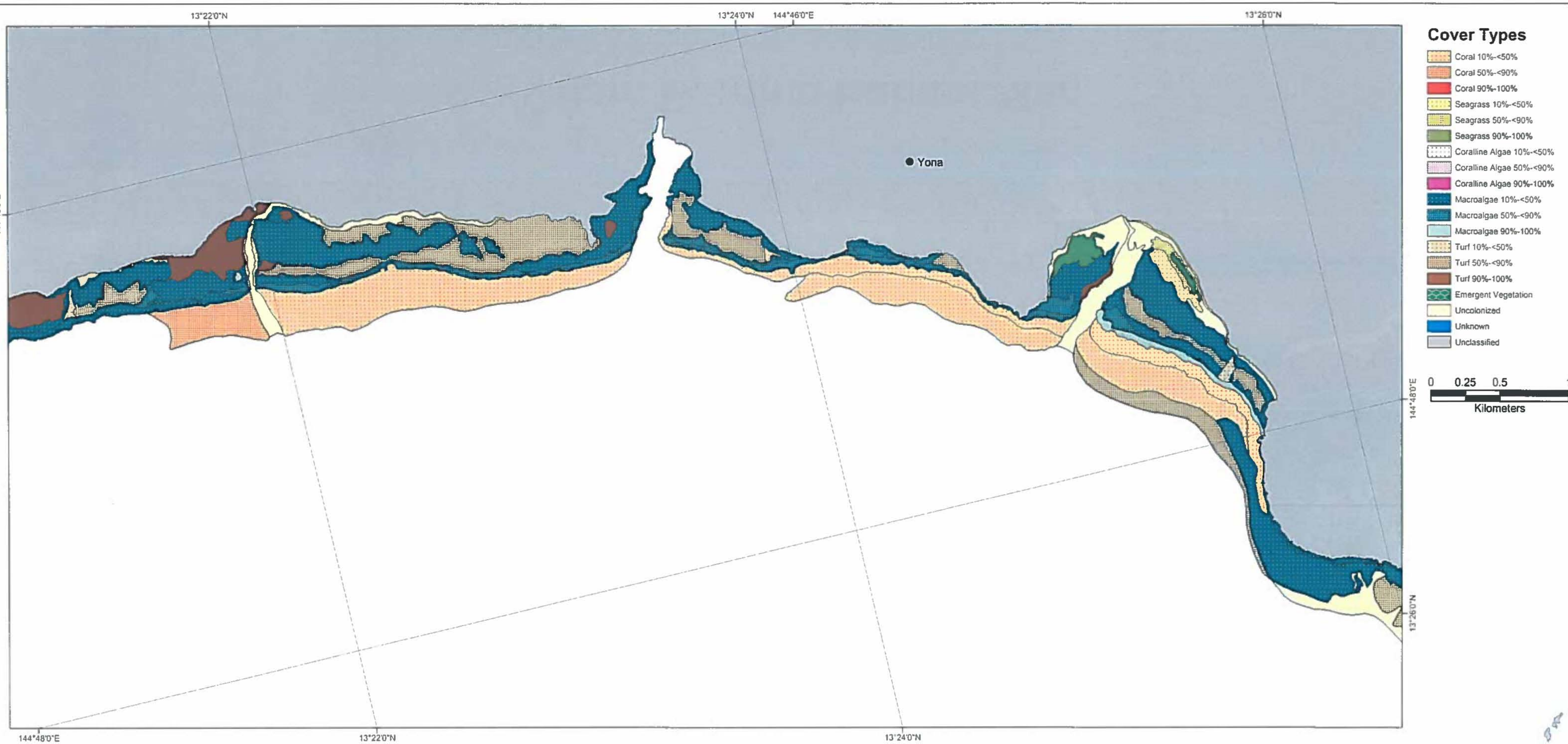

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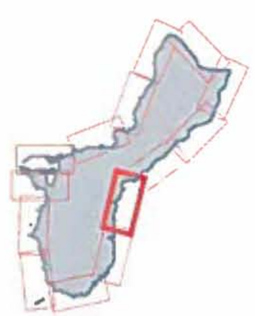
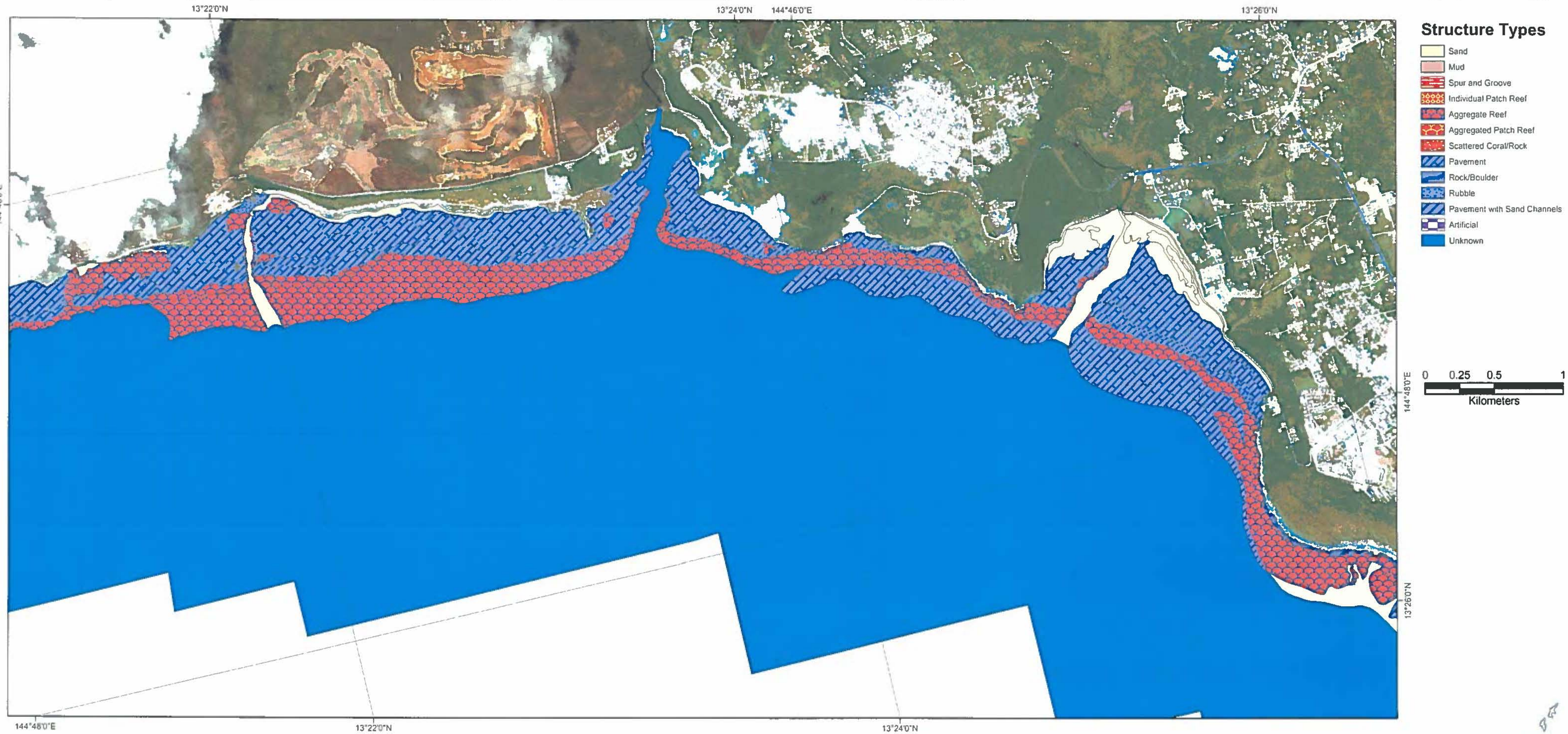


Guam Benthic Habitat Map

Frame 5 - Biological Cover



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Guam Benthic Habitat Map

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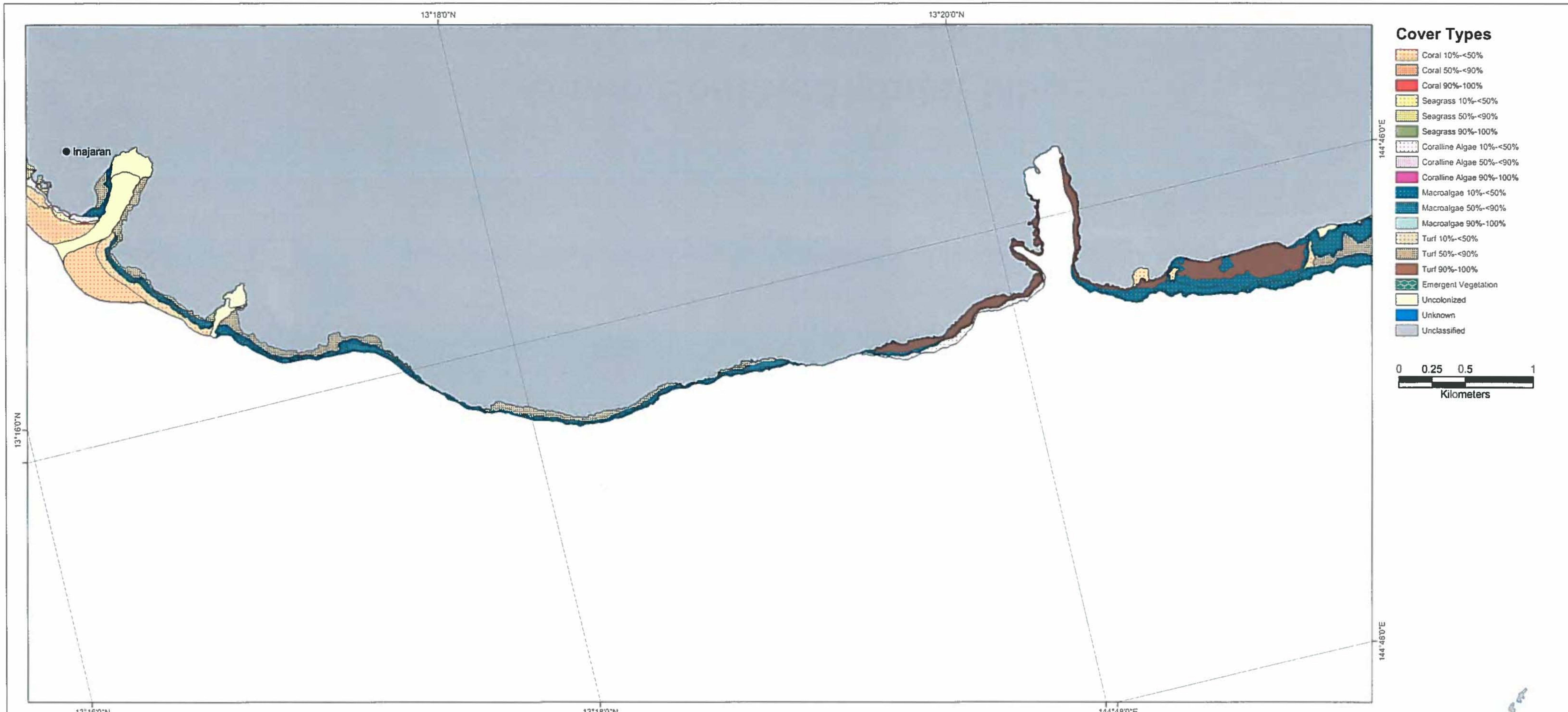

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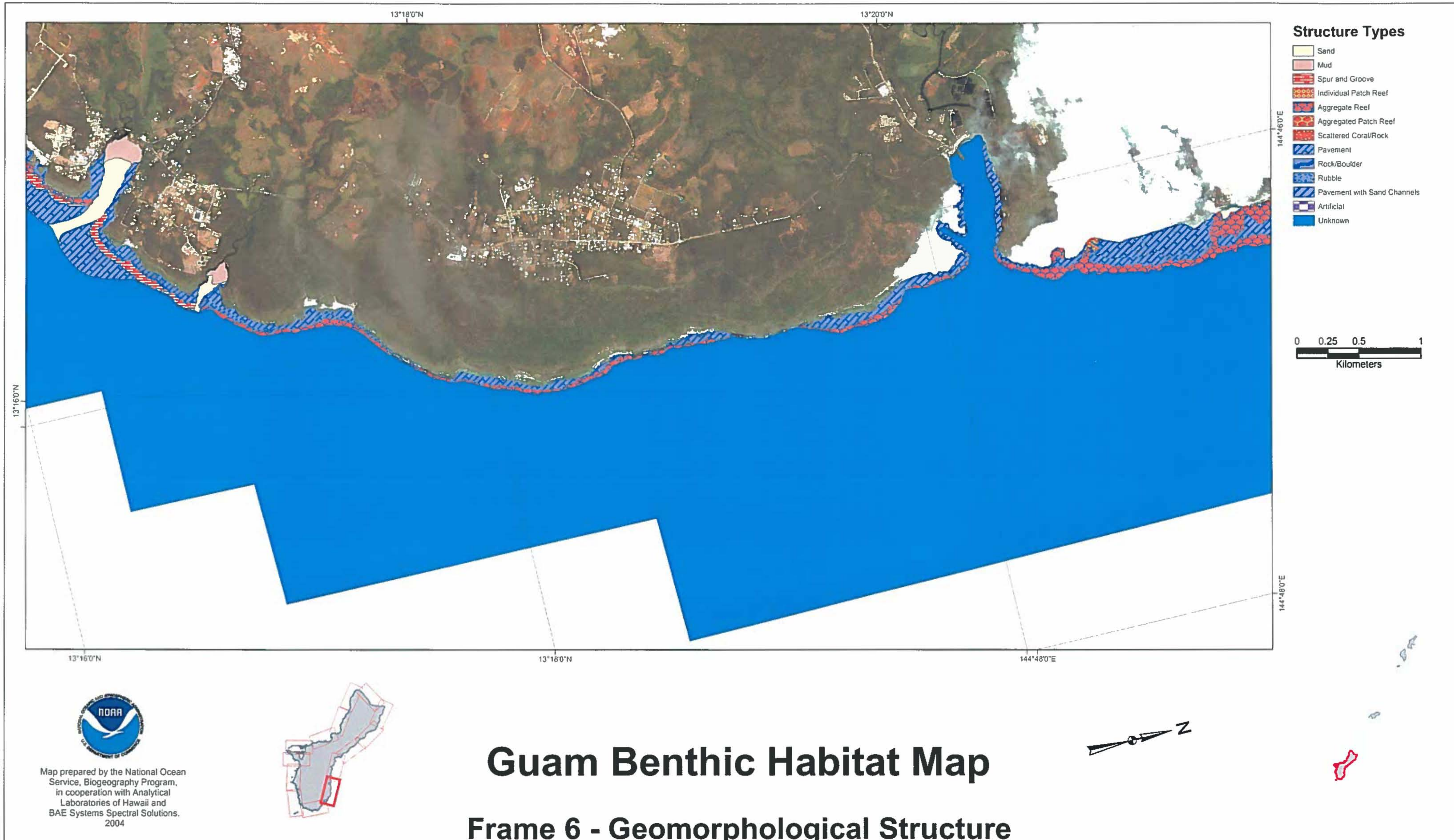
Guam Benthic Habitat Map

Frame 6 - Biological Cover



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Guam Benthic Habitat Map

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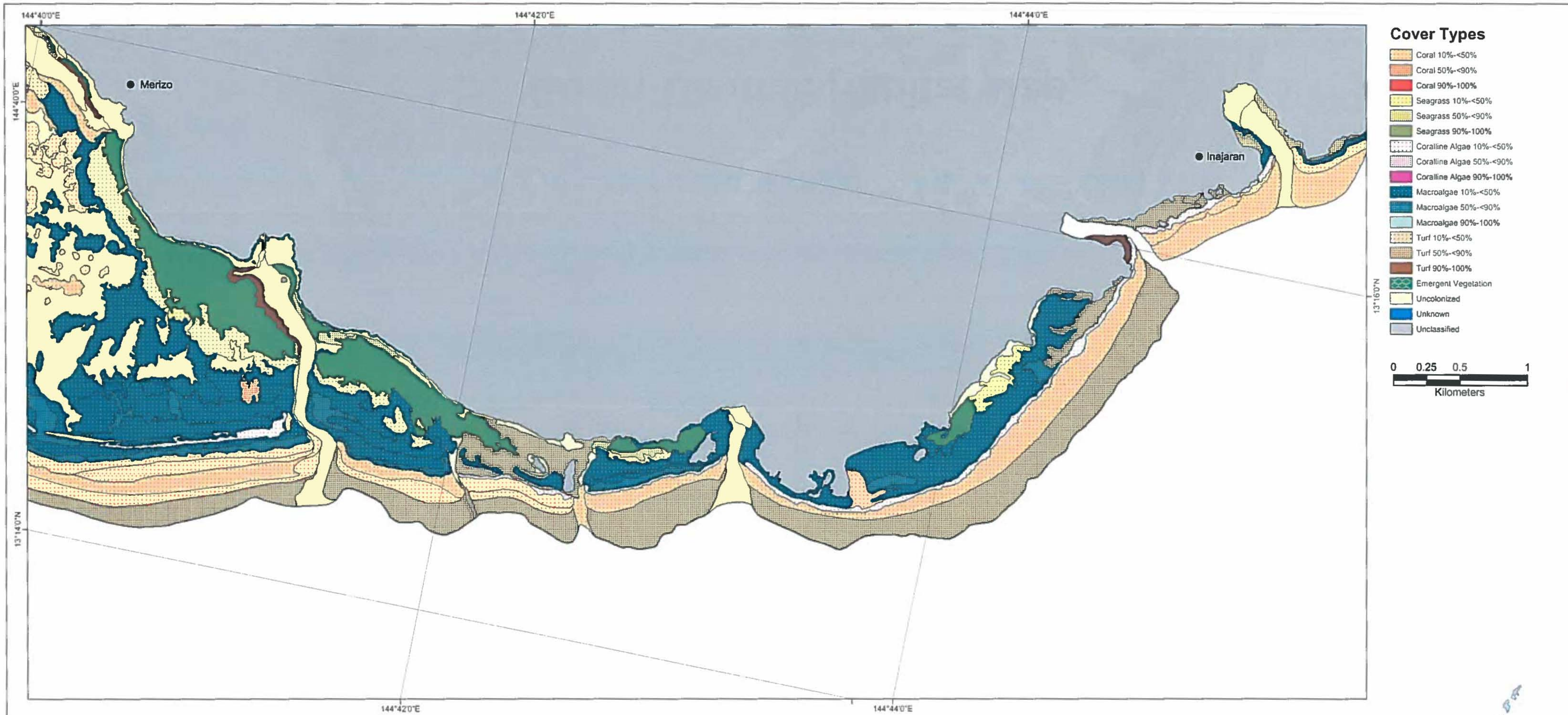

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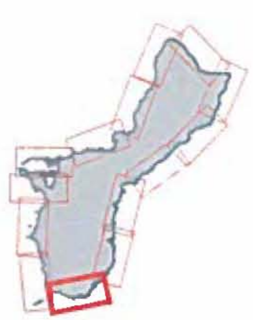
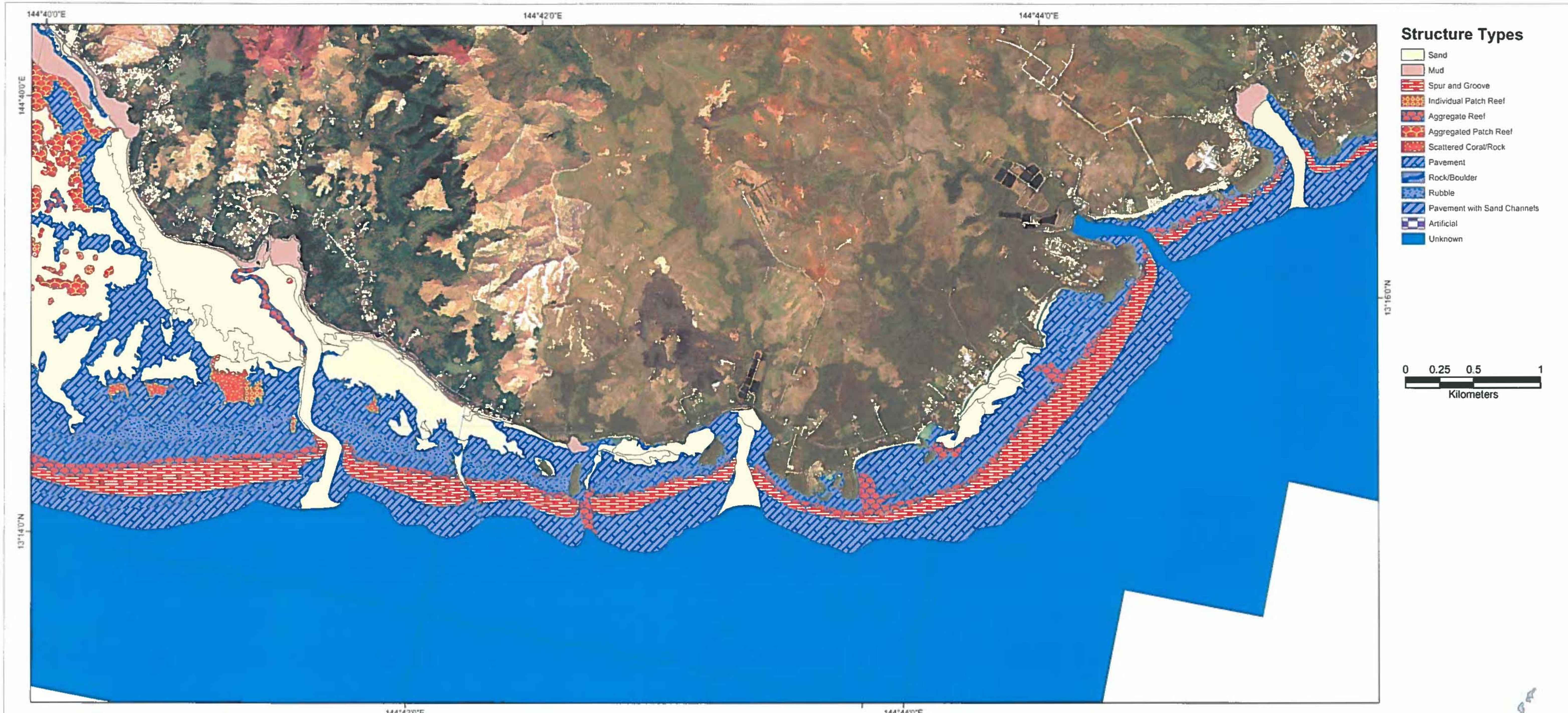


Guam Benthic Habitat Map

Frame 7 - Biological Cover



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Guam Benthic Habitat Map

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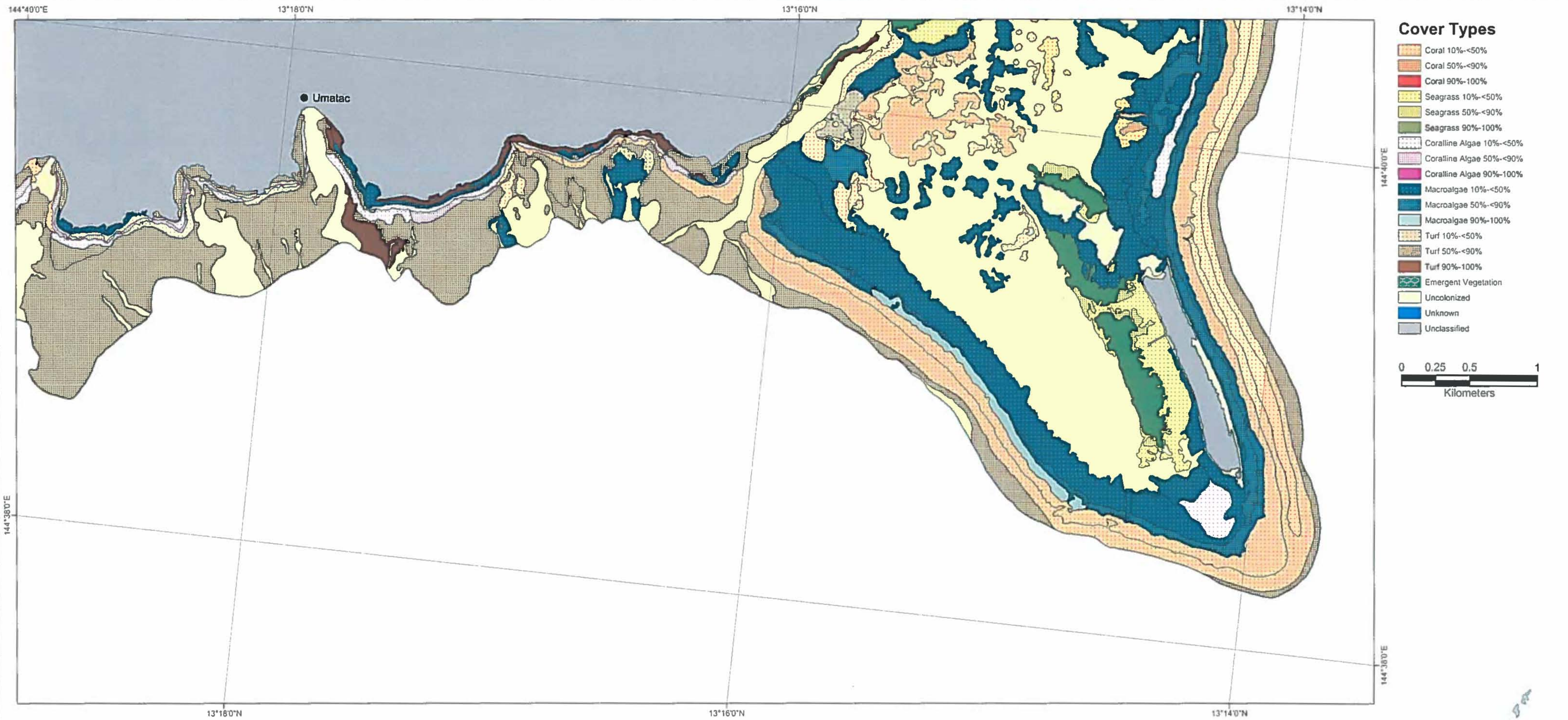
Frame 7 - Geomorphological Structure



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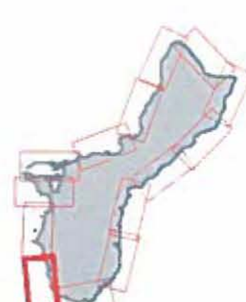
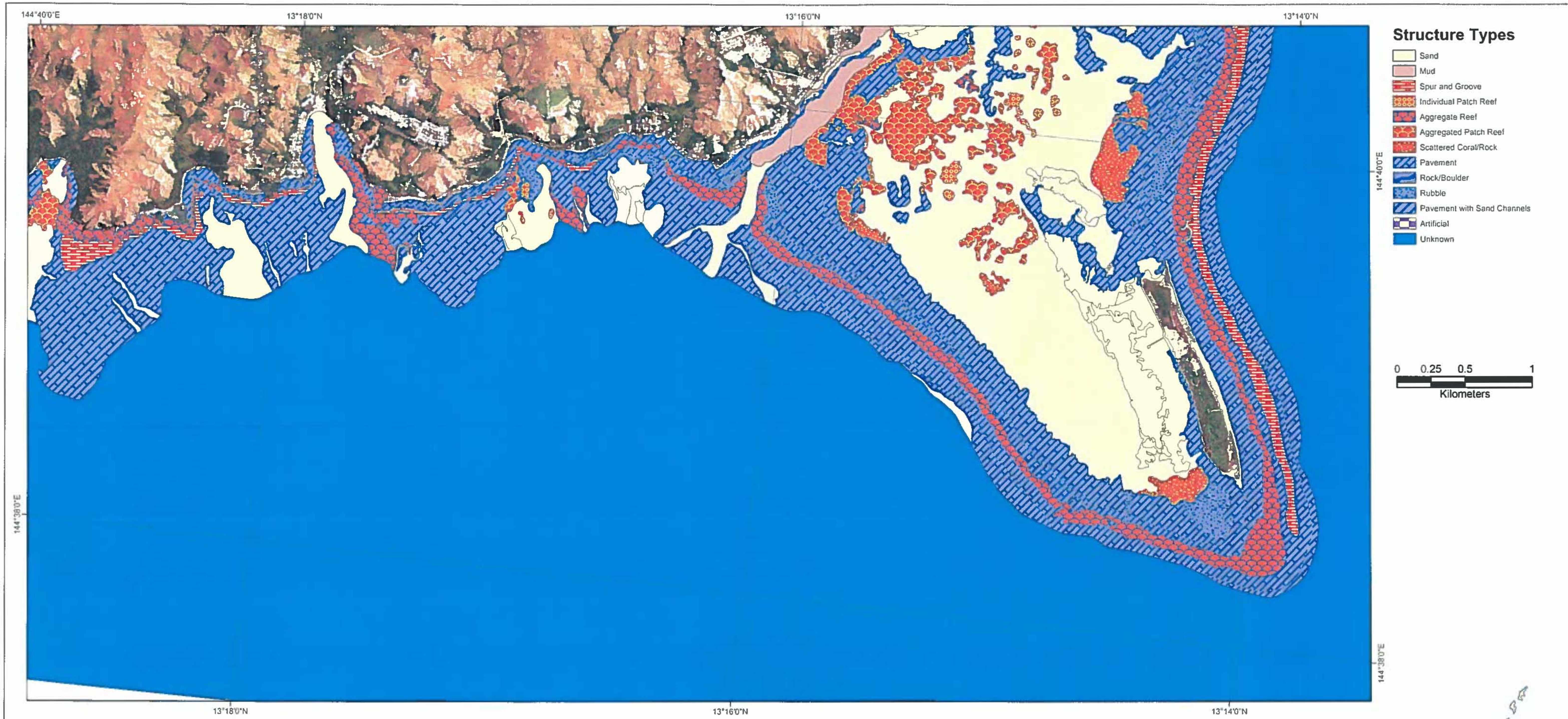


Guam Benthic Habitat Map

Frame 8 - Biological Cover



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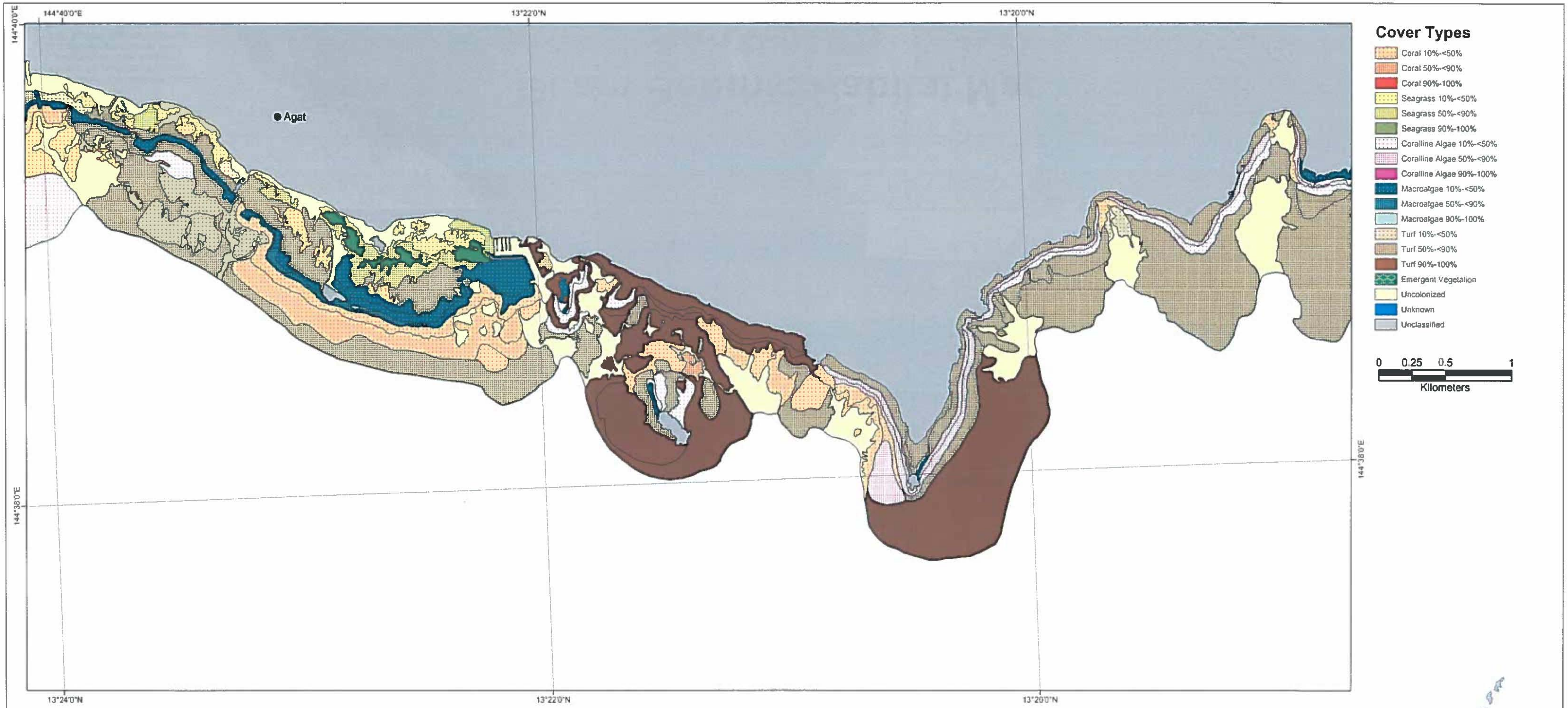
Guam Benthic Habitat Map

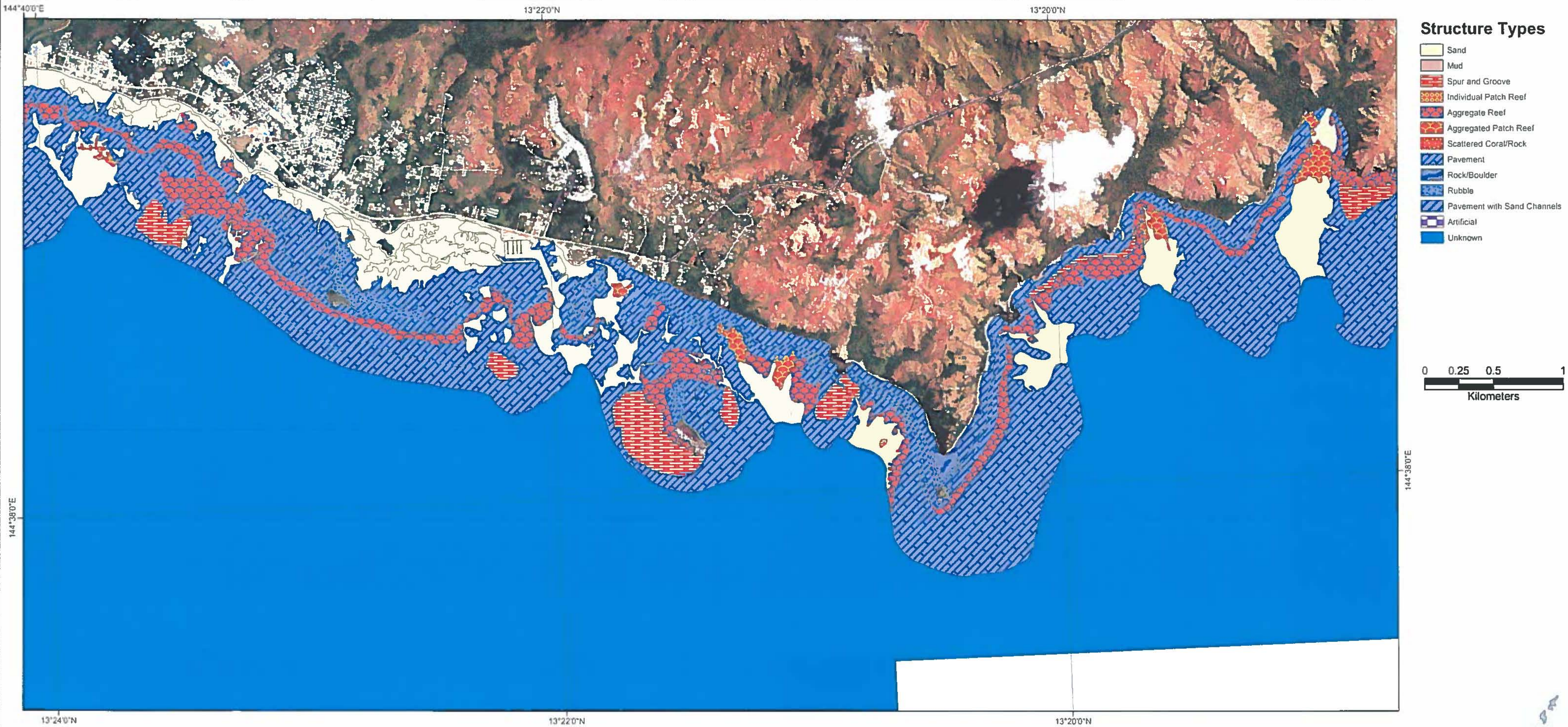
Frame 8 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

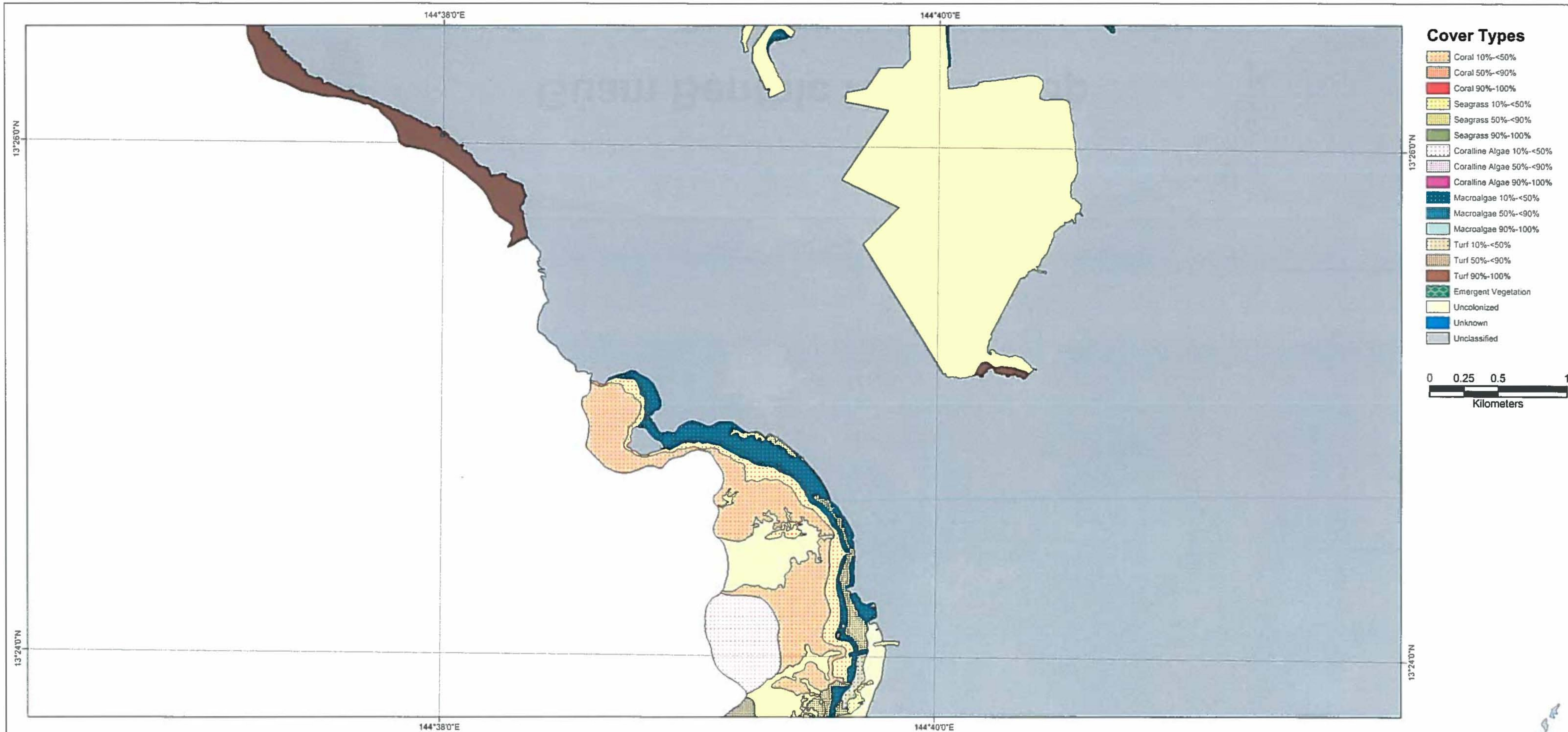
Frame 9 - Biological Cover



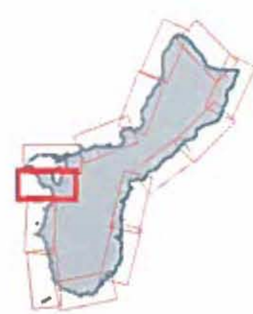
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

Frame 9 - Geomorphological Structure



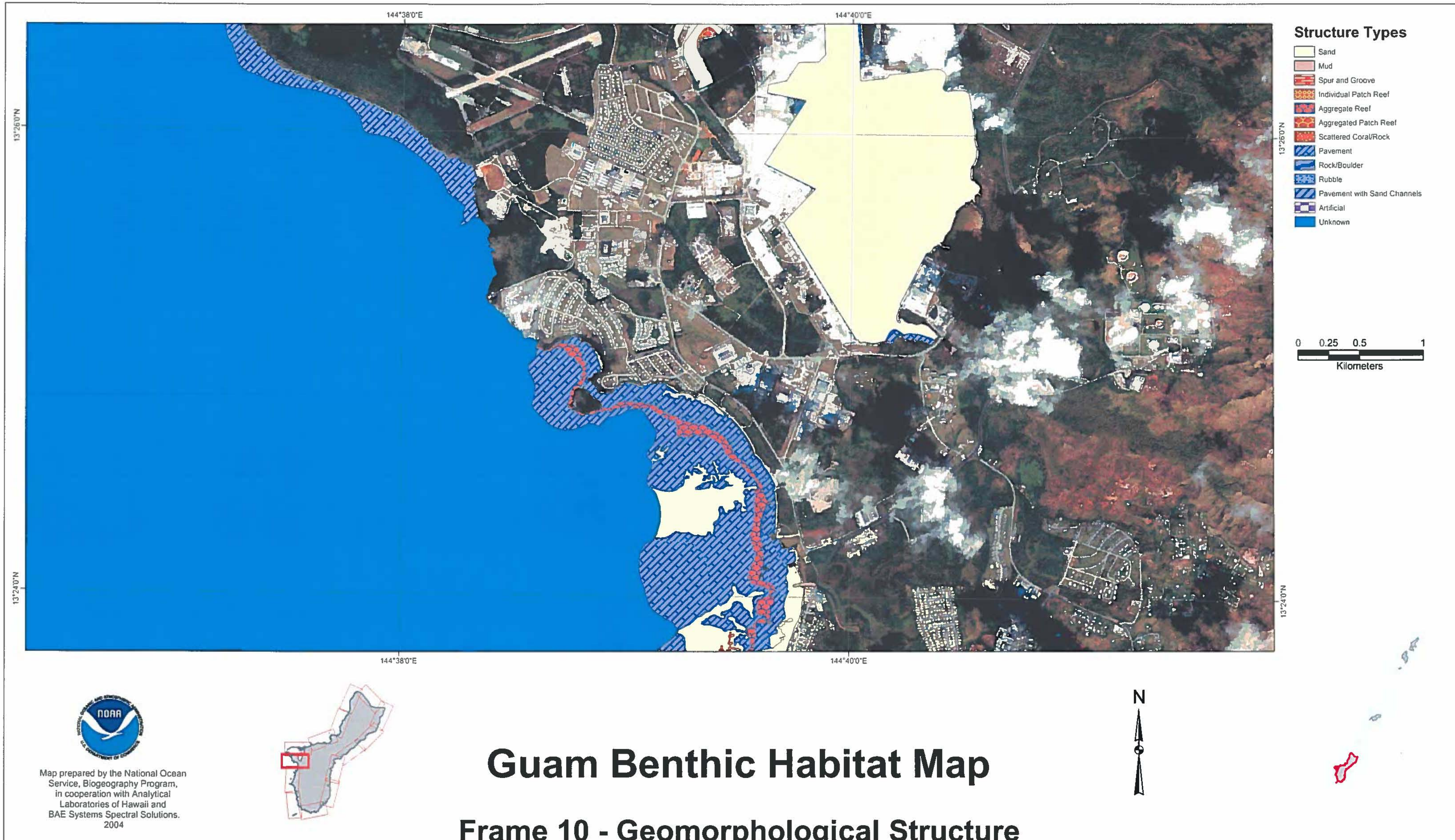
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



Guam Benthic Habitat Map

N

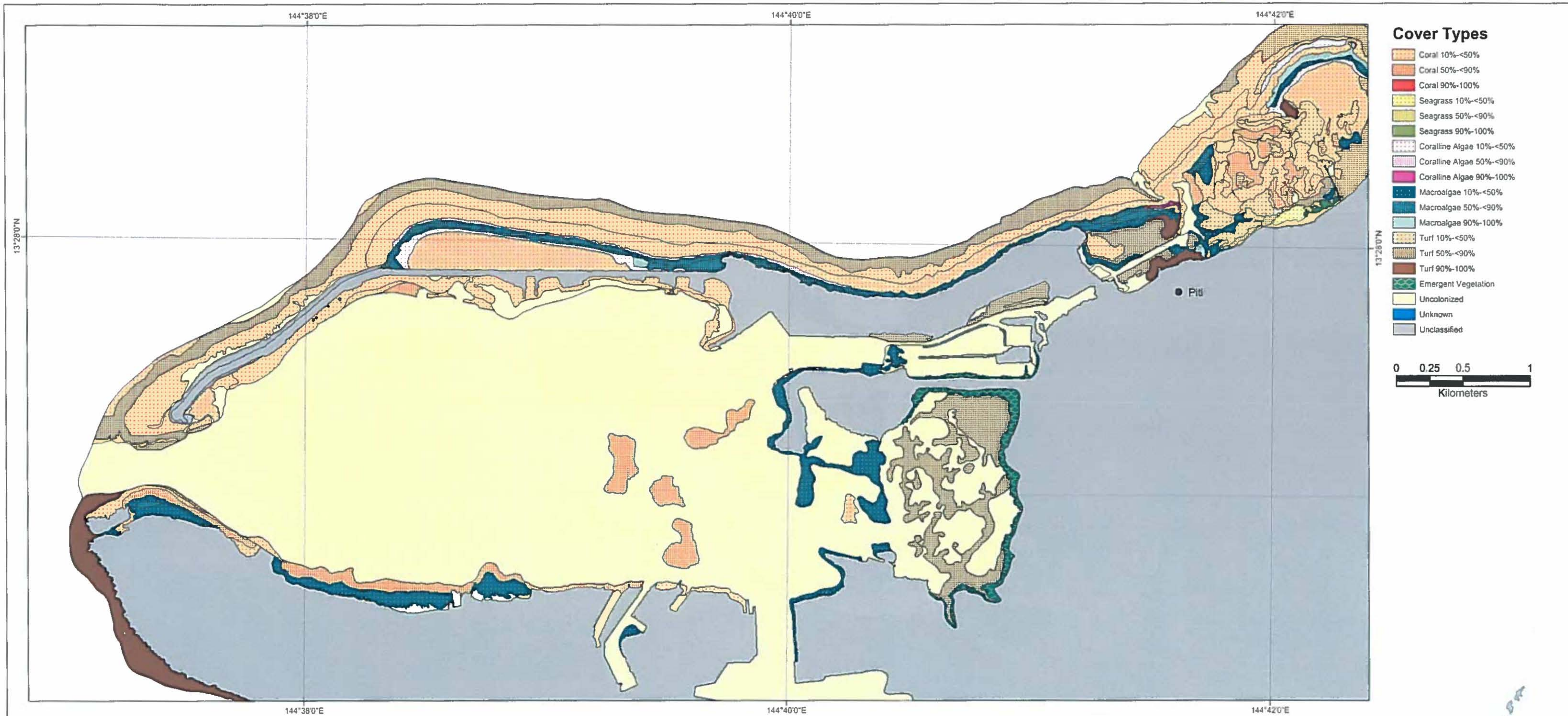
Frame 10 - Biological Cover



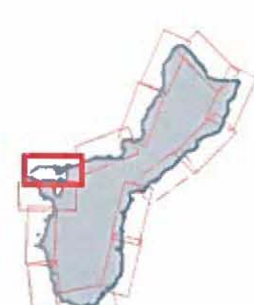
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

