Biogeographic Characterization of Essential Fish Habitats Affected by Human Activities in the Coastal Zone of Puerto Rico

Final Project Report

NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch
and National Marine Fisheries Service Caribbean Field Station, Puerto Rico

Puerto Rico Department of Natural and Environmental Resources

Caribbean Fisheries Management Council

August 2010

By

NOAA/NOS/NCCOS/CCMA Biogeography Branch
1305 East West Highway (SSMC4, N/SCI-1)
Silver Spring, MD 20910

Contributors

Christopher F. G. Jeffrey
Peter W. Mueller
Matt S. Kendall
Ken Buja
Kimberly Edwards
Sarah D. Hile
Lisamarie Carrubba

NOAA Technical Memorandum NOS NCCOS 115

Mention of trade names or commercial products does not constitute endorsement or recommendation for their use by the United States government.

Citation for this document:

Jeffrey, C.F.G., P.W. Mueller, M.S. Kendall, K. Buja, K. Edwards, S.D. Hile, and L. Carrubba. 2010. Biogeographic Characterization of Essential Fish Habitats Affected by Human Activities in the Coastal Zone of Puerto Rico. NOAA Technical Memorandum NOS NCCOS 115. Silver Spring, MD. 31 pp.

1.1. Goal

The overall purpose of this project was to collect available information on the characteristics of essential fish habitats in protected and non-protected marine areas around the islands of Puerto Rico. Specifically, this project compiled historical information on benthic habitats and the status of marine resources into a Geographic Information System (GIS) by digitizing paper copies of existing marine geologic maps that were developed for the Caribbean Fishery Management Council (CFMC) for areas around the Commonwealth of Puerto Rico. In addition, information on benthic habitat types, Essential Fish Habitat (EFH) requirements, and fishing and non-fishing impacts to marine resources were compiled for two priority areas: La Parguera and Vieques. The information obtained will help to characterize and select habitats for future monitoring of impacts of fishing and non-fishing activities and to develop management recommendations for conservation of important marine habitats. The project focused specifically on areas identified as priorities for conservation by the Puerto Rico Department of Natural and Environmental Resources (DNER) and the Local Action Strategy Overfishing Group.

1.2. Background

Non-fishing activities often result in negative impacts to the coral reef ecosystem, including associated fishing resources, around Puerto Rico, in particular due to the loss of benthic habitat. Recreational activities that result in trampling of seagrasses and corals, cutting of mangrove roots and branches to create areas of shade or tie up boats; coastal development that results in erosion and sediment transport to the sea, clearing of mangroves, seagrasses, and other wetlands, and water quality changes; and boat groundings are some of the non-fishing activities that have been identified as impacting the coral reef ecosystem. As part of Goal Number 4 of the Local Action Strategy Plan, Overfishing Theme, the Puerto Rico government, through the DNER, is working to reduce the negative impacts of non-fishing activities to the coral reef ecosystem, including associated fishery resources.

This project was initiated as part of NMFS Southeast Regional Office's participation in the NOAA Coral Reef Conservation Program (CRCP). This project was also a component of NMFS' efforts on behalf of the Coral Reef Task Force established by President Clinton in June 1998 through Executive Order #13089 (http://coralreef.gov/about/executive_order13089.pdf). The Executive Order is titled "Coral Reef Protection" and seeks to "preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral reef ecosystems and marine environment."

1.3. Methods

1.3.1 Project planning

The first phase of this project involved meetings with staff from the collaborating agencies: NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch (CCMA BB) and National Marine Fisheries Service (NMFS) Caribbean field Station, DNER, and CFMC. Initial conference calls and meetings were held to scope out the specific project goals and objectives, to identify paper maps to be digitized, and to prioritize areas for the project. CCMA BB worked with NMFS Caribbean Field Station to develop a prioritized list of information to be compiled on benthic habitat types, EFH requirements, and fishing and non-fishing impacts to marine resources.

1.3.2. Geo-referencing images and digitizing thematic map elements

The second phase of the project involved digitizing and geo-referencing existing (historical) paper maps of geologic features around Puerto Rico. Hardcopy maps were provided to CCMA BB project Team by Lisamarie Carrubba (NFMS Caribbean Field Station). Maps were reviewed in detail by the project team to determine the elements that could be digitized and geo-referenced (Table 1). Many of the hardcopy maps were composite maps containing a main map with smaller inset maps. Each entire map sheet was scanned then the most important features such as sediment types were selected from each digital scan for geo-referencing. Table 1 provides descriptions and figure labels for all inset maps that were selected for geo-referencing. The map sheets were scanned by REIGER© (Clarksburg MD, www.reiger.com) to produce digital photographic copies in Tagged Image File Format (TIFF). The hardcopy maps were drawn at various scales but were scanned 1:1 at 300 dpi. Scanned images were digitized at 1:10,000.

Table 1. Images, features, and products digitized from hardcopy geologic maps of Puerto Rico.

Map#	Map Image	Map Title	Products
I-2207	I-2207 Sheet 1	Marine Geologic Map of the North Insular Shelf of Puerto Rico: Río de Bayamón to Río Grand de Loiza, 1992.	GeoTIFF image, Digitized shapefile
	I-2207 Sheet 2	Marine Geologic Map of the North Insular Shelf of Puerto Rico: Río de Bayamón to Río Grand de Loiza, 1992.	Not scanned
I-1861	I-1861 West Section	Bottom Sediment Types of the Northern Insular Shelf of Puerto Rico: Punta Peñon to Punta Salinas, 1987	GeoTIFF image, Digitized shapefile
	I-1861 East Section	Bottom Sediment Types of the Northern Insular Shelf of Puerto Rico: Punta Peñon to Punta Salinas, 1987	GeoTIFF image, Digitized shapefile
	I-1861 Figure 2	Abundance of fine sand (0.125-0.25 mm) on the Rio de La Plata shelf	Not scanned
	I-1861 Figure 3	Areal distribution of percent calcium carbonate in northern shelf sediments	Not scanned
	I-1861 Figure 4	Dispersal paths of sand and mud	Not scanned
	I-1861 Figure 5	The abundance of heavy mineral in the carbonate-free, medium sand (o.25-0.5 mm) fraction of Rio de La Plata shelf sediments	Not scanned
	I-1861 Figure 7	The concentration of magnetite in the carbonate-free, medium sand (o.25-0.5 mm) fraction of Rio de La Plata shelf sediments	Not scanned
I-1265	I-1265	Marine Geologic Map of the Puerto Rico Insular Shelf: Isla Caja de Muertos Area, 1981	GeoTIFF image, Digitized shapefile
	I-1265 Figure 1	Index map showing locations of National Ocean Survey bathymetric surveys used in contouring bathymetry for mapped area	Not scanned

Table 1. Continued…

Map#	Map Image	Map Title	Products
I-1265 continued	I-1265 Figure 2	Map showing turbidity of shelf waters as measured by visible depth of the secchi disk, and average reading taken over two years. Highly turbid water covers much of the Ponce Basin, which is floored by silt and clay	Not scanned
	I-1265 Figure 3	Map showing percentage of insoluble residue in superficial shelf sediments	Not scanned
I-1418	I-1418	Marine Geologic Map of the Puerto Rico Insular Shelf: Northwestern Area, Río Grande de Añasco to Río Camuy, 1983	GeoTIFF image, Digitized shapefile
	I-1418 Figure 4	Map of the land and offshore areas adjacent to the insular shelf of northwestern Puerto Rico showing generalized geologic structure	TIFF image
I-2263	I-2263	Marine Geologic Map of the Puerto Rico Insular Shelf: Guánica to Ponce Area, 1991	GeoTIFF image, Digitized shapefile
	I-2263 Figure 1	Map showing geology between Guanica and Ponce	Not scanned
	I-2263 Figure 3	Map showing the Guayanilla Canyon system	Not scanned
	I-2263 Figure 6	Carbonate content of superficial bottom sediment, in weight percent	Not scanned
I-2387	I-2387	Geologic Maps of the Southwestern Insular Shelf of Puerto Rico: Parguera to Guánica, 1994	Three GEOTIFFS and digitized shapefiles
I-2615	I-2615	Marine Geologic Map of the Southwestern Insular Shelf of Puerto Rico: Mayaguez to Cabo Rojo, 1999	GeoTIFF image, Digitized shapefile
I-2612	I-2612	Marine Geologic Map of the Northeastern Insular Shelf of Puerto Rico: Luquillo Area, 1998	GeoTIFF image, Digitized shapefile
MF-1017	MF-1017	Grove and Trumbull-Surfical Geologic Maps and Data on Three Potential Offshore Sand Sources on the Insular Shelf of Puerto Rico. 1978	Three GeoTIFF images
Control # 06-0816003		Aerial photo of Joyuda at a scale of 1:2000 taken March 28, 2005	TIFF image
Control # 06-0817004		Aerial photo of Mayaguez at a scale of 1:5000 taken July 3, 1995	TIFF image