Frame 10 - Geomorphological Structure

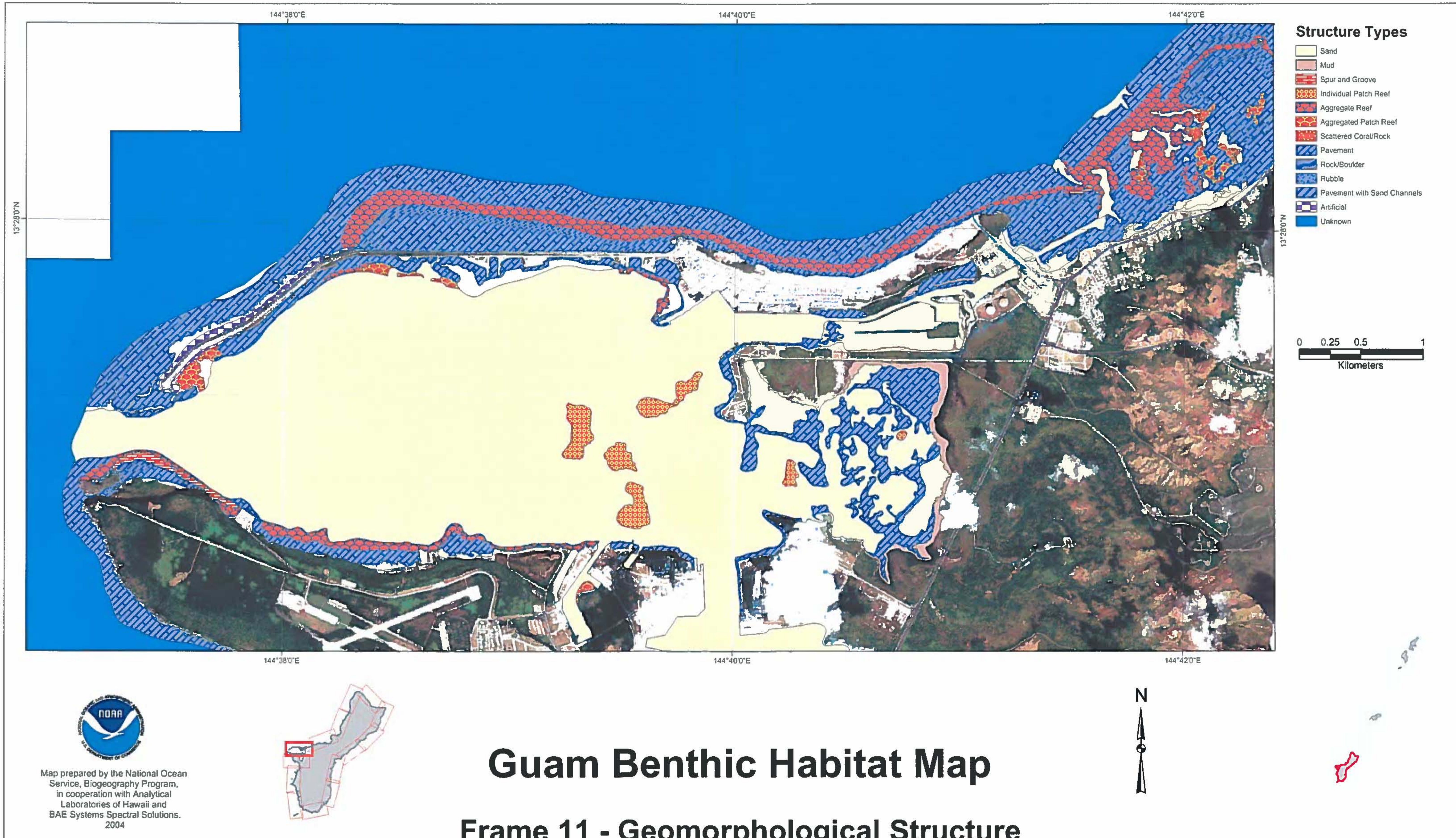


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



Guam Benthic Habitat Map

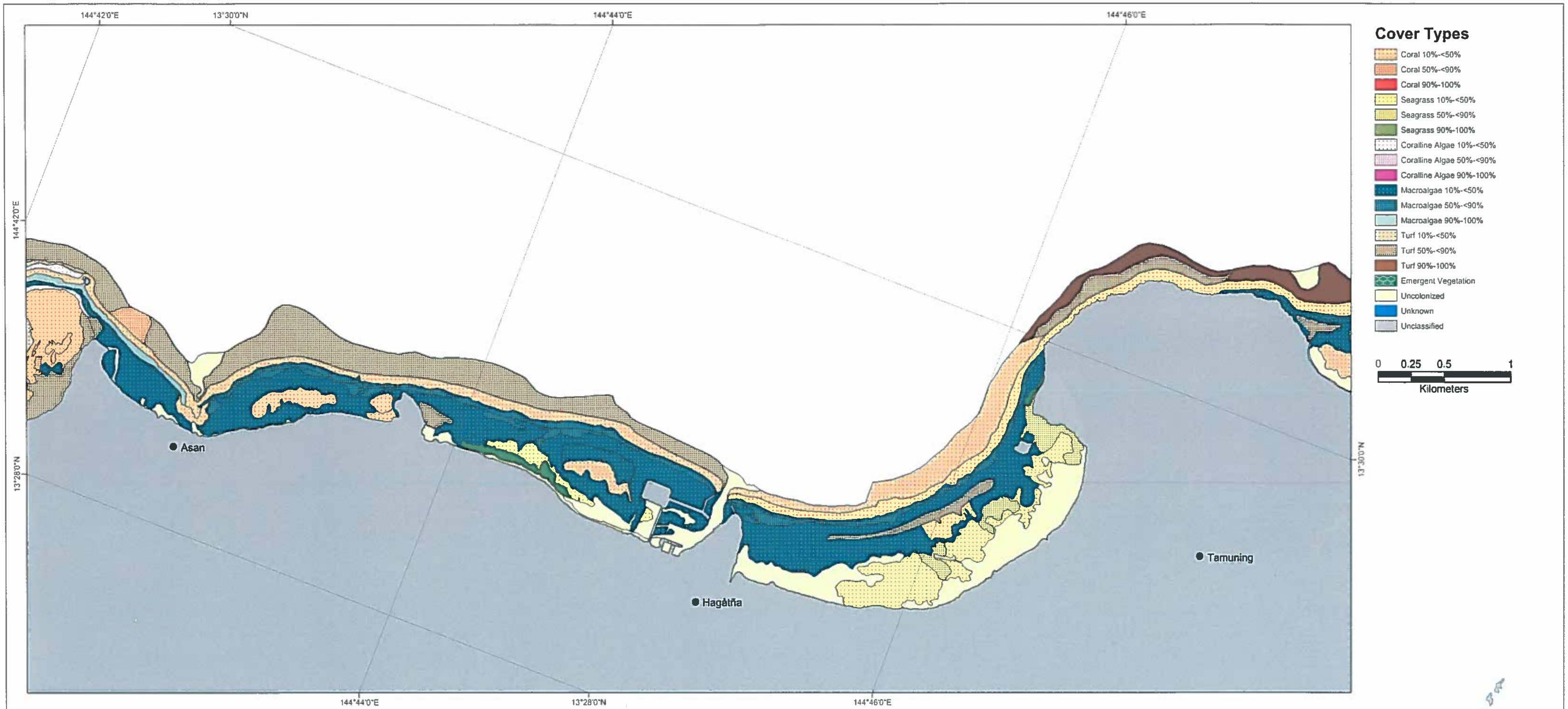
Frame 11 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

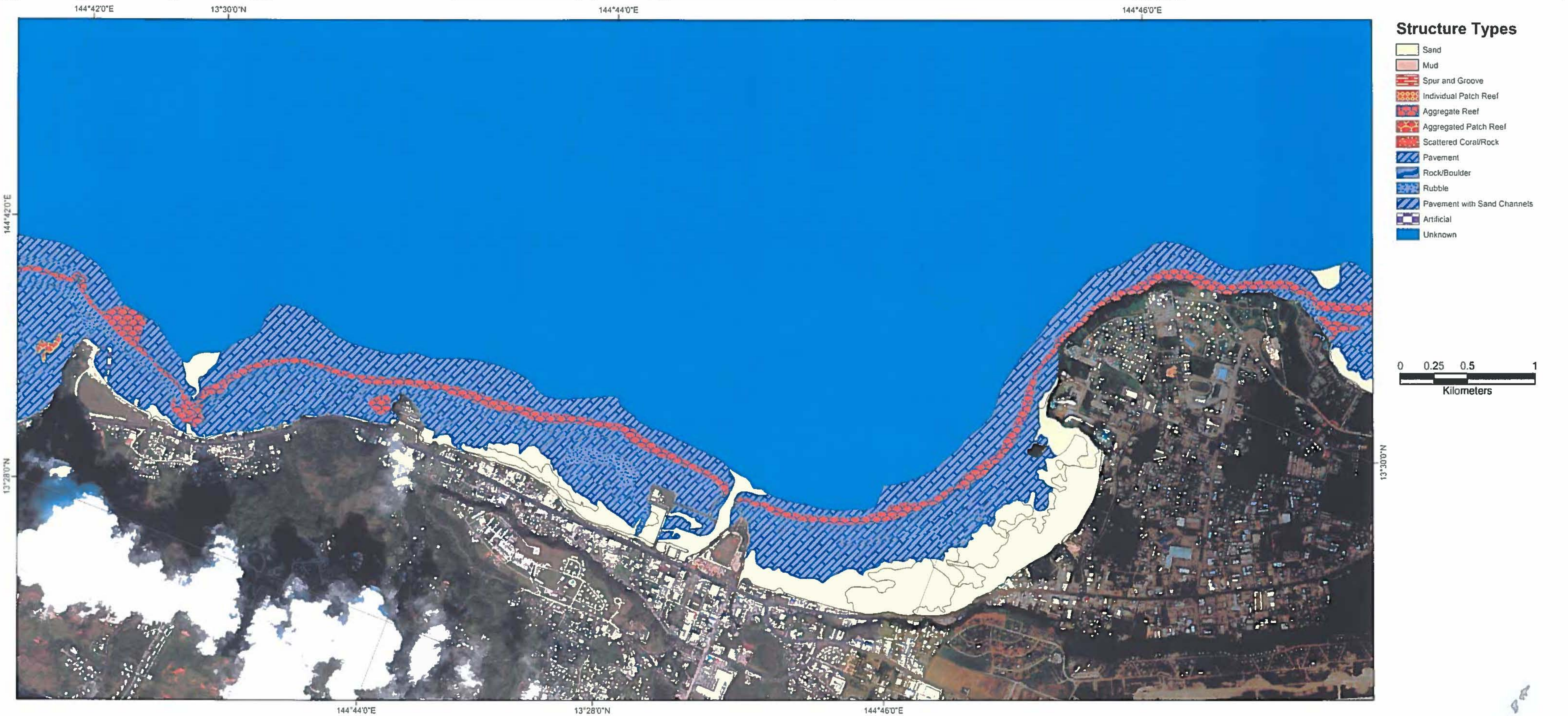
Frame 11 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

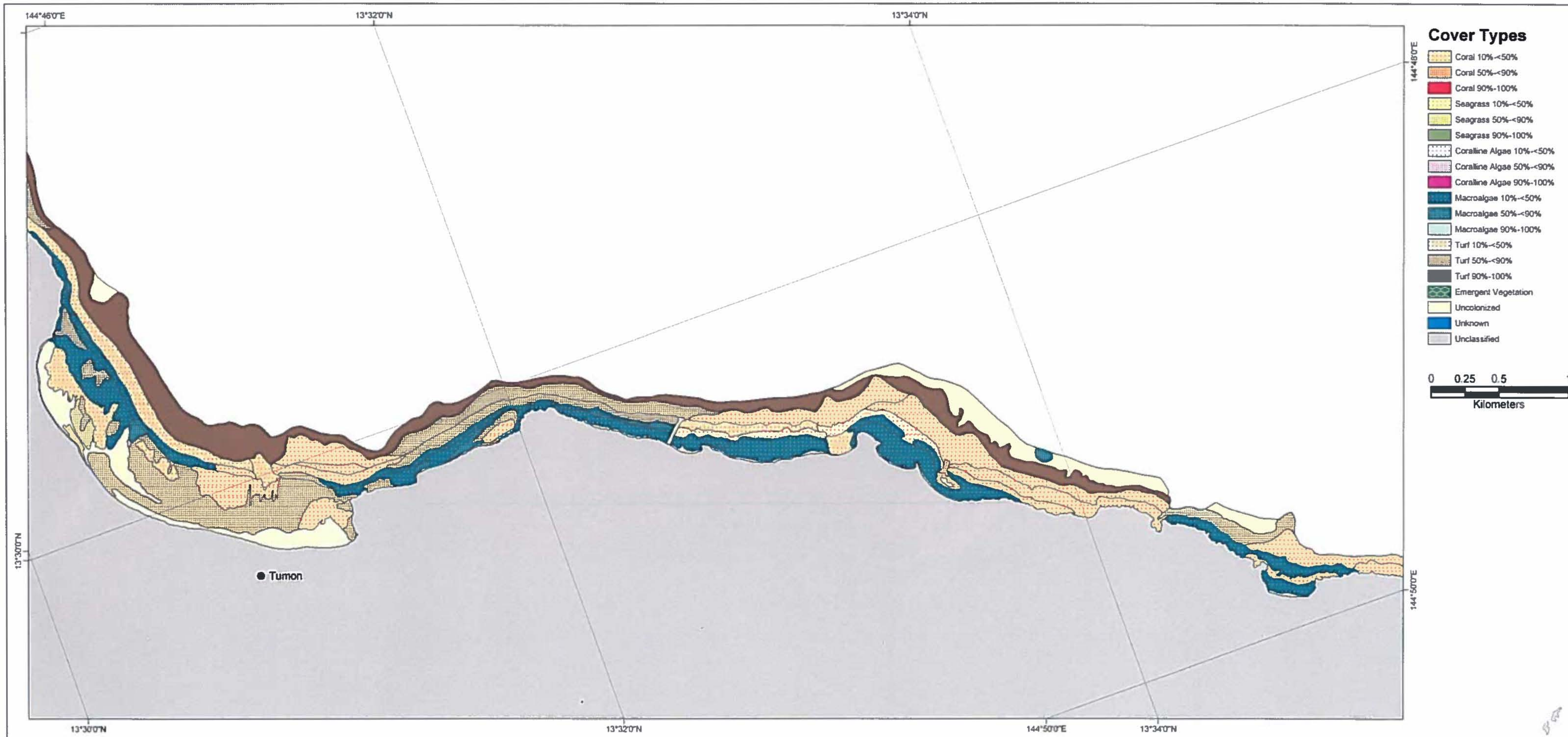
Frame 12 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

Frame 12 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

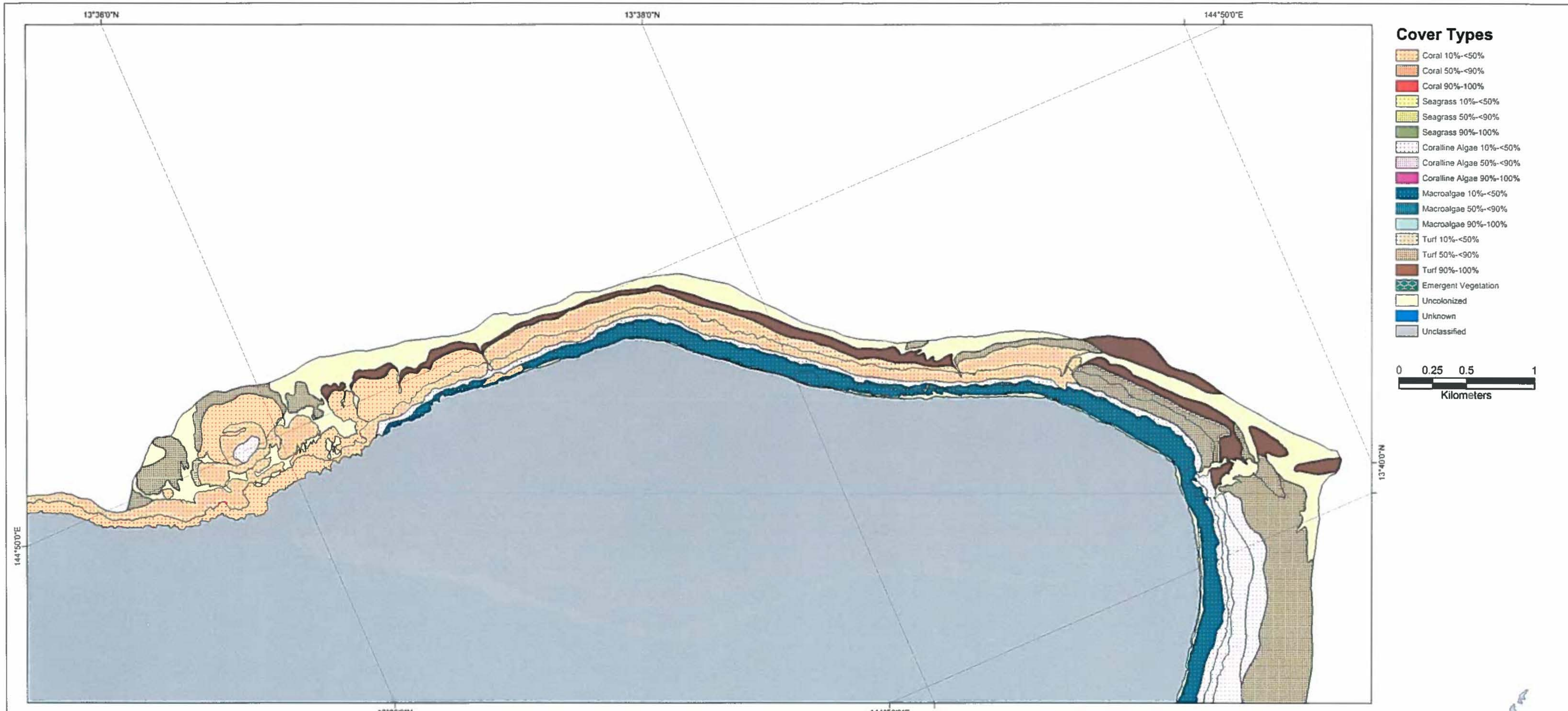
N

Frame 13 - Biological Cover

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

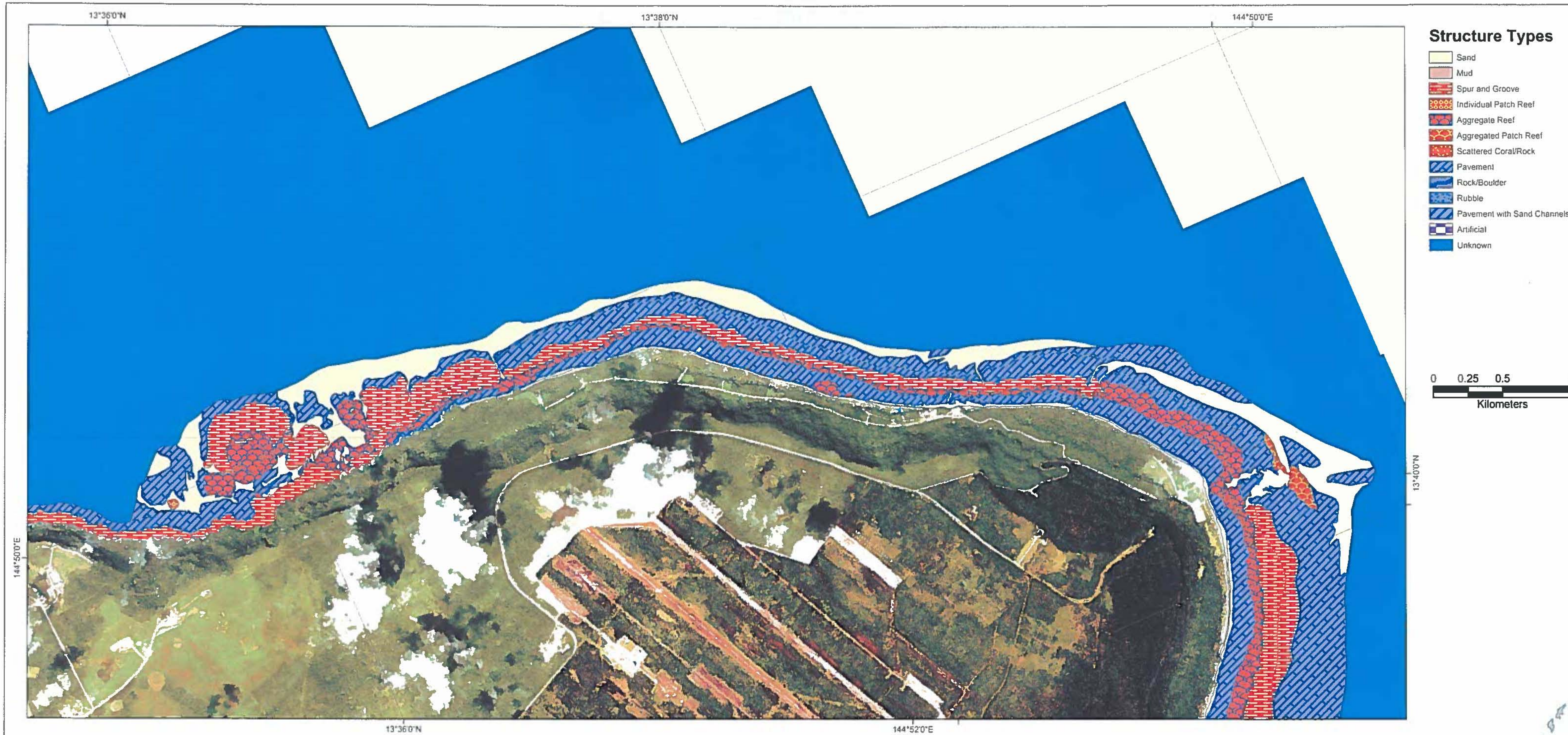
Frame 13 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

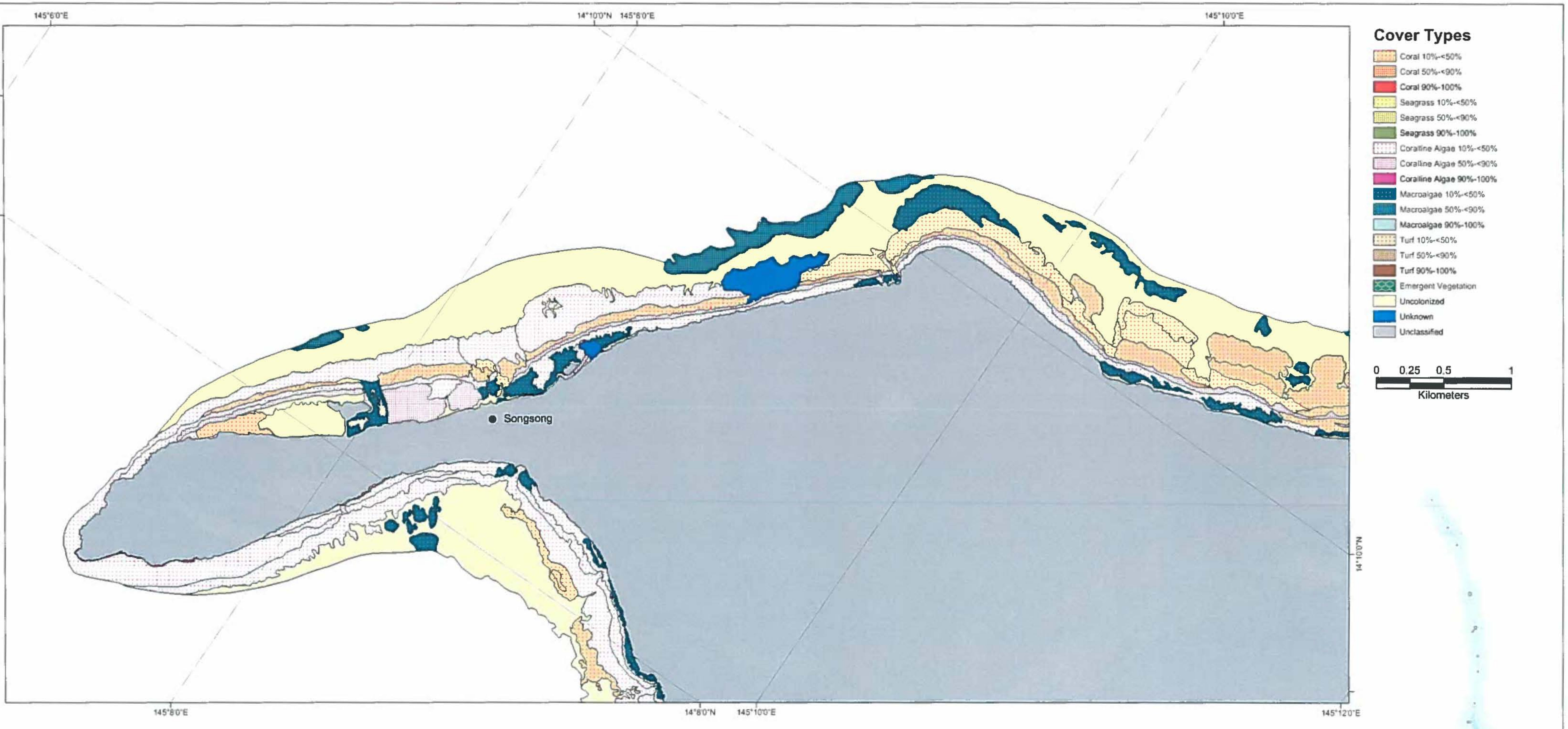
Frame 14 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Guam Benthic Habitat Map

Frame 14 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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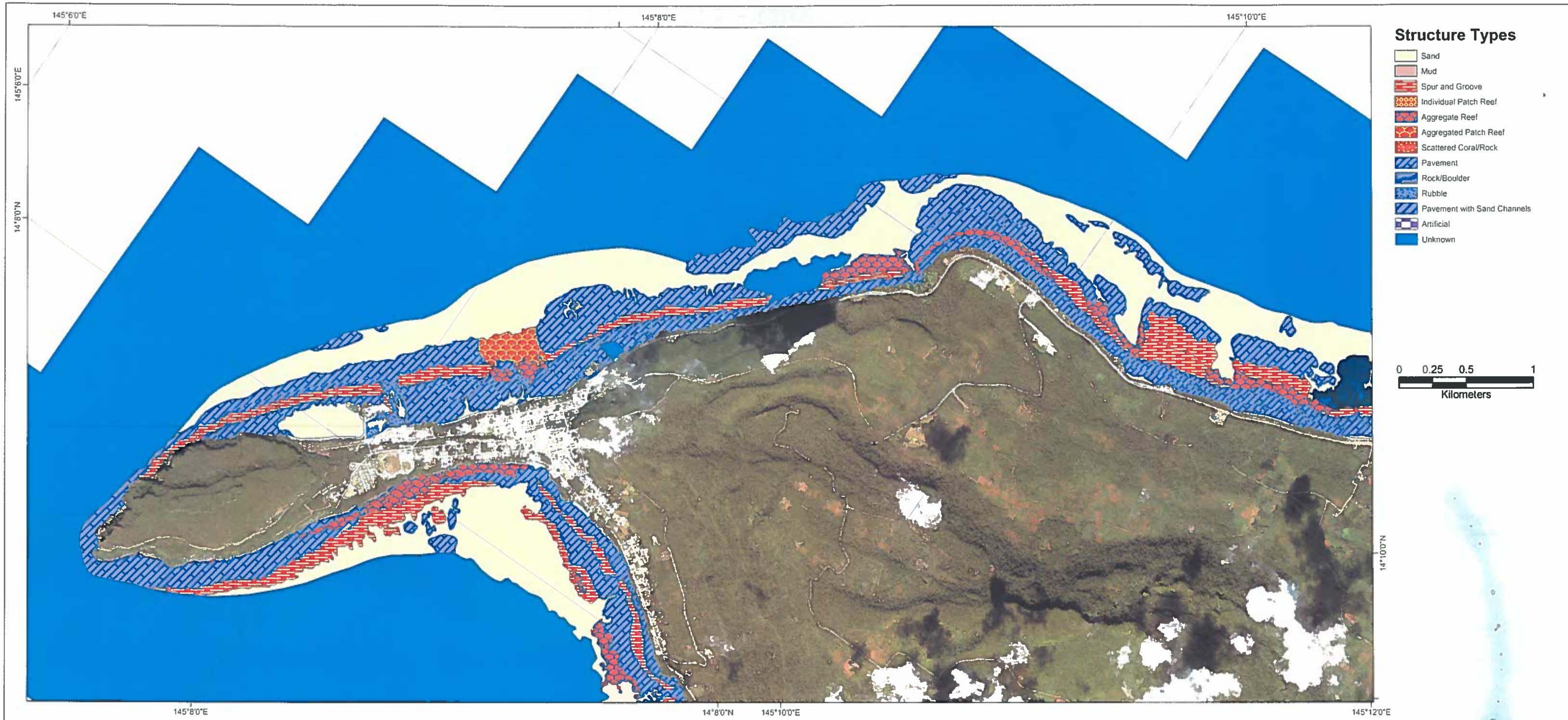
Rota Benthic Habitat Map

Frame 15 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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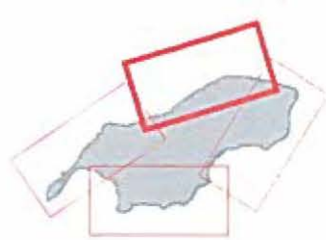
Rota Benthic Habitat Map

Frame 15 - Geomorphological Structure

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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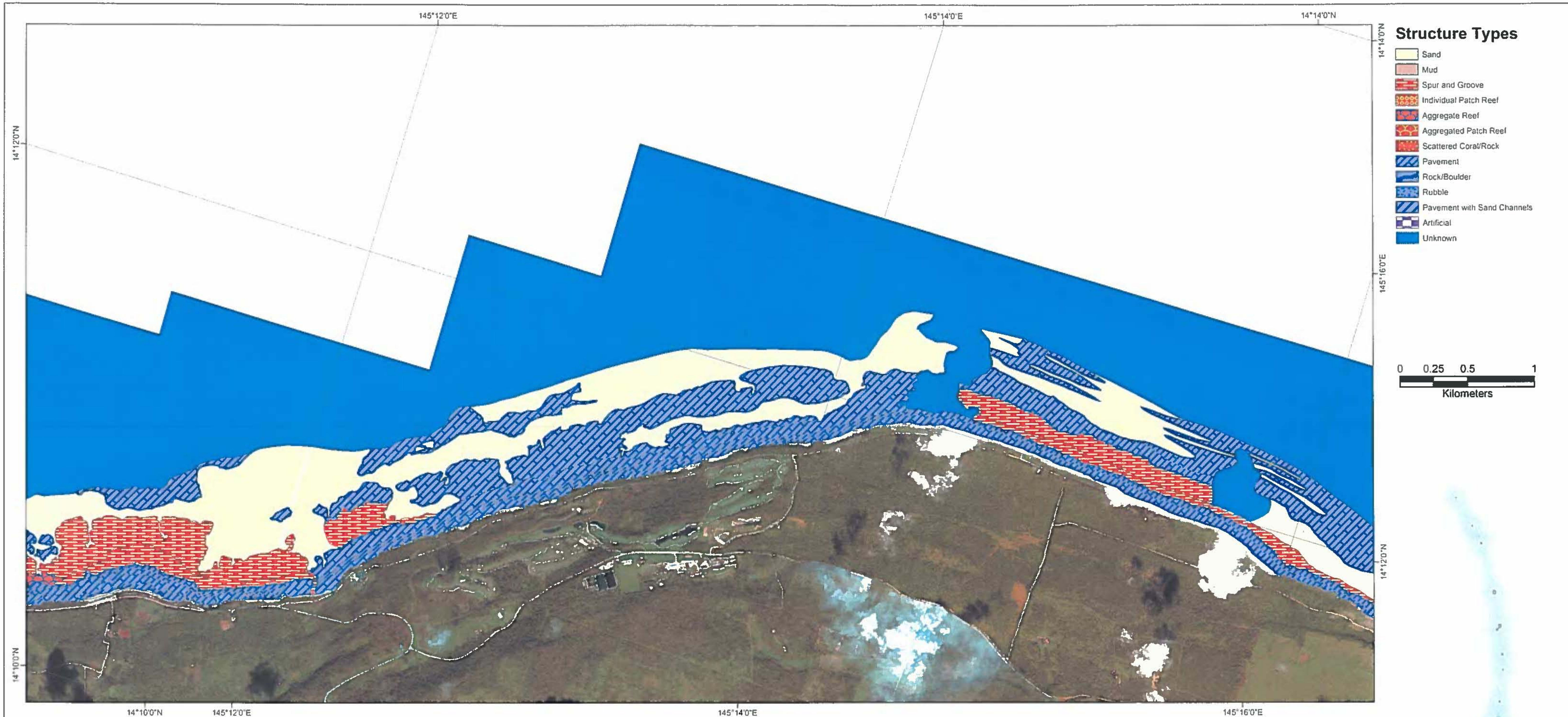
Rota Benthic Habitat Map

Frame 16 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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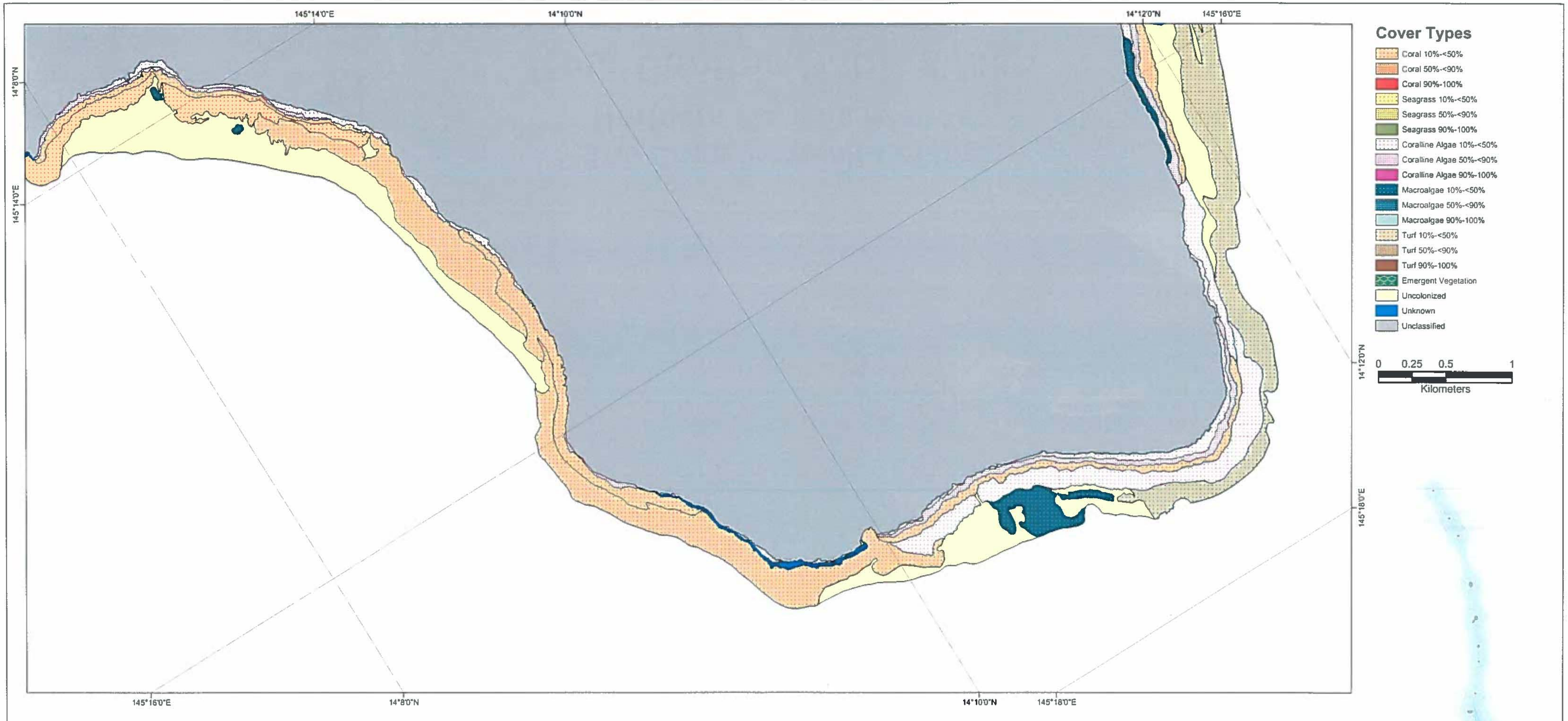
Rota Benthic Habitat Map

Frame 16 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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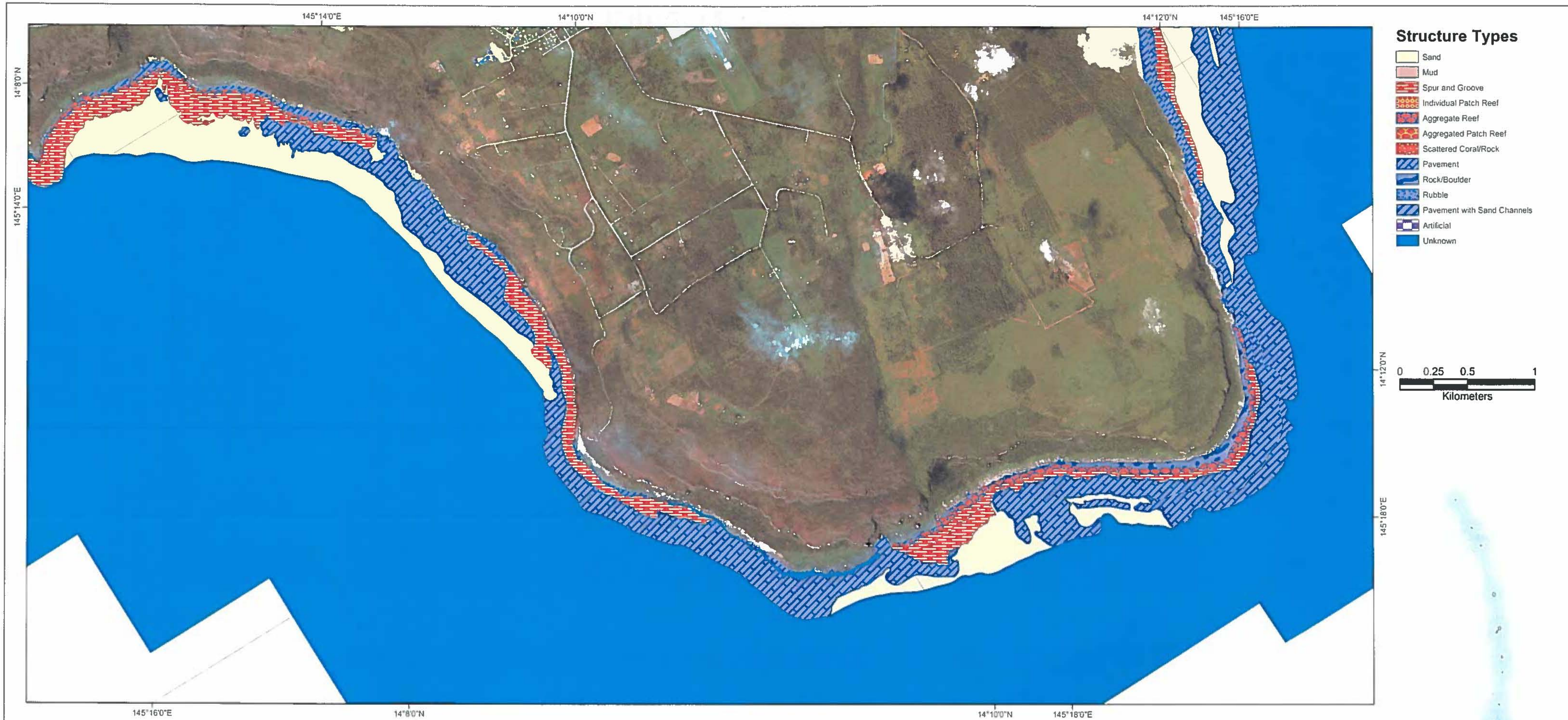
Rota Benthic Habitat Map

Frame 17 - Biological Cover



NOAA

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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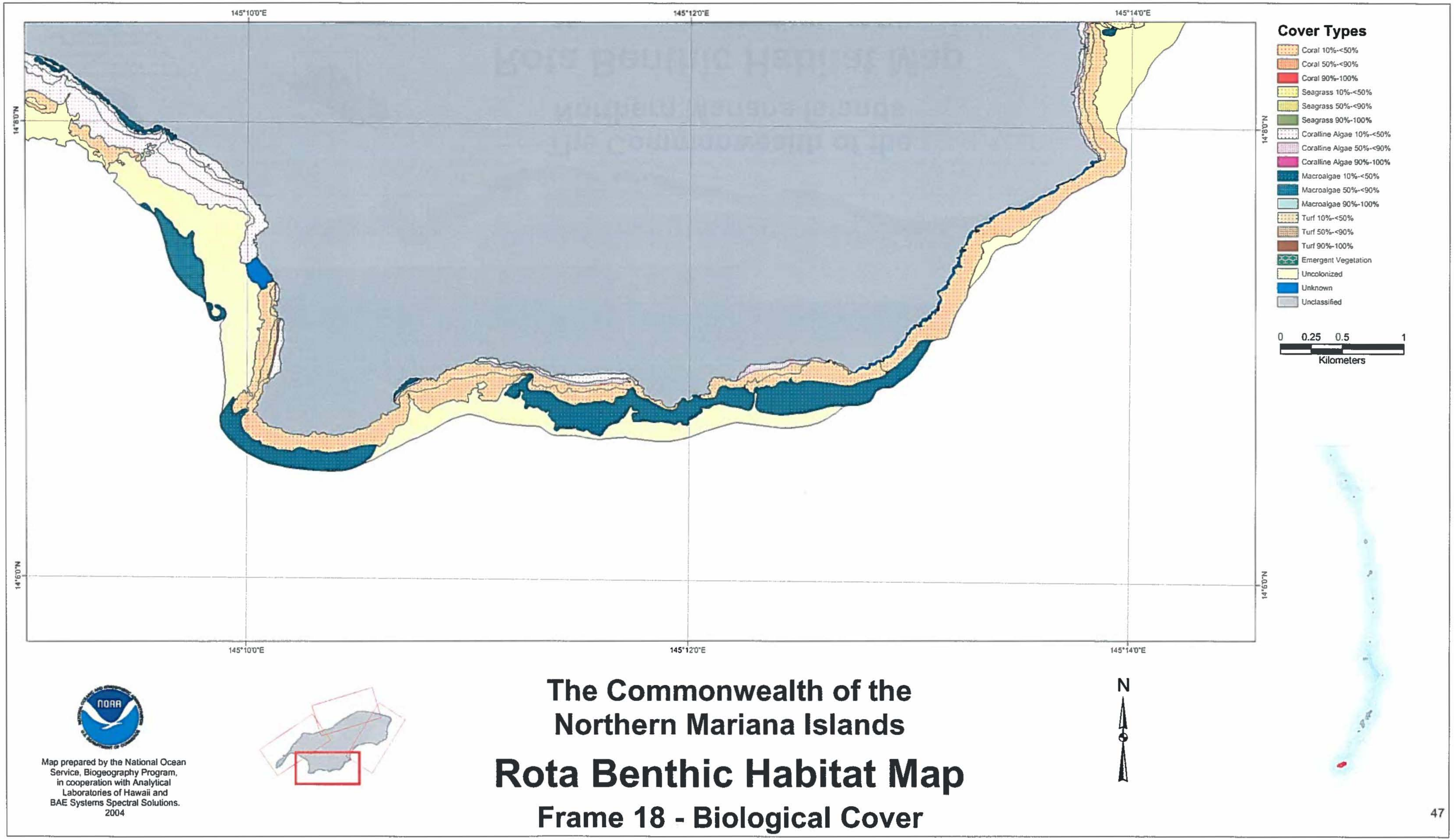
Rota Benthic Habitat Map

Frame 17 - Geomorphological Structure

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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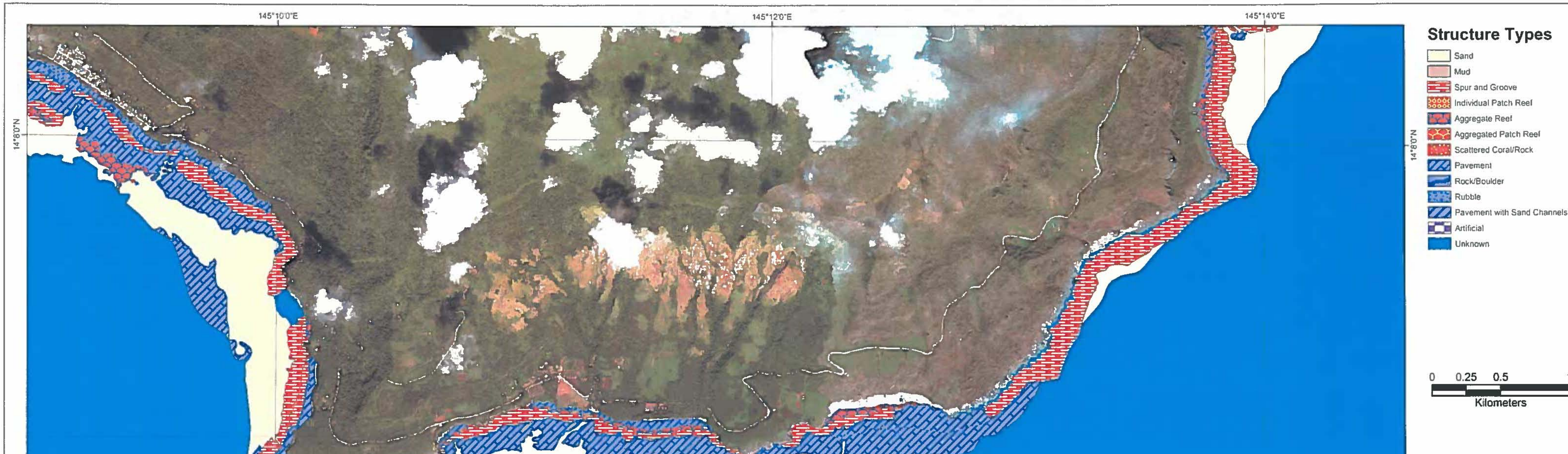
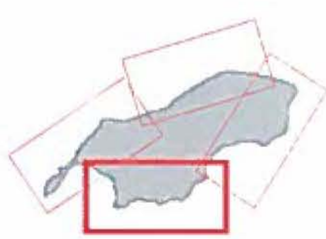
Rota Benthic Habitat Map

Frame 18 - Biological Cover





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Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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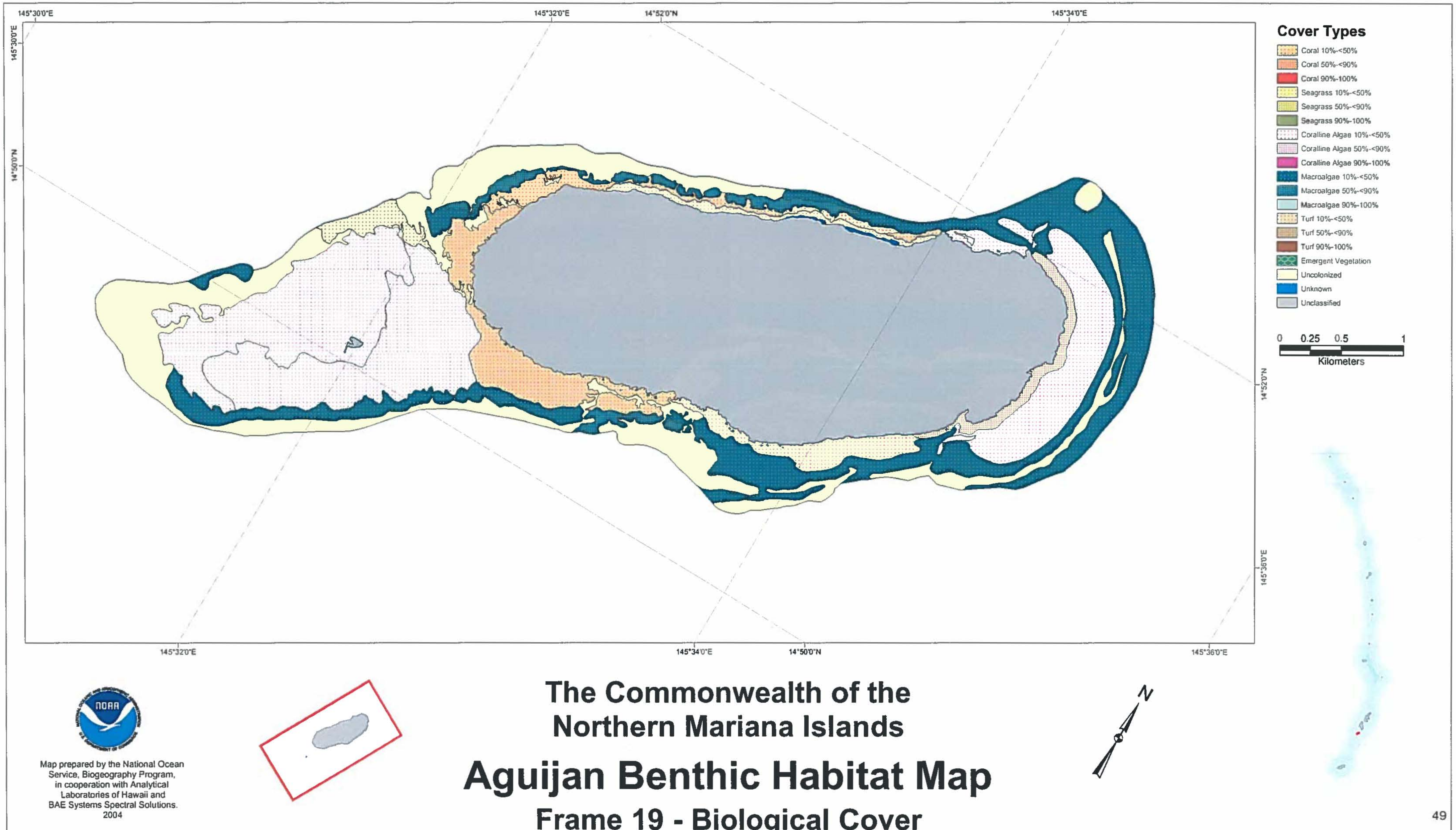
Rota Benthic Habitat Map

Frame 18 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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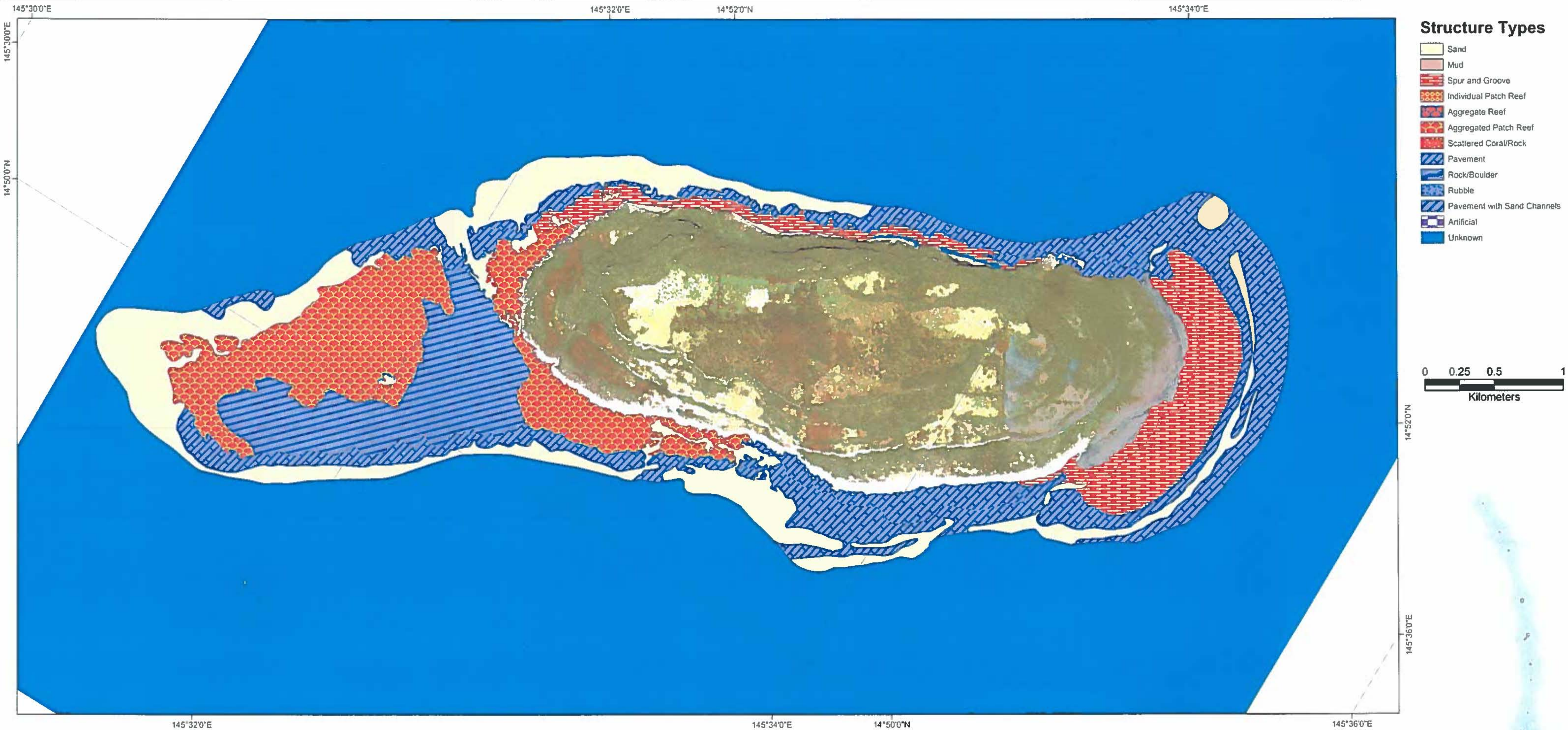
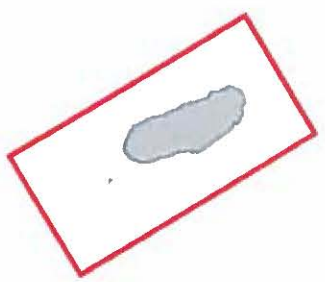
Aguijan Benthic Habitat Map

Frame 19 - Biological Cover





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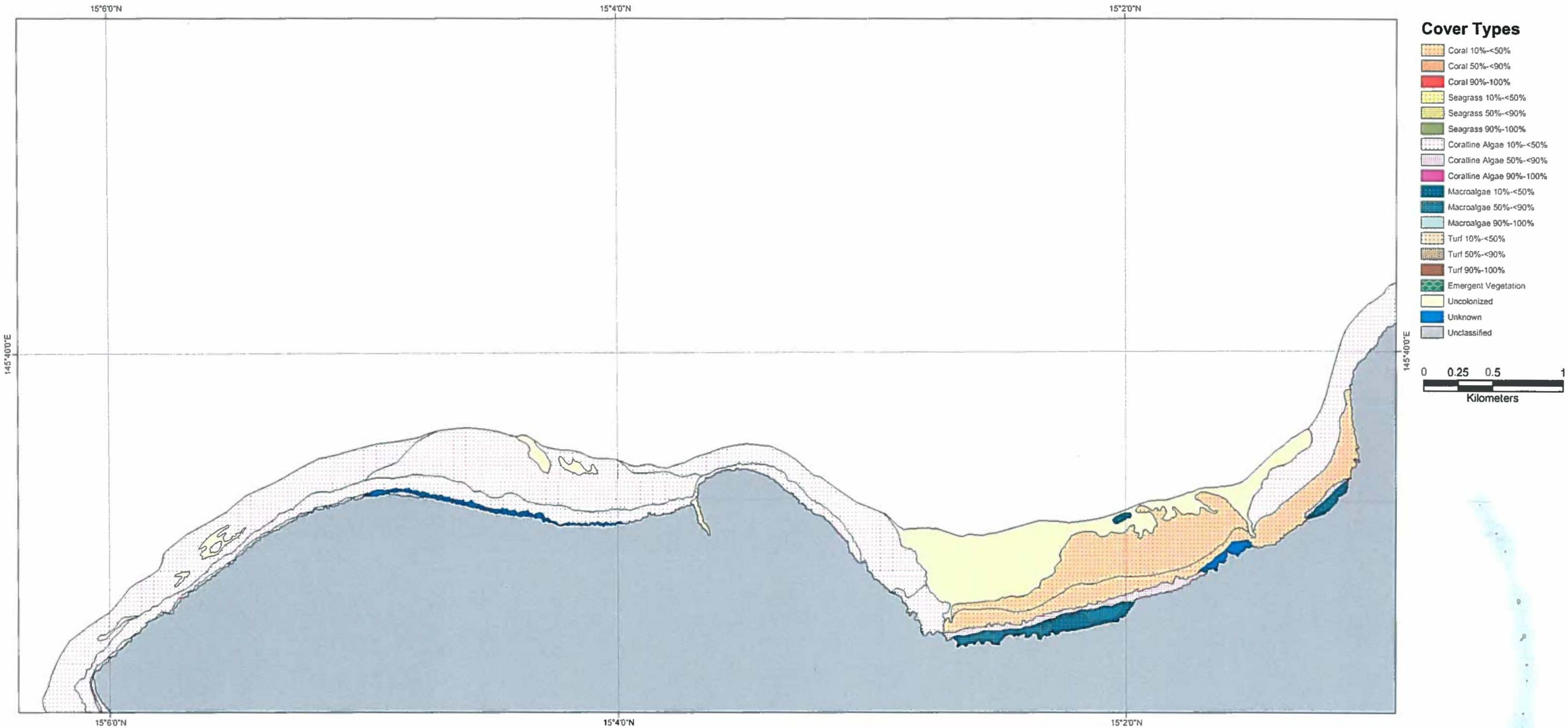
Aguijan Benthic Habitat Map

Frame 19 - Geomorphological Structure

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions.
2004



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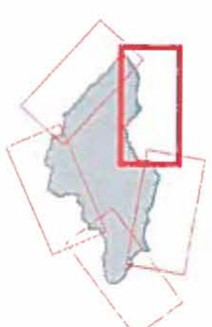

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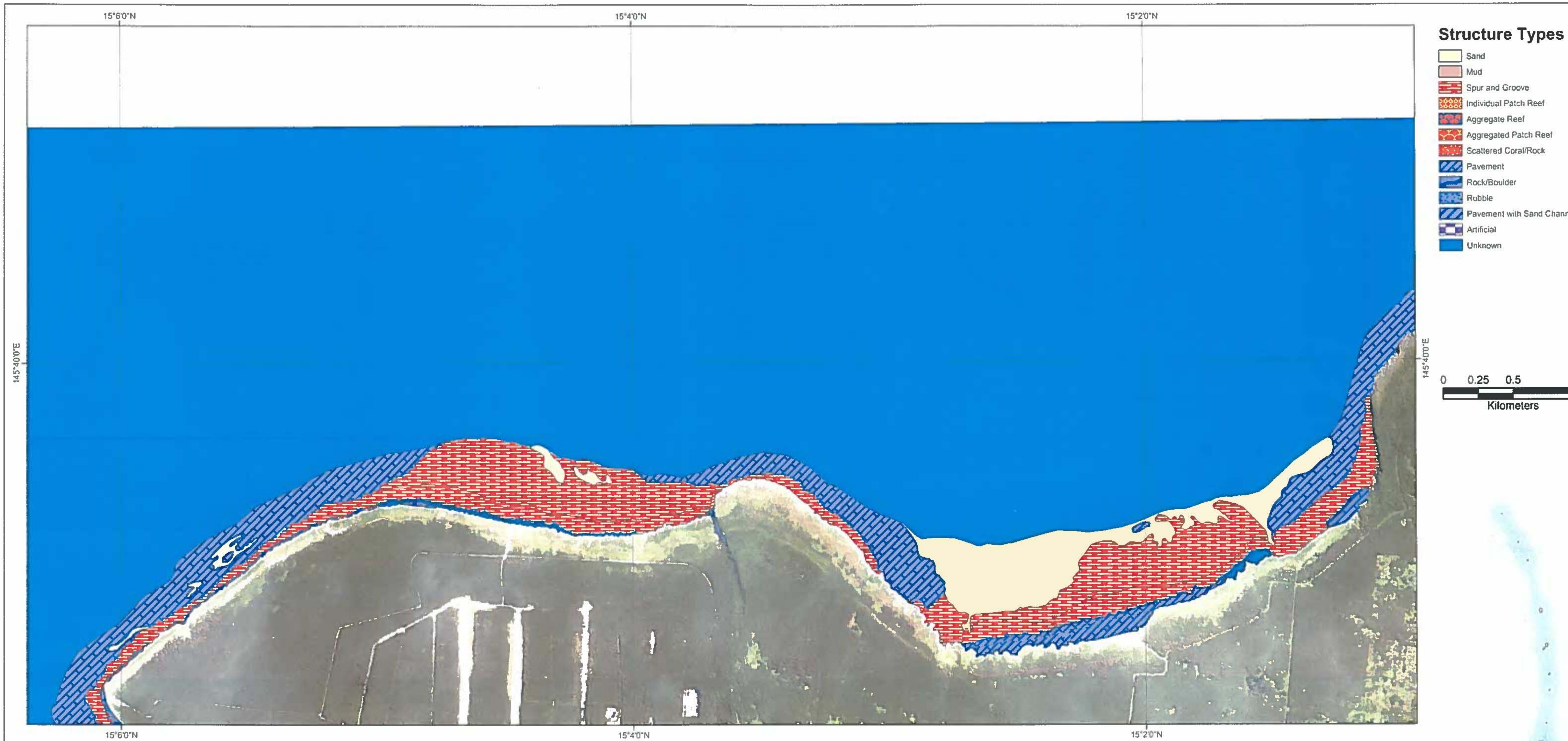
Tinian Benthic Habitat Map

Frame 20 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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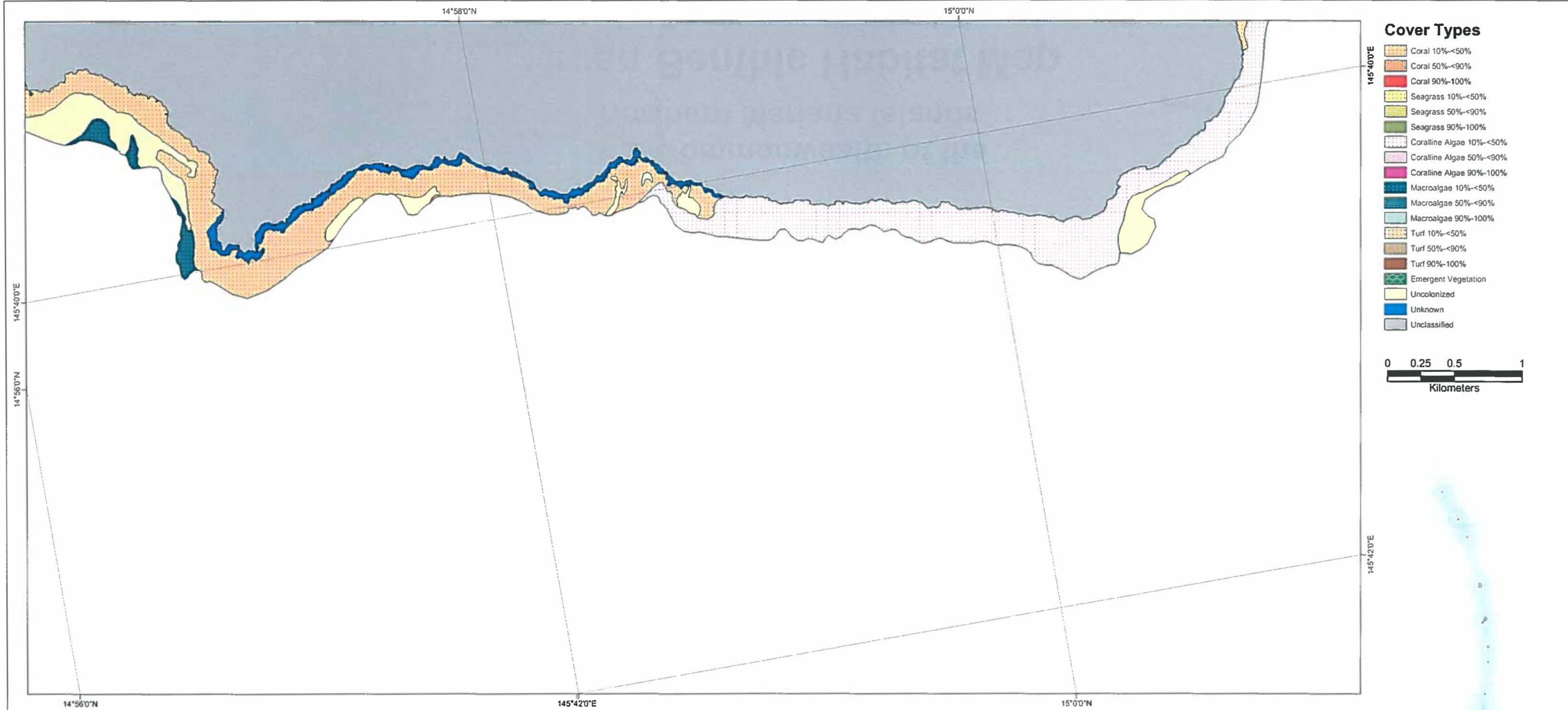
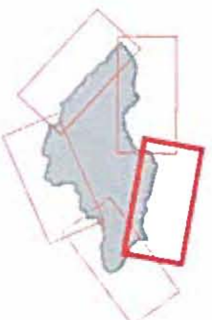
Tinian Benthic Habitat Map

Frame 20 - Geomorphological Structure

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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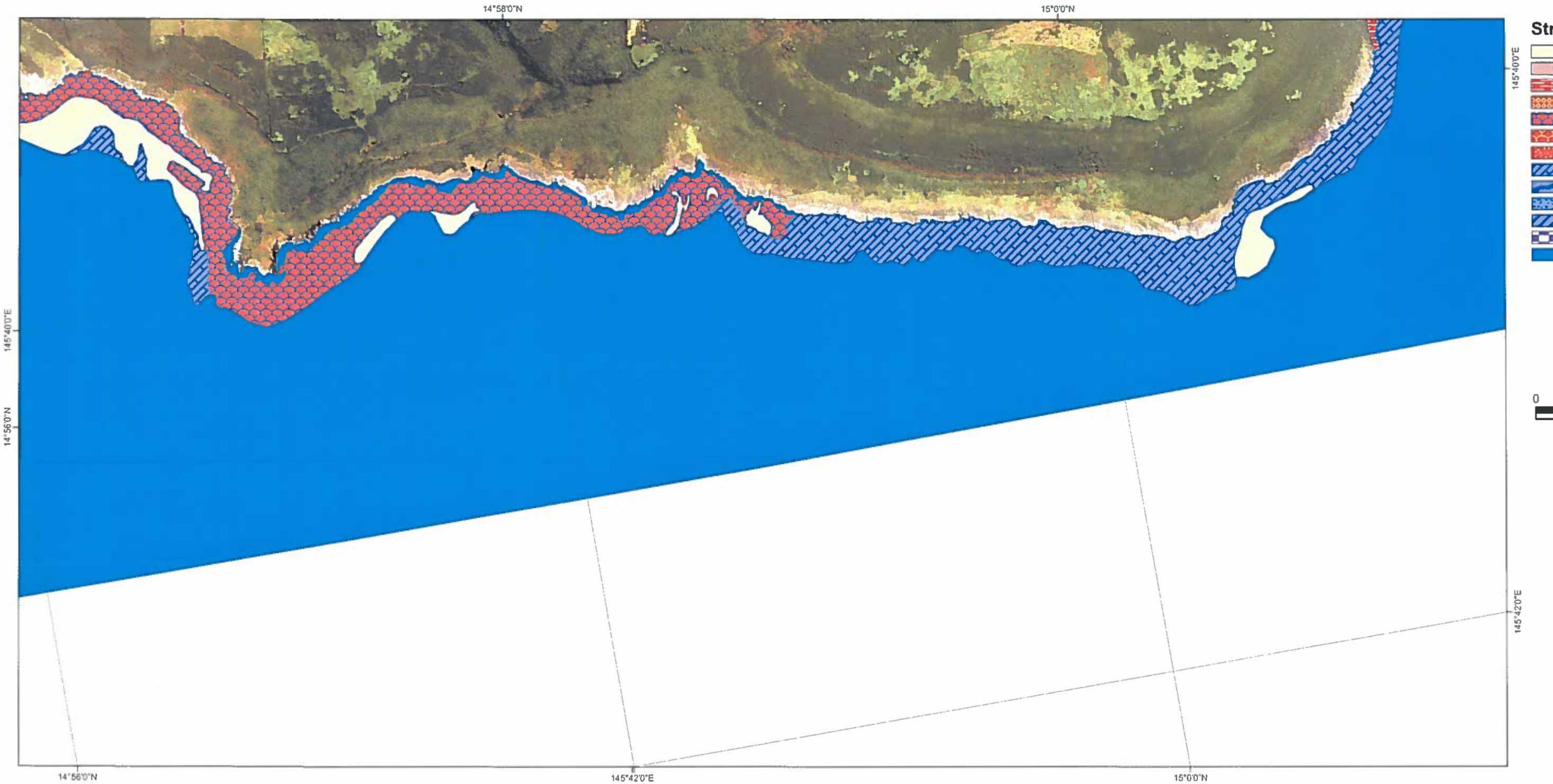
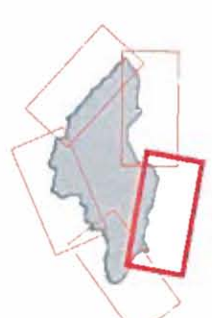
Tinian Benthic Habitat Map

Frame 21 - Biological Cover





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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Tinian Benthic Habitat Map

Frame 21 - Geomorphological Structure

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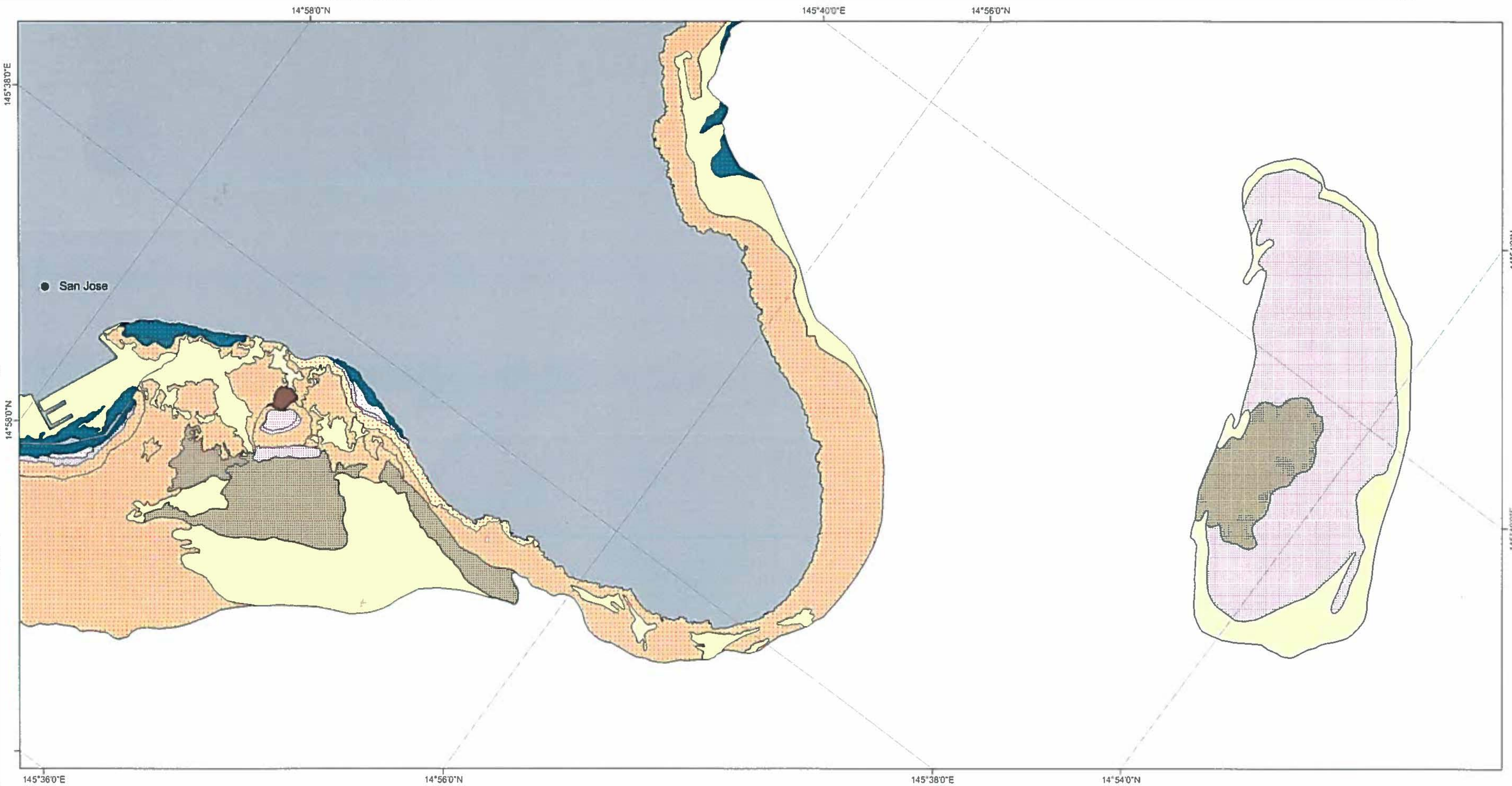
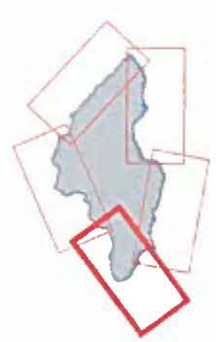


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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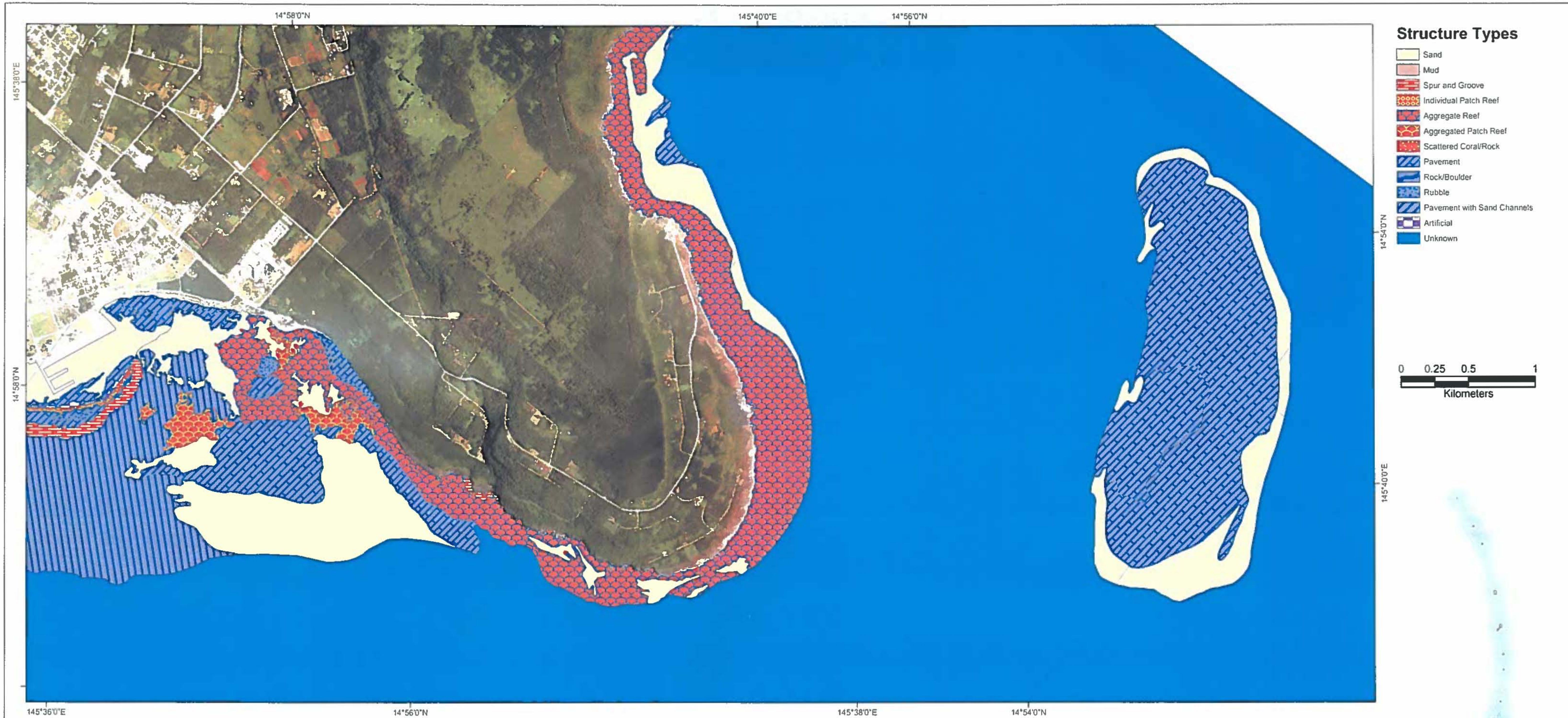
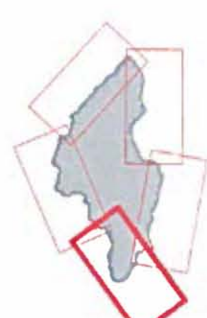
Tinian Benthic Habitat Map

Frame 22 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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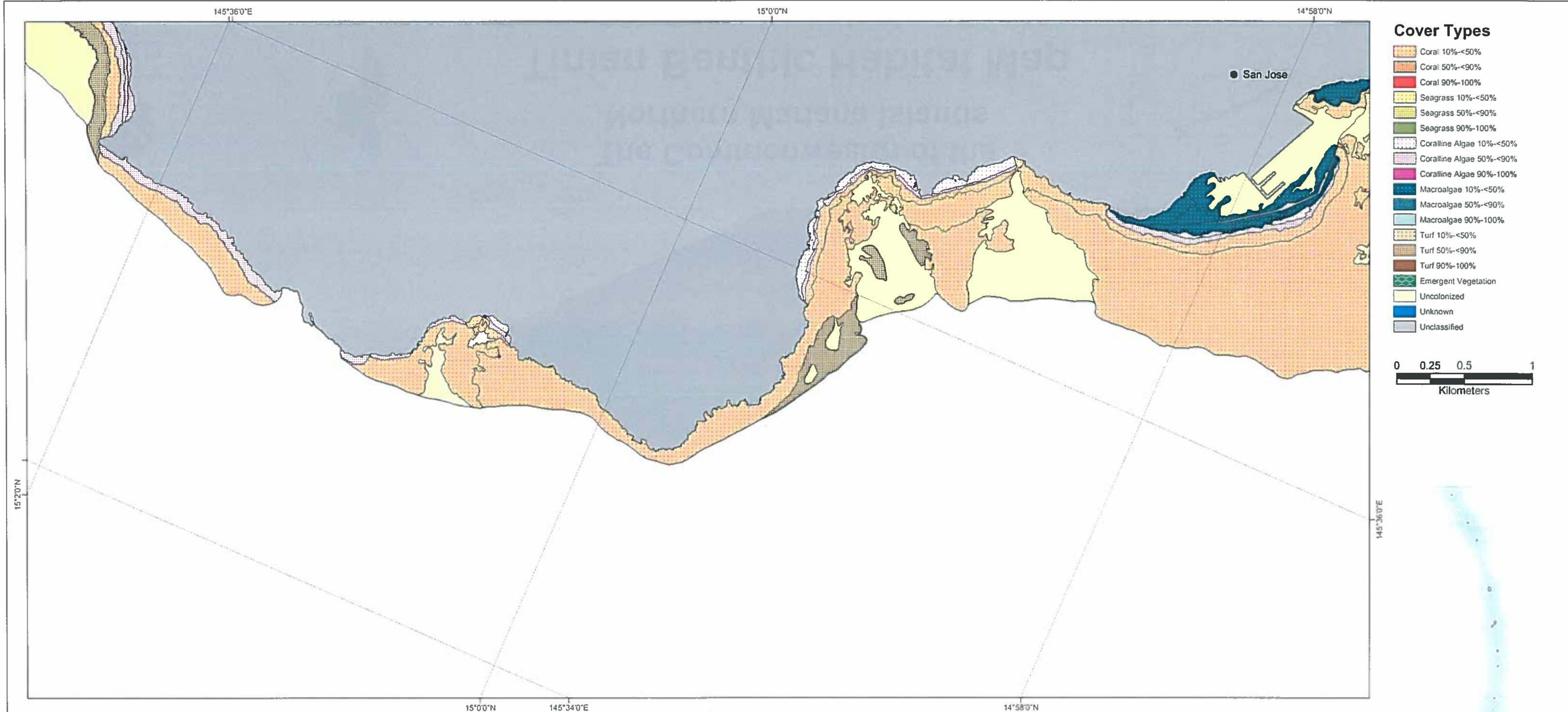
Tinian Benthic Habitat Map

Frame 22 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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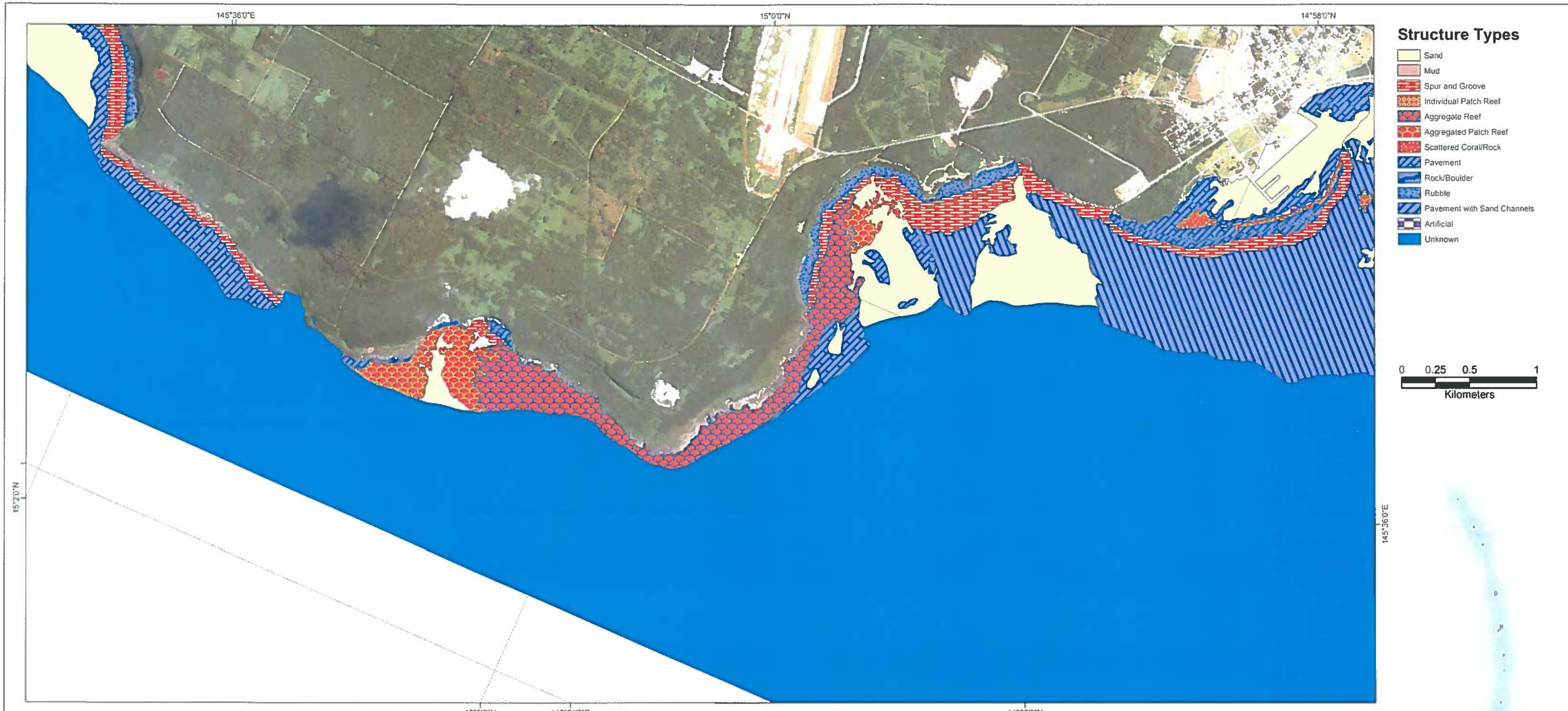
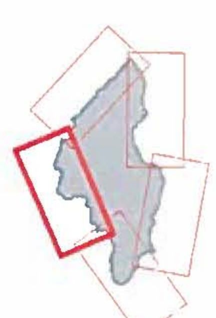
Tinian Benthic Habitat Map

Frame 23 - Biological Cover





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions.
2004

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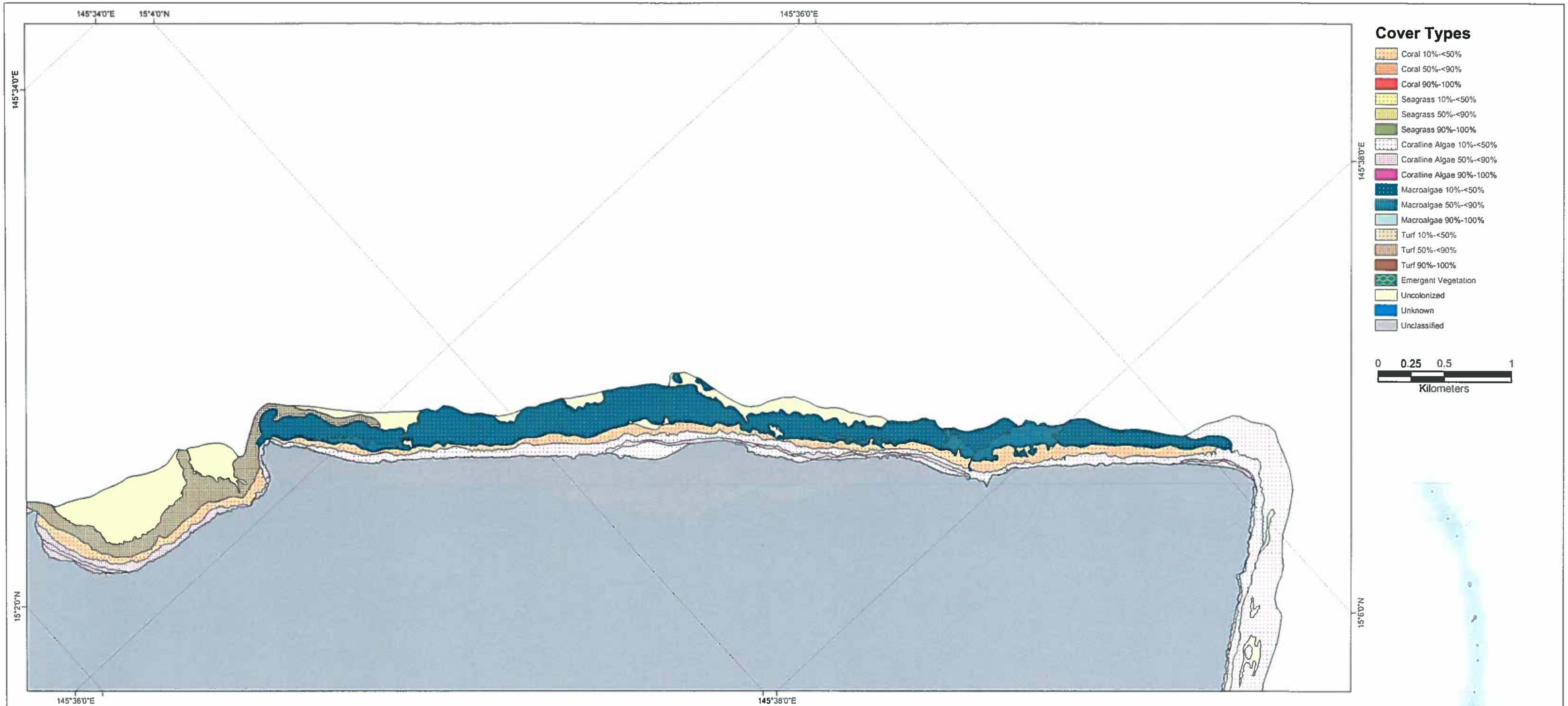
Tinian Benthic Habitat Map

Frame 23 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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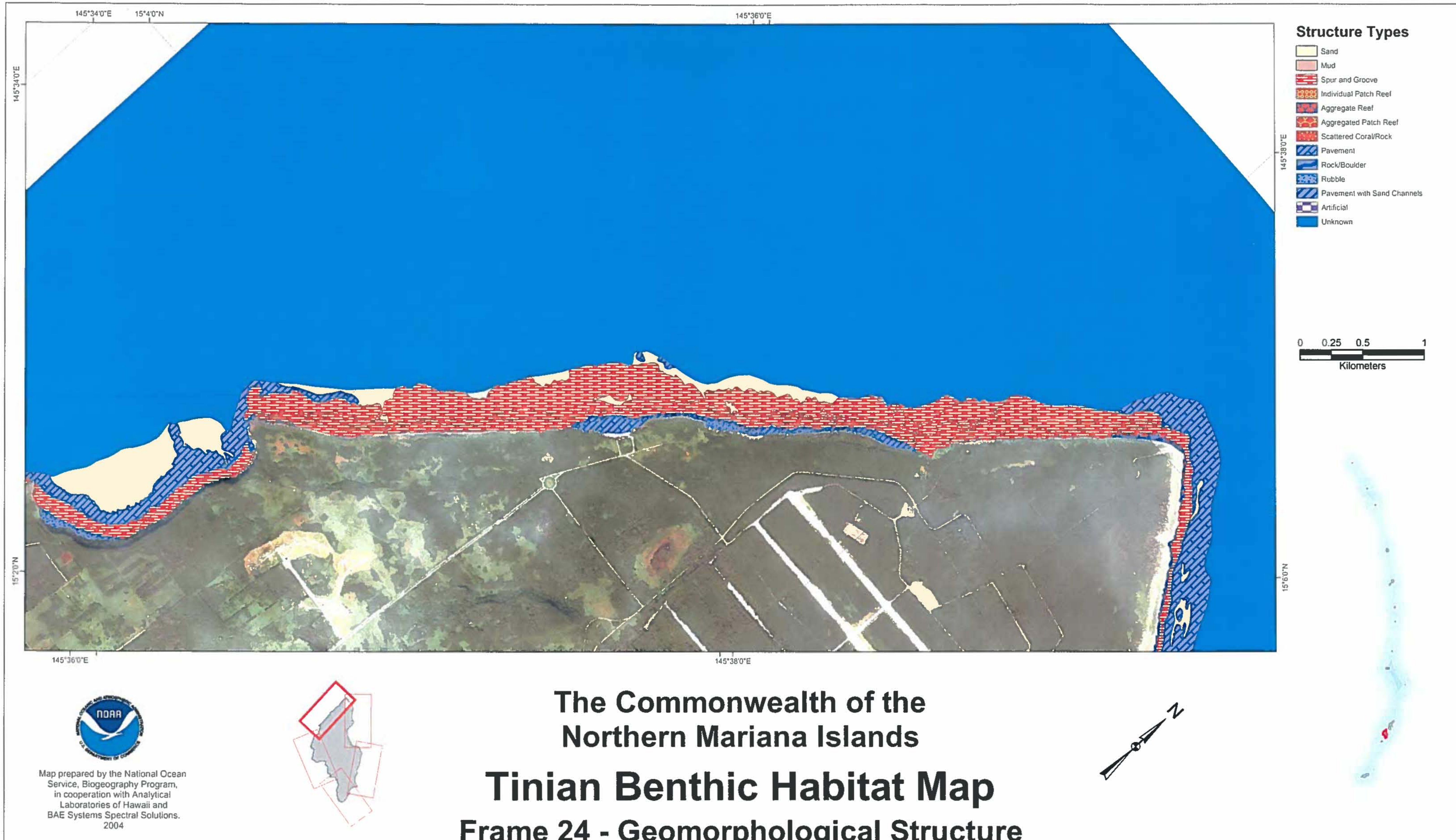
Tinian Benthic Habitat Map