The TIFF images of hardcopy maps were geo-referenced for (1) conversion to GeoTIFF images and (2) digitizing thematic map elements for compatibility and use with ArcGIS software. The hardcopy maps and the resulting scanned digitized images contained limited information on map projection and development techniques. Based on the information available, it was assumed that most of the maps were projected in the Universal Transverse Mercator System (UTM) and were referenced to the North American Datum of 1927 (NAD27).

1.3.2.1. Conversion from TIFF to GEOTIFF

To convert from TIFF to GeoTIFF images, each image was imported into an ArcMap data frame. A second data frame was created with its projection set to Geographic Coordinate System, North American Datum 1927. A graticule was constructed with XTools Pro based on latitude and longitude values from the coordinate grid in the map image. Next, eight ground control points were selected at intersecting graticule lines to georeference the image (Figure 1). The ArcGIS georeference tool was then used to conduct a 1st order polynomial transformation of the selected points, and the resulting georeferenced image (now in GeoTIFF) was exported in NAD27 (Figures 2 and 3). The ArcGIS Reproject Tool was then used to reproject the GeoTIFF in NAD83. A third data frame was created with its properties set to either UTM zone 19N or 20N depending on the geographic location of the image in Puerto Rico.

1.3.2.2. Digitization of GeoTIFF images

To convert GeoTIFF images to ARGIS shapefiles, thematic map features observed in the GeoTIFF images were then digitized at a scale of 1:10000 (Figure 4). The resulting digitized shapefile was overlaid onto georeferenced aerial imagery for Puerto Rico and a benthic habitat shapefile (Kendall *et al*. 2001) to determine the relative accuracy of line positions (Figure 5). If needed, the shapefile's position was adjusted to obtain the closest fit of digitized features to corresponding features in the aerial imagery and benthic map. The digitized features were then attributed with the classifications provided in paper maps.

1.3.3. Development of an annotated bibliography

Biogeographic characterization studies done in Puerto Rico by CCMA were compiled and reviewed to determine their utility for identification of EFH as defined by NMFS.

1.4. Results and Products

1.4.1. Planning

The initial meetings determined the number and types of existing marine geologic paper maps to be digitized, identified priority areas for which historical information will be compiled; and, specified the extent (in terms of years and location) of historical information on EFH to be compiled for priority and non-priority areas around Puerto Rico. The meetings resulted in the development of a final Work Plan, which guide the implementation of the project http://ccma.nos.noaa.gov/ecosystems/coastalocean/efh_pr.html).

1.4.2. Geo-referencing images and digitizing thematic map elements

A total of 17 TIFF images were scanned from 10 hardcopy geologic maps and two aerial photos (Table 1). Of these, 14 images were georeferenced and converted to GeoTIFFs, and eleven were digitized to ArcGIS shapefiles. TIFF images of the two aerial photos and 16 seamless image database (SID) files provided by Lisamarie Carrubba were not georeferenced or digitized because ground-truth data for locations of features in those images were not provided.

All TIFF, GeoTIFF, SID images are included in the DVD ROM that accompanies this report and can be viewed through the "NMF_Pr_Geologic_Maps_Final_Deliverables.mxd" Arc GIS project (also on the DVD). The ArcGIS project contains four data frames (Table 2).

Table 2. Name and description of data frames in ArcGIS project - NMF_Pr_Geologic_Maps_ Final_Deliverables.mxd (see accompanying DVD).

Name of data frame	Description
Final_shapefiles	Eleven finalized shapefiles produced from digitizing the hard-copy USGS Geologic Maps of Puerto Rico; Also contains the shapefile (p_rico) with delineated benthic habitats for Puerto Rico (Kendall *et al*. 2001, http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_pr_mapping.html)
Scanned_images	Scanned images of hard copy USGS Geologic Maps of Puerto Rico Also contains the shapefile (p_rico)
Delineated_polygons	Fifteen shapefiles initially digitized from the hard-copy maps. Note that the polygon boundaries did not line up exactly with the Puerto Rico shorelines; Also contains the shapefile (p_rico)
Scanned_aerial_ photos	Aerial photo of Joyuda at a scale of 1:2000 taken March 28, 2005 Aerial photo of Mayaguez at a scale of 1:5000 taken July 3, 1995
Carruba_SID_ Images	Sixteen SID images for areas around Puerto Rico; Provided by Lisamarie Carrubba, NOAA Fisheries, Caribbean Field Office P.O. Box 1316, Boqueron, PR 00622

Figure 5 shows the line features digitized from a georeferenced image (Map I-2263) overlaid on a georeferenced satellite image of Puerto Rico. At a scale of 1:40,000, the georeferenced shoreline digitized from Map I-2263 did not co-register very well with the shoreline of the image. Therefore, line features had to be shifted 5 meters east and 111 meters south to obtain a better positional match with corresponding features in the satellite imagery (Figure 6). After they were shifted, digitized line features generally matched up with corresponding features from the satellite imagery such that their relative positions were indistinguishable at a scale of 1:40,000 (Figure 7). However, at a scale of 1:10,000, the position of digitized features on average was about 50-60 m away from corresponding features in the satellite image (Figure 8).

1.4.3. Annotated bibliography

A total of 25 studies on coral reef ecosystem characterizations in Puerto Rico were reviewed and compiled into an annotated bibliography (Appendix A). These studies were conducted by CCMA BB in collaboration with several partners and generally supported identification of EFH in through characterizations of benthic habitats, reef fish assemblages, environmental stressors such as pollutants, and observed interrelationships among these components. The bibliography was added to an existing annotated bibliography on coral reef communities developed by Stephanie Williams for NMFS Caribbean Field Office.

1.5. References

Kendall, M.S., M.E. Monaco, K.R. Buja, J.D. Christensen, C.R. Kruer, M. Finkbeiner, and R.A. Warner. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (on-line).

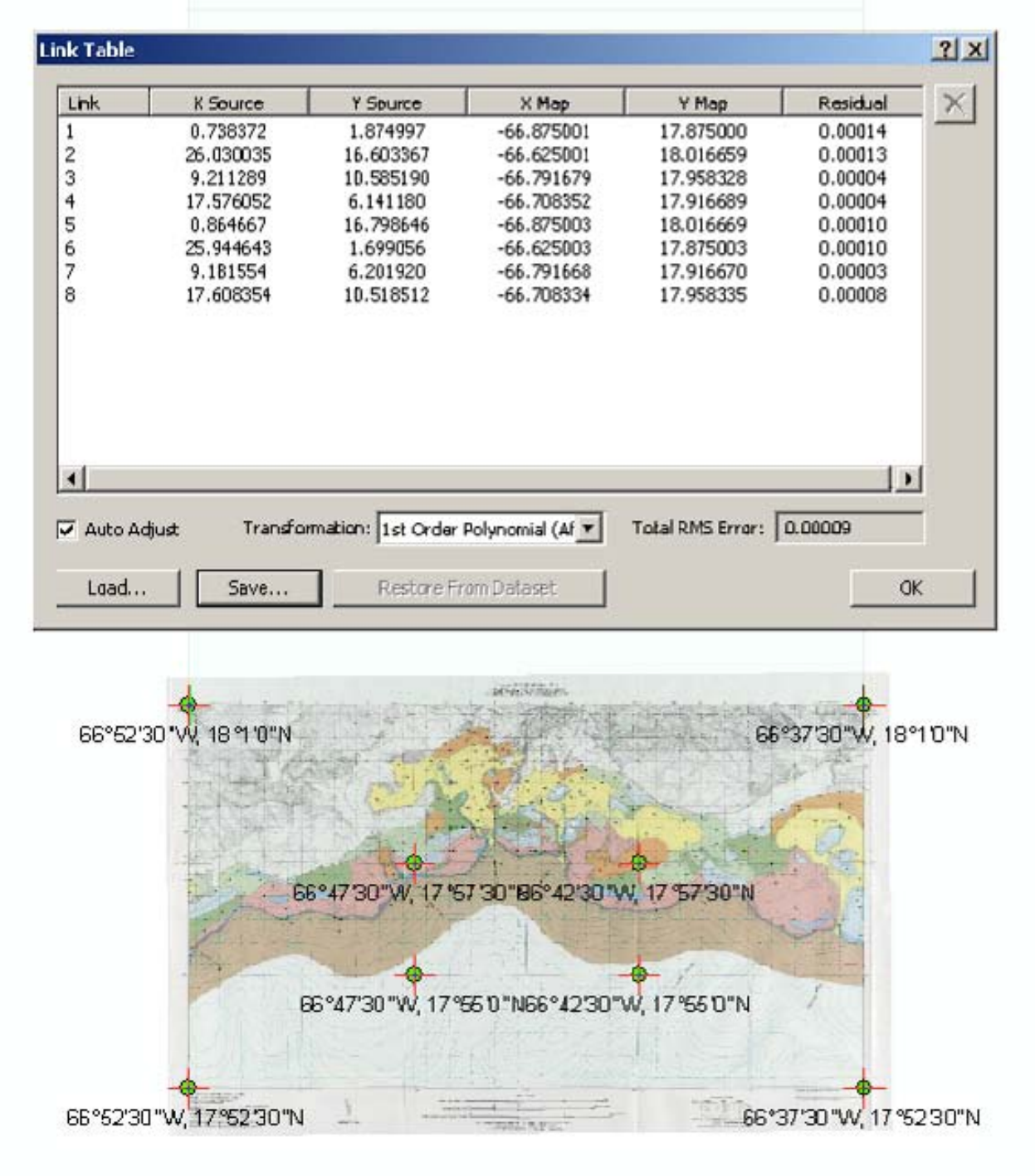

Figure 1. Points and the transformation used to georeference scanned image of paper maps.

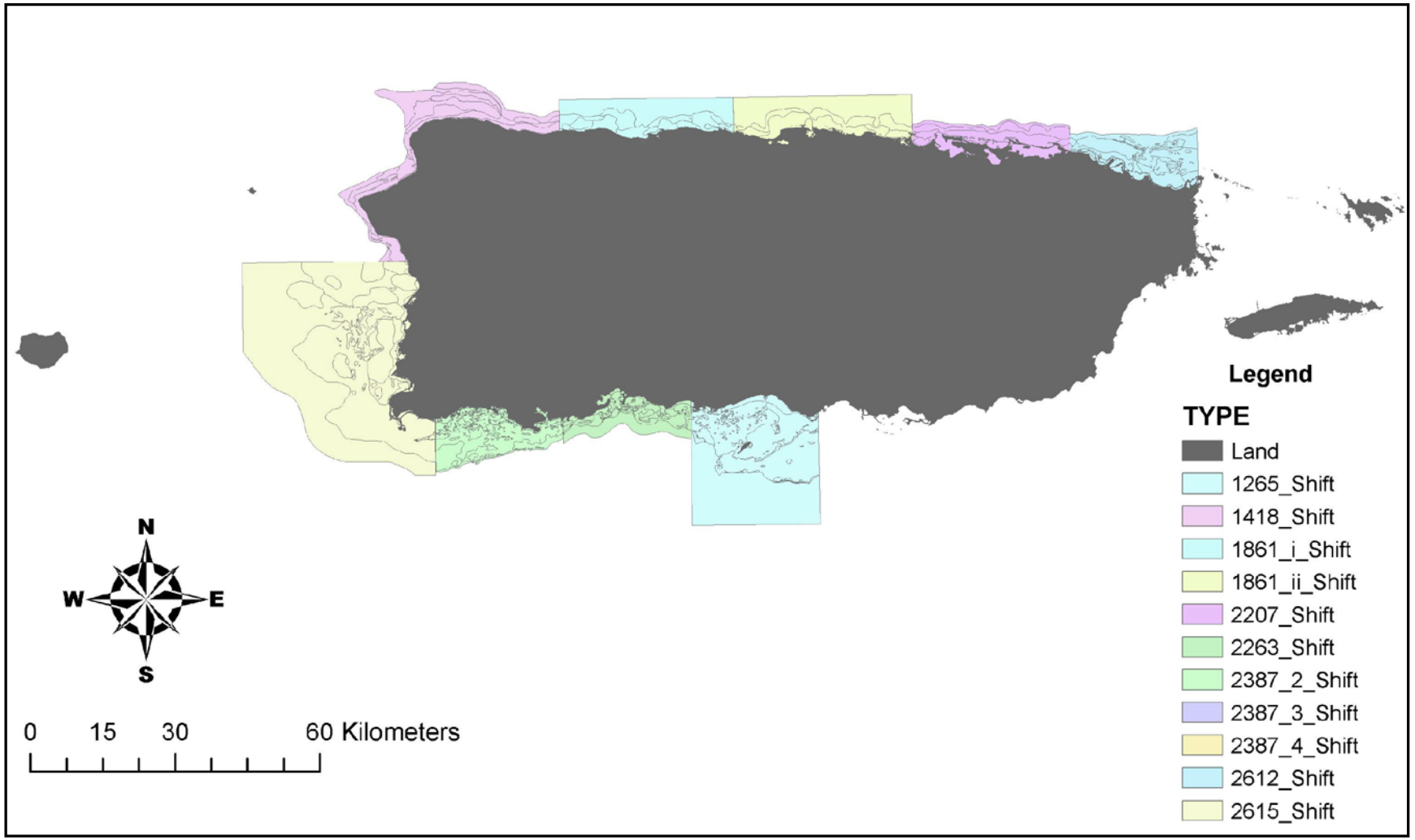

Figure 2. Map of Puerto Rico overlaid with georeferenced images developed from hardcopy geologic maps.