Frame 24 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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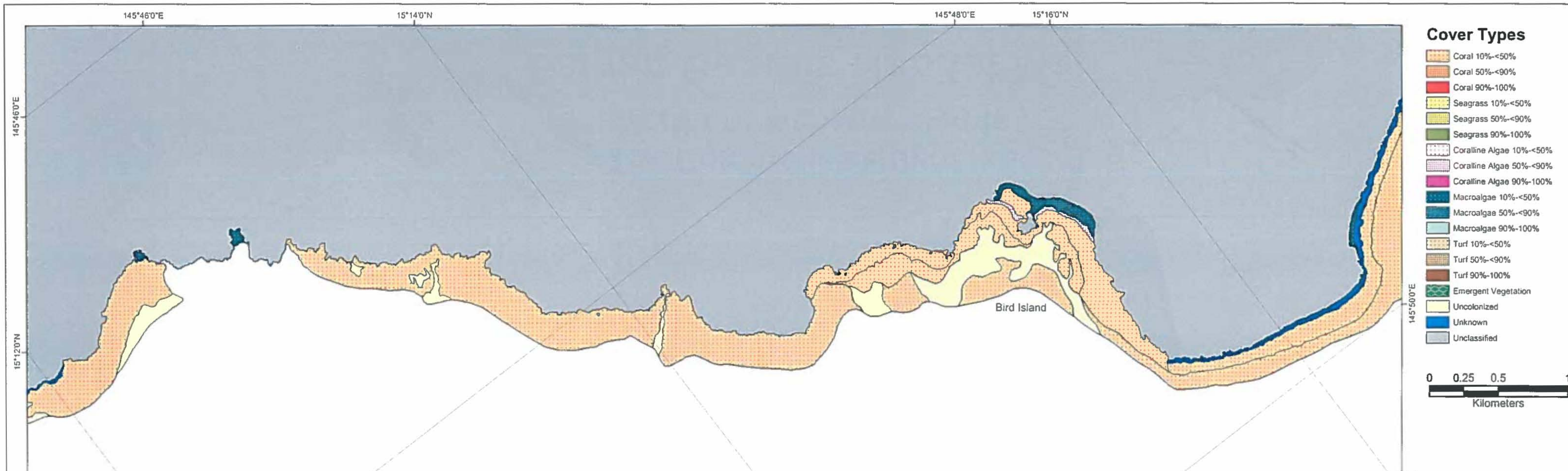
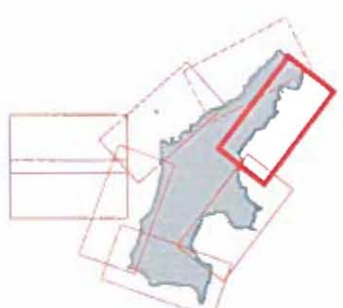
Tinian Benthic Habitat Map

Frame 24 - Geomorphological Structure





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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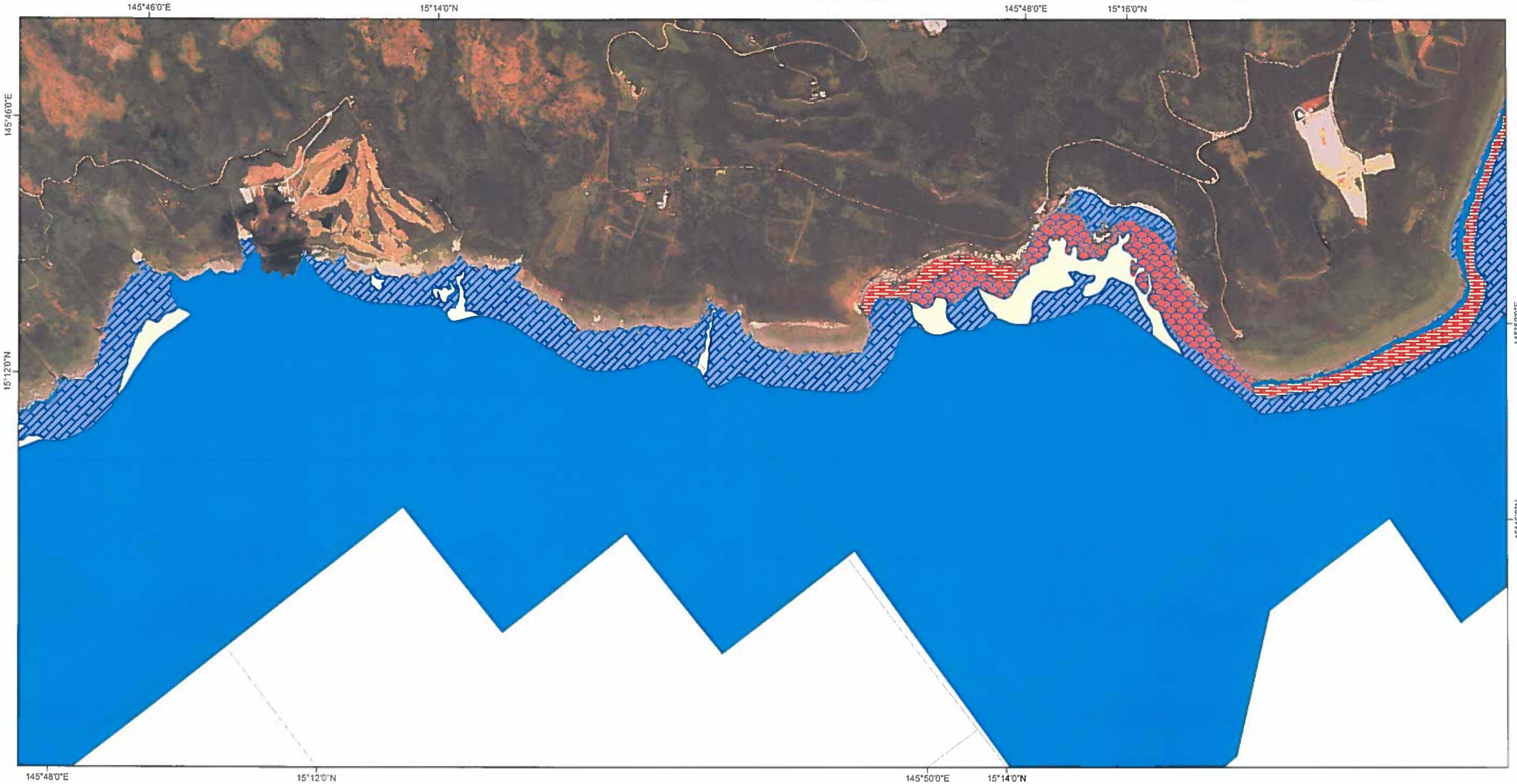
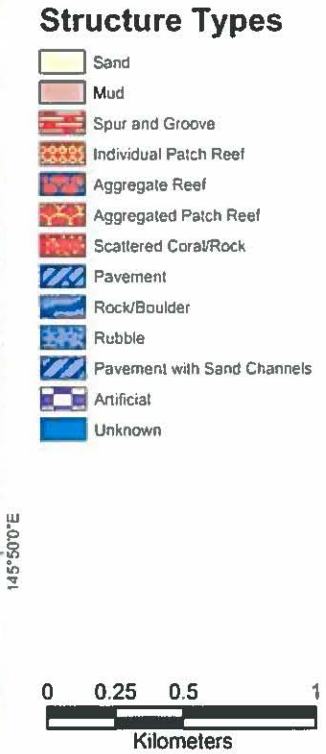
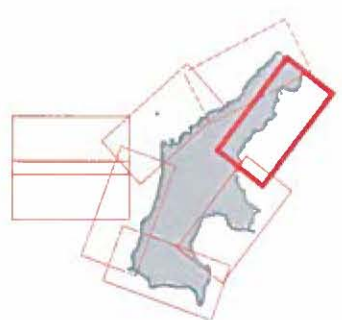
Saipan Benthic Habitat Map

Frame 25 - Biological Cover







Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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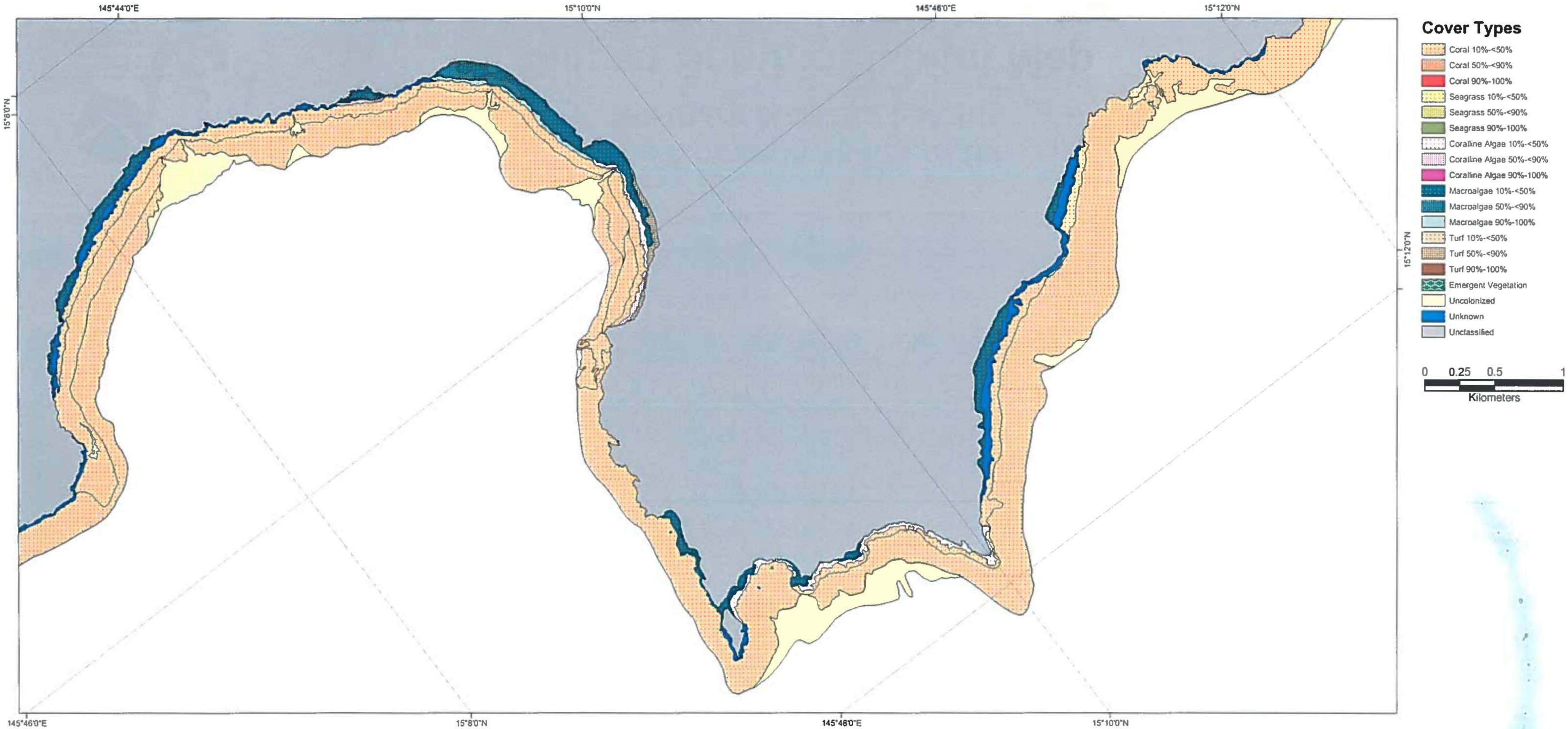
Saipan Benthic Habitat Map

Frame 25 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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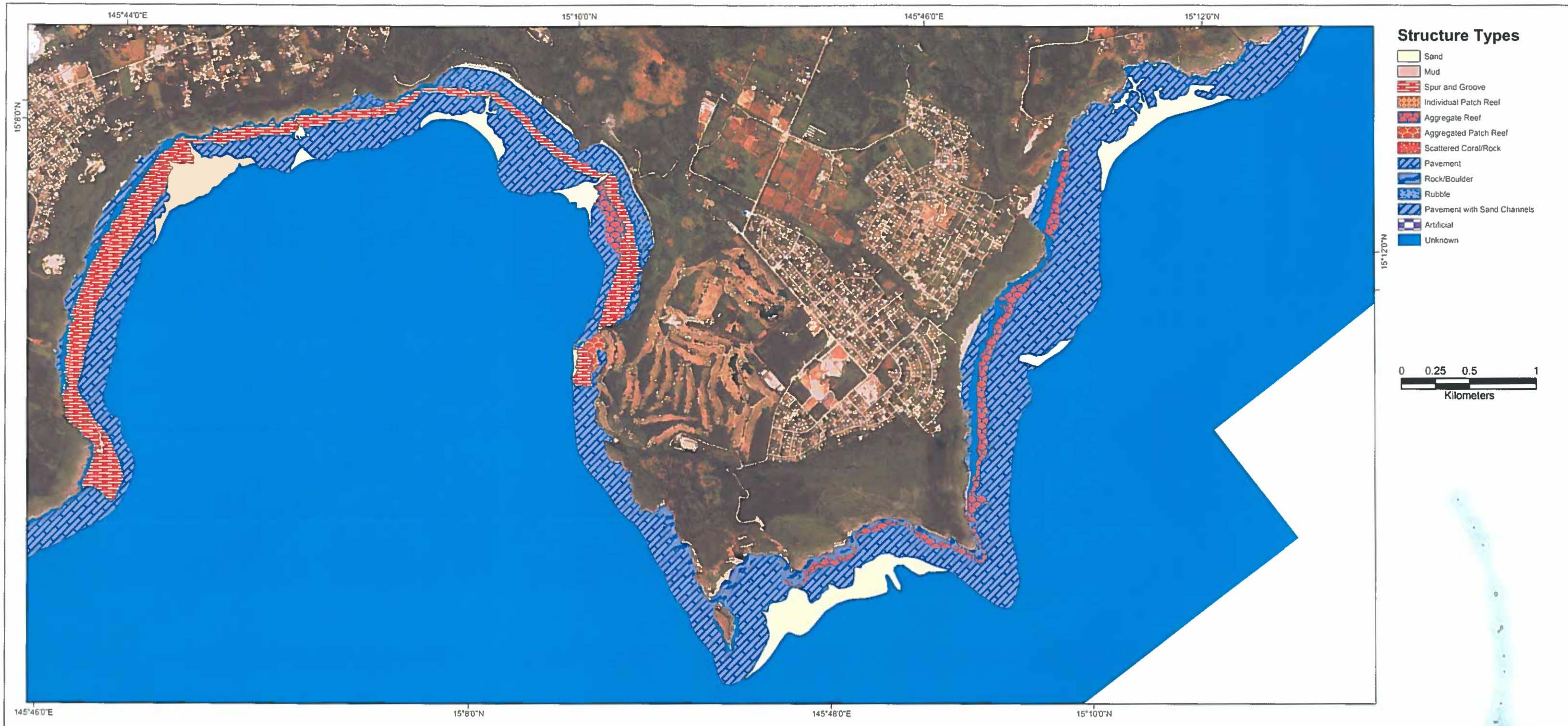
Saipan Benthic Habitat Map

Frame 26 - Biological Cover

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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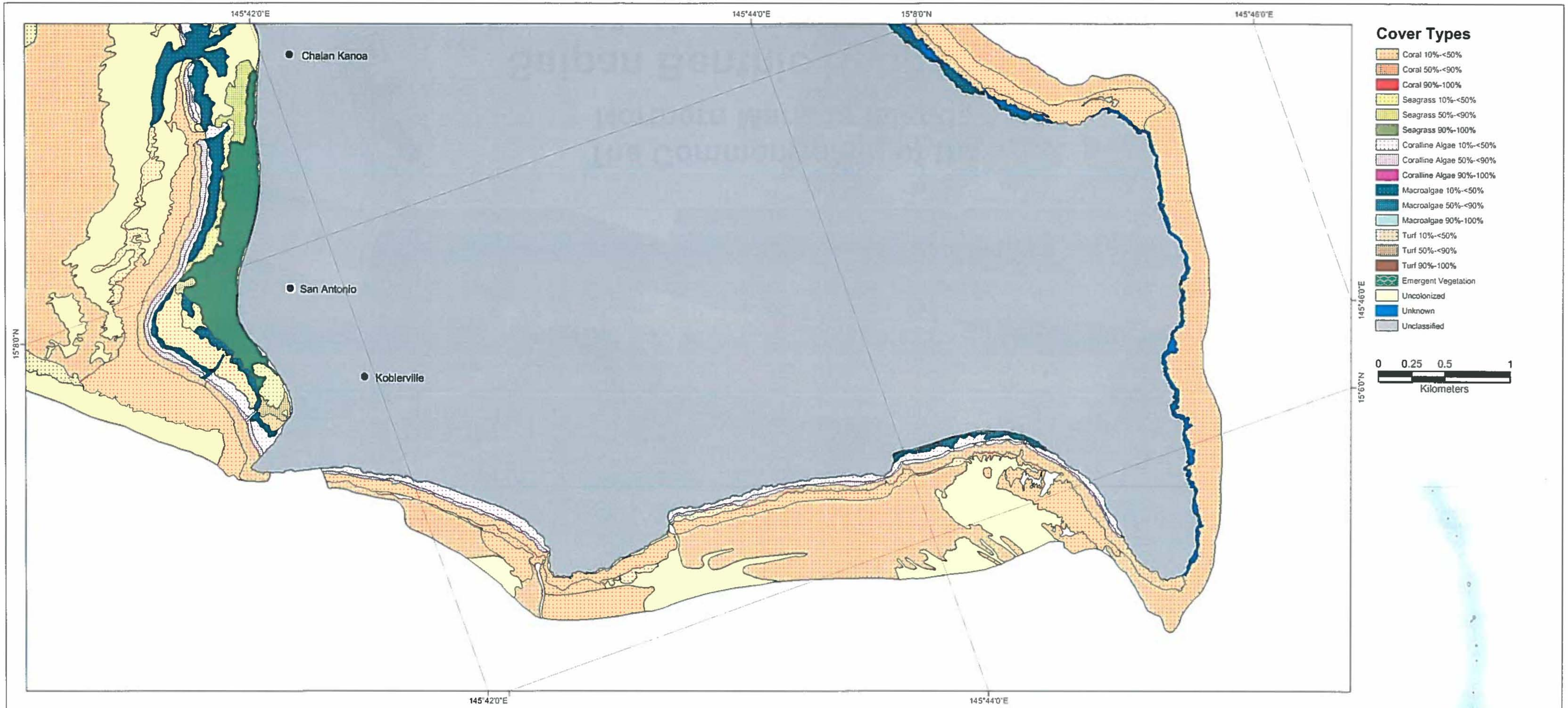
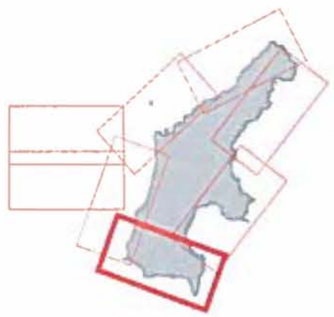
Saipan Benthic Habitat Map

Frame 26 - Geomorphological Structure





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Saipan Benthic Habitat Map

Frame 27 - Biological Cover

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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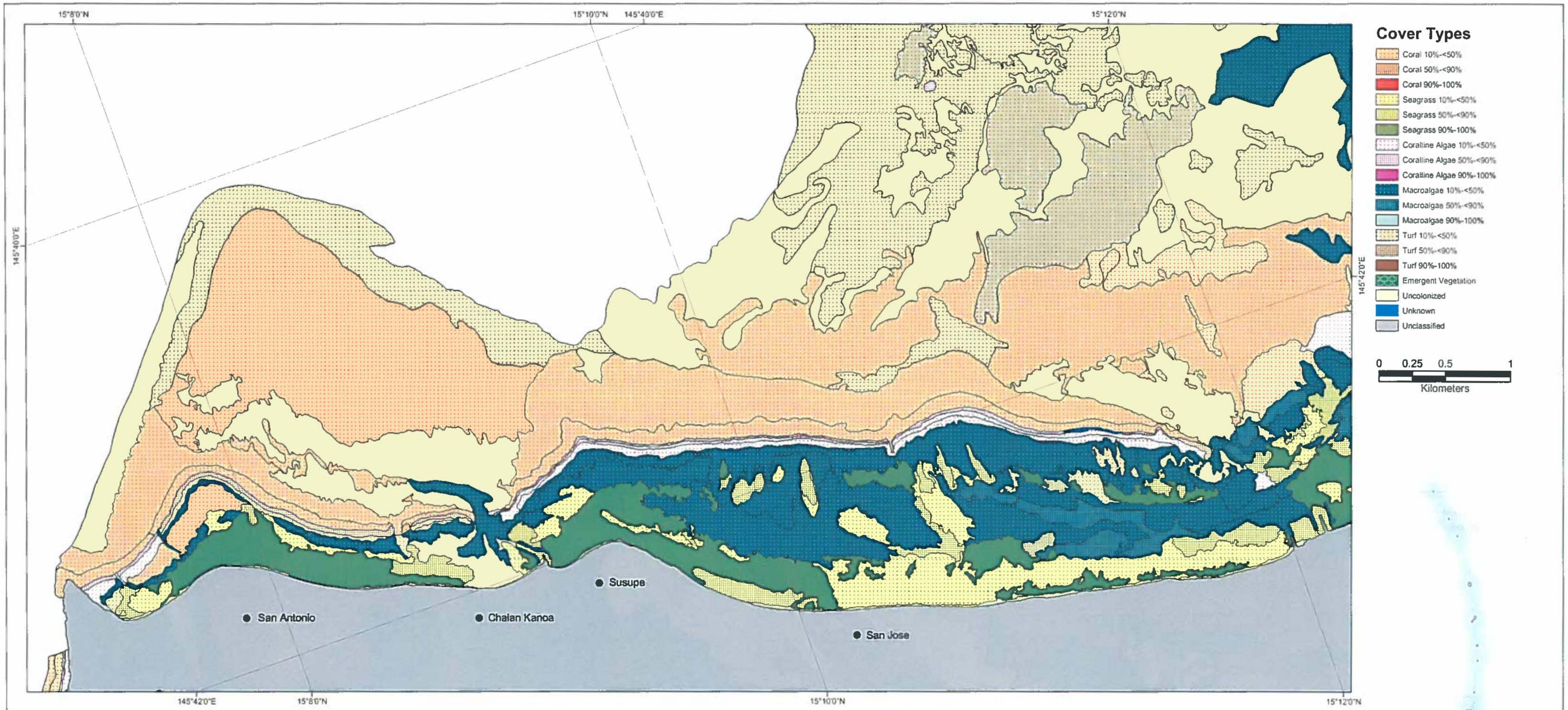
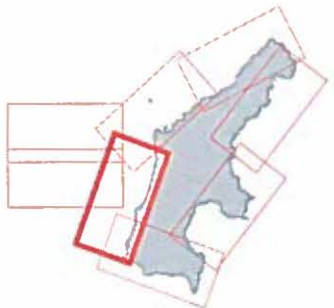
Saipan Benthic Habitat Map

Frame 27 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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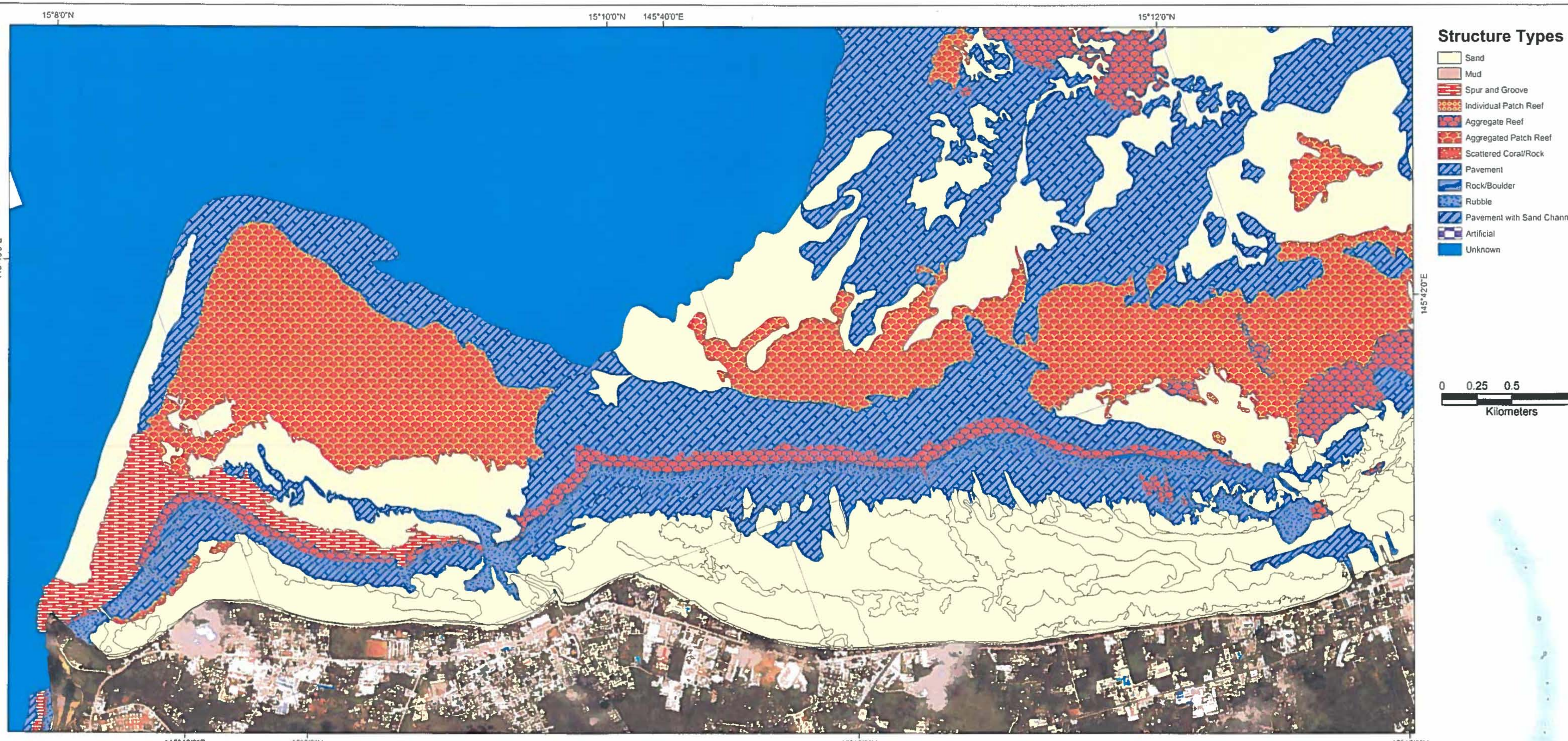
Saipan Benthic Habitat Map

Frame 28 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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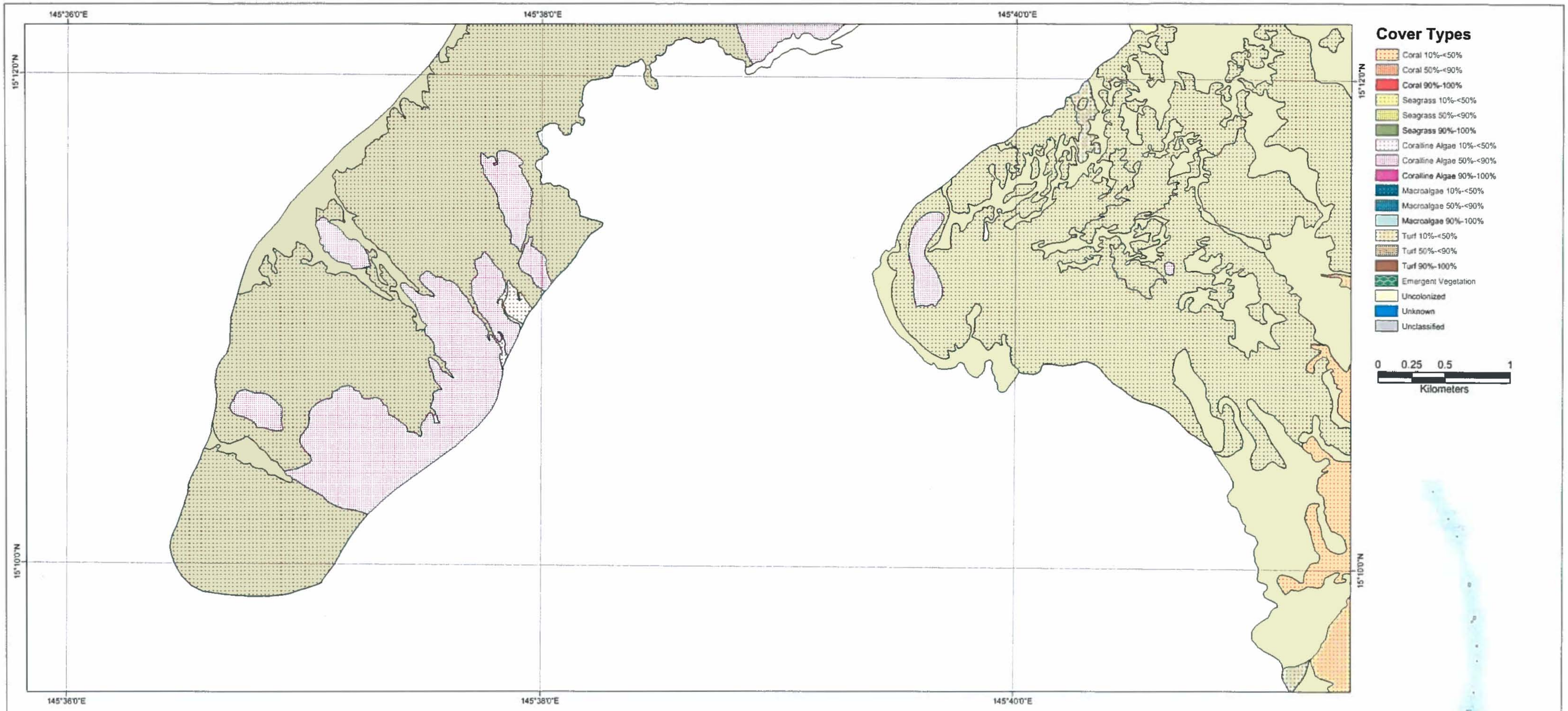
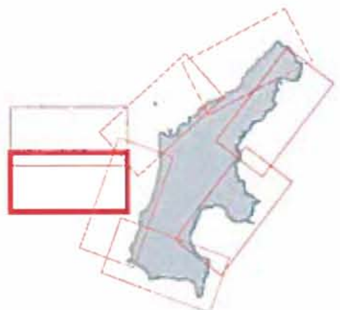
Saipan Benthic Habitat Map

Frame 28 - Geomorphological Structure





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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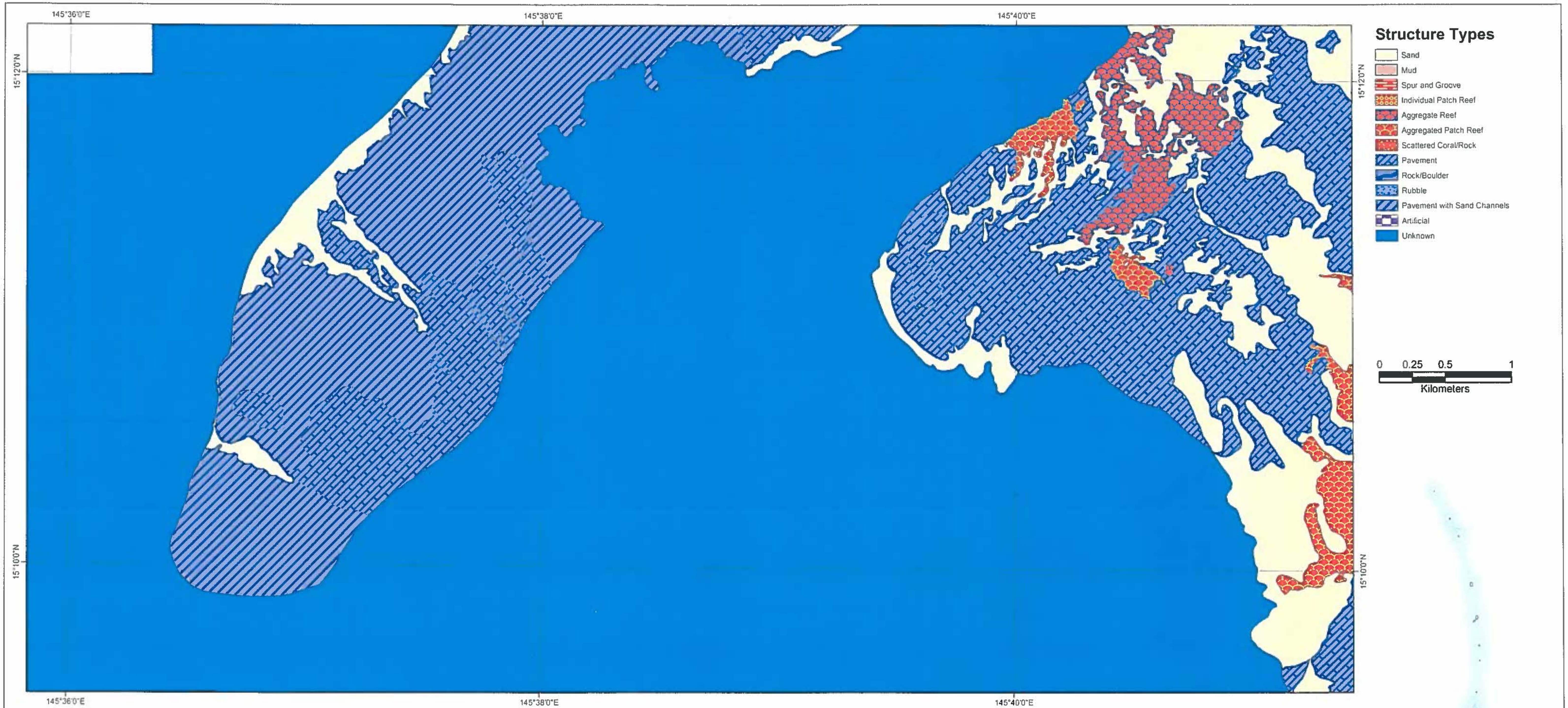
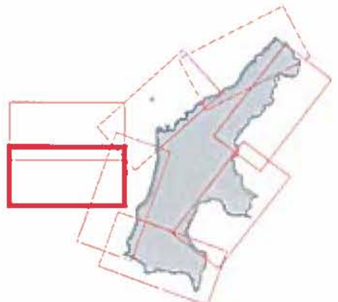
Saipan Benthic Habitat Map

Frame 29 - Biological Cover

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

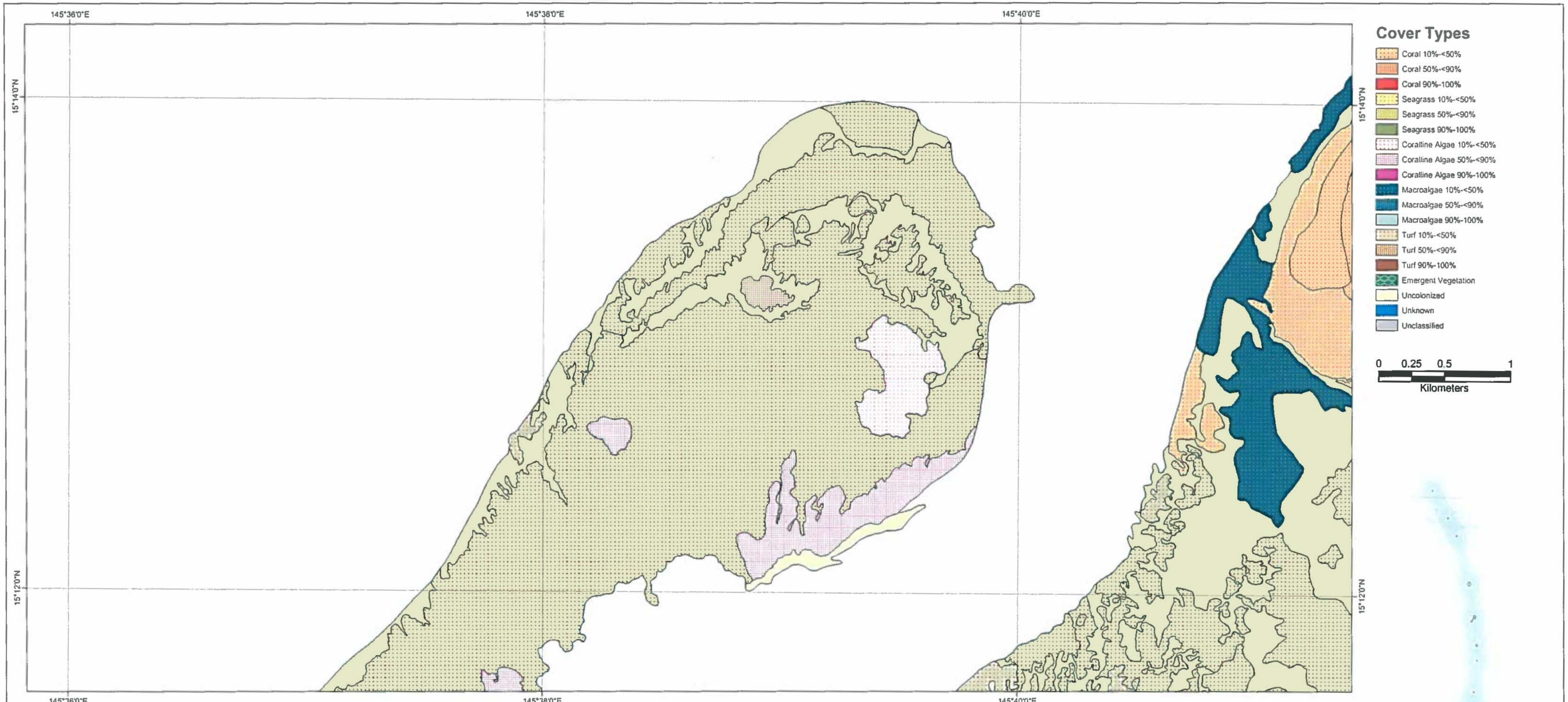


The Commonwealth of the Northern Mariana Islands

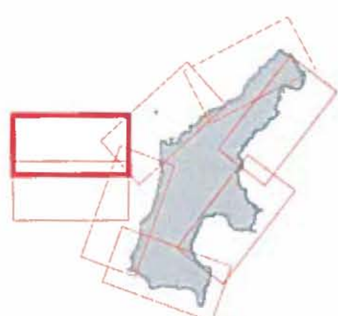
Saipan Benthic Habitat Map

Frame 29 - Geomorphological Structure

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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Saipan Benthic Habitat Map

Frame 30 - Biological Cover

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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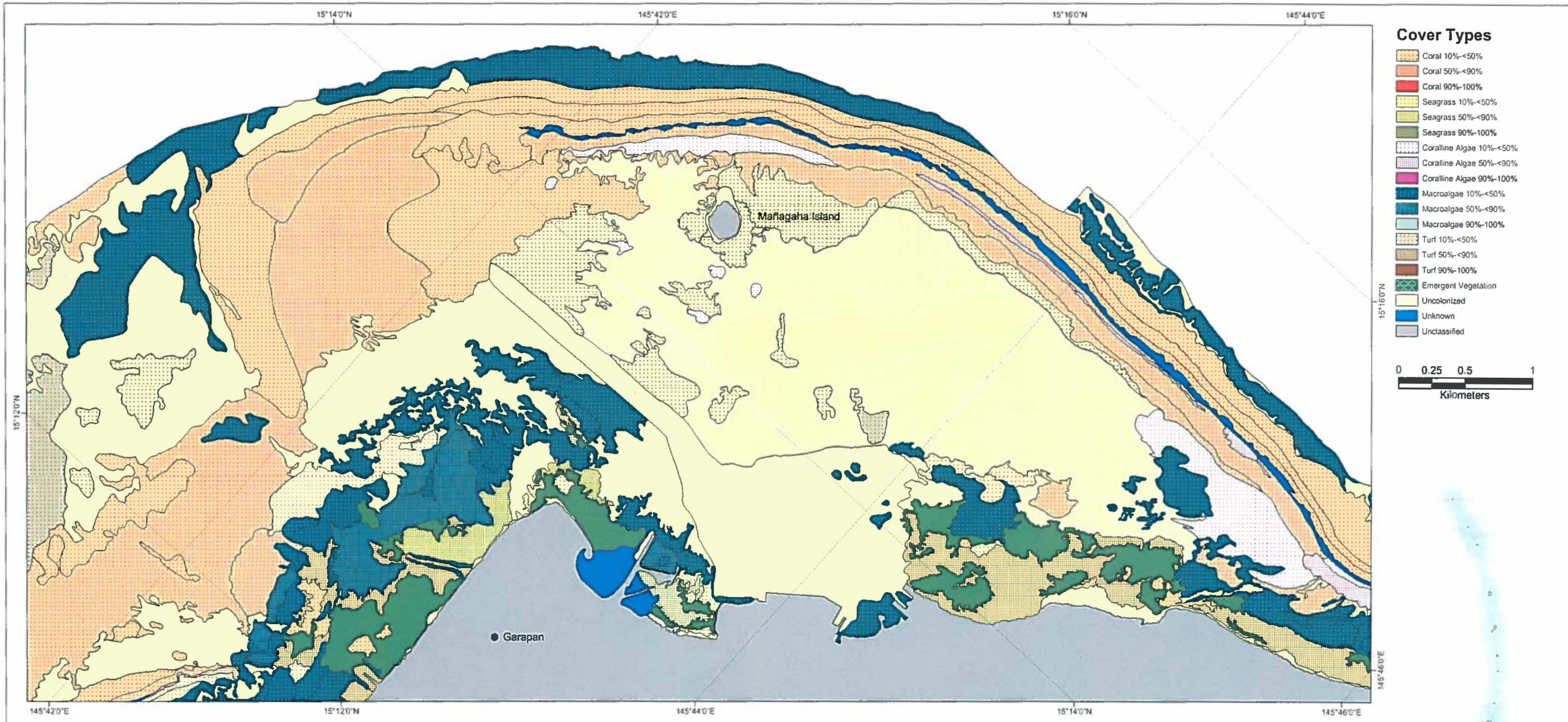
Saipan Benthic Habitat Map

Frame 30 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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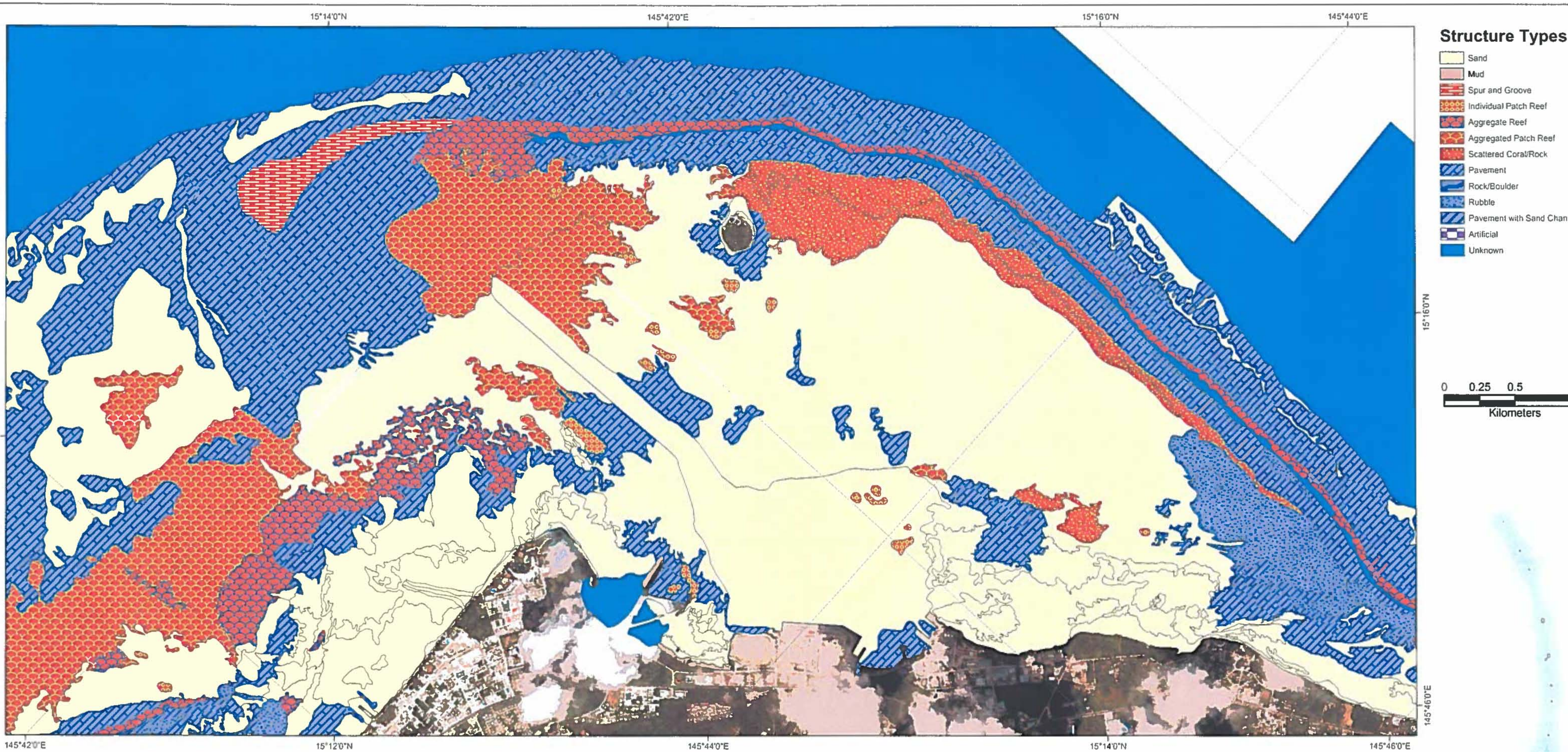
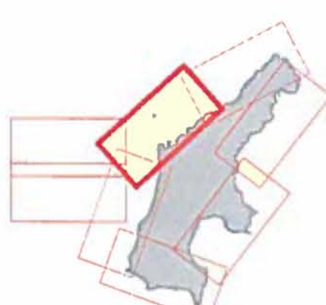
Saipan Benthic Habitat Map

Frame 31 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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Saipan Benthic Habitat Map

Frame 31 - Geomorphological Structure

N

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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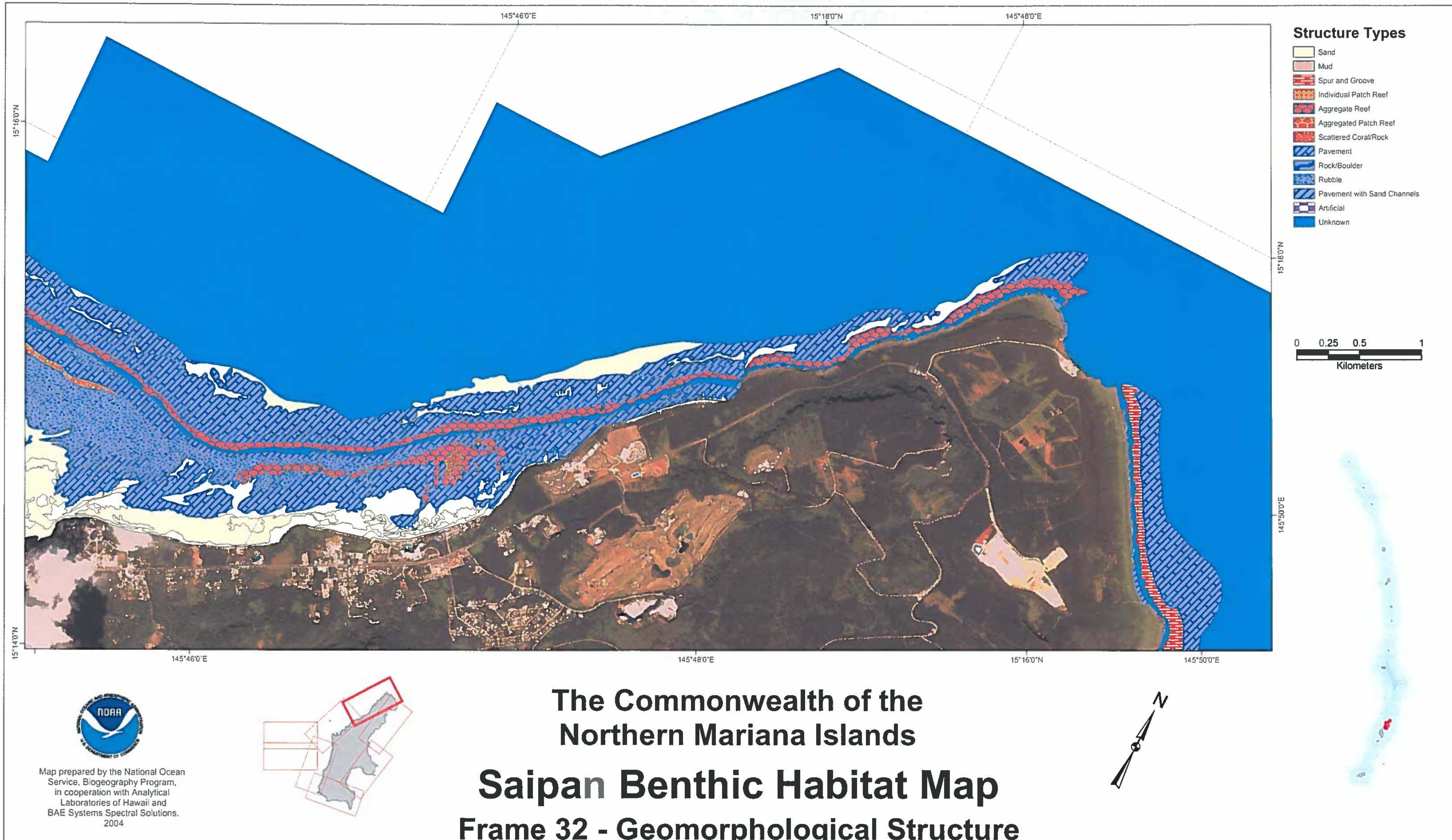
Saipan Benthic Habitat Map