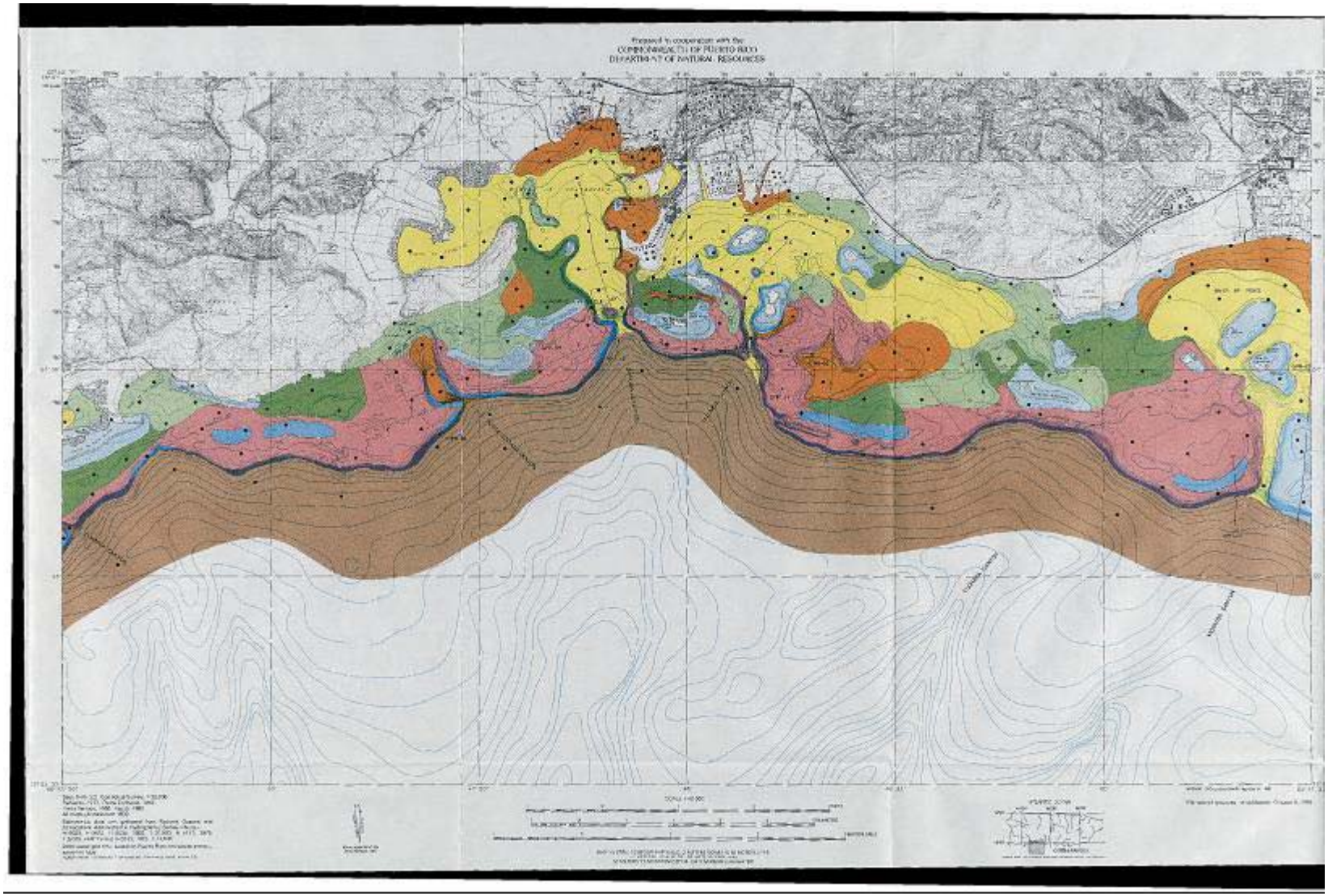

Figure 3. Georeferenced image of map I-2263 showing the geology of Guanica and Ponce. The polygons represent geologic deposits (Alluvian deposits, Swamp deposits, Beach deposits, Ponce Limestone, Juana Diaz formation, Undifferentiated formations); Black dot indicate sample locations; lines represent seismic flows.

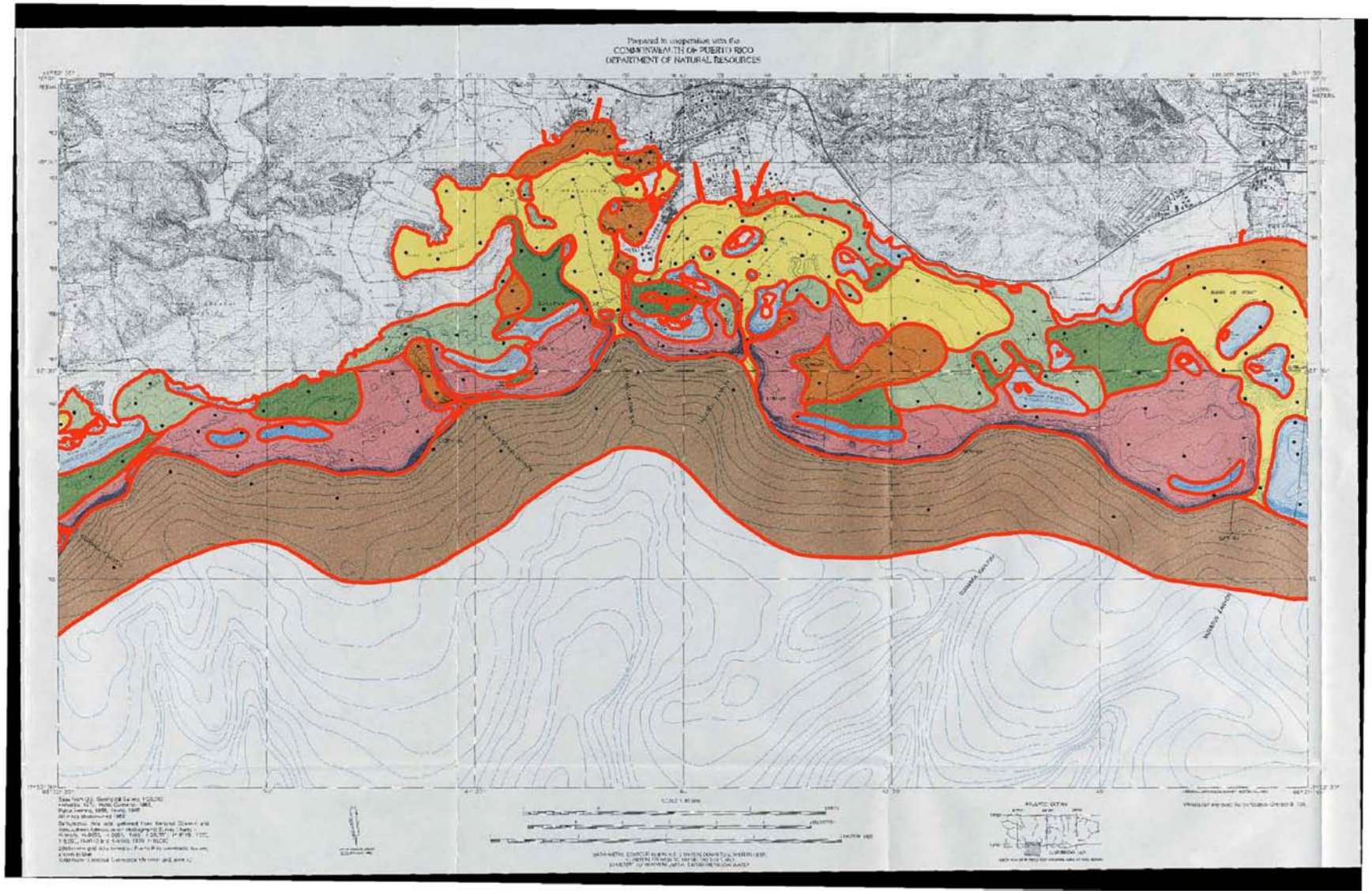

Figure 4. Line features (in red) outlining the major thematic elements (sediments types) drawn from the georeferenced image of map-2263.