Frame 32 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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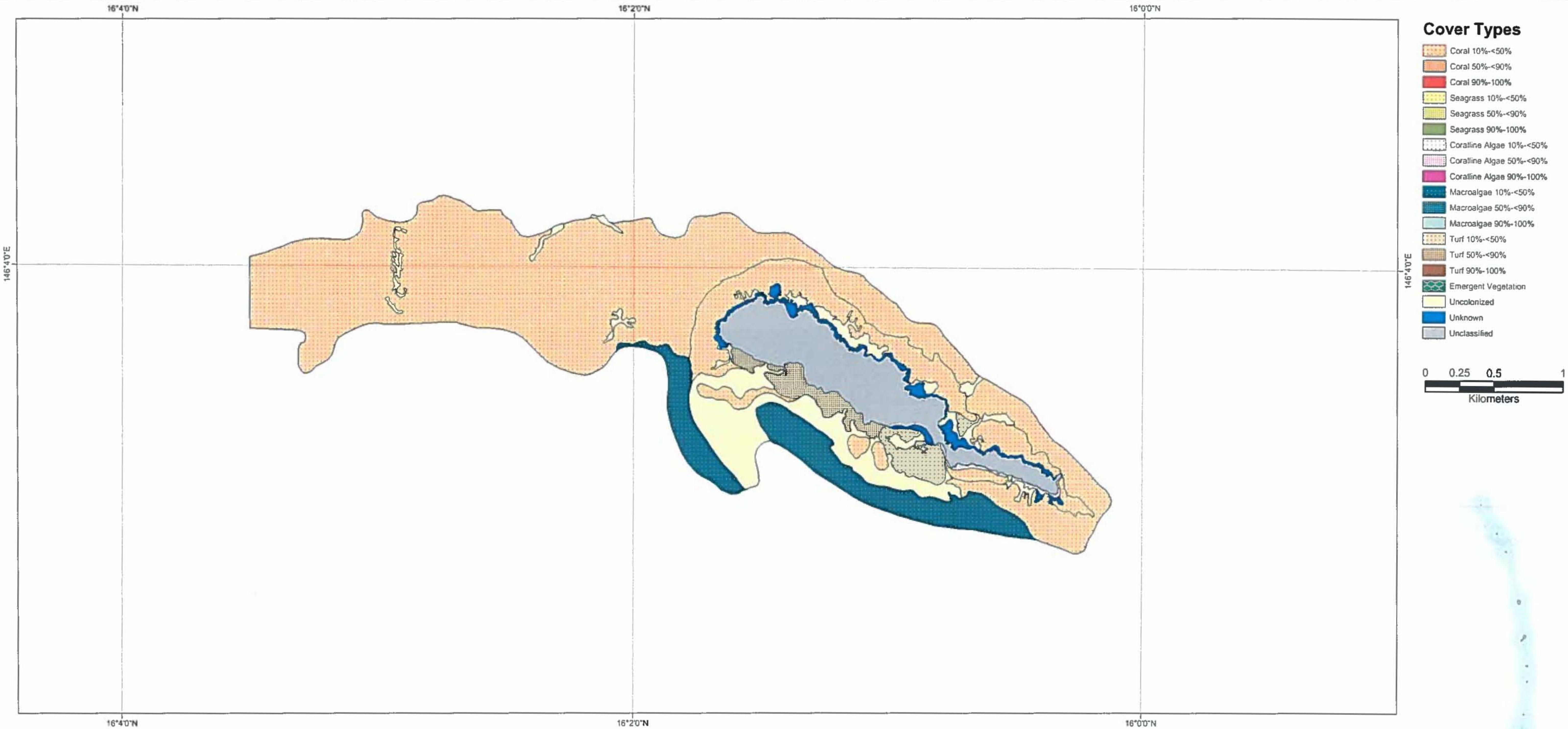
Saipan Benthic Habitat Map

Frame 32 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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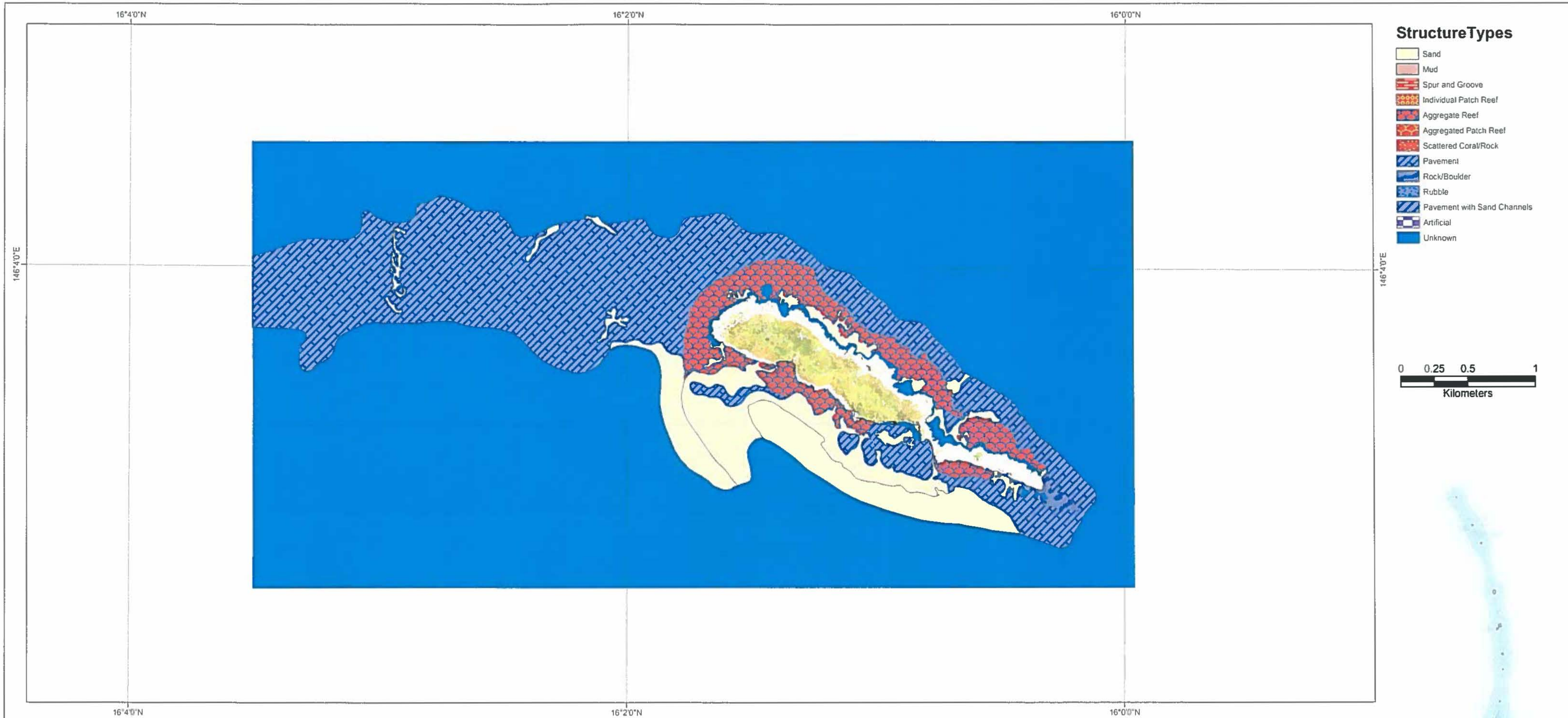
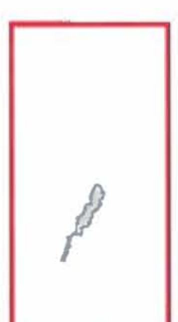
Farallon de Medinilla Benthic Habitat Map

Frame 33 - Biological Cover

N





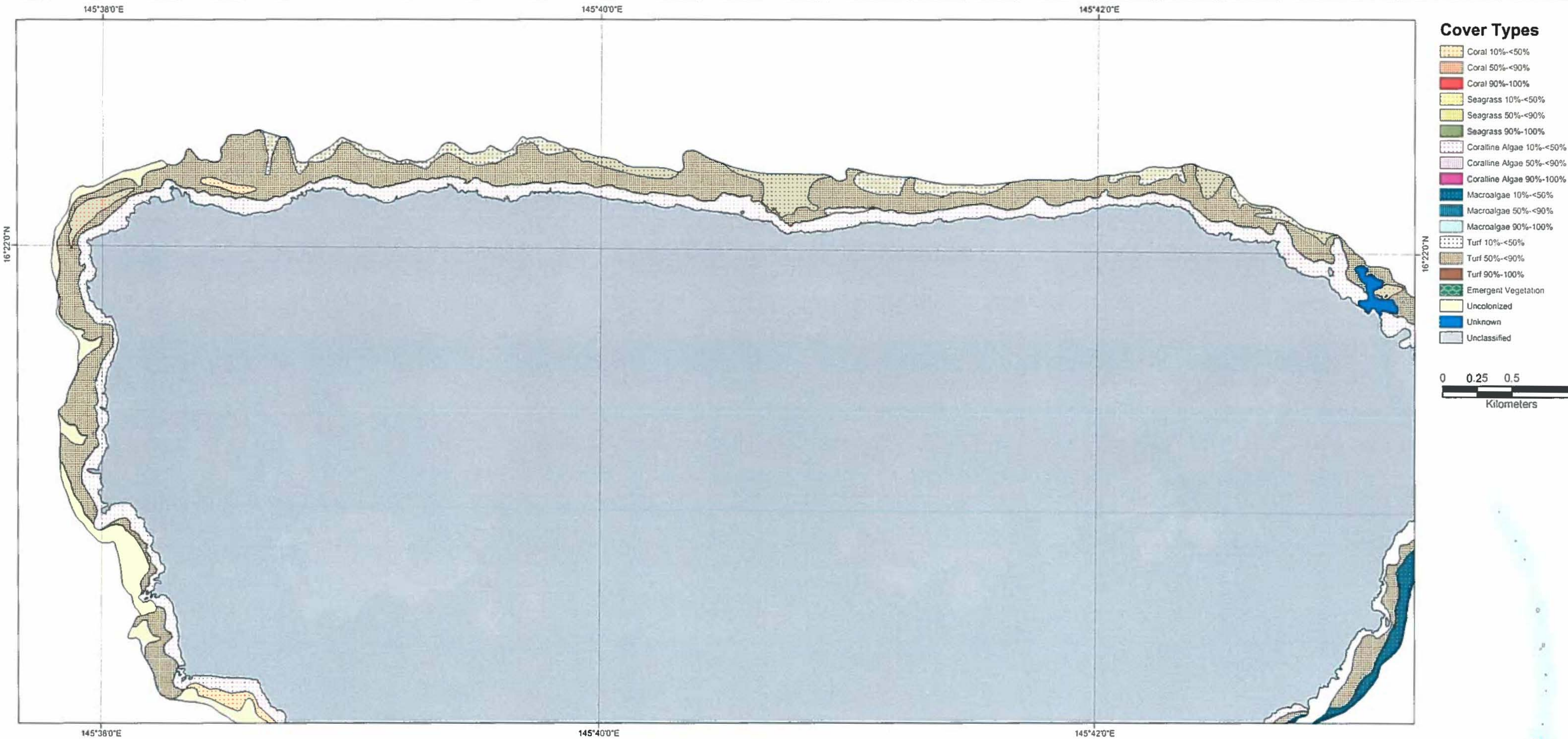
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

The Commonwealth of the Northern Mariana Islands

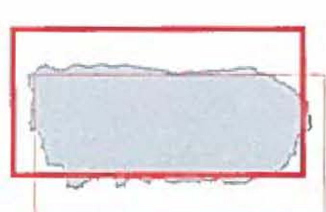
Farallon de Medinilla Benthic Habitat Map

Frame 33 - Geomorphological Structure

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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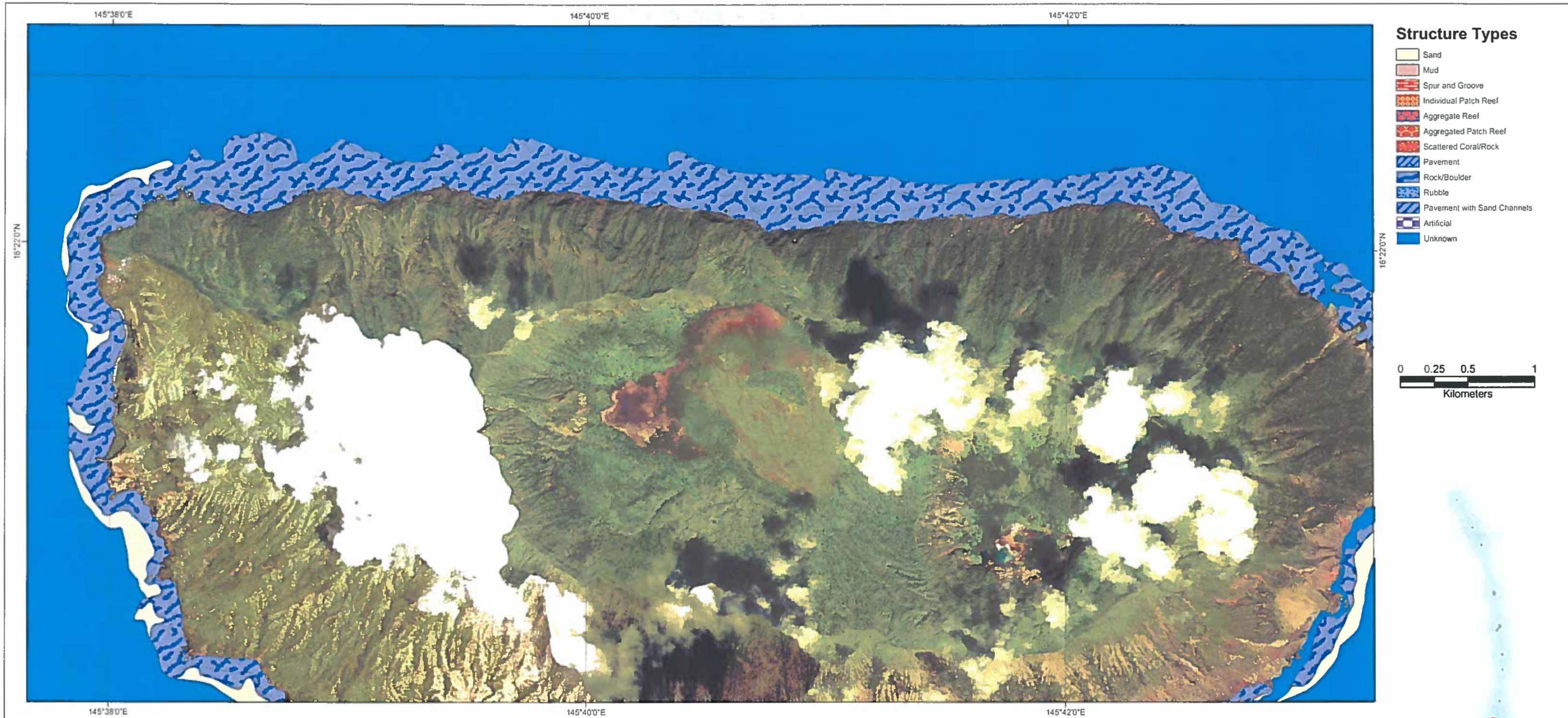
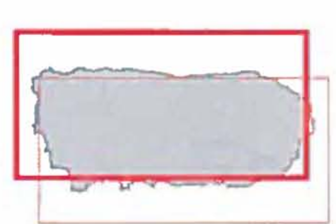
Anatahan Benthic Habitat Map

Frame 34 - Biological Cover

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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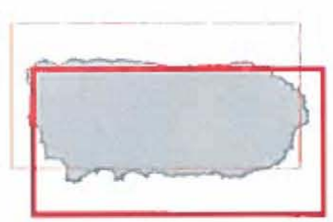
Anatahan Benthic Habitat Map

Frame 34 - Geomorphological Structure



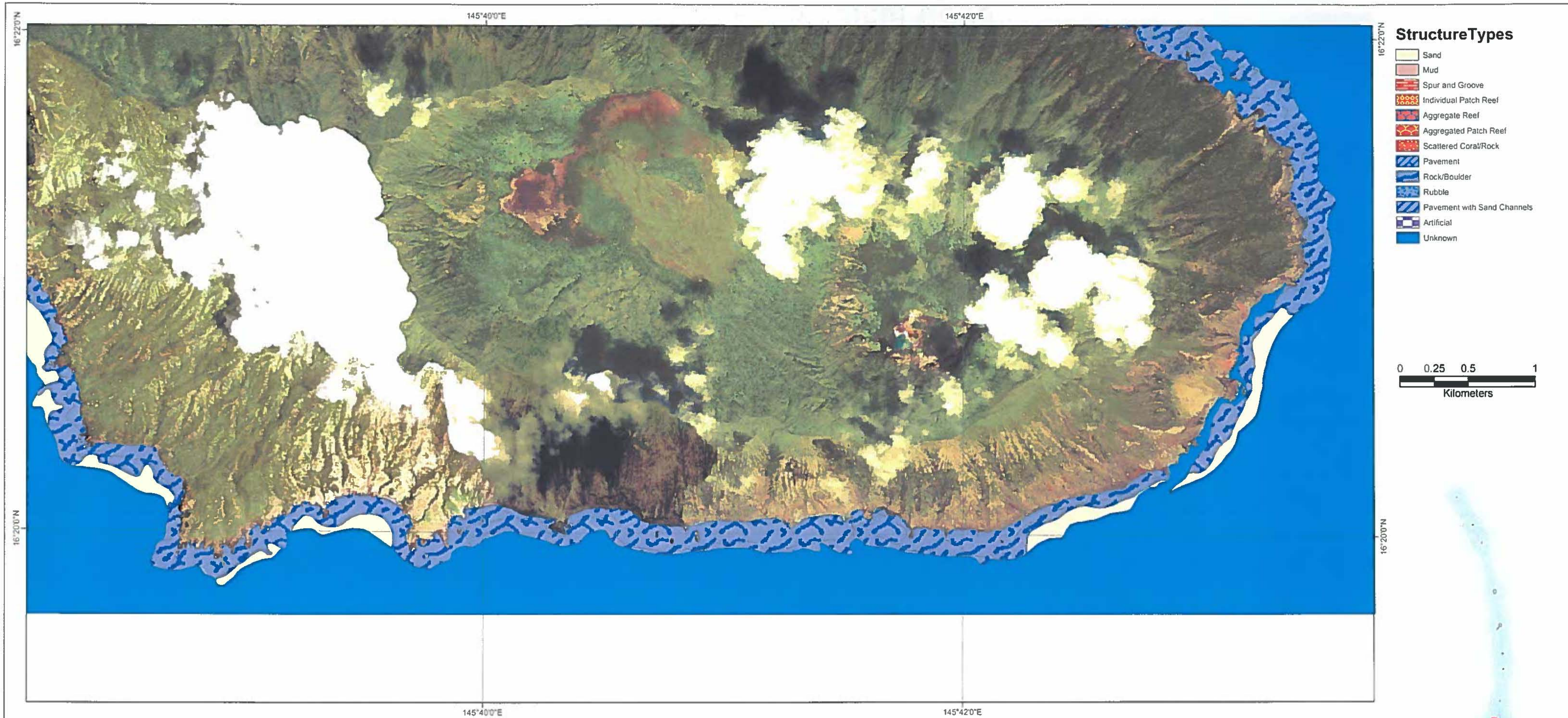
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

The Commonwealth of the Northern Mariana Islands

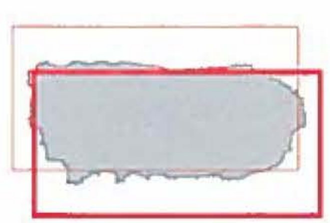
Anatahan Benthic Habitat Map

Frame 35 - Biological Cover

N



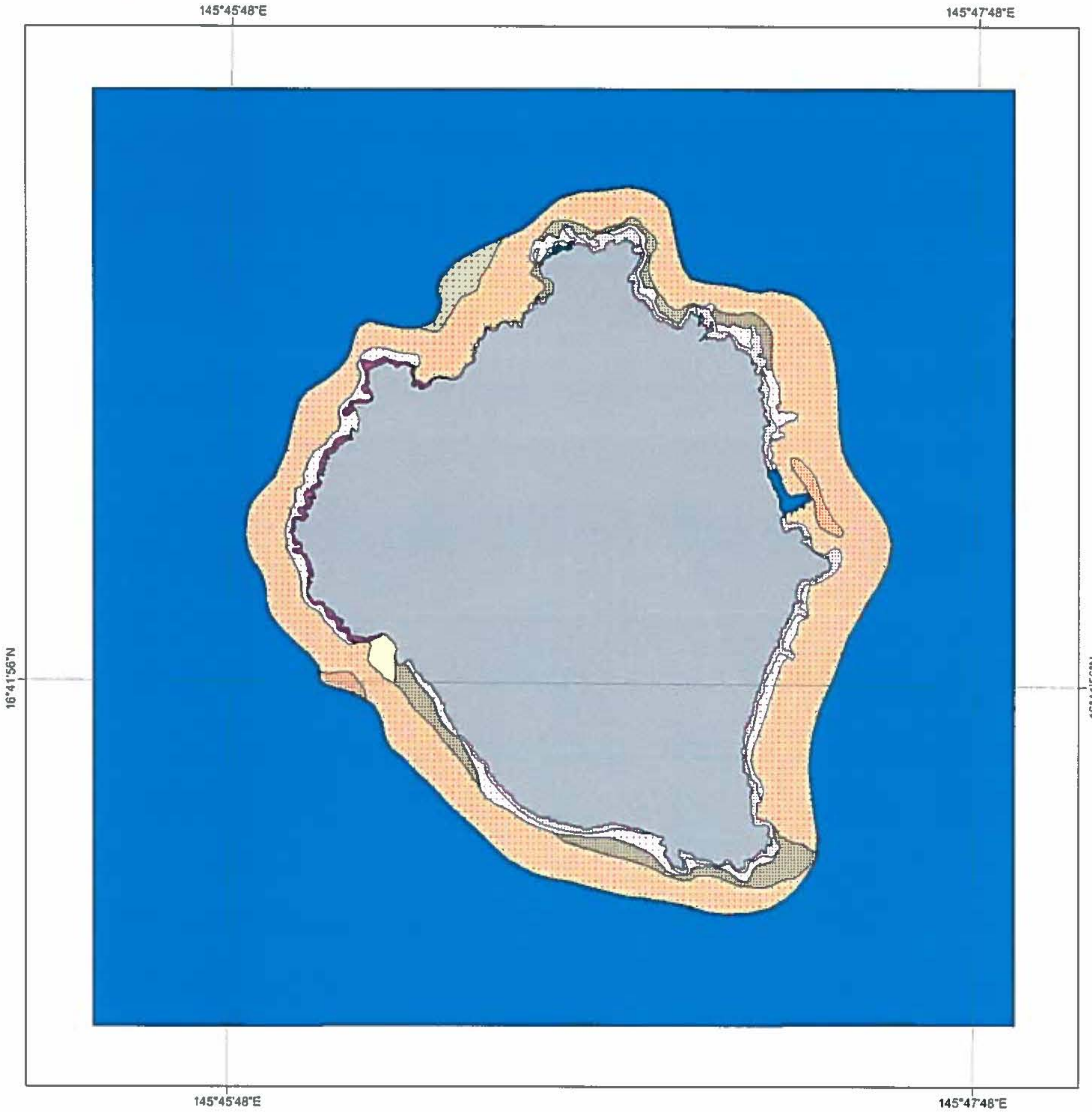
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

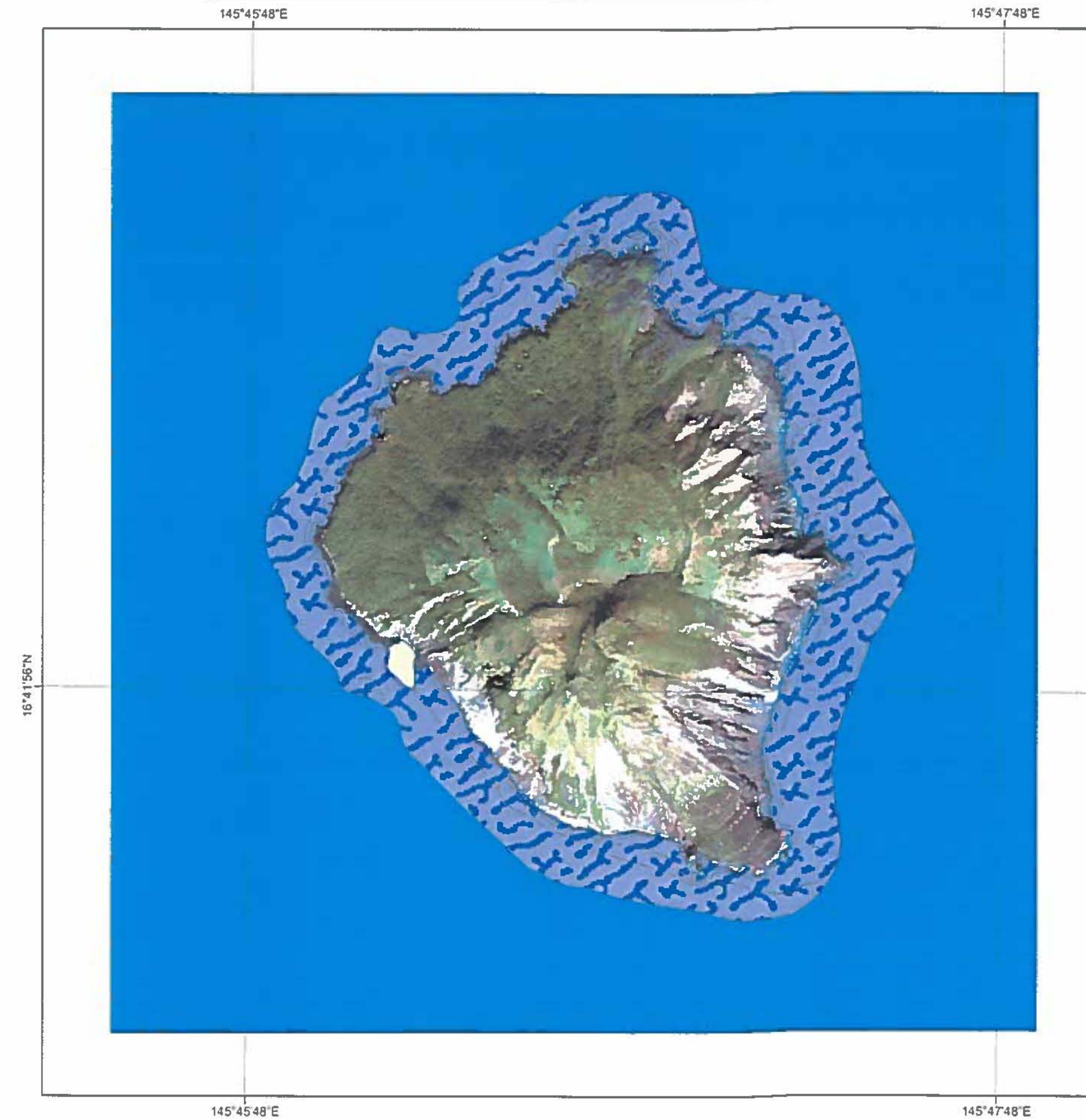


The Commonwealth of the Northern Mariana Islands

Anatahan Benthic Habitat Map

Frame 35 - Geomorphological Structure





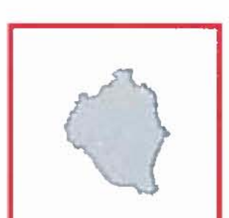
Cover Types

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

Structure Types

- Sand
- Mud
- Spur and Groove
- Individual Patch Reef
- Aggregate Reef
- Aggregated Patch Reef
- Scattered Coral/Rock
- Pavement
- Rock/Boulder
- Rubble
- Pavement with Sand Channels
- Artificial
- Unknown

0 0.25 0.5 1
Kilometers



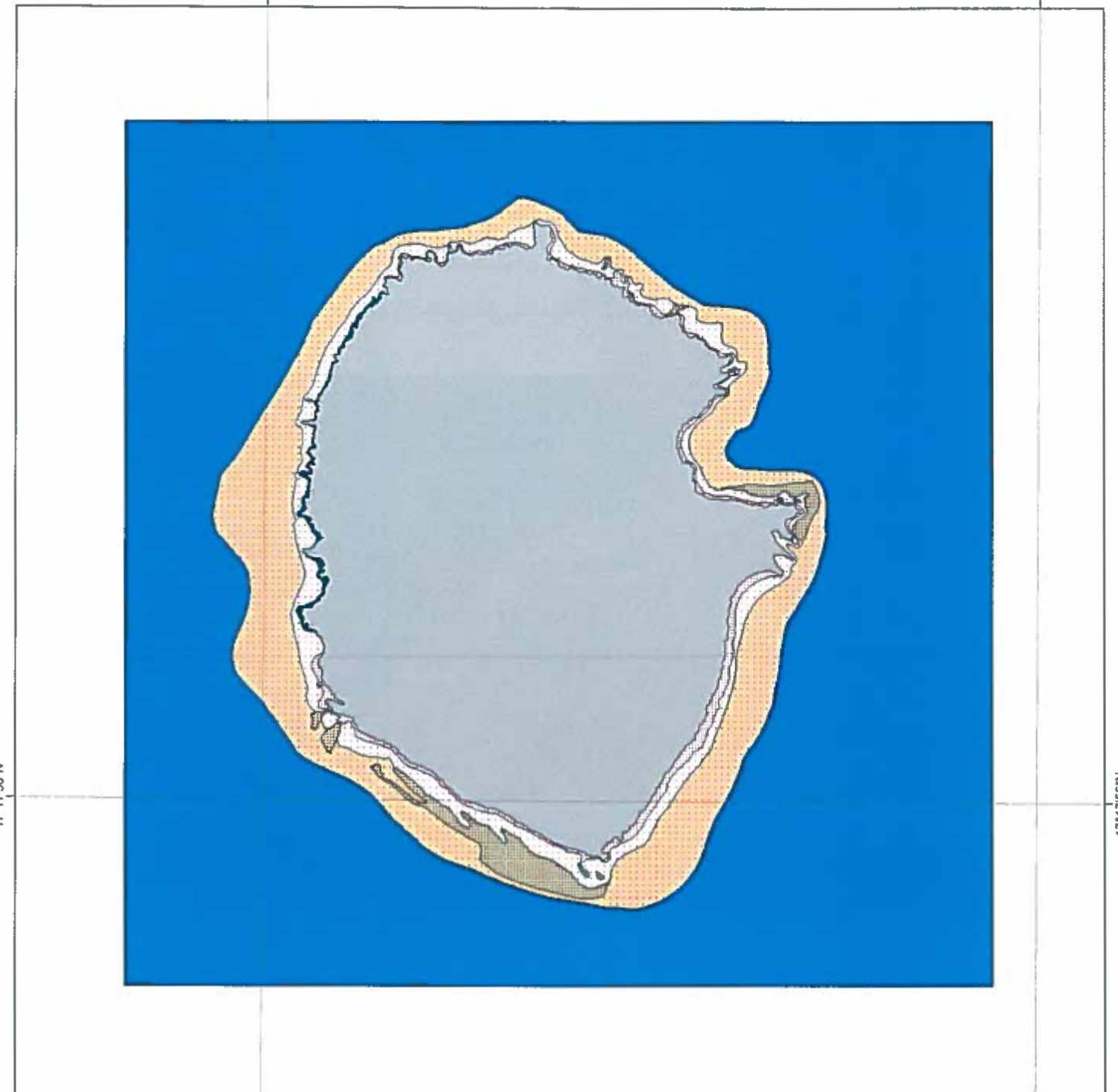
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

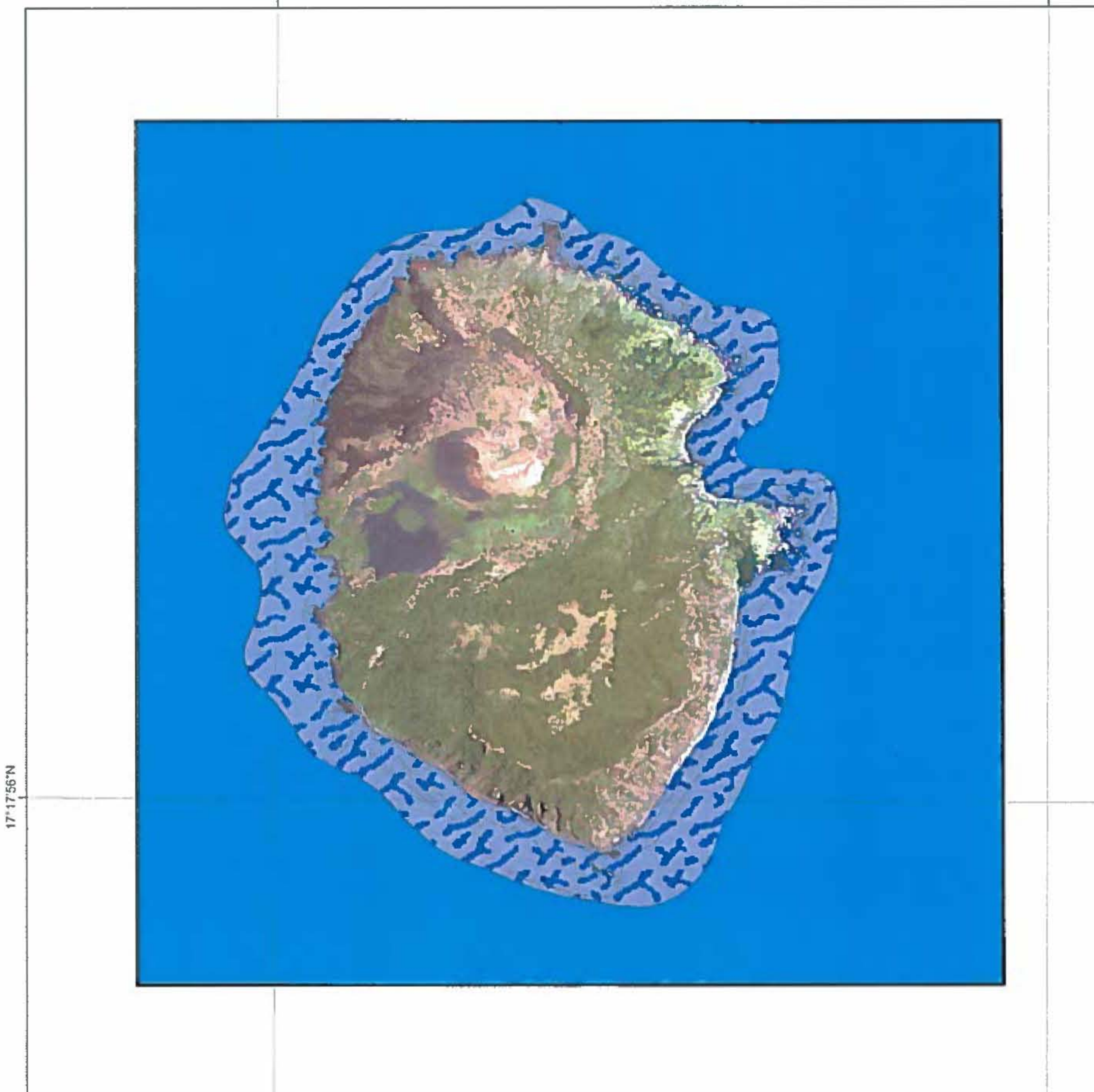
The Commonwealth of the Northern Mariana Islands

Sarigan Benthic Habitat Map

Frame 36 - Biological Cover and Geomorphological Structure

N





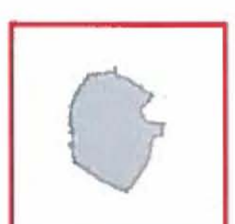
Cover Types

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

Structure Types

- Sand
- Mud
- Spur and Groove
- Individual Patch Reef
- Aggregate Reef
- Aggregated Patch Reef
- Scattered Coral/Rock
- Pavement
- Rock/Boulder
- Rubble
- Pavement with Sand Channels
- Artificial
- Unknown

0 0.25 0.5 1
Kilometers



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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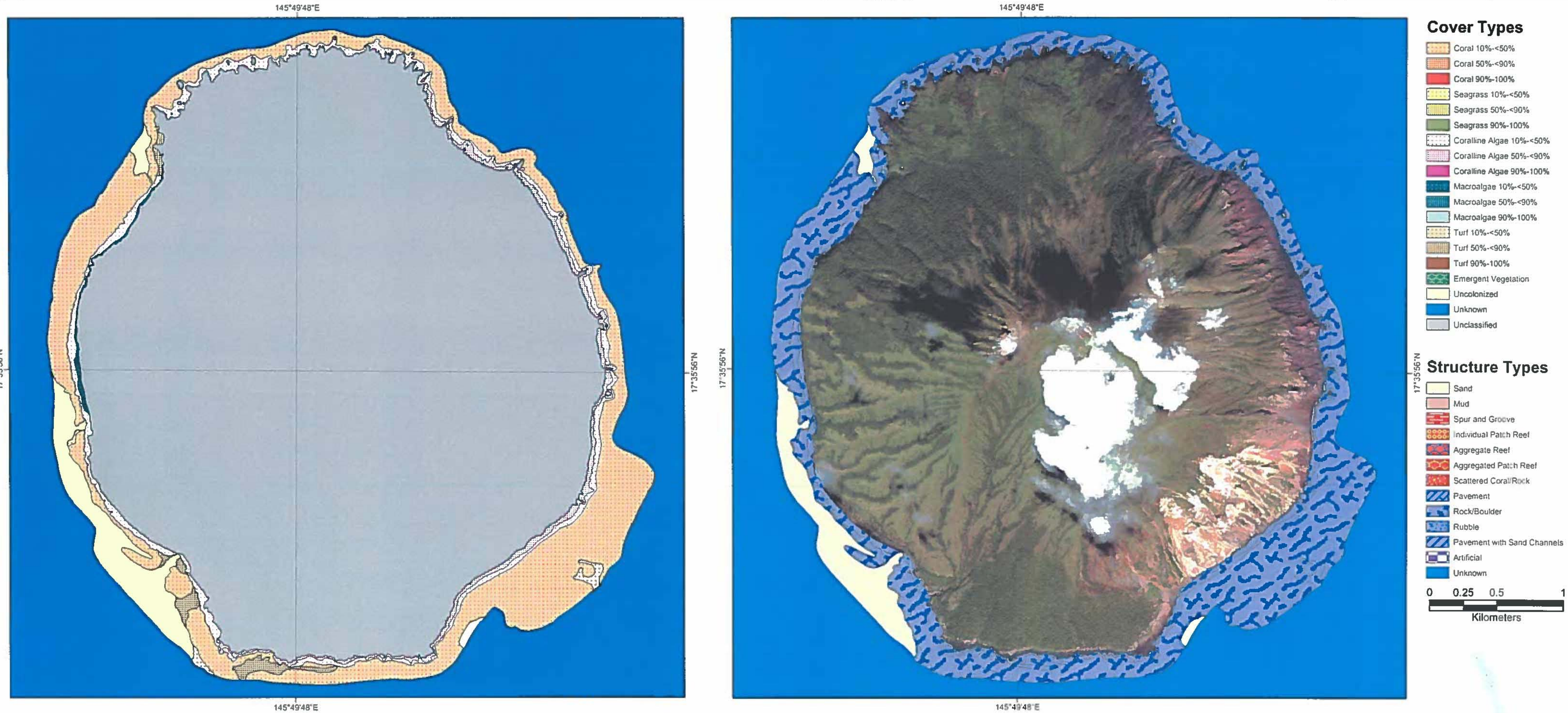
Guguan Benthic Habitat Map

Frame 37 - Biological Cover and Geomorphological Structure

N



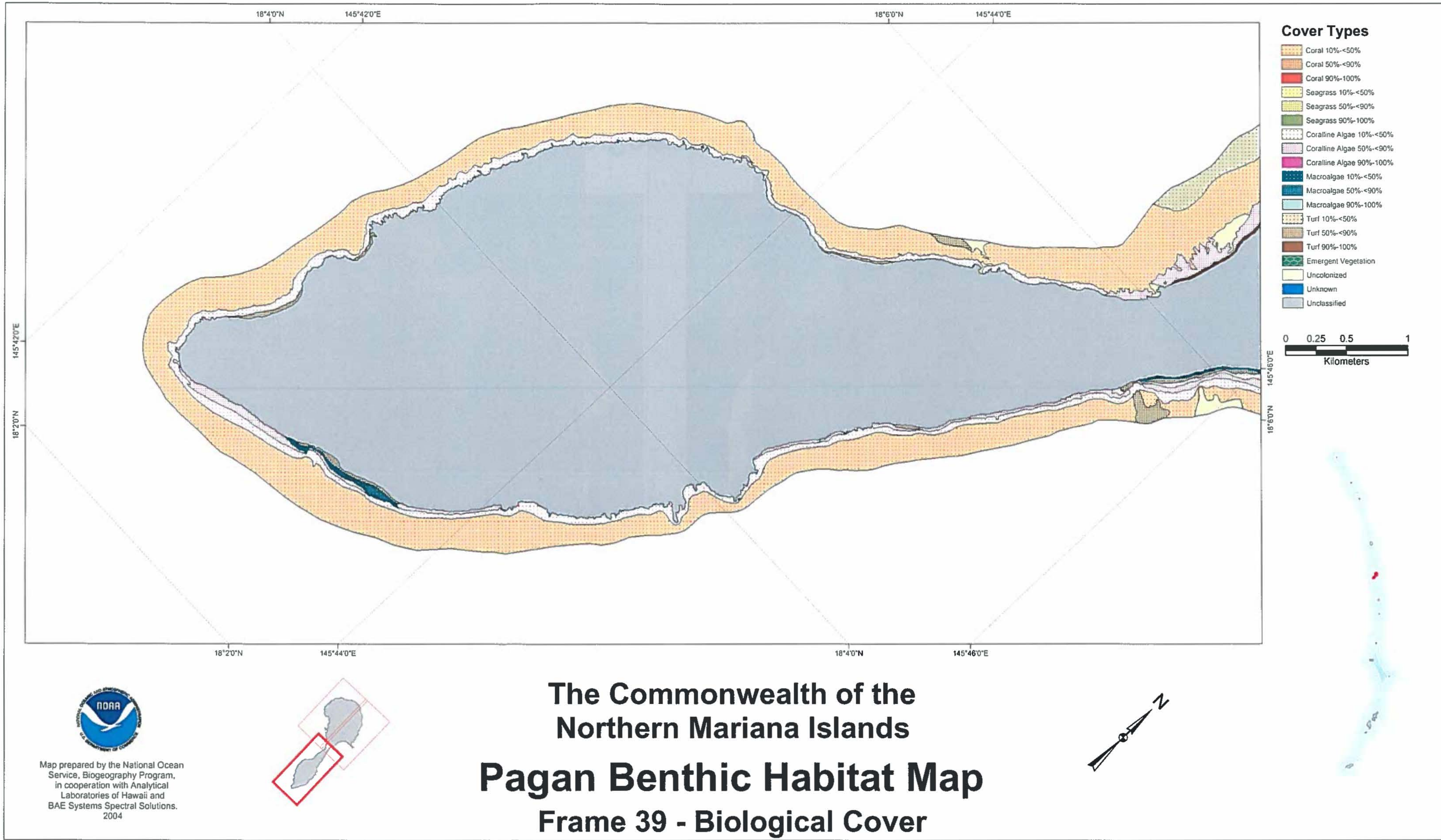
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions
2004

The Commonwealth of the Northern Mariana Islands

Alamagan Benthic Habitat Map

Frame 38 - Biological Cover and Geomorphological Structure

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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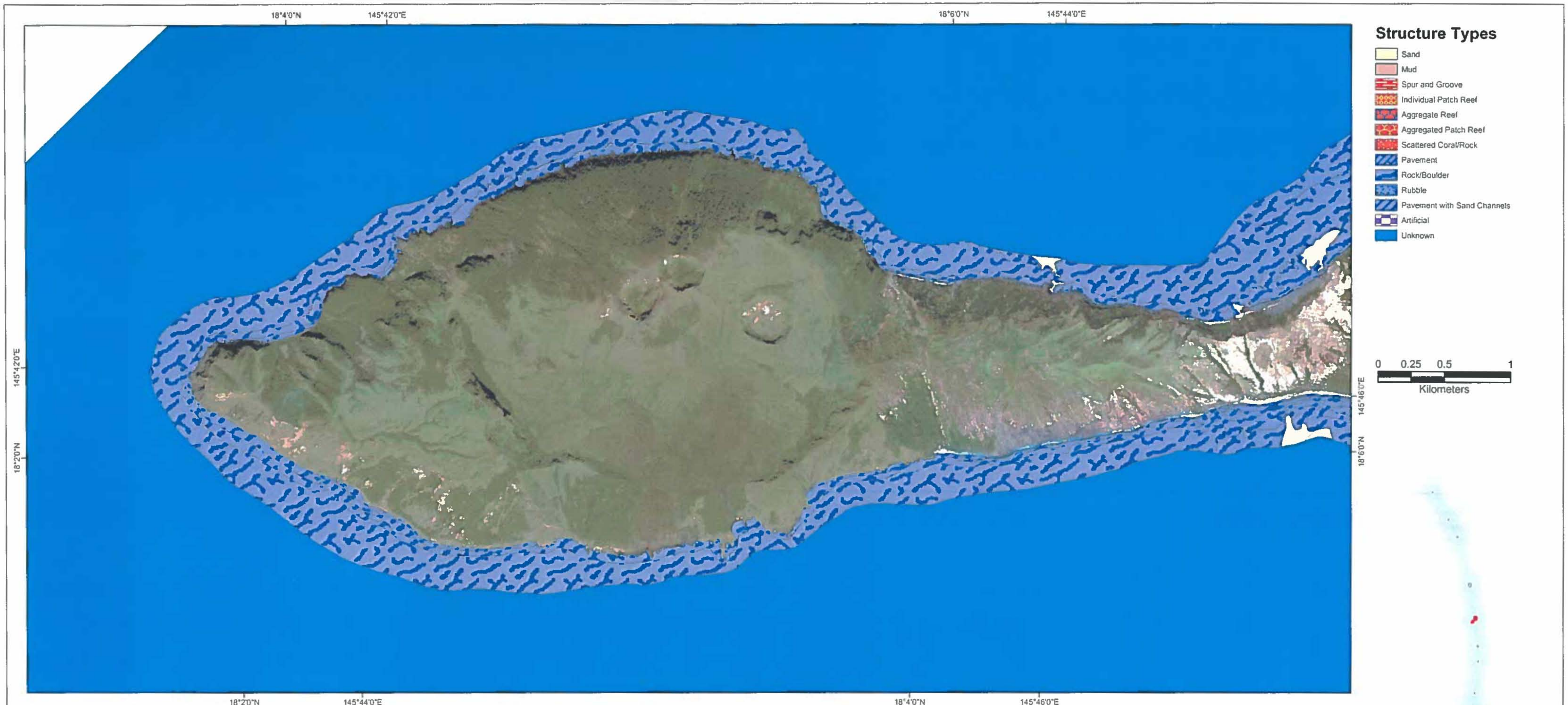
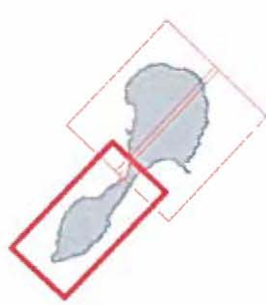
Pagan Benthic Habitat Map