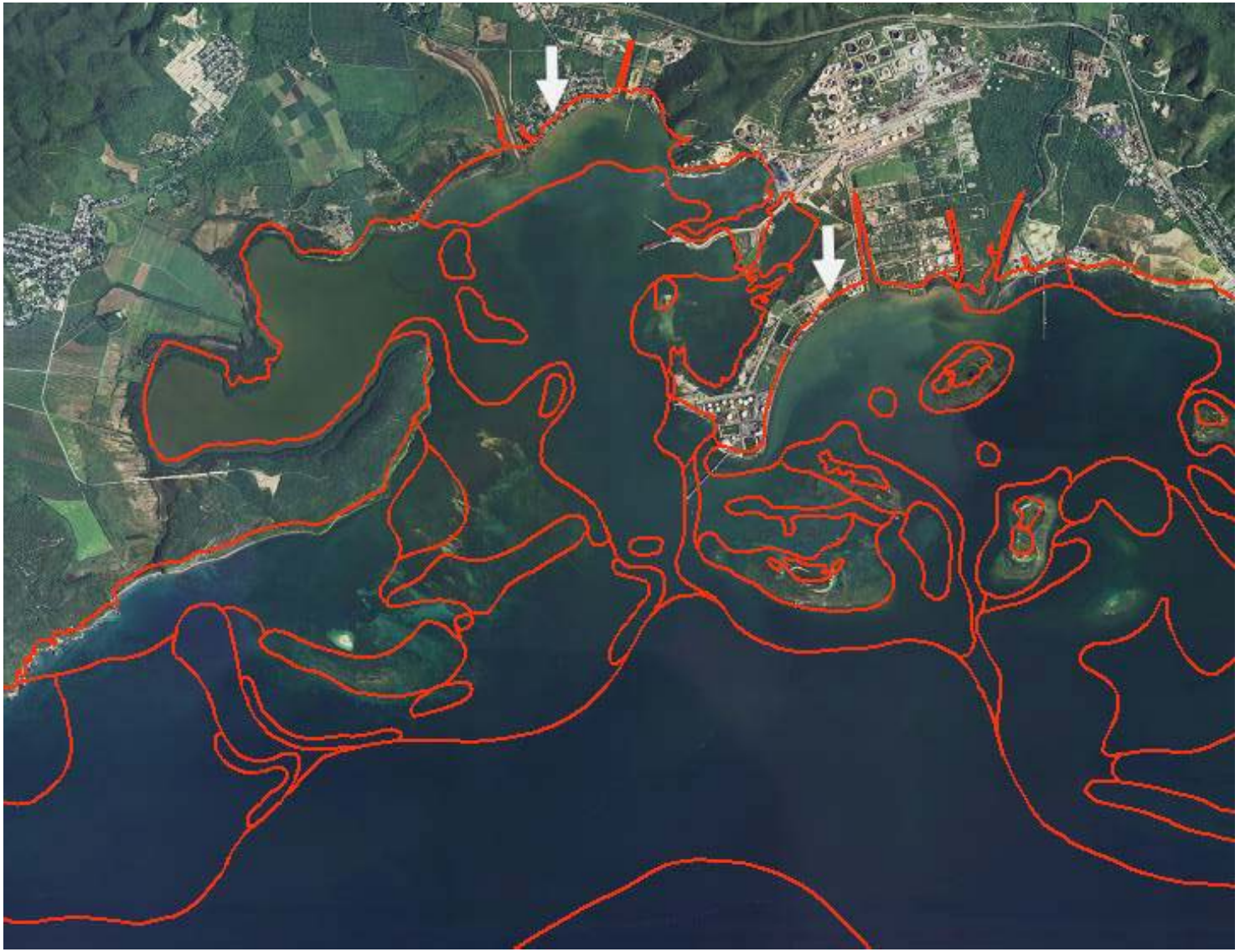

Figure 5. Line features (in red) from the georeferenced image of map-2263 overlaid on satellite imagery. White arrows indicate mismatch between georeferenced line features and shoreline depicted in satellite image. Map scale = 1:40,000

Figure 6. Line features (in red) from the georeferenced image of map-2263 shifted (in green) to obtain a better fit to shoreline in satellite imagery. The line features were shifted 5 m east and 111 m south to obtain a better fit.

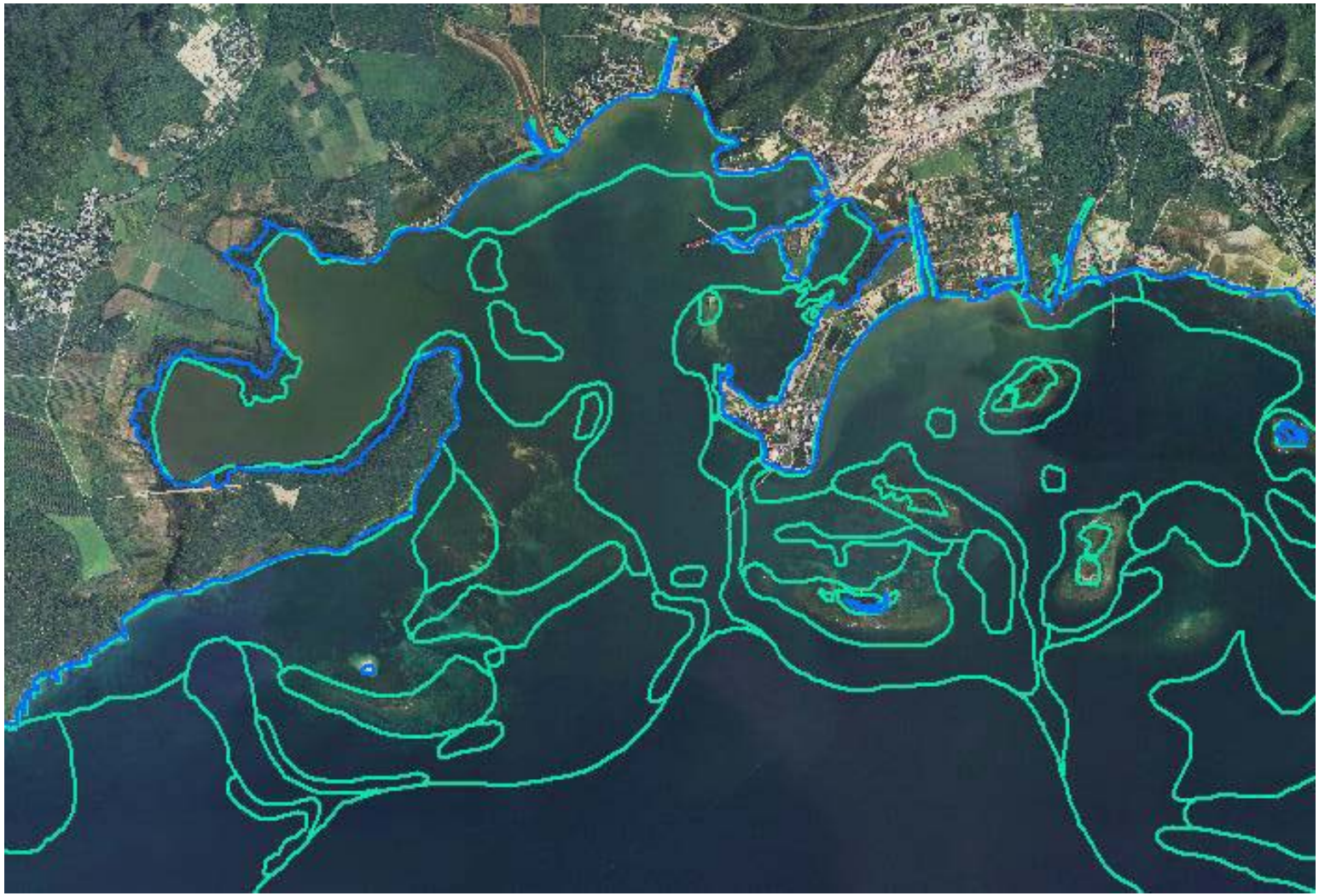

Figure 7. Shifted (in green) shoreline feature from the georeferenced image of map I-2263 overlaid on satellite imagery. The blue line represents the shoreline feature from NOAA benthic habitat map (Kendall et al., 2001). Green line depicts the shoreline along the seaward edge of mangrove habitat whereas the blue line depicts the shoreline along the landward edge of mangrove habitats. Map scale = 1:40,000.

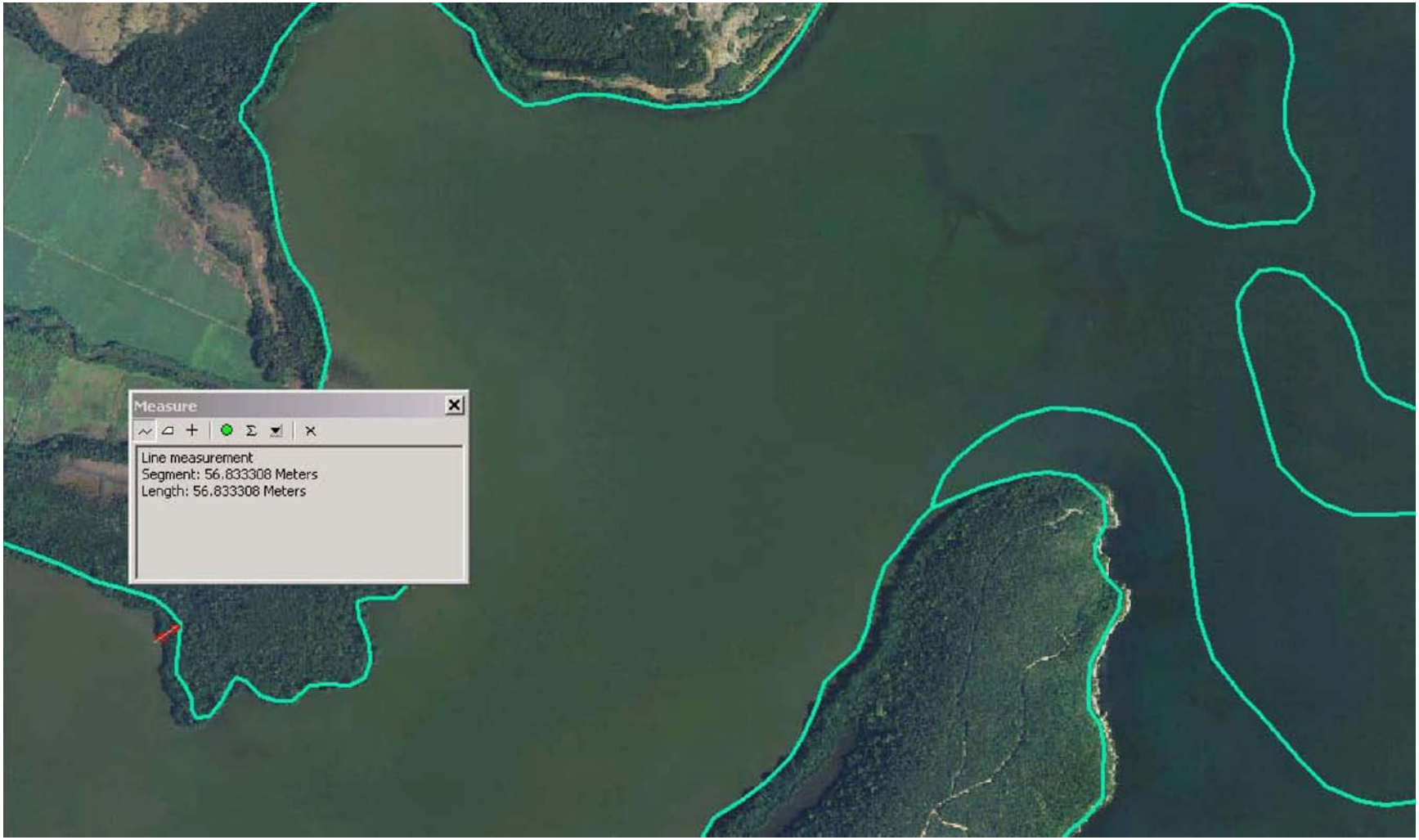

Figure 8. Shifted (in green) shoreline feature from the georeferenced image of map I-2263 overlaid on satellite imagery on a scale of 1:10,000. Differences (~ 50 meters) in the position of the “green” georeferenced shoreline and the shoreline in the satellite image become apparent at higher resolution.

Appendix 1

Annotated Bibliography of Coral Reef Ecosystem Characterizations to support identification of Essential Fish Habitats (EFH) In Puerto Rico and Island Dependencies

Submitted to:

Lisamarie Carrubba, Ph.D. (lisamarie.carrubba@noaa.gov)

NOAA Fisheries
Caribbean Field Office
P.O. Box 1310
Boquerón, PR 00622

Submitted by:

Christopher F.G. Jeffrey, Ph.D.
Kimberly Edwards
Sarah Hile

NOAA/NOS/NCCOS Center for Coastal Monitoring and Assessment
1305 East West Highway

Definition of Essential Fish Habitat (EFH):

The 1996 amendments to the Magnuson Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) require the National Marine Fisheries Service (NMFS) and regional fisheries management councils (FMC) to "identify and protect important marine and anadromous fish habitats" (NOAA, 2008). To do this, agencies must identify 'Essential Fish Habitat' (EFH) in all fisheries management plans (FMP) and for all marine fish species managed under a federal FMP.

According to the Magnuson-Stevens Act, EFH is defined as "those waters and substrates necessary to fish for spawning, breeding, feeding or growth to maturity" (NOAA, 2008). Components of this statement are further clarified as, "waters include aquatic areas and their associated physical, chemical and biological properties; substrate includes sediment underlying the waters; necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and spawning, breeding, feeding, or growth to maturity covers all habitat types utilized by a species throughout its life cycle" (NOAA, 2008).

The amendments proactively support the maintenance of suitable marine habitat by requiring that all new FMP define EFH for focal species. In addition, any activity supported by federal funds that may potentially affect EFH must be reviewed by NMFS for comments/recommendations on potential adverse impacts to EFH. Common activities that lead to adverse impacts include, "port development, marine disposal of dredged materials, development of coastal wetlands, coastal transportation projects such as roadways, pollutant discharges, and certain resource extraction activities such as mining, logging, and oil and gas exploration" (NOAA, 2008).

References:

NOAA, 2008. Essential Fish Habitat: A Marine Fish Habitat Conservation Mandate for Federal Agencies. US Caribbean. National Marine Fisheries Service. Habitat Conservation Division. 18 pp. http://www.nmfs.noaa.gov/habitat/habitatprotection/efh/index.htm; http://www.caribbeanfmc.com/.

Annotated Bibliography on EFH

Following is a bibliographic review of studies conducted by CCMA that are relevant to EFH as defined by the NMFS. This review and resulting bibliography is an addition to an existing annotated bibliography on coral reef communities developed for by Stephanie Williams for NMFS Caribbean Field Office.

Ault, J.S., S.G. Smith, J. Luo, M.E. Monaco, and R.S. Appeldoorn. 2008. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. Environmental Conservation. 35: 221-231.

The sustainability of multispecies coral reef fisheries is a key conservation concern given their economic and ecological importance. Empirical estimation and numerical model analyses were conducted to evaluate exploitation status via resource reference points (or sustainability benchmarks) for coral reef fishes of the snapper-grouper complex in Puerto Rico. Mean size (*L*, in length) of animals in the exploited part of the population was estimated from fishery-dependent and fishery-independent size composition data and used as an indicator variable of exploitation rates. In application, fishing mortality rates estimated from *L* of various data sources were comparable. Of the 25 reef fish species assessed, 16 were below 30% spawning potential ratio (SPR), six were above 30% SPR, and three could not be reliably determined owing to low sample sizes. These findings indicate that a majority of snapper-grouper species in Puerto Rico are currently fished at unsustainable levels.

Keywords: average size, coral-reef fish, fishery exploitation, Puerto Rico

Bauer, L.J., C. Menza, K.A. Foley, and M.S. Kendall. 2008. An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico. Part I: Historical Data Synthesis. NOAA Technical Memorandum NOS NCCOS 86. Silver Spring, MD. 121 pp.

This report is Part I of an ecological characterization of the marine resources of Vieques, Puerto Pico. The purpose of this work, conducted by CCMA's Biogeography Branch in consultation with NOAA's Office of Reponse and Restoration and other local and regional partners, is to provide resource managers and the people of Vieques with a synthesis of historical data and information on the marine ecology of Vieques, and to identify gaps where future research is needed. The report is divided into chapters based on the physical environment, habitat types, and major faunal groups. Part II of this assessment is a joint effort encompassing the work of CCMA's Biogeography Branch and CCMA's Coastal and Oceanographic Assessment, Status and Trends Branch. This work will build upon previous efforts by presenting new data on benthic habitats, associated biological communities, nutrients, and contaminant concentrations in coral and sediments. Together, both components of the characterization will provide research and monitoring tools in order to support effective management and conservation of the island's marine resources.