Frame 39 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



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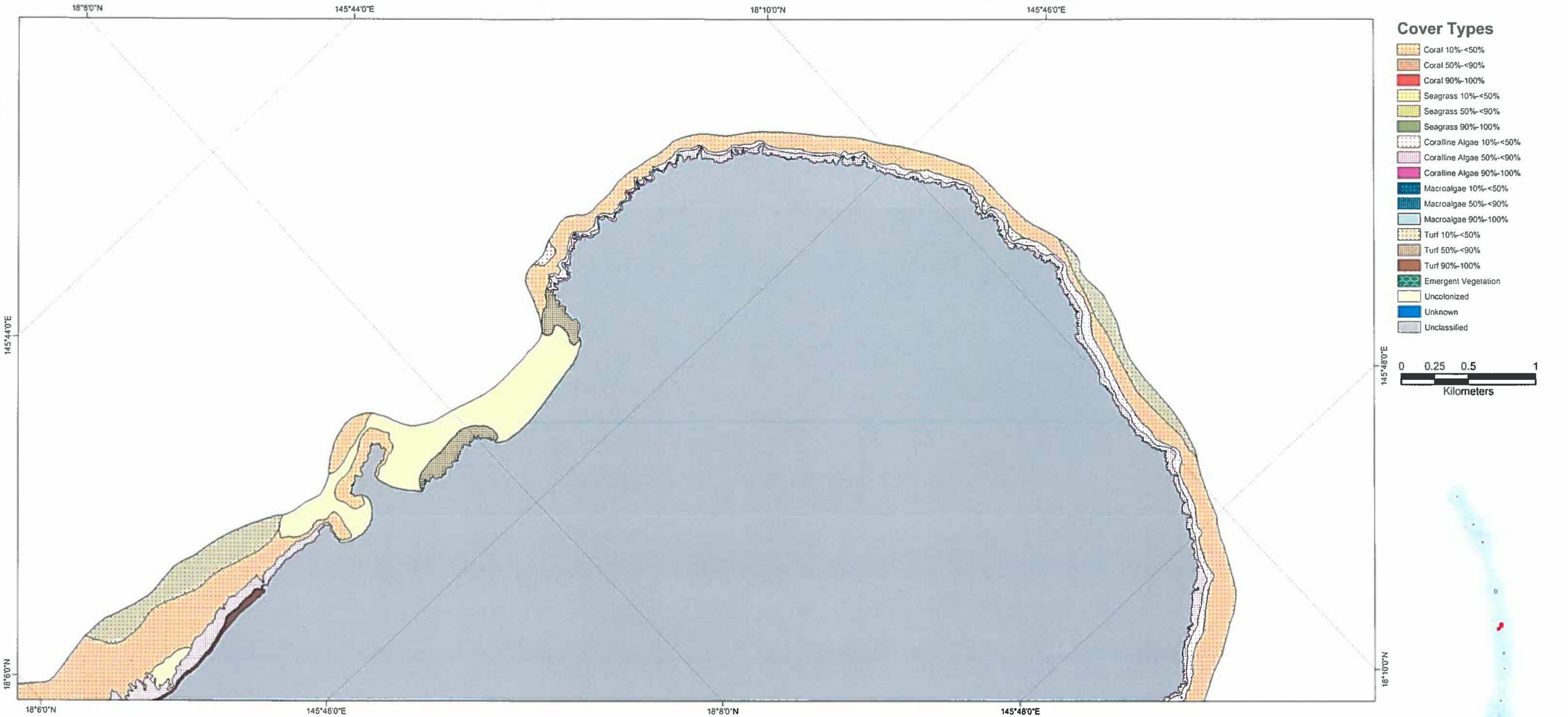
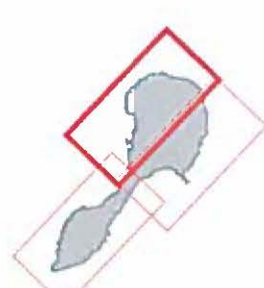
Pagan Benthic Habitat Map

Frame 39- Geomorphological Structure





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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Pagan Benthic Habitat Map

Frame 40 - Biological Cover

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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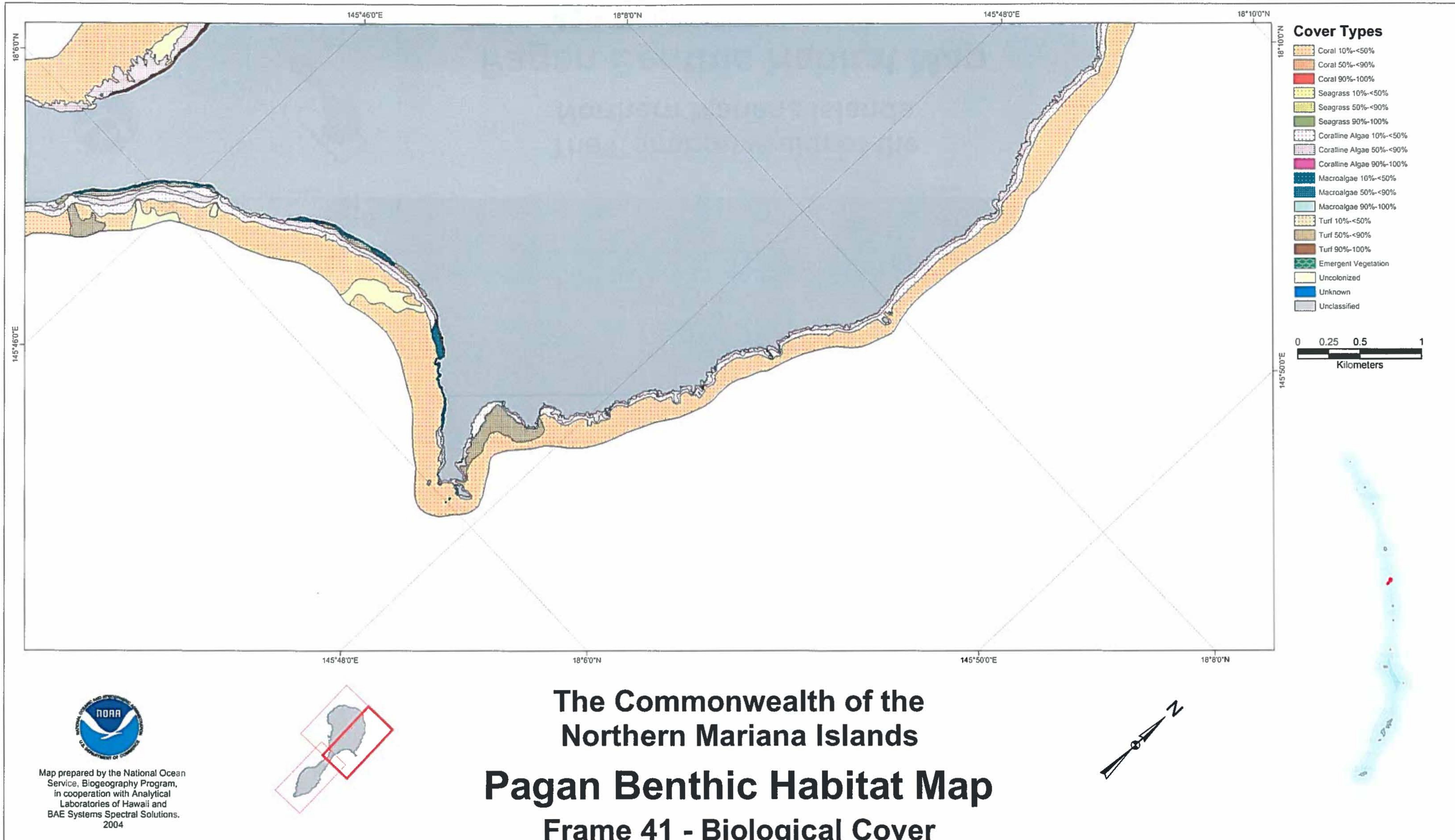
Pagan Benthic Habitat Map

Frame 40 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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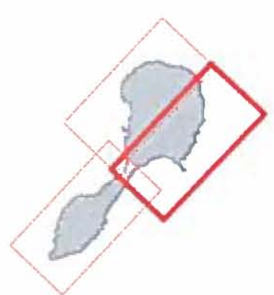
Pagan Benthic Habitat Map

Frame 41 - Biological Cover

Structure Types

- Sand
- Mud
- Spur and Groove
- Individual Patch Reef
- Aggregate Reef
- Aggregated Patch Reef
- Scattered Coral/Rock
- Pavement
- Rock/Boulder
- Rubble
- Pavement with Sand Channels
- Artificial
- Unknown

0 0.25 0.5 1
Kilometers



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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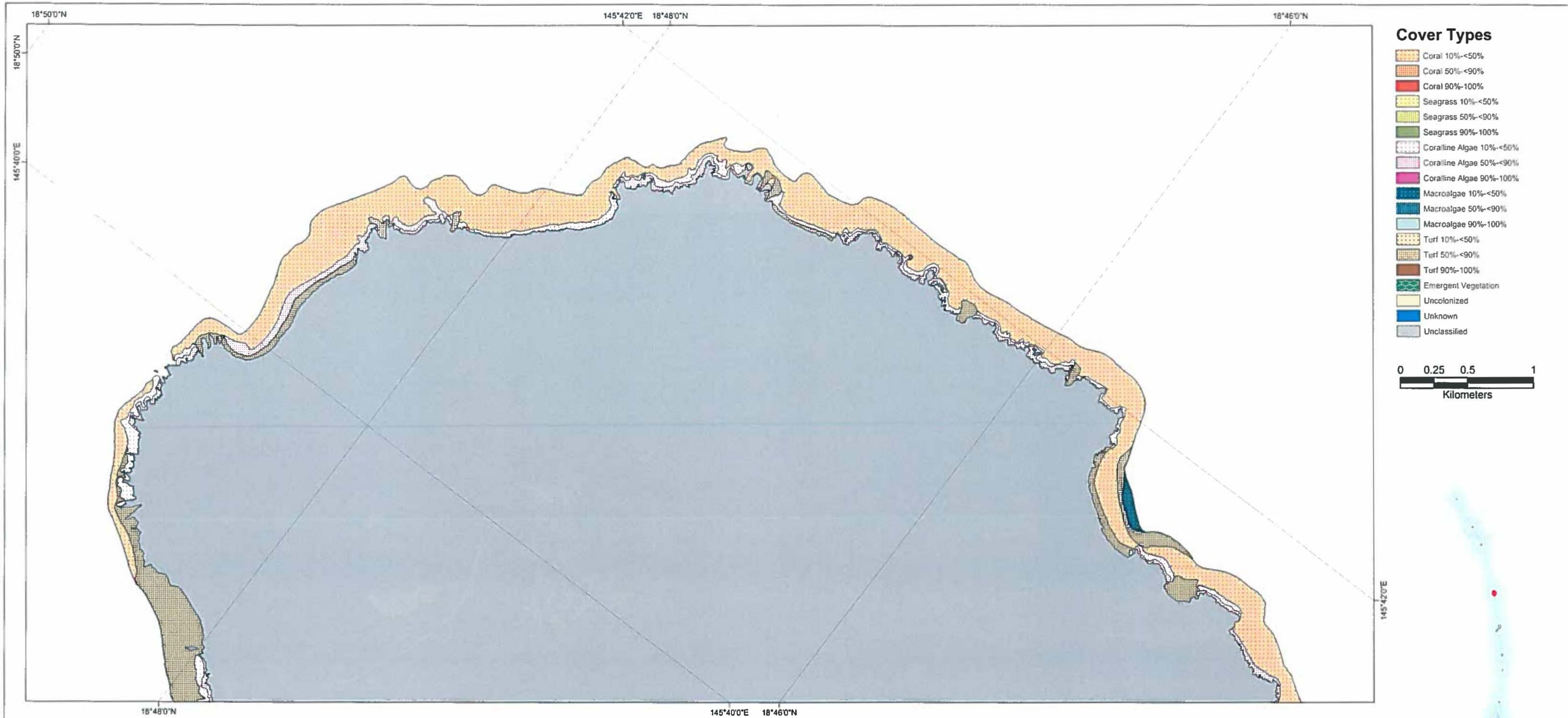
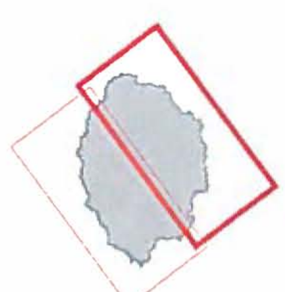
Pagan Benthic Habitat Map

Frame 41 - Geomorphological Structure

N





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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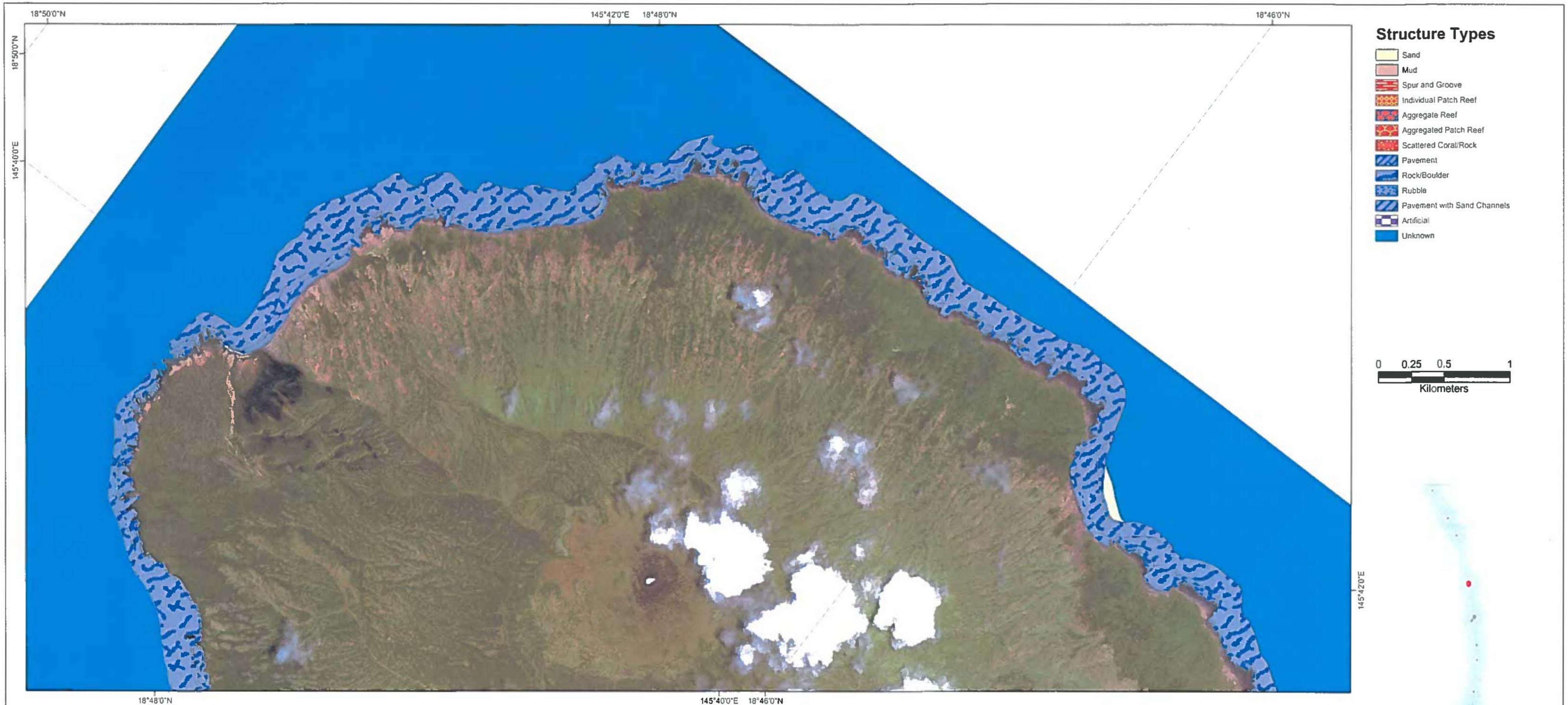
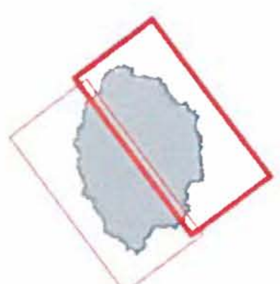
Agrihan Benthic Habitat Map

Frame 42 - Biological Cover





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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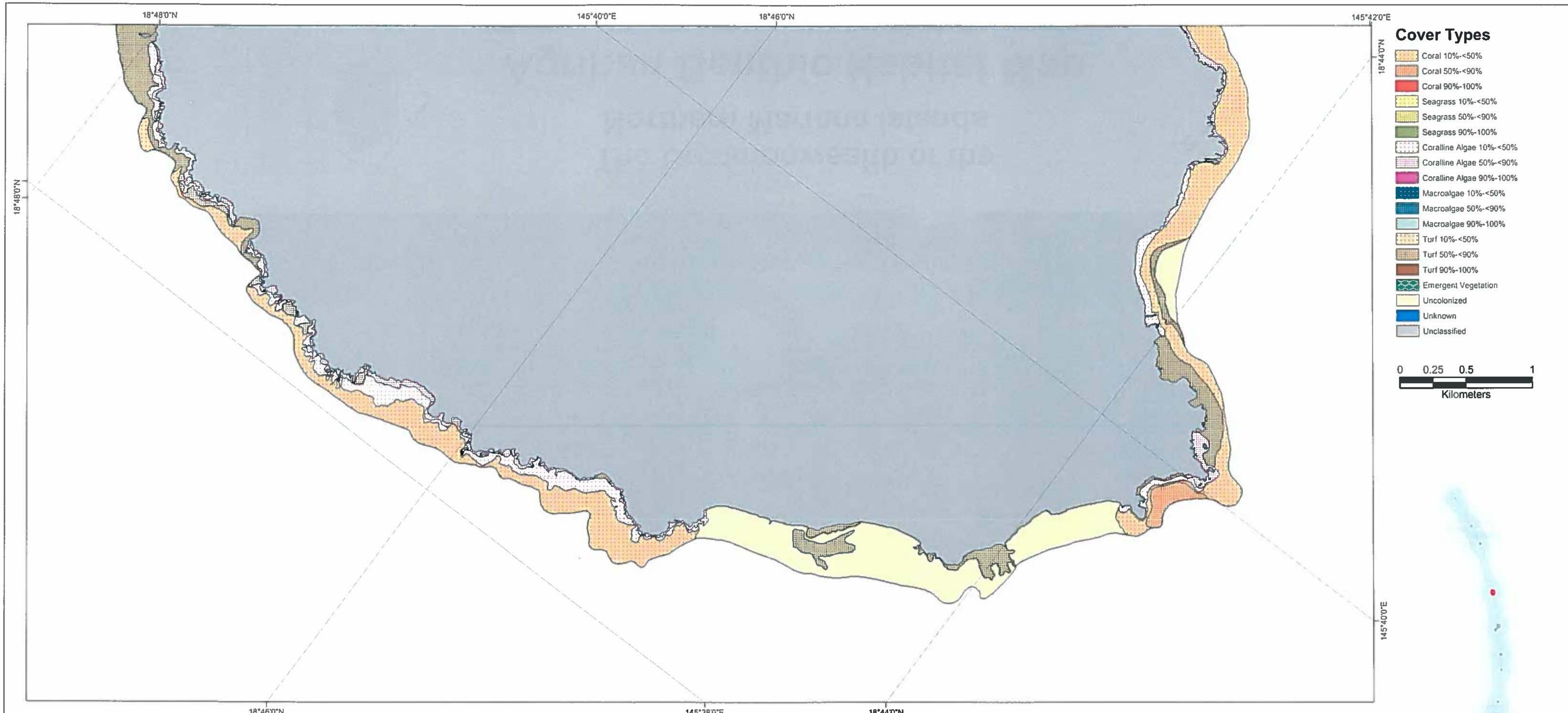
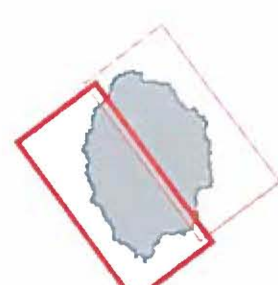
Agrihan Benthic Habitat Map

Frame 42 - Geomorphological Structure

N



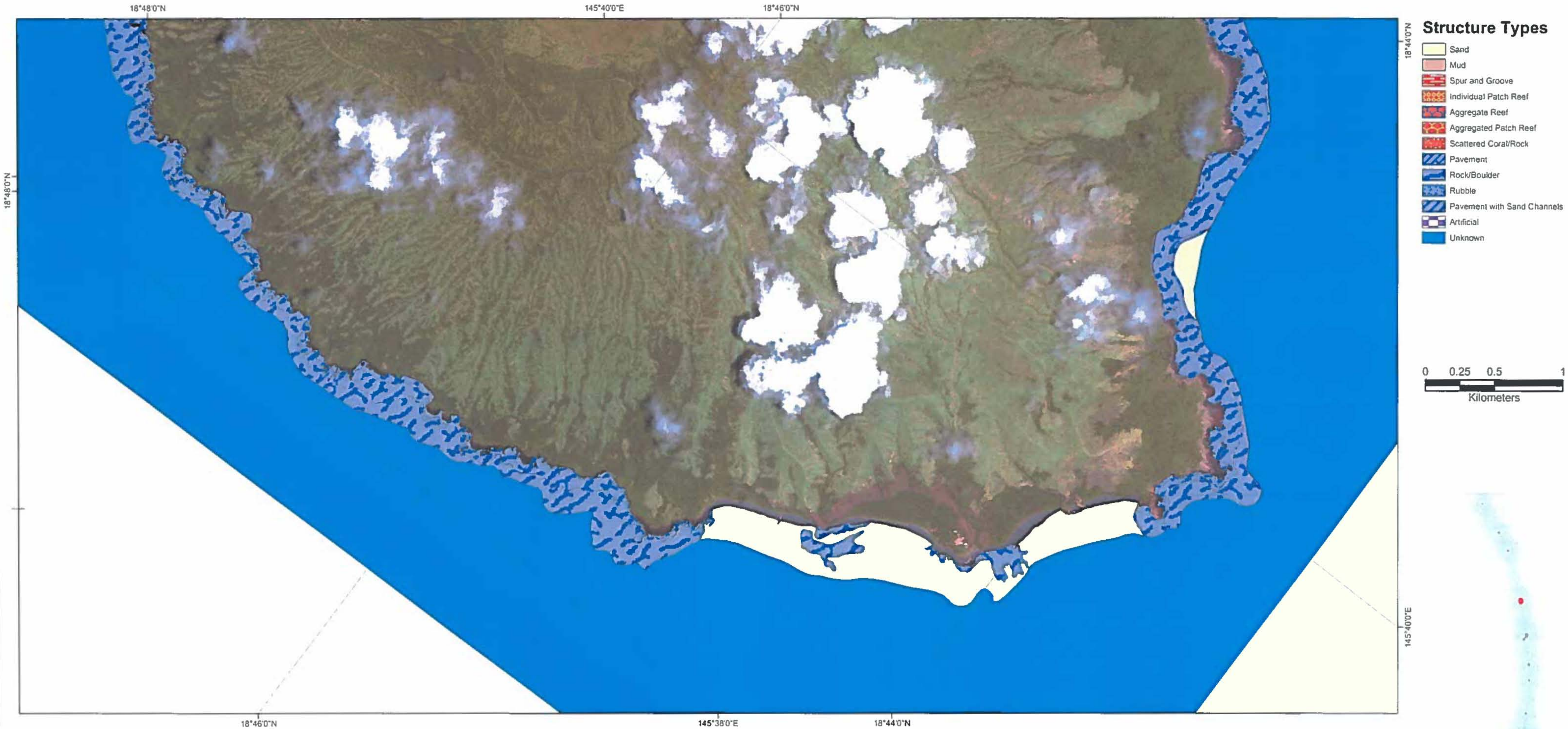
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

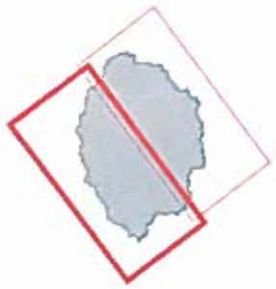


The Commonwealth of the Northern Mariana Islands

Agrihan Benthic Habitat Map

Frame 43 - Biological Cover





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

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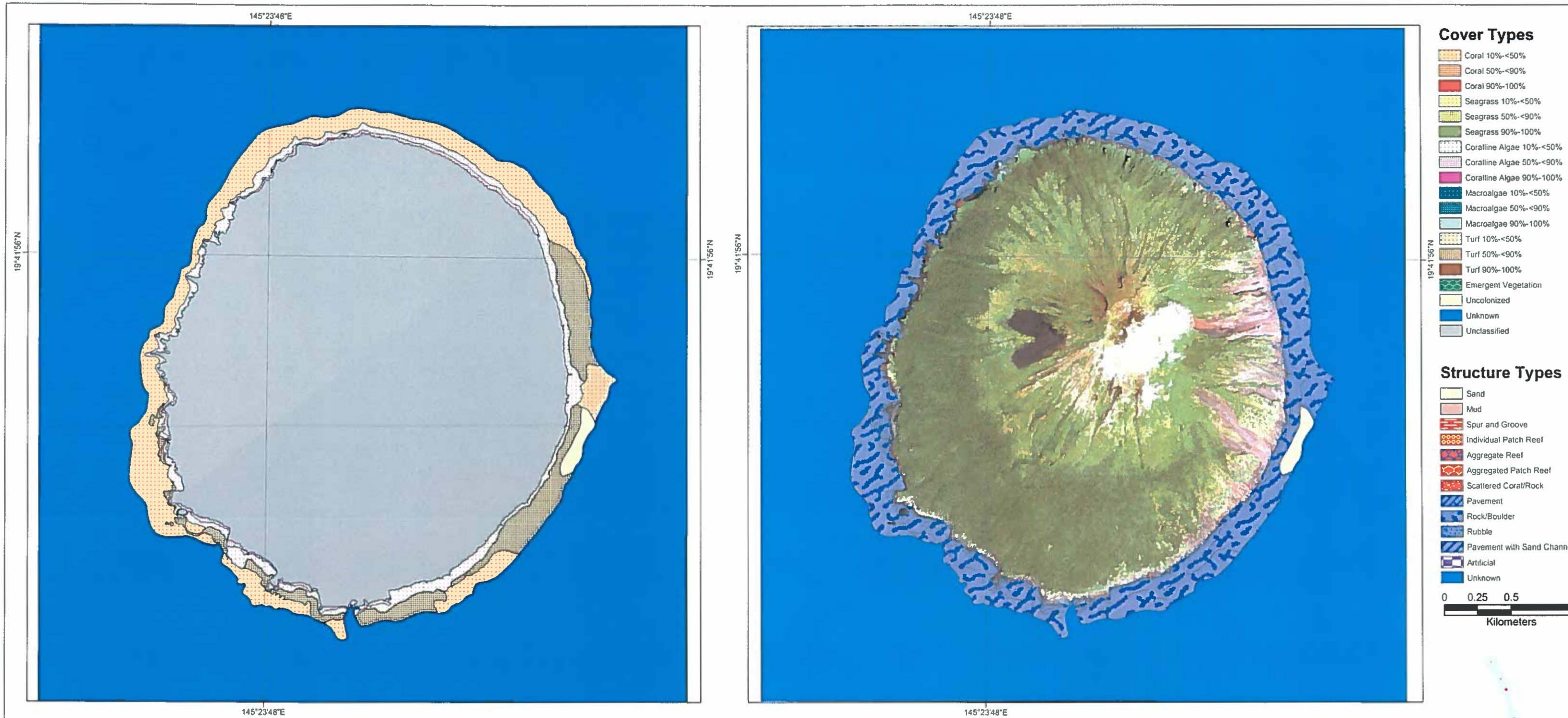
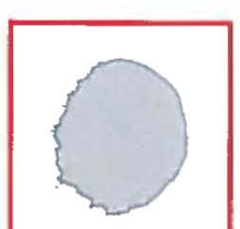
Agrihan Benthic Habitat Map

Frame 43 - Geomorphological Structure





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

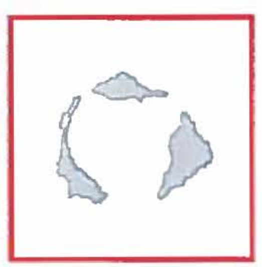
The Commonwealth of the Northern Mariana Islands

Asuncion Island Benthic Habitat Map

Frame 44 - Biological Cover and Geomorphological Structure

N

Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

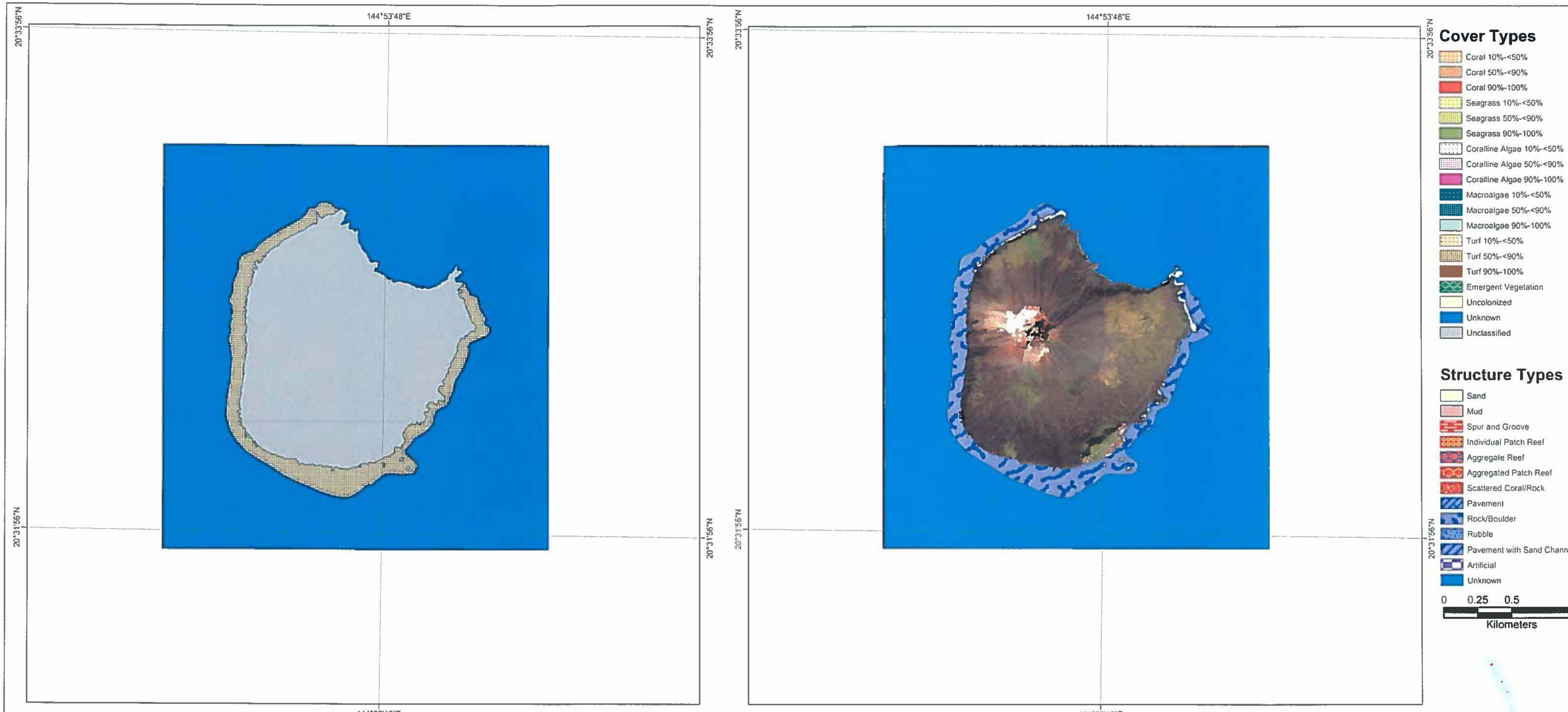


The Commonwealth of the Northern Mariana Islands

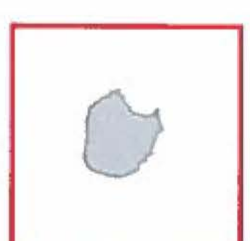
Maug Islands Benthic Habitat Map

Frame 45 - Biological Cover and Geomorphological Structure

N



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

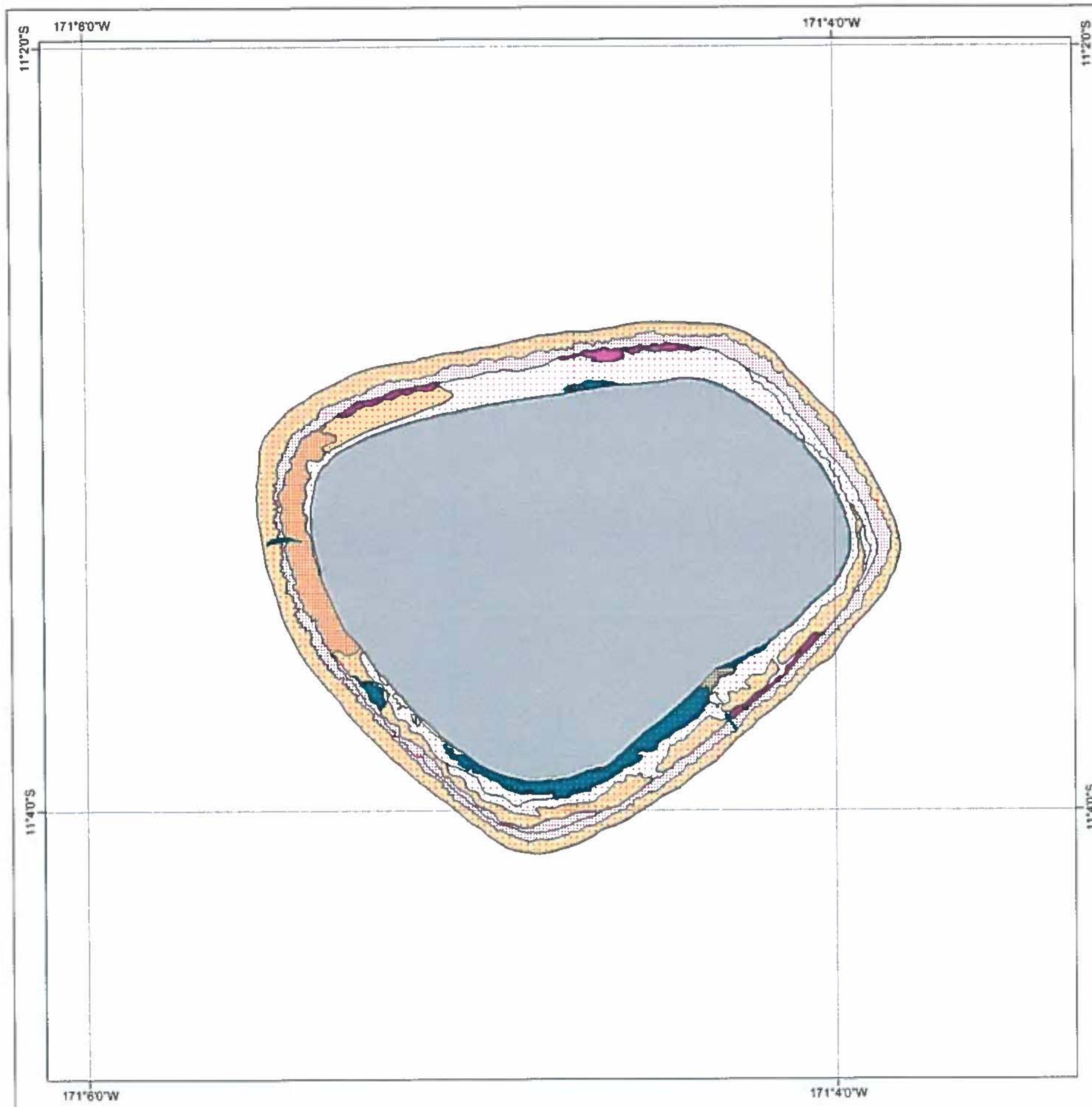


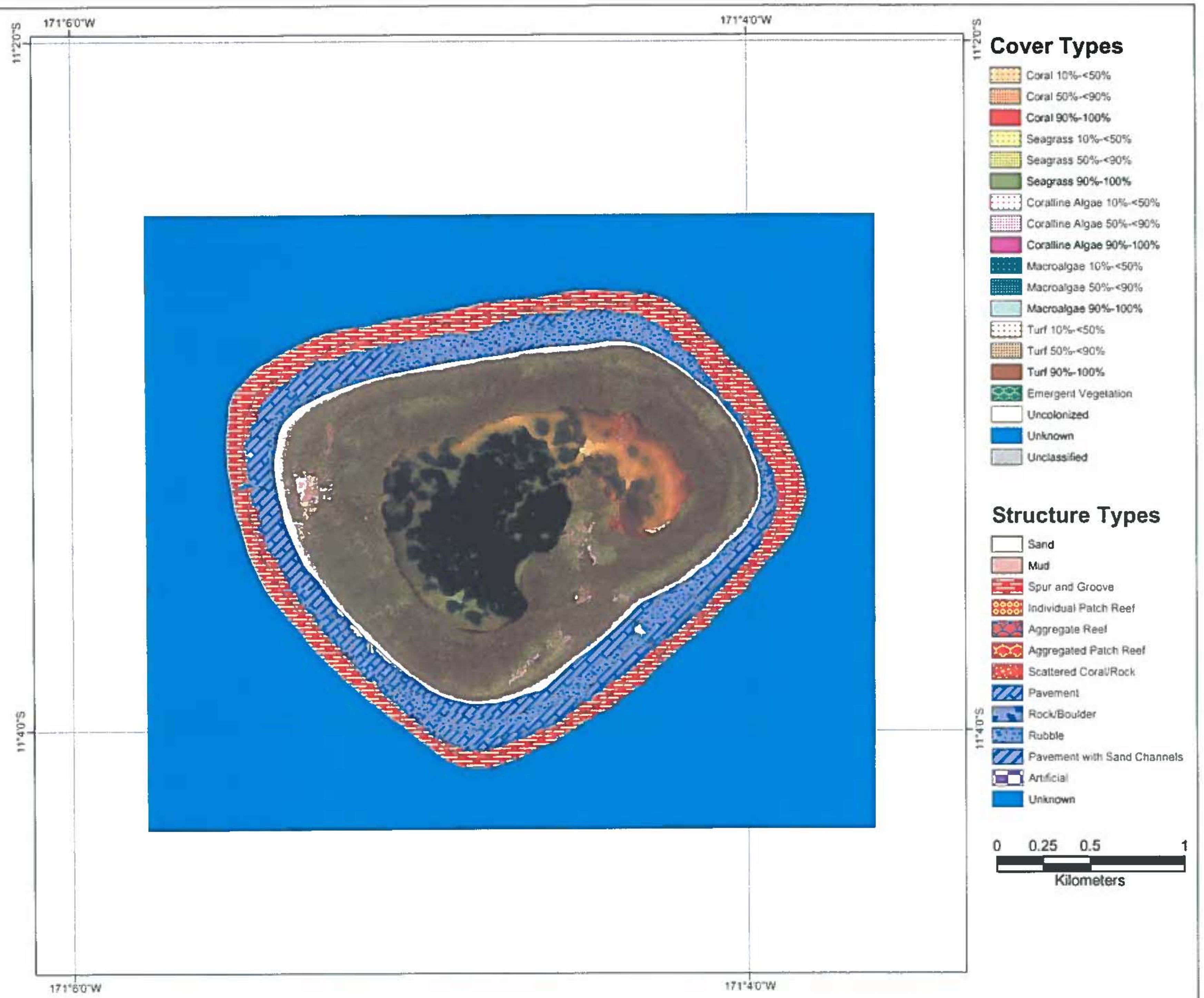
The Commonwealth of the Northern Mariana Islands

Farallon de Pajaros Benthic Habitat Map

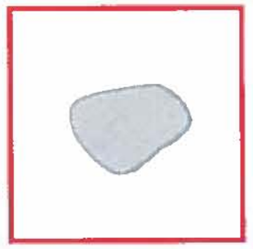
Frame 46 - Biological Cover and Geomorphological Structure

N





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

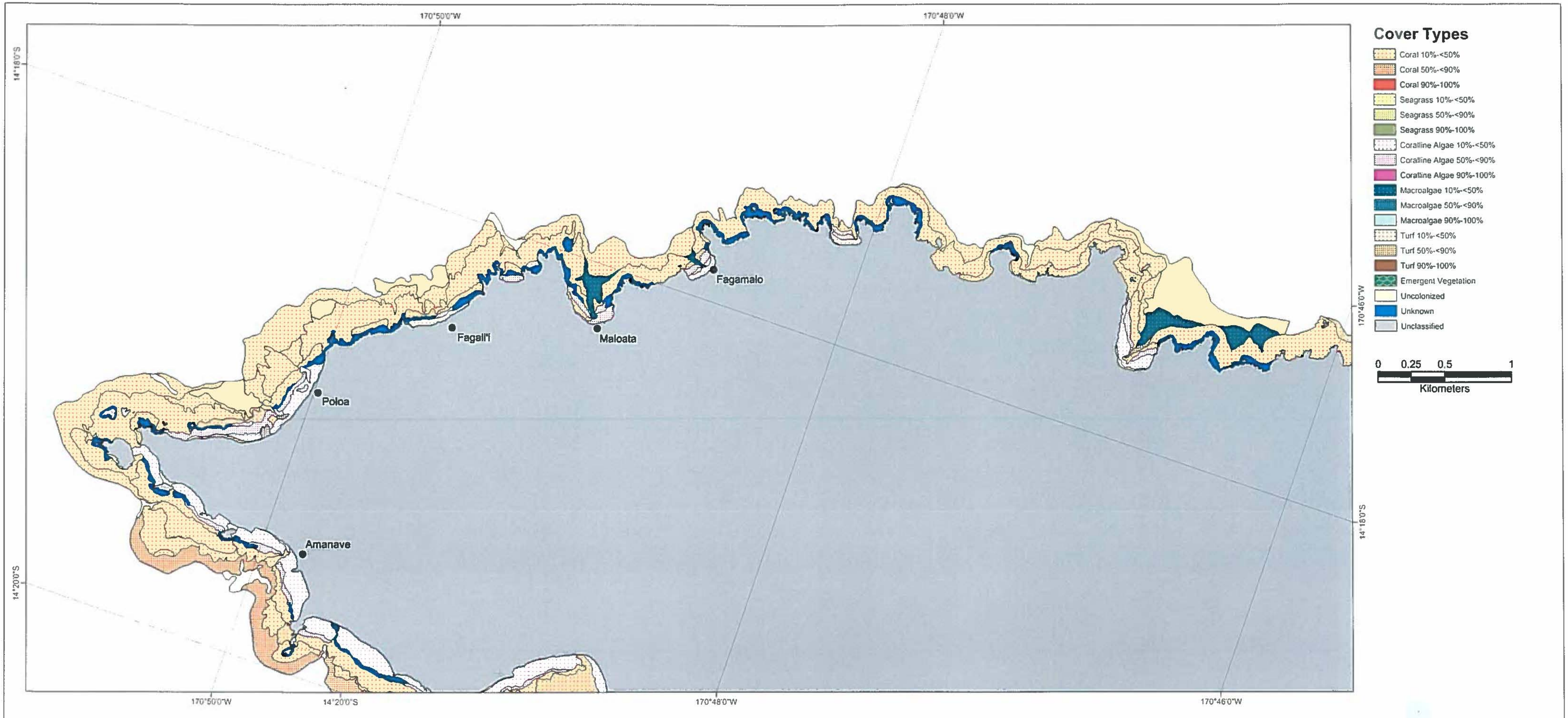


American Samoa

Swains Island Benthic Habitat Map

Frame 47 - Biological Cover and Geomorphological Structure

N

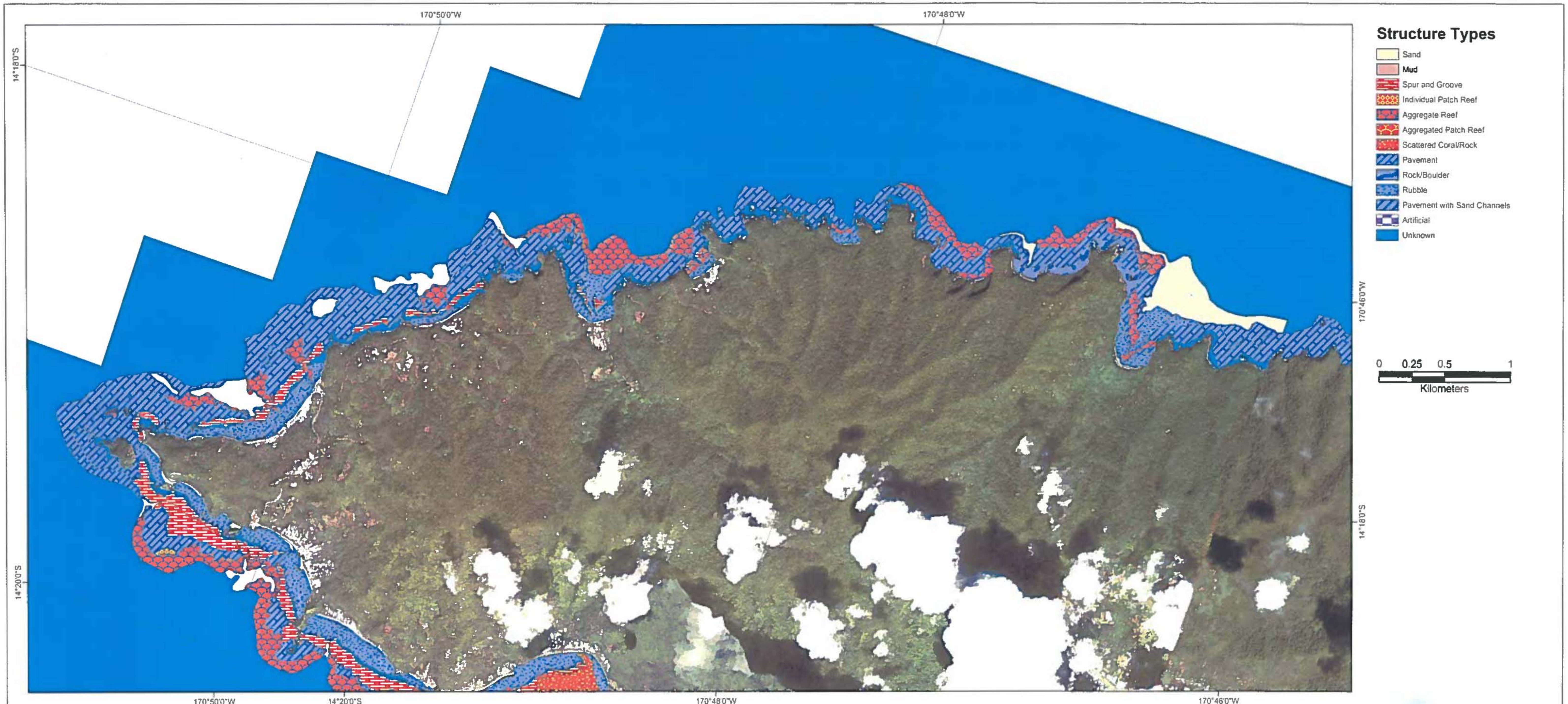


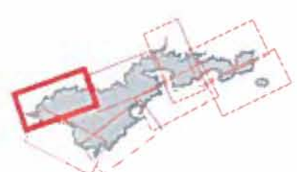
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 48 - Biological Cover