Available at:
http://ccma.nos.noaa.gov/ecosystems/coralreef/Vieques_characterization.pdf

Bauer, L.J. and M.S. Kendall (eds.). 2010. An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico Part II: Field Studies of Habitats, Nutrients, Contaminants, Fish, and Benthic Communities. NOAA Technical Memorandum NOS NCCOS 110. Silver Spring, MD. 174 pp.

This report is Part II of an ecological characterization of the marine resources of Vieques, Puerto Rico. The purpose of this work, conducted by NOAA's National Centers for Coastal Ocean Science (NCCOS) in consultation with NOAA's Office of Response

and Restoration and other local and regional partners, was to provide natural resource managers with a spatially comprehensive characterization of the marine ecosystem surrounding Vieques. In the first part of this assessment, previously existing data and descriptions from published reports and assessments were integrated into a synthesis report. Part II of this assessment is a joint NCCOS effort encompassing the work of CCMA's Biogeography Branch, CCMA's Coastal and Oceanographic Assessment, Status and Trends (COAST) Branch, and the Center for Fisheries and Habitat Research (CCFHR). This work builds upon previous efforts by presenting new data on benthic habitats, associated biological communities, nutrients, and contaminant concentrations in coral and sediments. Together, both components of the characterization will provide research and monitoring tools in order to support effective management and conservation of the island's marine resources.

Available at:
http://ccma.nos.noaa.gov/ecosystems/coralreef/vieques/vieques_part_ii_lowres.pdf

Biogeographic Characterization Branch (BCB) and Caribbean Fisheries Management Council (CFMC). 1998. Product overview: Products and services for the identification of Essential Fish Habitat in Puerto Rico and the US Virgin Islands. Silver Spring, MD. National Ocean Service and Caribbean Fisheries Management Council. San Juan, PR. 81 pp.

Information and maps were developed for the region for which the Caribbean Fishery Management Council has jurisdiction. This region includes the insular shelf area around Puerto Rico and the U.S. Virgin Islands. The Reef Fish Fishery Management Plan includes 139 species in 37 families. Because of the time constraints and limited availability of data, 15 representative species of high priority were selected by the Council. EFH products including life history tables, plots of catch distribution, and habitat suitability models were produced for priority species. Future efforts may address additional species, life stages, habitats, as well as threats to EFH.

Summary and additional information available at:
http://ccma.nos.noaa.gov/products/biogeography/efh/carib-efh/products.html

Christensen, J.D., C. Jeffrey, M.E. Monaco, C. Caldow, M.S. Kendall, and R.S. Appledoorn. 2003. Cross-shelf habitat utilization patterns of reef fishes in southwestern Puerto Rico. Gulf and Caribbean Research 14: 9-27.

In June 2000, the National Ocean Service and University of Puerto Rico initiated a long-term reef-fish-monitoring program in La Parguera, Puerto Rico. Objectives of this ongoing work are to: 1) develop spatially-explicit estimates of reef fish habitat utilization patterns to aid in defining essential habitats, and 2) provide a quantitative and ecologically sound foundation to delineate marine reserve boundaries. Central to this effort are recently completed digital and georeferenced benthic habitat maps for the near-shore waters of Puerto Rico. The GIS-based map served as a framework for development of a spatially stratified reef-fish-monitoring program across the shelf. Simultaneous collections of fish size and abundance data, and micro-scale habitat distribution and quality data were taken along a 25 x 4 m transect for each monitoring station. Sampling included coral reef, mangrove, and seagrass habitats within three

cross-shelf zones unique to the insular shelf of La Parguera (inner lagoon, outer lagoon, and bank-shelf). A total of 106 stations were surveyed during the first year of sampling. Over 50,000 fishes, representing 123 species and 36 families were counted. Analyses showed clear patterns of habitat utilization across the seascape, and ontogenetic shifts in habitat selection within some species. Results also indicated that habitat type was more important than cross-shelf location in determining spatial patterns among reef fishes in the study area. Mesoscale spatially-explicit logistic models were developed to estimate distribution and expected density of some species among habitats.

Clark, R.D., S. Pittman, C. Caldow, J. Christensen, B. Roque, R.S. Appeldoorn, and M.E. Monaco. In Press. Nocturnal fish movement and trophic flow across habitat boundaries in a coral reef ecosystem (SW Puerto Rico). Caribbean Journal of Science.

Many marine fishes inhabiting shallow-water coral reef ecosystems undertake nocturnal migrations that connect a variety of habitat types across the seascape. Few studies have quantified the extent of cross-habitat movements for fish, or the influence of habitat adjacencies on nutrient flows and trophodynamics. To investigate the patterns of nocturnal cross-boundary movements of fish and quantify trophic connectivity, fish were sampled at night with gillnets set along the boundaries between dominant habitat types (coral reef-seagrass and mangroves-seagrass) in southwestern Puerto Rico. The direction of movement, fish length, weight and stomach content were identified and recorded for individual fish. Forty-five percent of fish at the coral reef-seagrass sites were entering reefs and 46% fish at mangrove-seagrass sites were entering mangroves. This exchange resulted in net energy gains of 0.16 kg/km of reef/seagrass habitats and a net loss of 0.06 kg/km at mangrove/seagrass habitats. Pelagic species (jacks, sharks, rays) accounted for 37% of prey biomass transport at coral reef-seagrass sites and 46% at mangrove-seagrass sites while grunts and snappers combined accounted for 7% and 15%, respectively. Crabs, mollusks, algae and fish were the most frequently encountered prey items at both habitats. The information on direction of fish movement together with analysis of prey data provided strong evidence of ecological linkages 31 between distinct adjacent habitat types and highlighted the need for greater inclusion of a mosaic of multiple habitats when attempting to understand ecosystem function including the spatial transfer of energy across the seascape.

Key Words: connectivity, habitat boundaries, coral reef ecosystems, mangroves, fish prey, nocturnal fish movement, seascape

Clark, R., M.E. Monaco, R.S. Appeldoorn, and B. Roque. 2005. Fish habitat utilization in a Puerto Rico coral reef ecosystem. pp. 467-486. In: R.L. Creswell (ed.). Proceedings of the 56th Annual Gulf and Caribbean Fisheries Institute. British Virgin Islands. 851 pp.

Over the past three years, the National Center for Coastal Ocean Science's (NCCOS) Center for Coastal Monitoring and Assessment (CCMA), in cooperation with the University of Puerto Rico's Marine Science Department, has conducted biological monitoring activities in La Parguera, Puerto Rico. Since many tropical fishes exhibit small or large scale migrations associated with foraging, passive fishing gears were deployed to capture adult and sub-adult fishes among several habitat types within the coral reef ecosystem to examine the relationship between fish habitat utilization patterns and habitat function. Three replicates of 100 meter gill nets were deployed to determine

fish movements across four habitat types, seagrass/reef, seagrass/mangrove, seagrass/unconsolidated bottom and, mangrove/unconsolidated sediments, located within three zones; lagoon, outer lagoon, and bank shelf. Nets were set proximal and parallel to habitat edges such that fishes moving across these boundaries were captured. This, coupled with gut content analyses will provide information necessary to describe feeding related migrations and to assess habitat function. From June 2000 through December 2002, 184 gill nets were deployed which captured 690 fishes comprising 72 species. Fish movement was inferred by noting fish orientation in the net and gut contents were removed in the laboratory and preserved for identification. Gut contents were identified to the lowest possible taxon and weighed (g). Herein, we provide preliminary results that describe fish movements and dietary components which will be used to determine the functional role of habitats for specific species and/or trophic guilds. These results support efforts to define Essential Fish Habitat (EFH) for federally managed species and can also be used in conjunction with other monitoring data to define ecologically-relevant boundaries for Marine Protected Areas (MPA's).