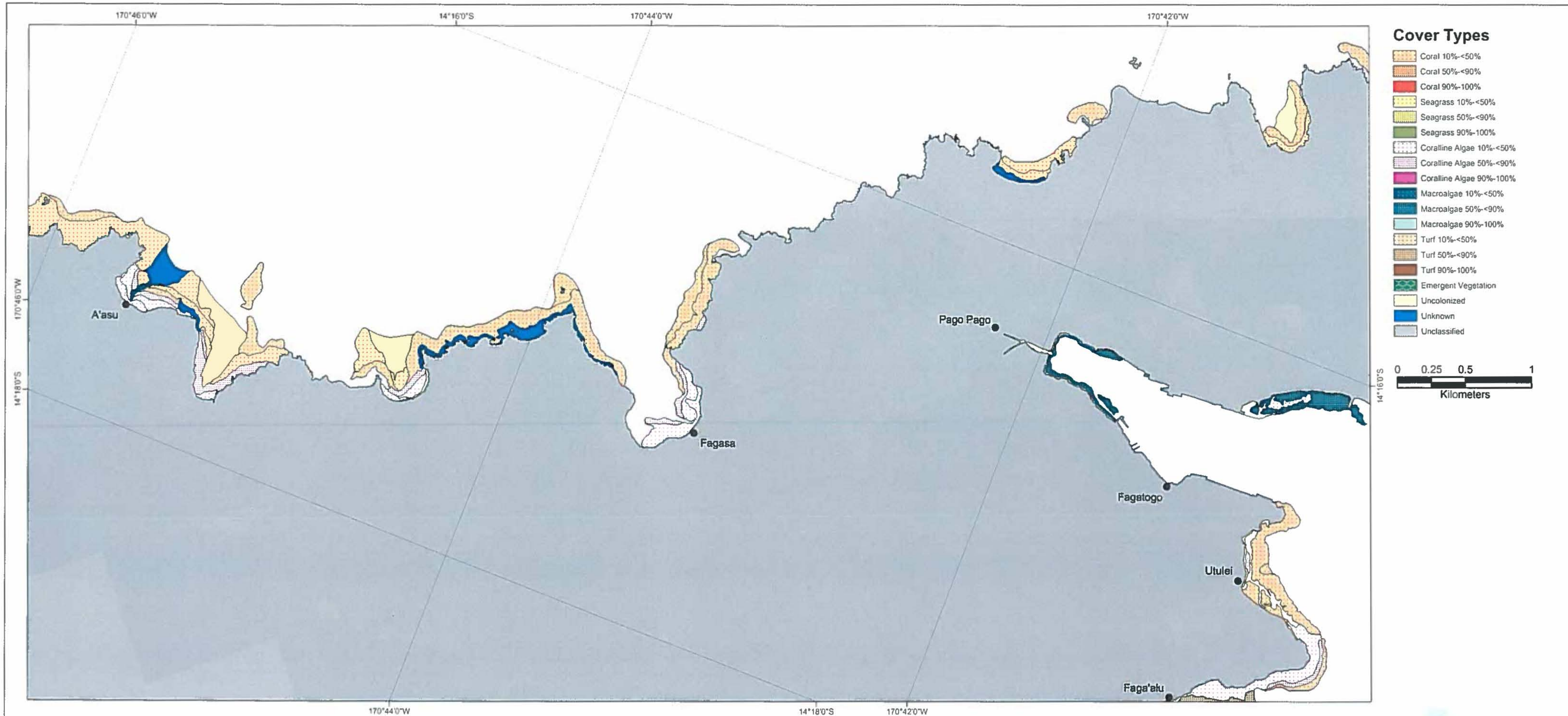
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 48 - Geomorphological Structure

N

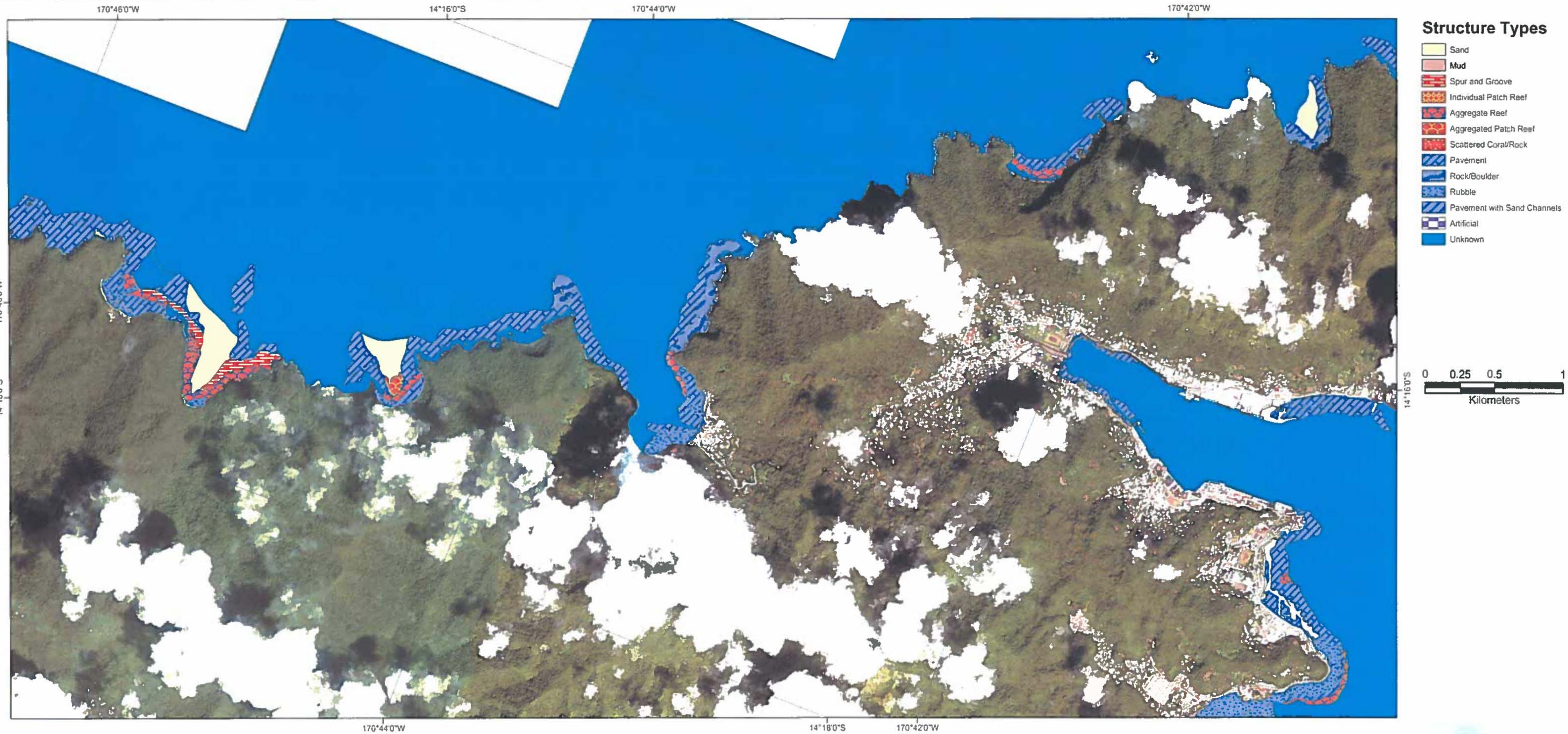


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 49 - Biological Cover



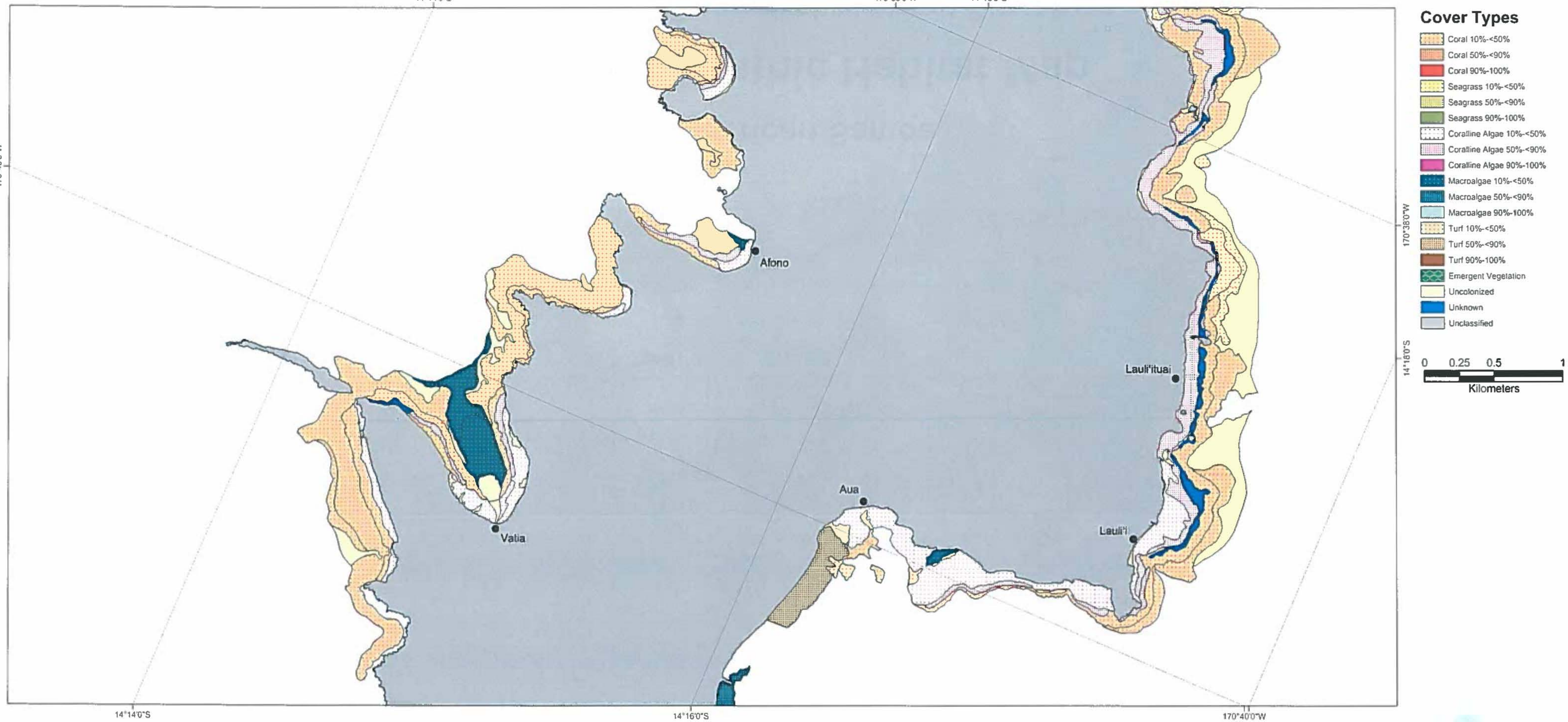
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 49 - Geomorphological Structure

N

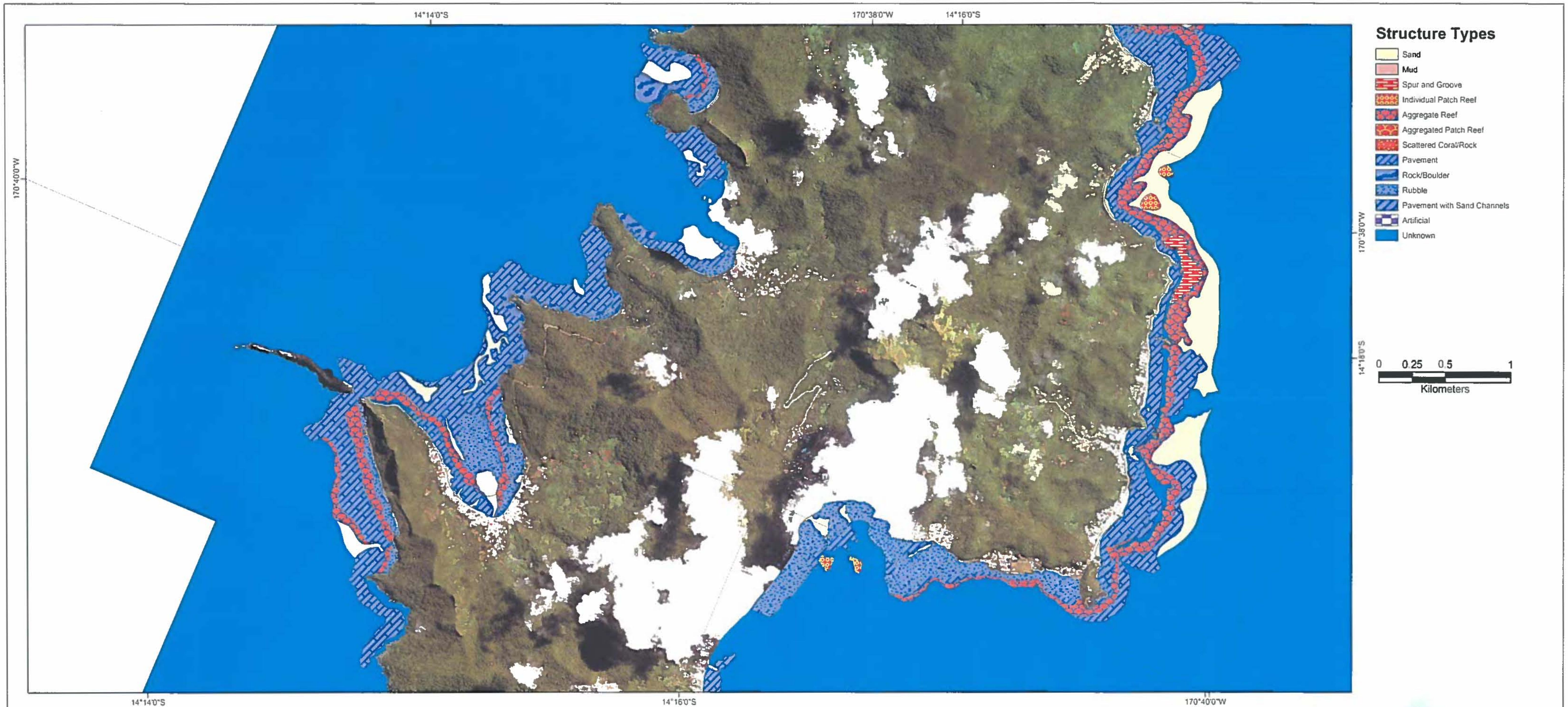


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 50 - Biological Cover

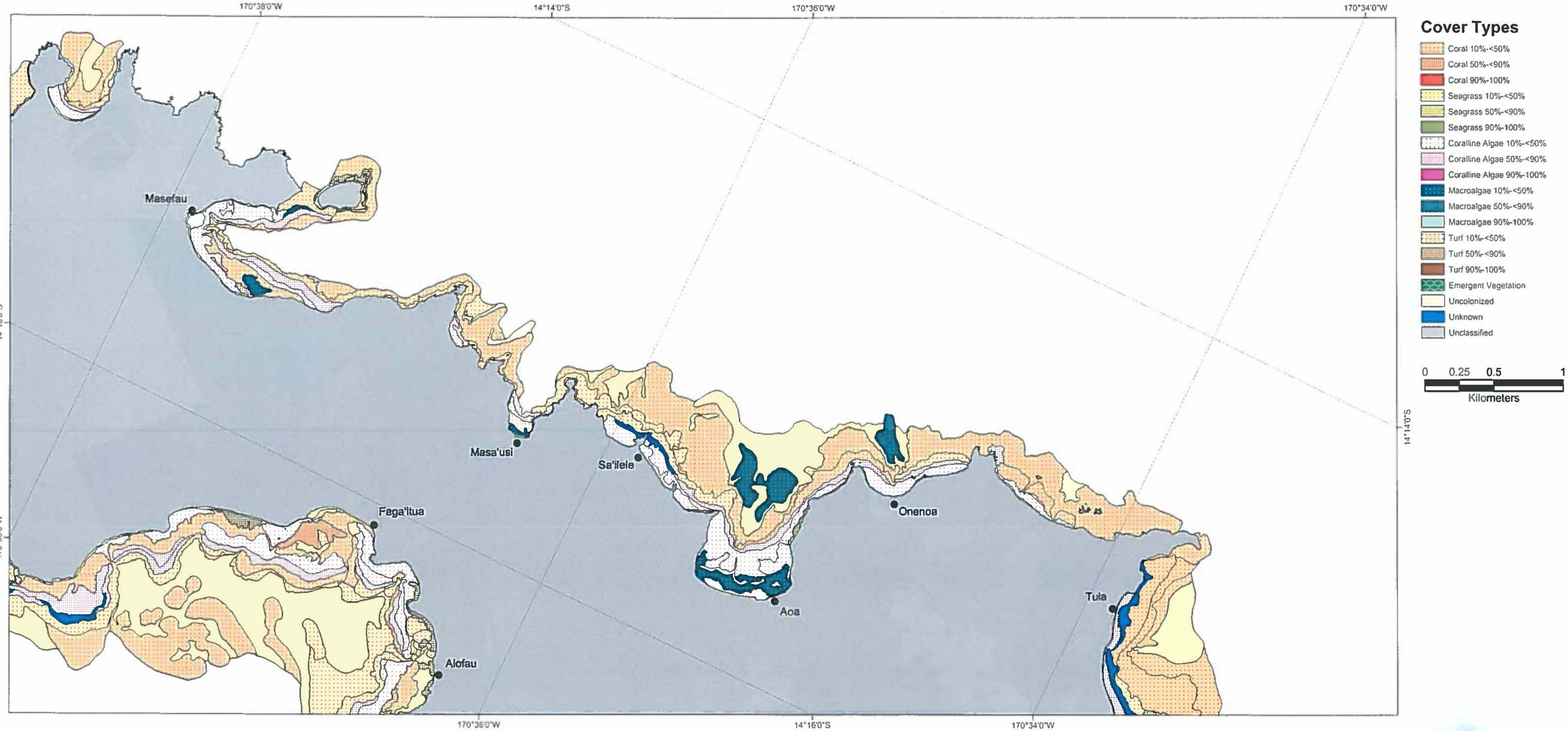


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

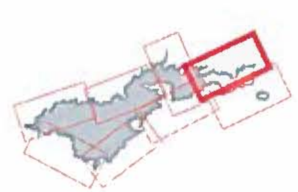
American Samoa

Tutuila Benthic Habitat Map

Frame 50 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

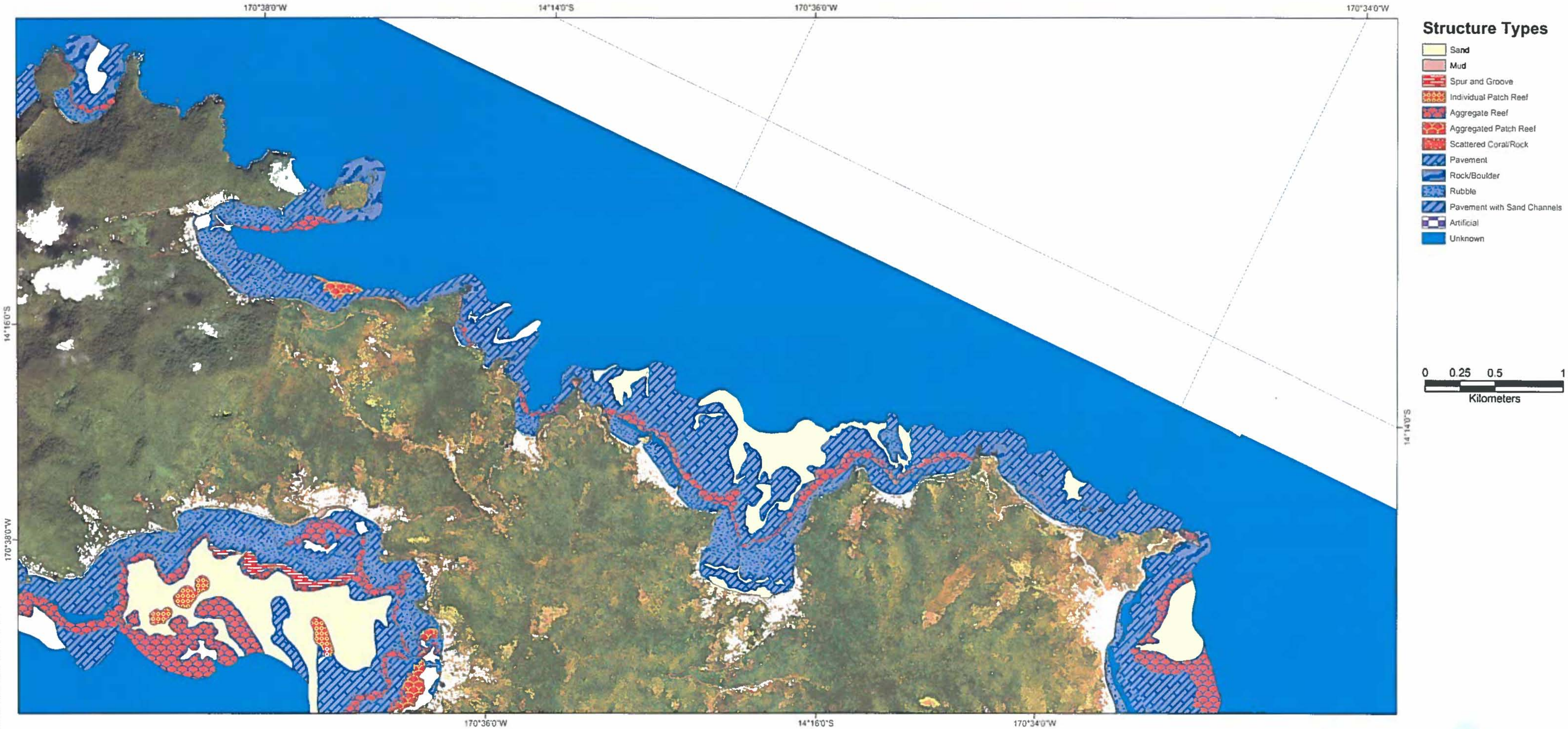


American Samoa

Tutuila Benthic Habitat Map

Frame 51 - Biological Cover

N

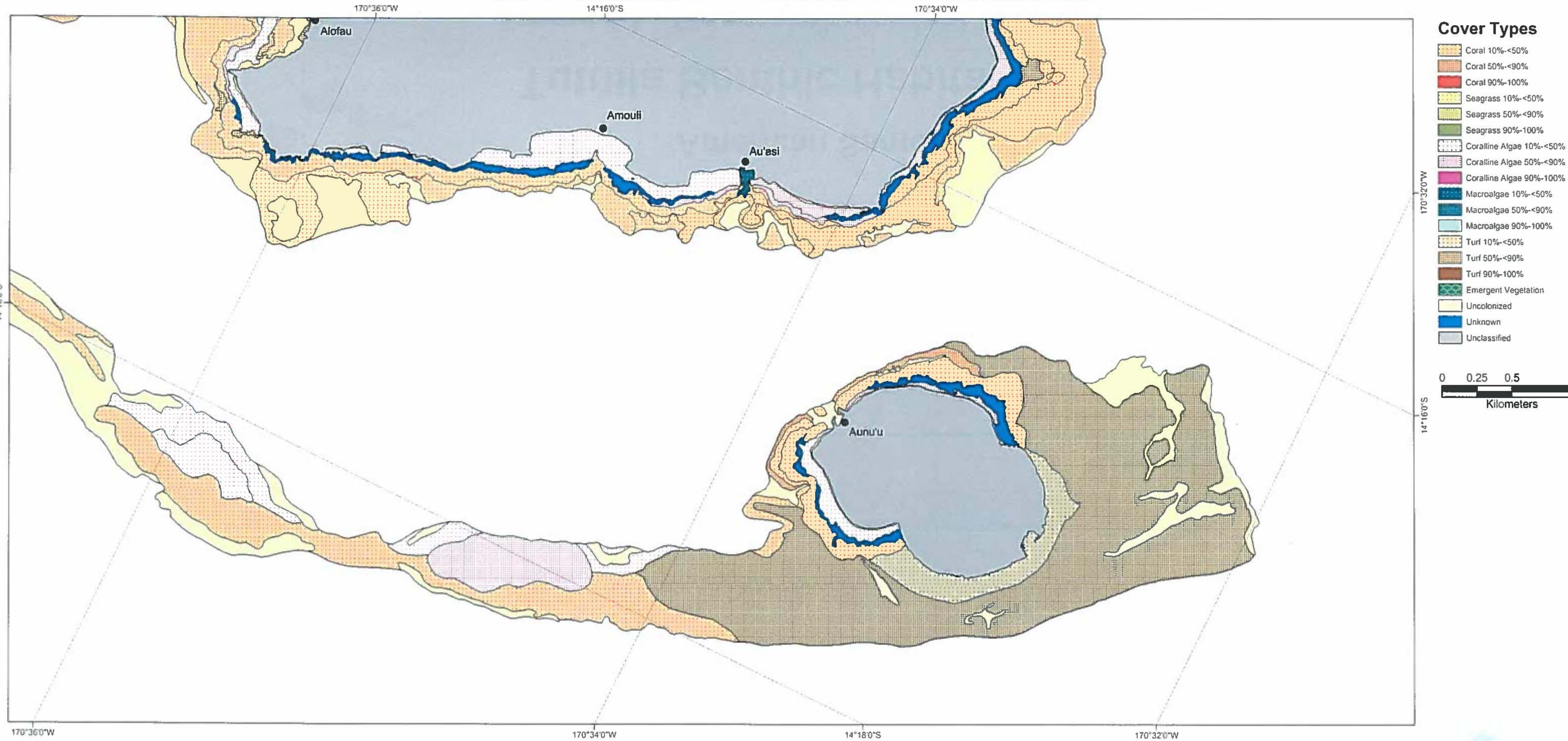


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 51 - Geomorphological Structure



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

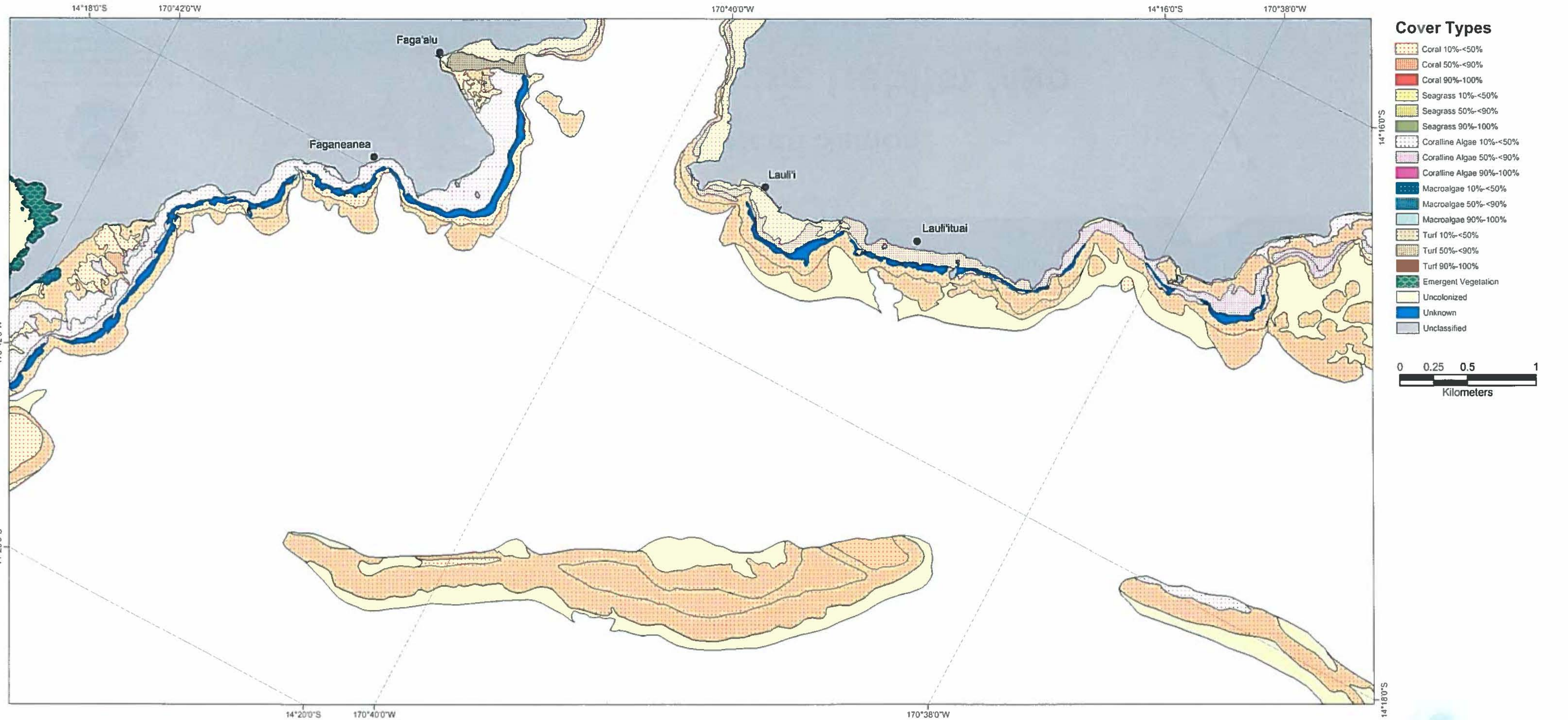
Frame 52 - Biological Cover

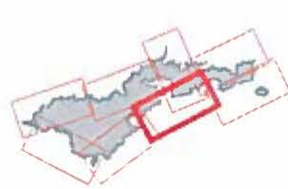
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 52 - Geomorphological Structure



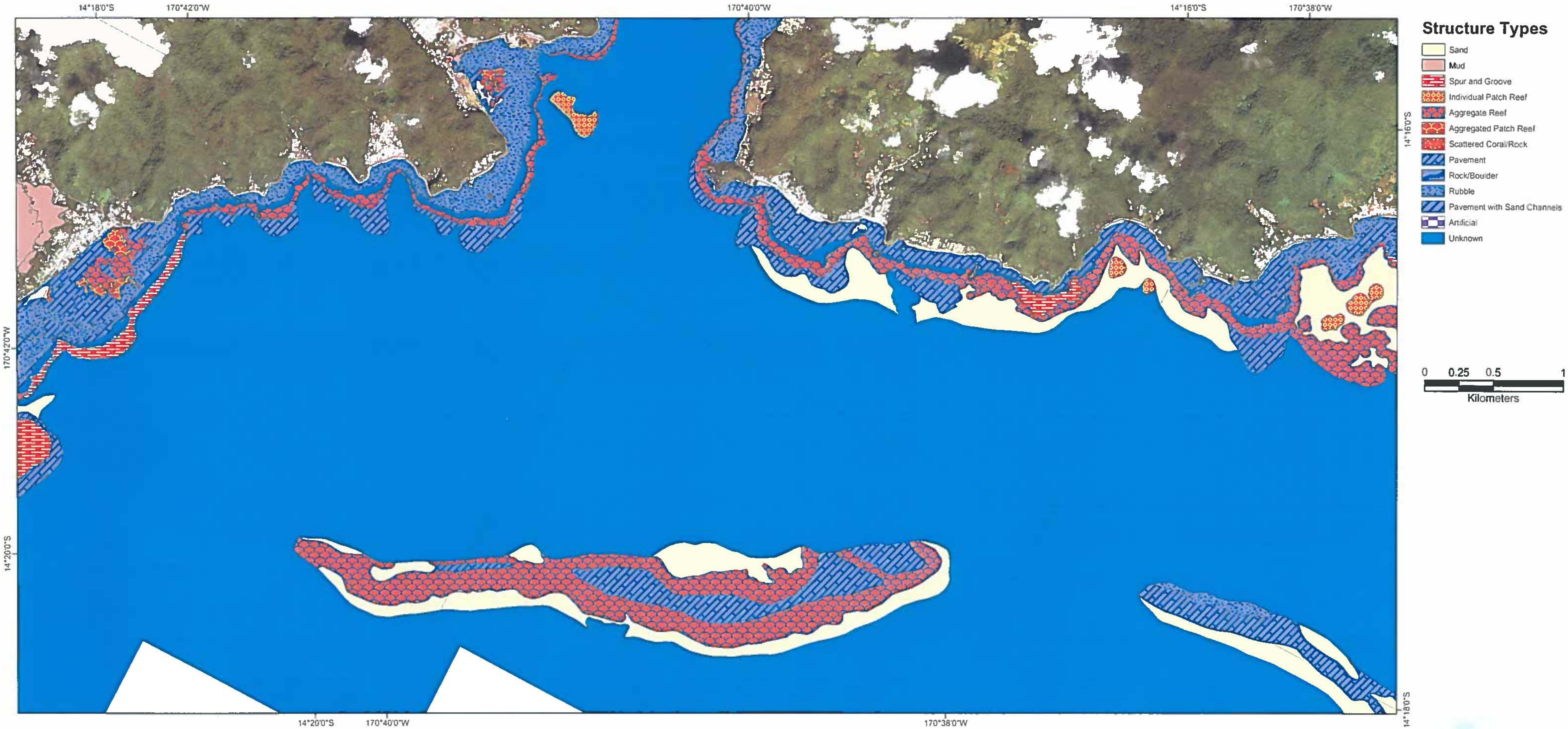


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

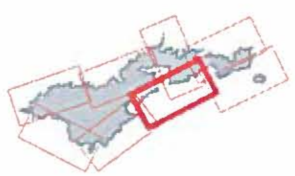
American Samoa

Tutuila Benthic Habitat Map

Frame 53 - Biological Cover



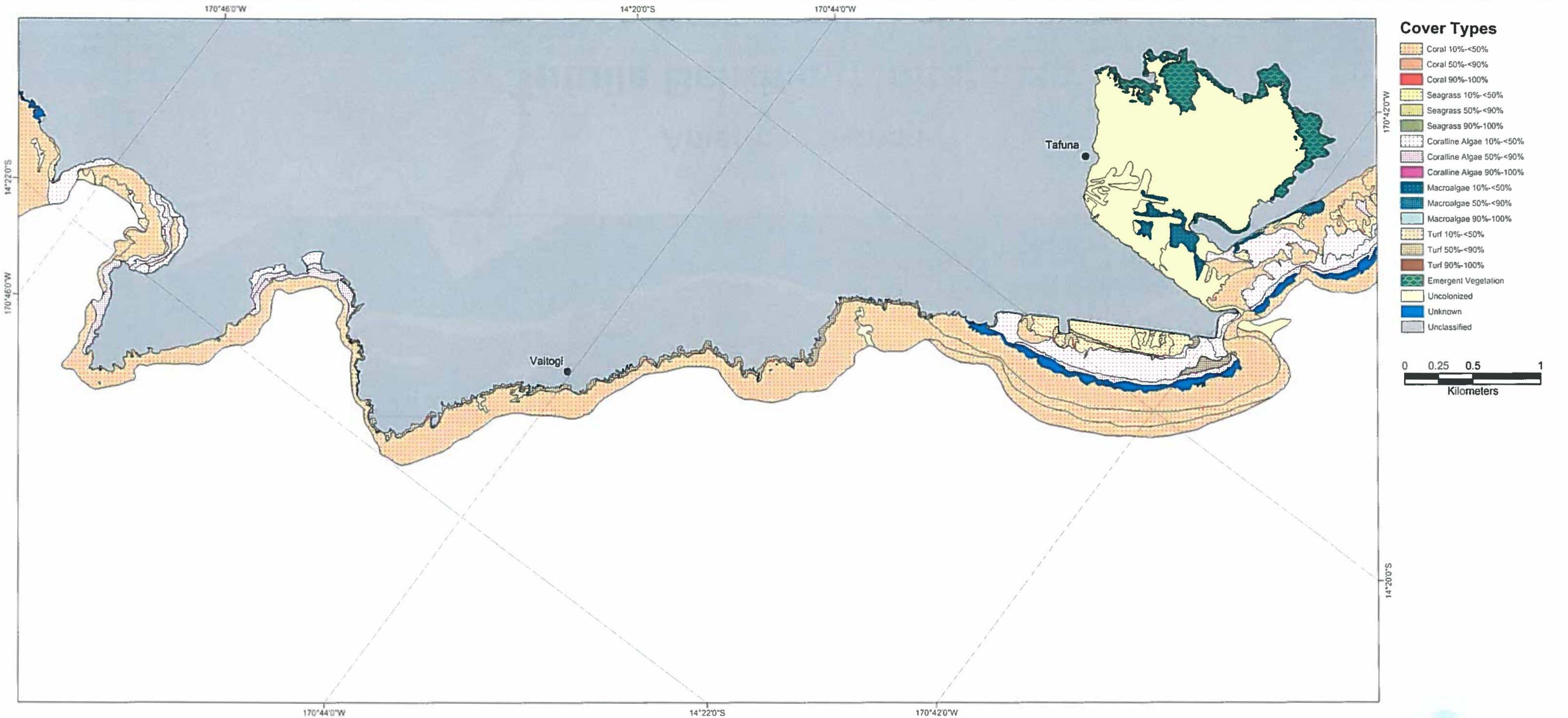
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



American Samoa

Tutuila Benthic Habitat Map

Frame 53 - Geomorphological Structure

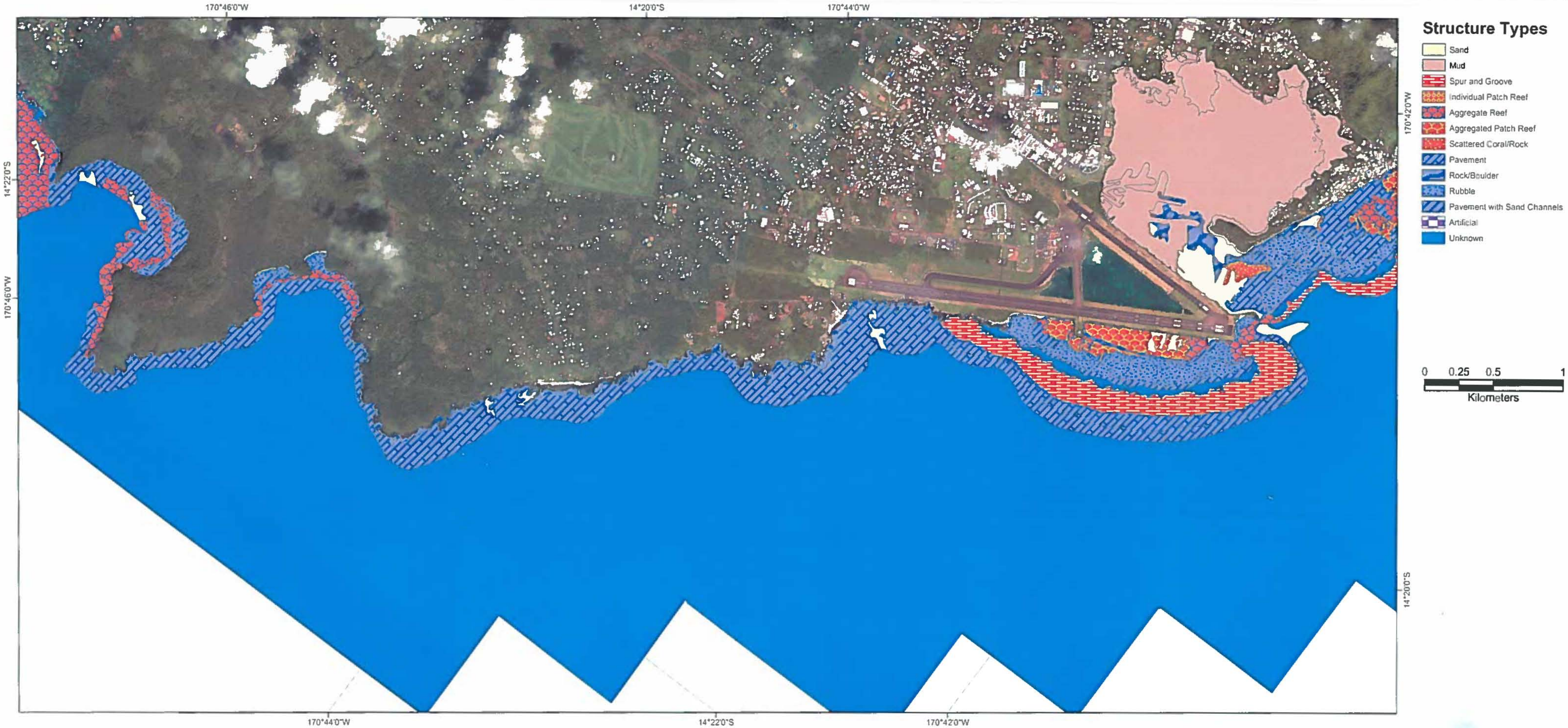


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

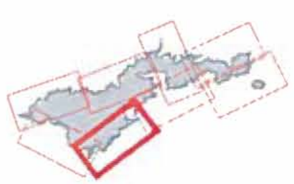
American Samoa

Tutuila Benthic Habitat Map

Frame 54 - Biological Cover



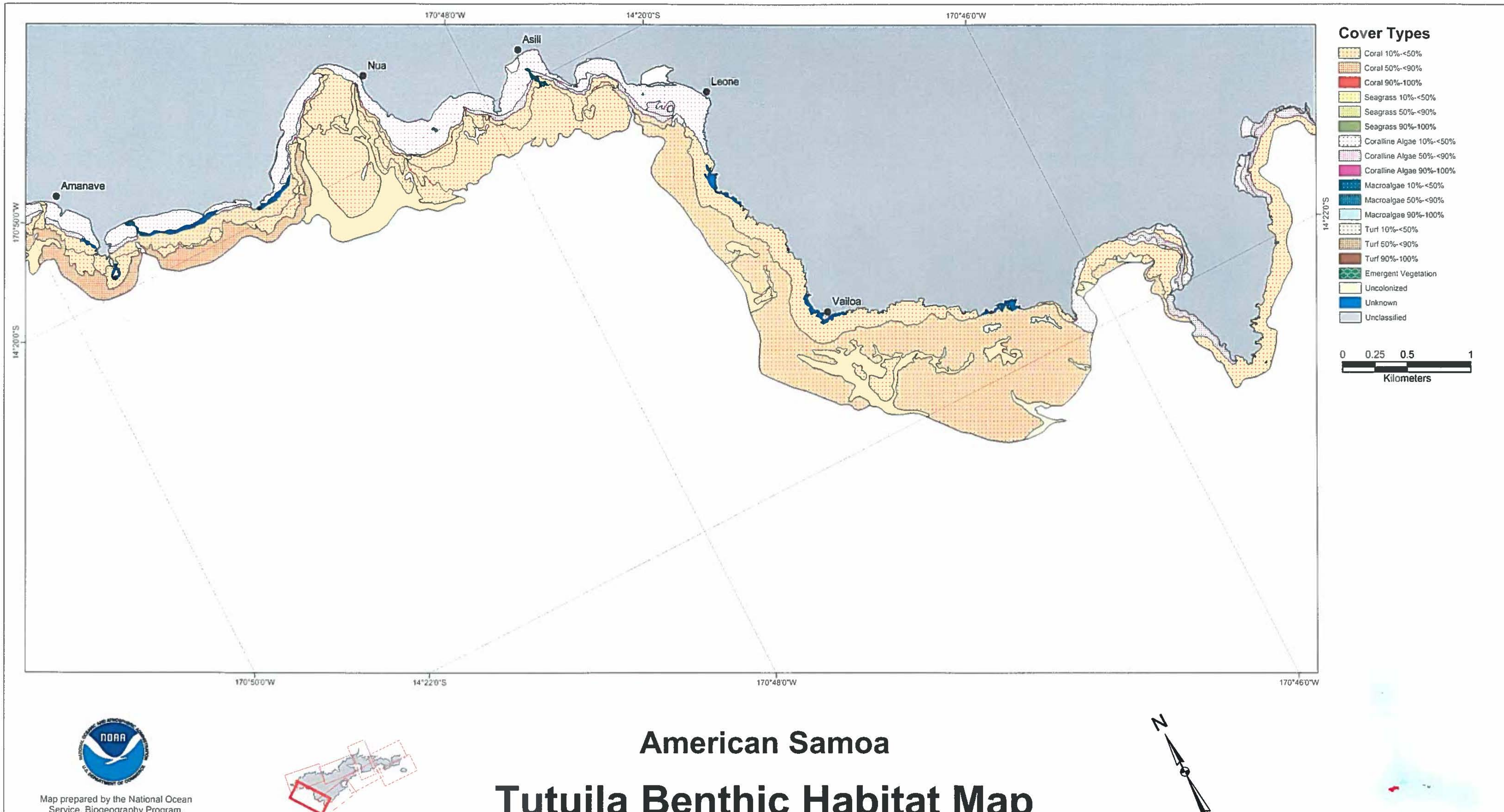
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



American Samoa

Tutuila Benthic Habitat Map

Frame 54 - Geomorphological Structure

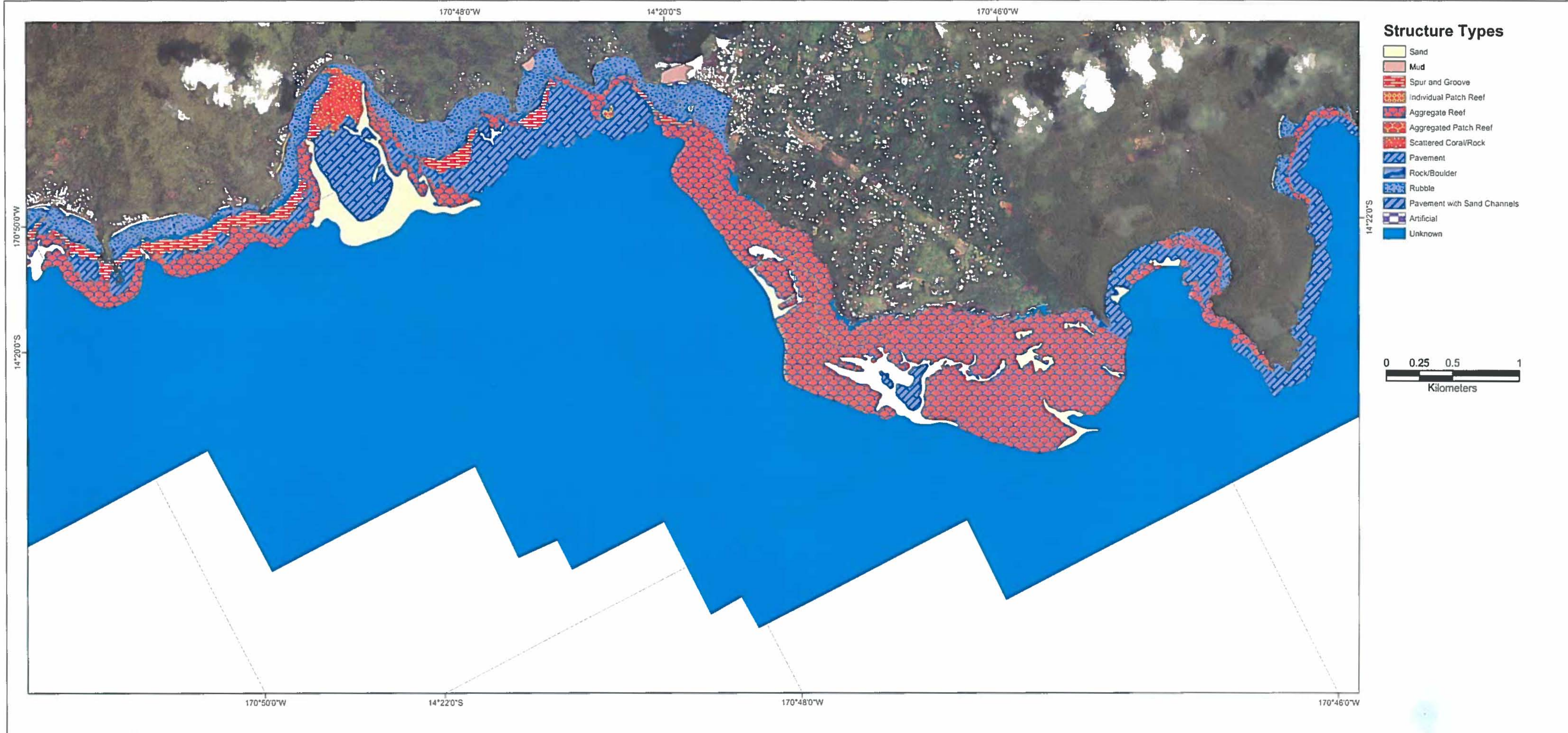


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 55 - Biological Cover

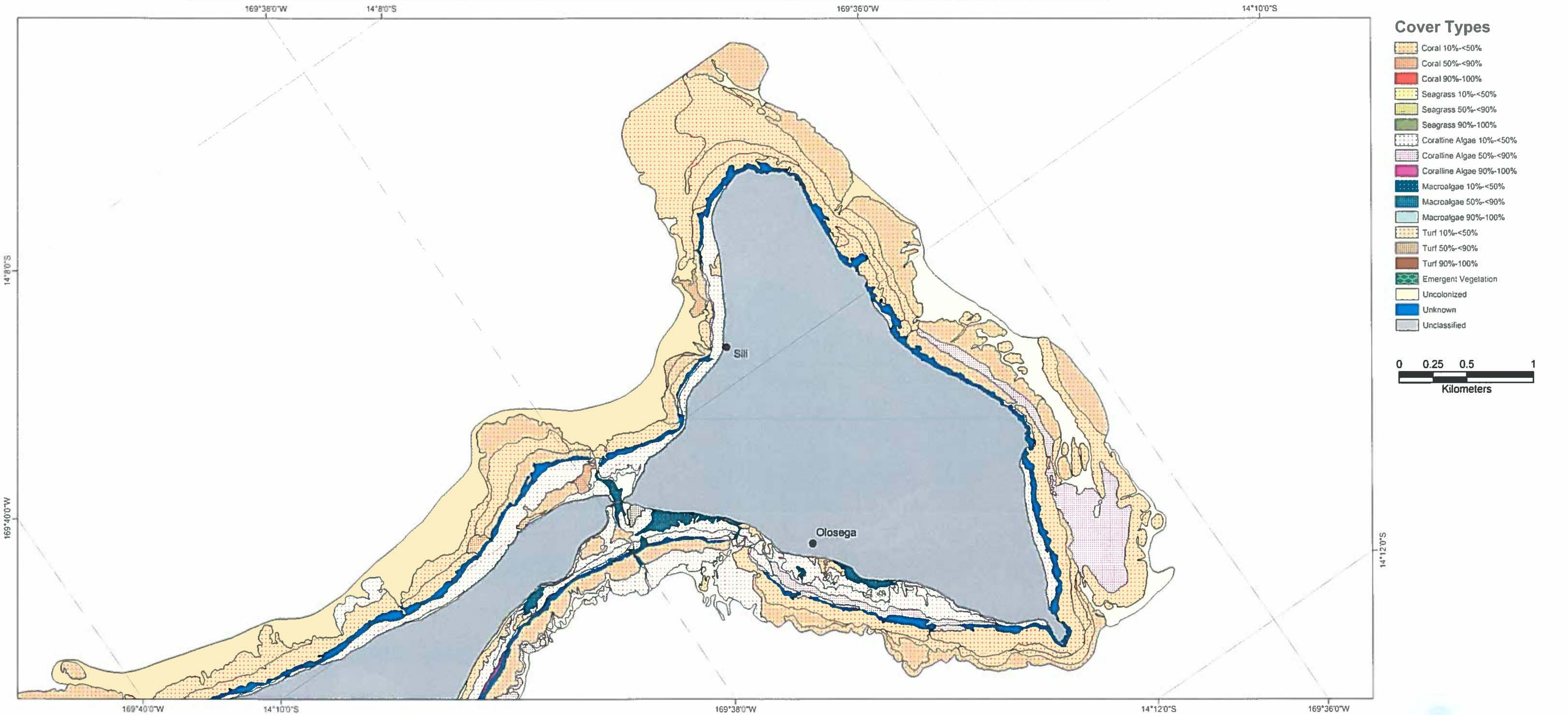


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Tutuila Benthic Habitat Map

Frame 55 - Geomorphological Structure

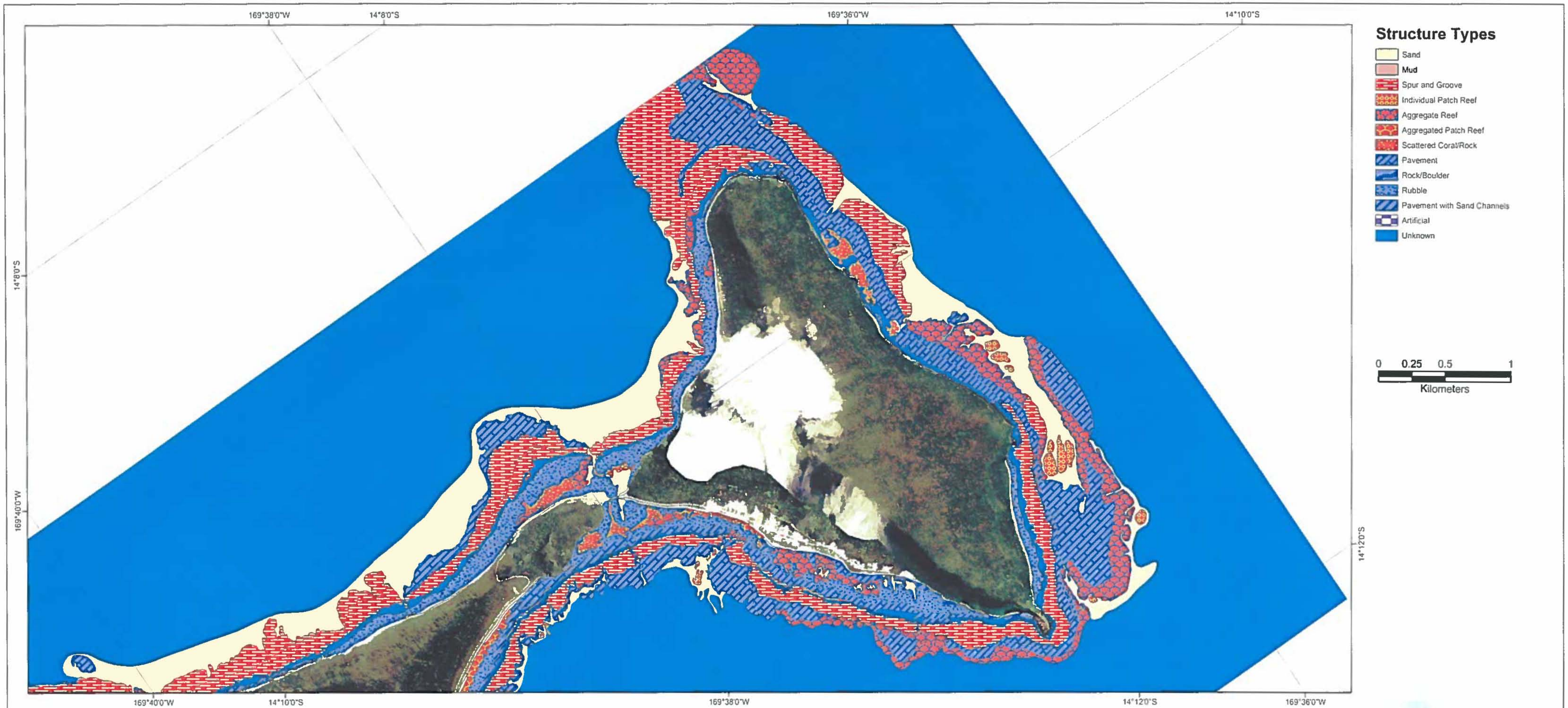


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

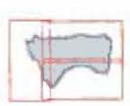
American Samoa

Manua Islands Benthic Habitat Map

Frame 56 - Biological Cover



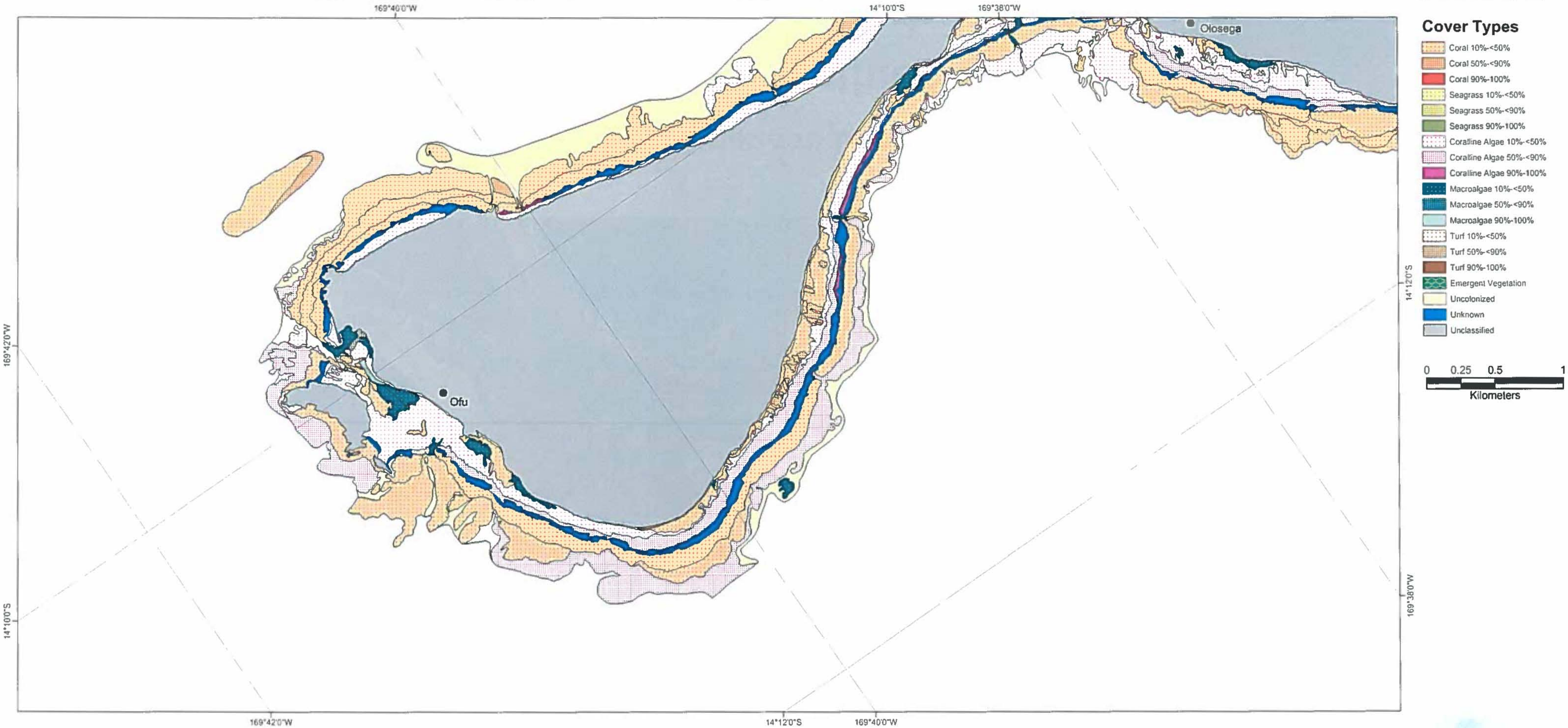
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



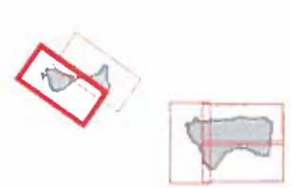
American Samoa

Manua Islands Benthic Habitat Map

Frame 56 - Geomorphological Structure



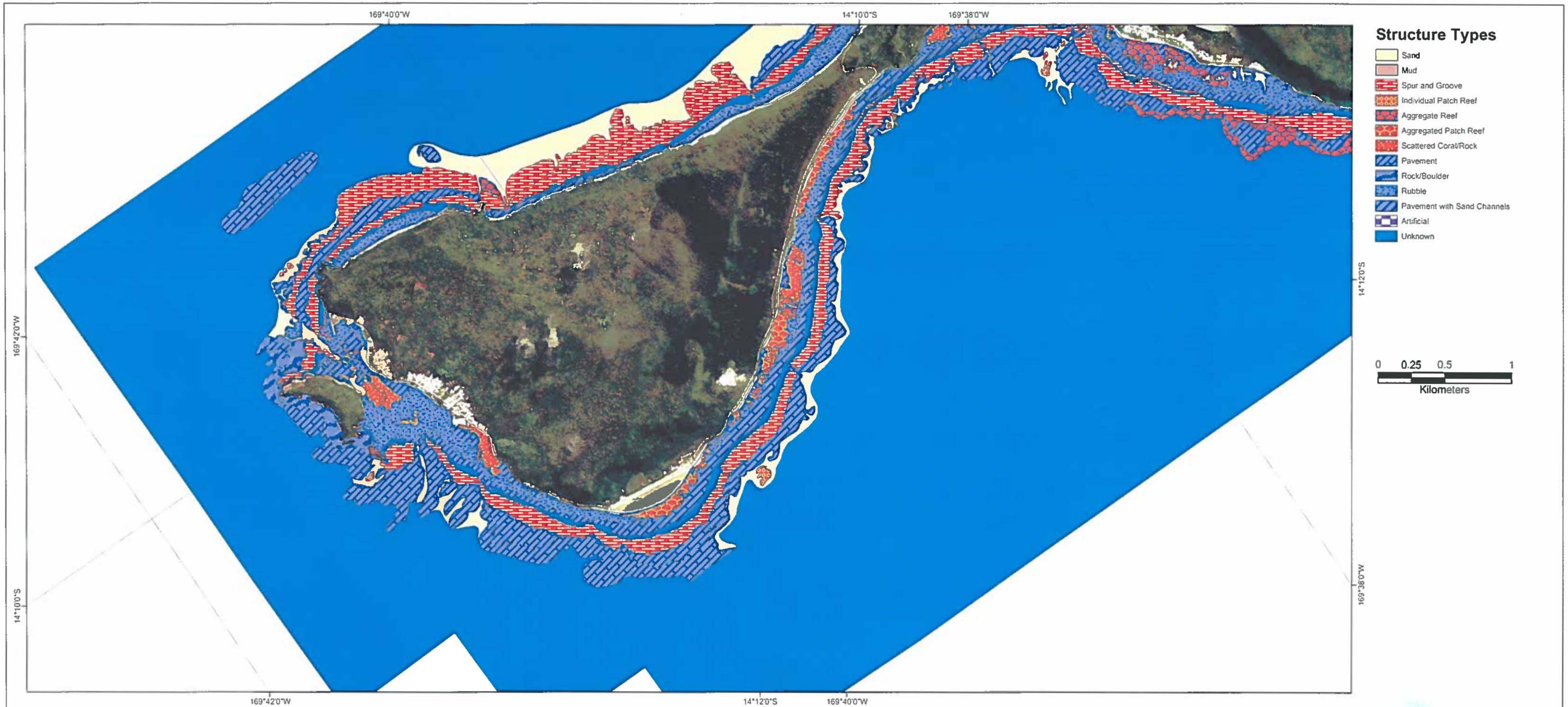
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



American Samoa

Manua Islands Benthic Habitat Map

Frame 57 - Biological Cover

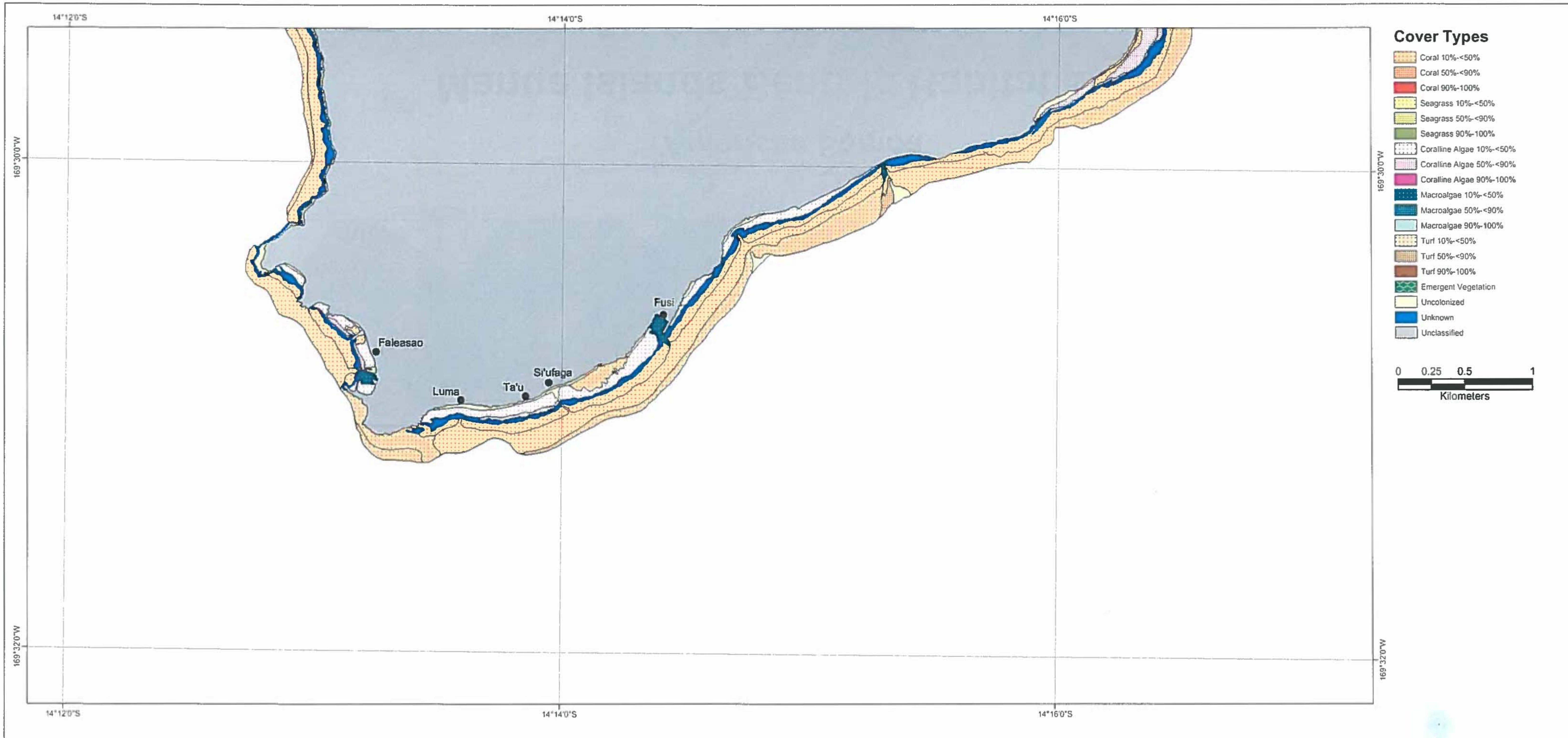


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Manua Islands Benthic Habitat Map

Frame 57 - Geomorphological Structure

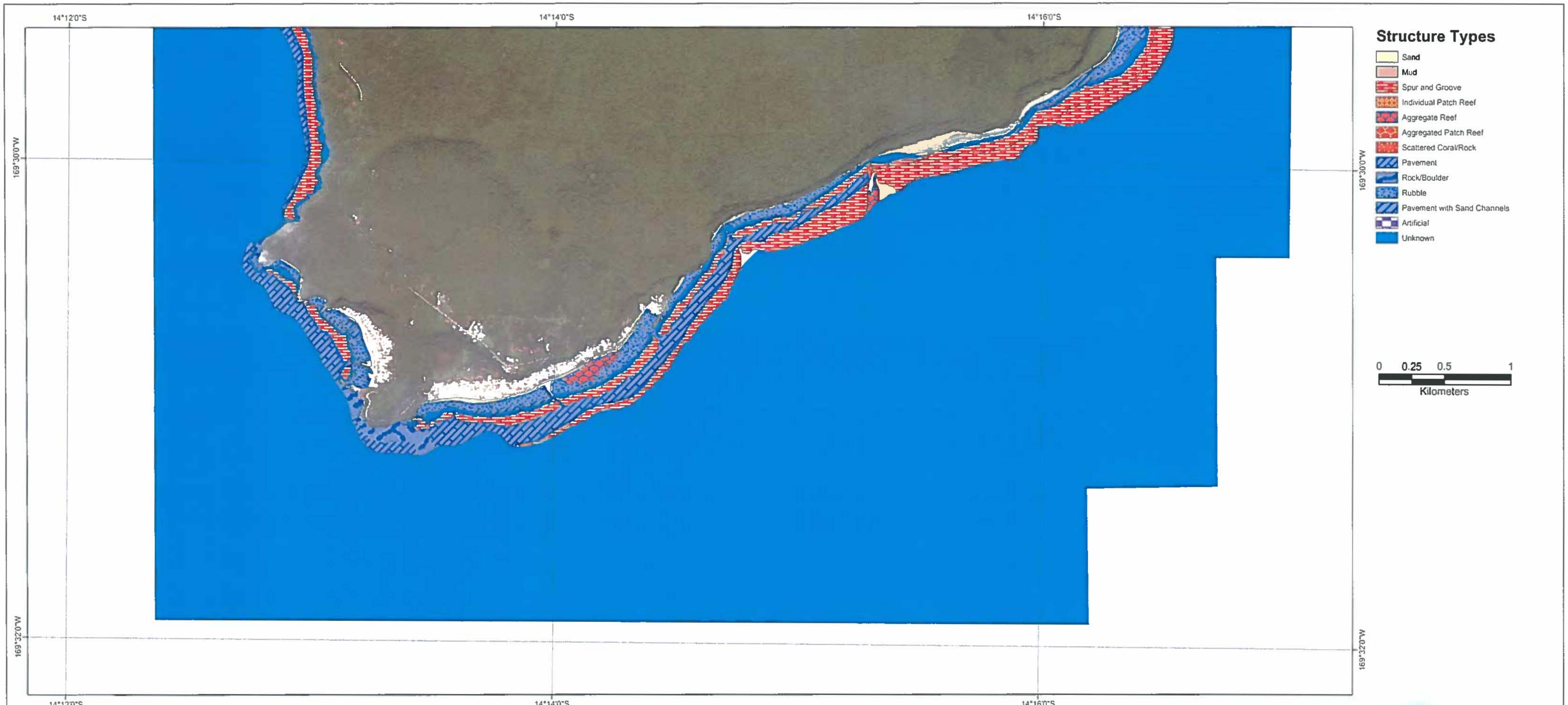


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

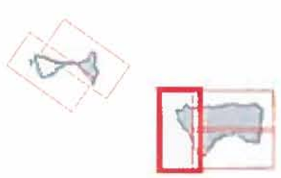
American Samoa

Manua Islands Benthic Habitat Map

Frame 58 - Biological Cover



Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

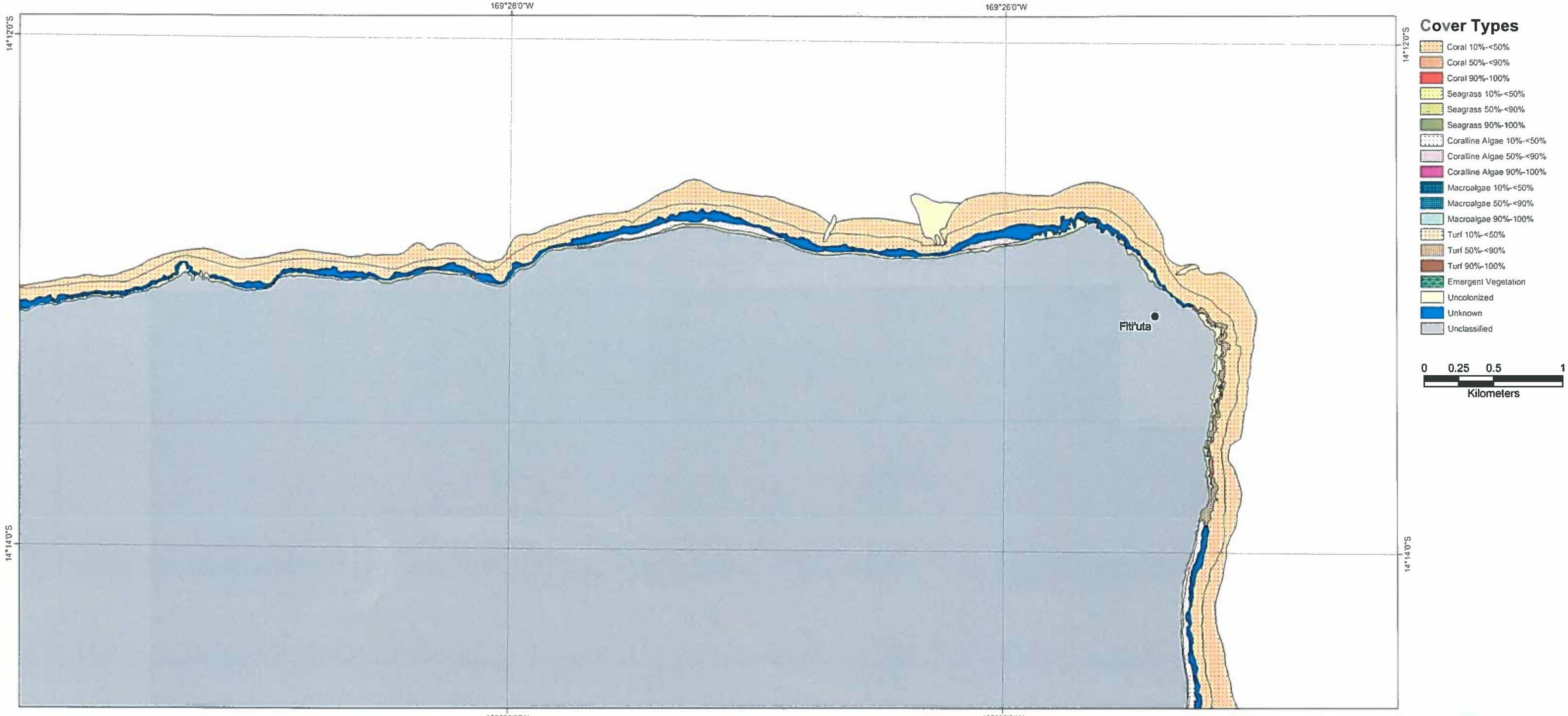


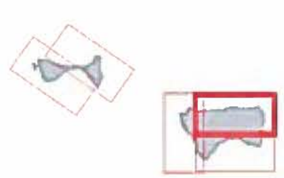
American Samoa

Manua Islands Benthic Habitat Map

Frame 58 - Geomorphological Structure

N



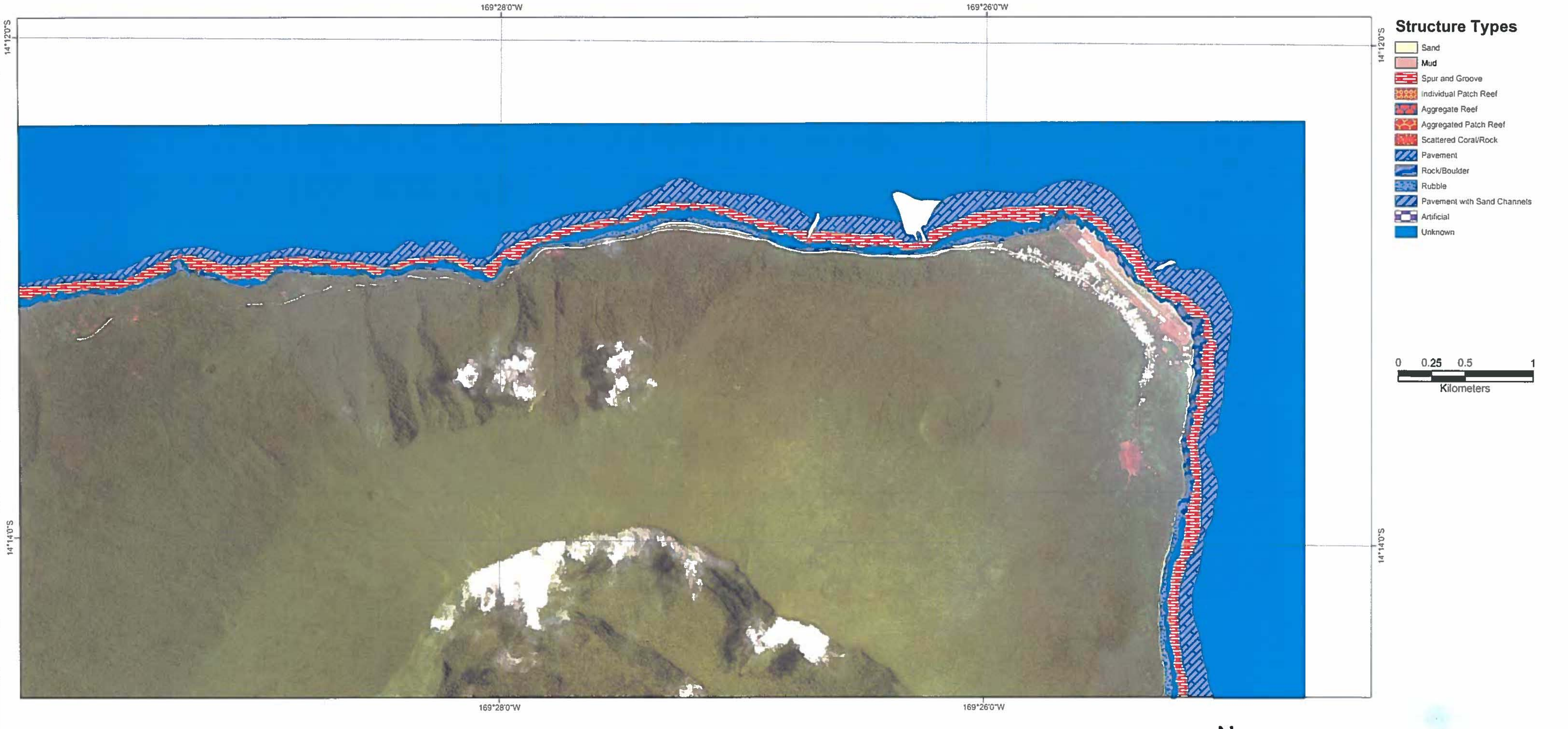


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Manua Islands Benthic Habitat Map

Frame 59 - Biological Cover

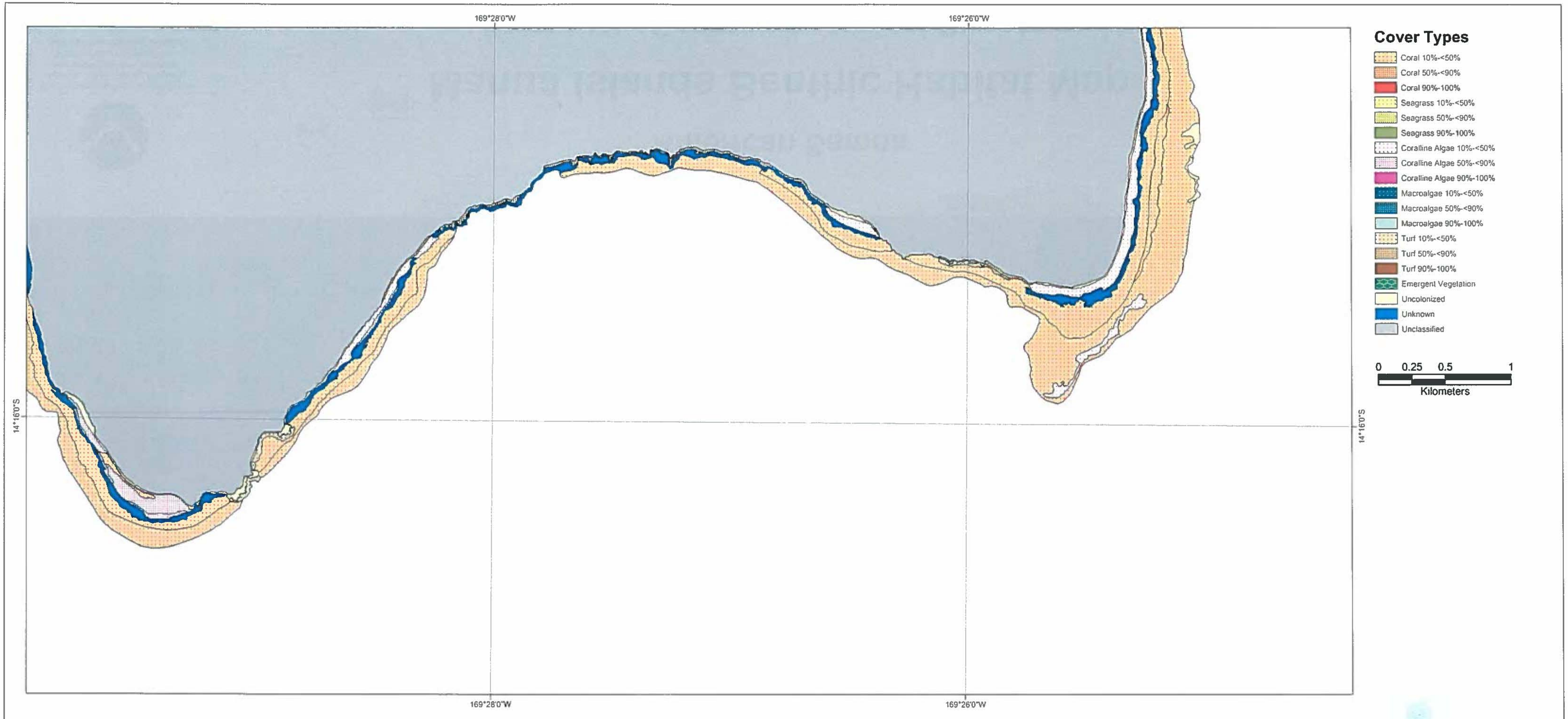


Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Manua Islands Benthic Habitat Map

Frame 59 - Geomorphological Structure

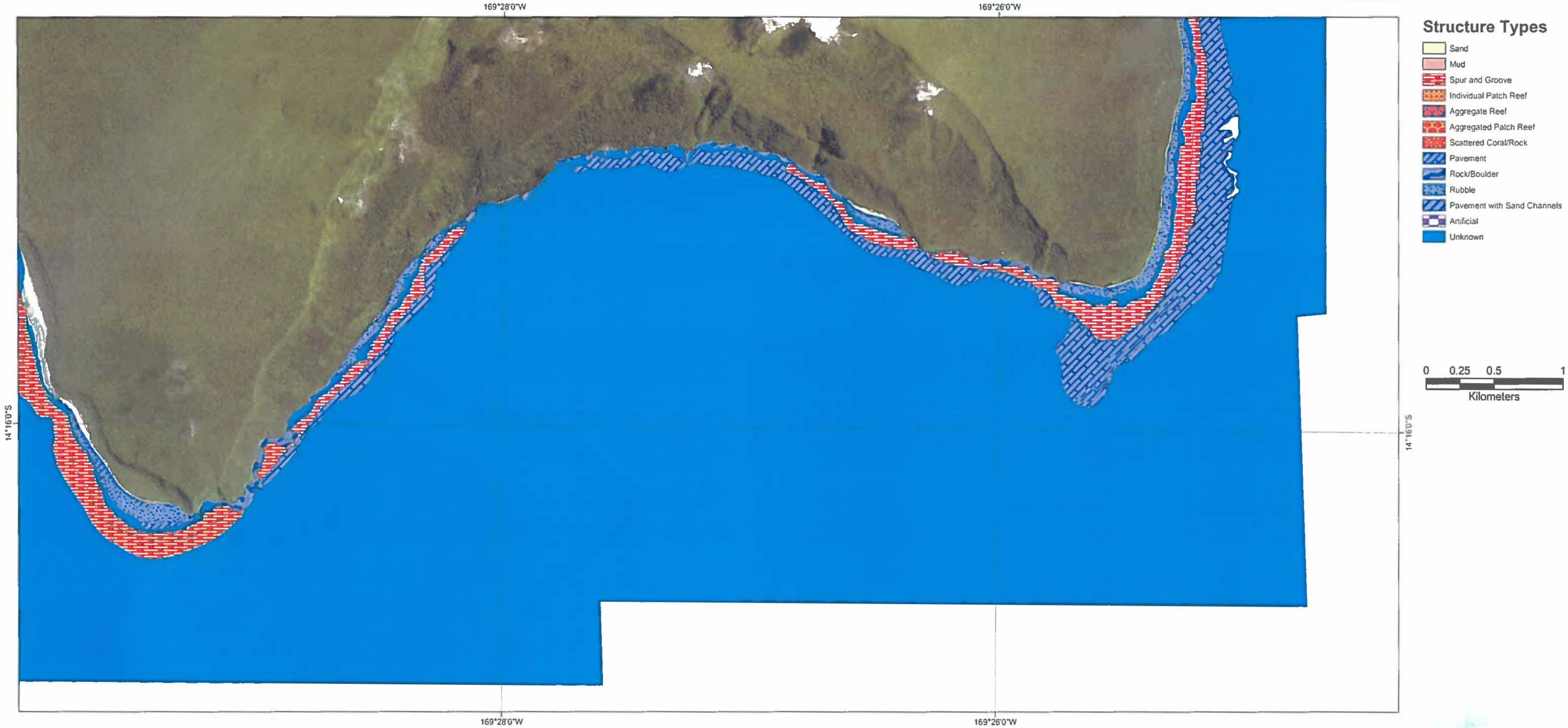


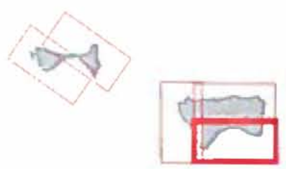
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

Manua Islands Benthic Habitat Map

Frame 60 - Biological Cover



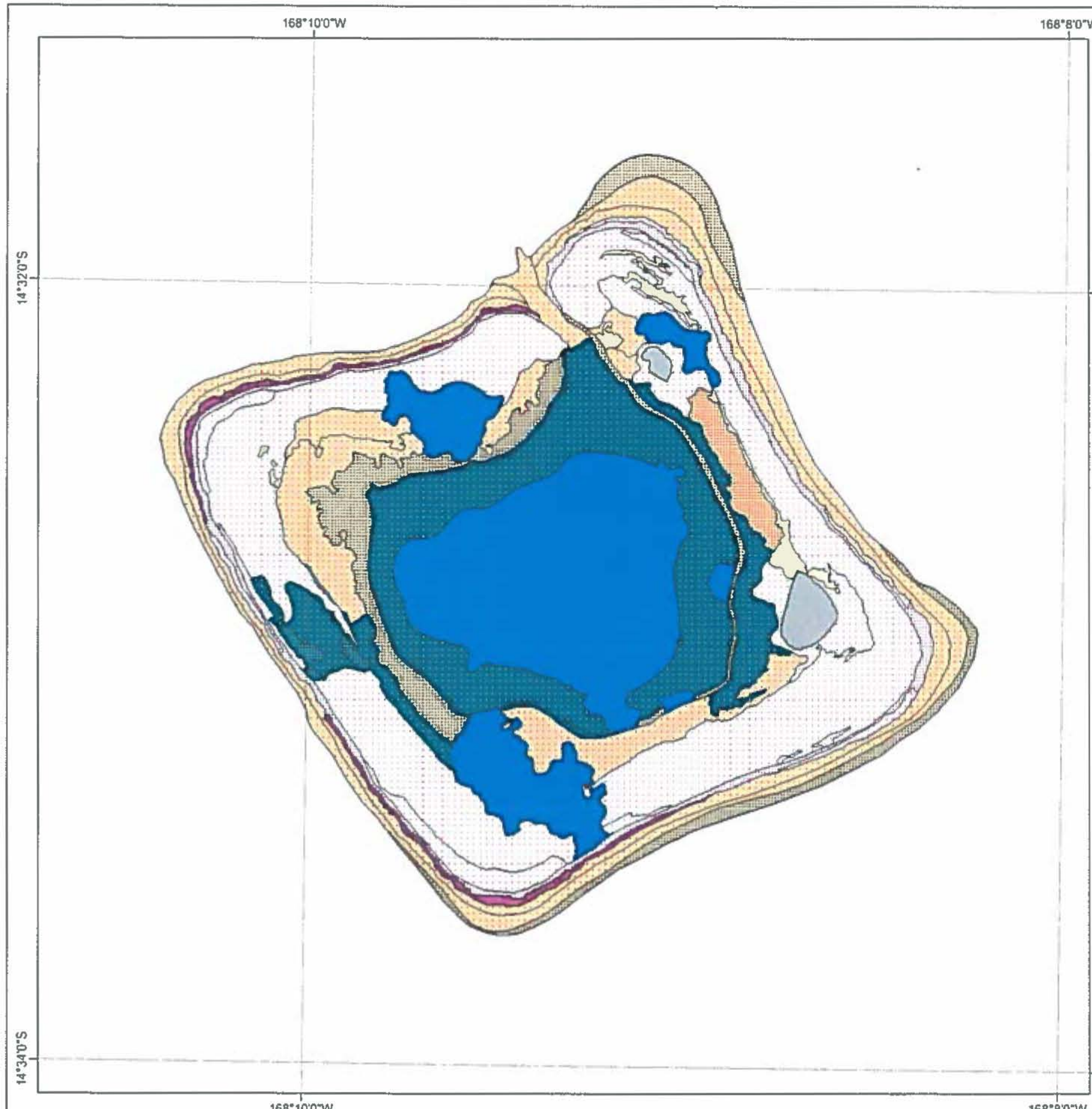


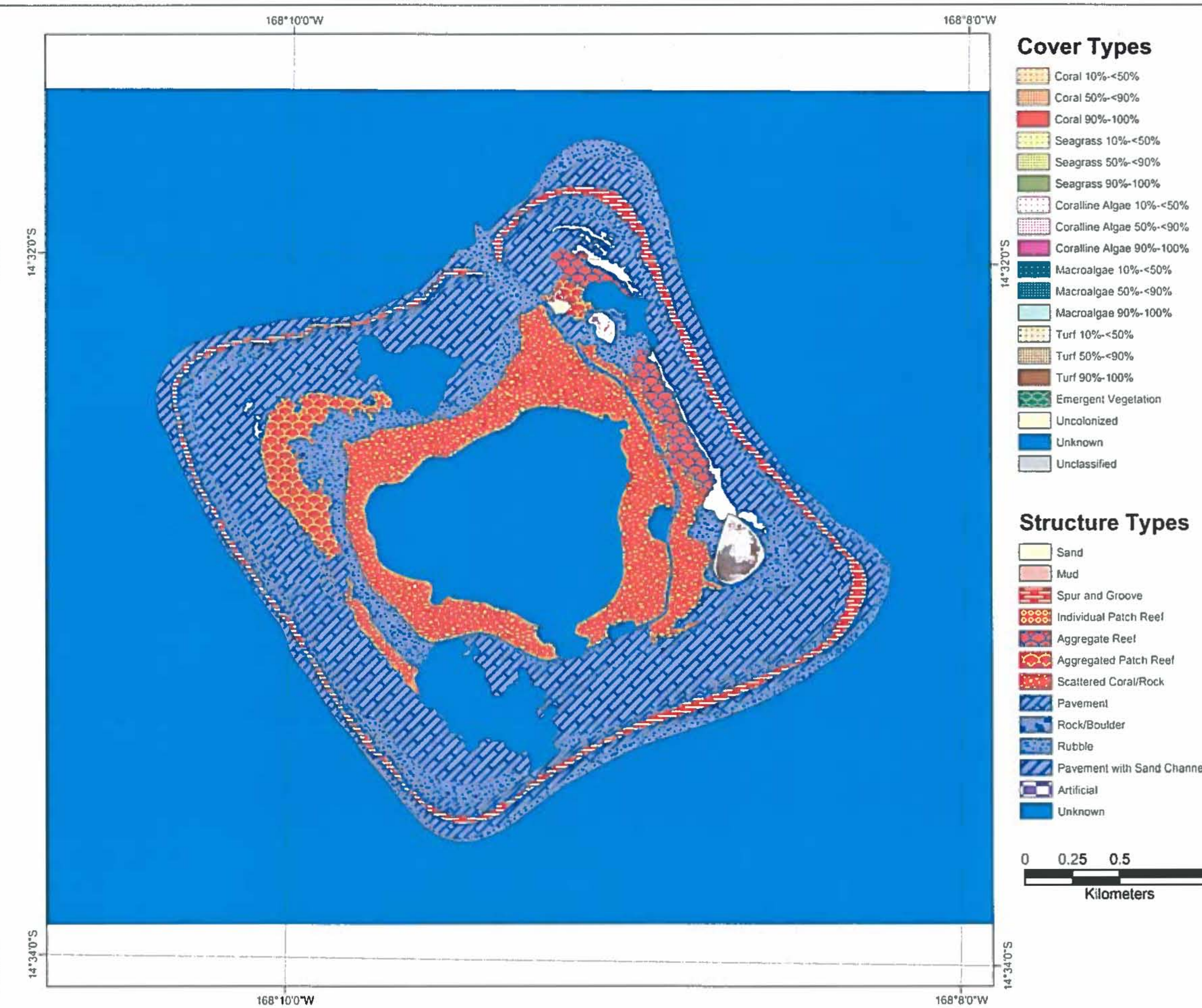
Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004

American Samoa

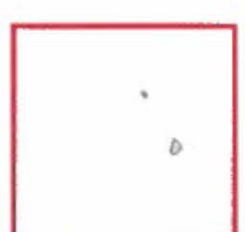
Manua Islands Benthic Habitat Map

Frame 60 - Geomorphological Structure





Map prepared by the National Ocean Service, Biogeography Program, in cooperation with Analytical Laboratories of Hawaii and BAE Systems Spectral Solutions. 2004



American Samoa

Rose Atoll Benthic Habitat Map

Frame 61 - Biological Cover and Geomorphological Structure