Key Words: coral reef ecosystem, fish, habitat function

García-Sais, J.R., R. Appeldoorn, A. Bruckner, C. Caldow, J.D. Christensen, C. Lilyestrom, M.E. Monaco, J. Sabater, E. Williams, and E. Diaz. 2005. The state of coral reef ecosystems of the commonwealth of Puerto Rico. pp. 91-134. In: J.E. Wadell (ed.). The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

The 569-page report was structured to provide information according to the primary threats, topics, and goals outlined in the National Coral Reef Action Strategy (NCRAS, 2002) and other guidance documents developed by NOAA's Coral Reef Conservation Program, the U.S. Coral Reef Task Force (USCRTF) and its member organizations. Following the Executive Summary, which distills general conclusions from the entire document, an introductory chapter provides information on national- and regional-level efforts to conserve coral reef ecosystems in the U.S. and FAS that fall outside the scope of any one jurisdiction. In the subsequent 15 chapters, local writing teams characterize the current understanding of the condition of the coral reef ecosystems in their respective jurisdictions. Writing teams were asked to: 1) introduce the types and geographical distribution of reefs within the jurisdiction; 2) discuss how each of the 13 key threats has manifested in the location; 3) describe existing monitoring programs; 4) present methods, results, and discussion for each monitoring data set, organized around the three primary themes of water quality, benthic habitats, and associated biological communities; 5) introduce the conservation and management actions currently being undertaken to respond to issues of concern; and 6) provide an overall summary of the status of each jurisdiction's coral reef ecosystems and priority recommendations for future research and management alternatives. This report represents an evolving effort to determine the condition of coral reef ecosystems at both local and national scales and serves as a vehicle for the dissemination of information about data collection activities in the U.S. and FAS. Data collection and integrated reporting of information are crucial to management efforts that strive to protect and conserve coral reefs, their associated habitats, and the organisms that depend on them. It is hoped that, through this report series, gaps in the current state of knowledge about U.S. coral reef ecosystems will be identified and filled, and that the availability of up-to-date, accurate, comprehensive

scientific information will enable managers to slow or halt the general decline in coral reef ecosystem health that has become evident in the last several decades.

Report and individual chapters available at:
http://ccma.nos.noaa.gov/ecosystems/coralreef/coral2008/welcome.html

García-Sais, J., R. Appeldoorn, T. Battista, L. Bauer, A. Bruckner, C. Caldow, L. Carrubba, J. Corredor, E. Diaz, C. Lilyestrom, G. Garcia-Moliner, E. Hernández-Delgado, C. Menza, J. Morrell, A. Pait, J. Sabater, E. Weil, E. Williams and S. Williams. 2008. The State of Coral Reef Ecosystems of Puerto Rico. pp. 75-116. In: J.E. Waddell and A.M. Clarke (eds.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73. Silver Spring, MD. 569 pp.

The 535-page report was structured to provide information according to the primary threats, topics, and goals outlined in the National Coral Reef Action Strategy (NCRAS, 2002) and other guidance documents developed by NOAA's Coral Reef Conservation Program, the U.S. Coral Reef Task Force (USCRTF) and its member organizations. Following the Executive Summary, which distills general conclusions from the entire document, an introductory chapter provides background information about the distribution of coral reef ecosystems in the U.S. and FAS, the different types of reefs that occur in these areas, and an estimate of the potential extent of shallow water coral reef ecosystems (including reefs, seagrass and macroalgae beds, sand patches, etc.) for each jurisdiction. The third chapter summarizes the current understanding of the key natural and anthropogenic threats to coral reef ecosystems that were identified in the NCRAS. This report represents an evolving effort to determine the condition of coral reef ecosystems at both local and national scales and serves as a vehicle for the dissemination of information about data collection activities in the U.S. and FAS. Data collection and integrated reporting of information are crucial to management efforts that strive to protect and conserve coral reefs, their associated habitats, and the organisms that depend on them. It is hoped that, through this and future reporting efforts, gaps in the current state of knowledge about U.S. coral reef ecosystems will be identified and filled, and that the availability of up-to-date, accurate, comprehensive scientific information will enable managers to slow or even halt the general decline in coral reef ecosystem health that has become evident in the last several decades.

Report and individual chapters available at:
http://ccma.nos.noaa.gov/ecosystems/coralreef/coral_report_2005/

Kelty, R. (ed.). K. Andrews, J. Wheaton, L. Nall, C. Beaver, W. Japp, B. Keller, V.R. Leeworthy, J.A. Bohnsack, T.Matthews, J. Ault, F. Ferro, G. Delgado, D. Harper, J. Hunt, B. Sharp, C. Pattengil-Semmens, S. Smith, R. Spieler, R.E. Dodge, D. Gilliam, B. Goodwin, G. Schmahl, E. Hickerson, J. R. Garcia, C. Lilyestrom, R. Appeldoorn, A. Bruckner, E. Williams, C. F.G. Jeffrey, U. Alauf, A. Riedlander, C. Rogers, J. Miller, J. Beets, R. Nemeth, S. Herzlieb, V. Mayor, W. Toller, Z. Hillis-Starr, S. Caseau and M. Miller. 2004. Status of Coral Reefs In The U.S. Caribbean And Gulf Of Mexico: Florida, Flower Garden Banks, Puerto Rico, U.S. Virgin Islands, Navassa. pp. 431-450. In: C. Wilkinson (ed.). Status of coral reefs of the world: 2004. Volume 2. Australian Institute of Marine Science, Townsville, Queensland, Australia. 557 p.

Mapping, monitoring, and management of coral reefs of Florida, the Flower Garden Banks National Marine Sanctuary (FGBNMS) northwestern Gulf of Mexico, Puerto Rico, U.S. Virgin Islands and Navassa have all improved with increased awareness and funding from the Government of the USA. Quantitative baseline surveys of coral reef communities have been completed in Puerto Rico at three current or proposed Natural Reserves. Monitoring is demonstrating trends in reef community health and structure in other sensitive coastal areas. The Tres Palmas Marine Reserve has been designated recently, and existing MPAs and revisions to fishing laws were evaluated based on these results. In the U.S. Virgin Islands (USVI), the Buck Island Reef National Monument has been expanded and a new park, the St. Croix East End Marine Park established in 2003. The monitoring programs in the USVI are now detecting changes in fish and coral community structure in and around the managed areas with a specific focus on elkhorn coral stands. Monitoring of water quality, reef diversity, growth, and populations of dominant fish and benthic organisms in Flower Garden Banks, Stetson Bank, and Navassa has assisted in evaluating impacts of climate change, tropical storms, fishing, and tourism pressures. An expanded Florida monitoring program is now completing the first integrated assessment of the reefs northwards from the Florida Keys. It is hoped that this increased attention to coral reef issues will continue, and that advances in the understanding of how coral reef ecosystems respond to anthropogenic stresses will result in better management plans that protect coastal resources by reducing those stresses. However, an improved understanding of the relative importance of how stresses contribute to or cause coral decline is needed. There is a need also to understand the linkages between watersheds and the functioning of coral reef ecosystems. It is essential to strengthen cross-boundary and cross-jurisdictional agreements to facilitate ecosystem-based management and information and technology transfer.

Keywords: coral reef monitoring, management, status reports

Kendall, M.S., M.E. Monaco, K.R. Buja, J.D. Christensen, C.R. Kruer, M. Finkbeiner, and R.A. Warner. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (on-line).

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service acquired aerial photographs for the nearshore waters of Puerto Rico and the U.S. Virgin Islands in 1999. These images were used to create maps of the region's coral reefs, seagrass beds, mangrove forests, and other important marine habitats. Mapped areas encompass the insular shelf between the shoreline and shelf edge except where turbidity prevented visualization of the bottom. A primary product of this project is a benthic habitat atlas; however, a detailed methods manual for creating the benthic maps, and text descriptions with associated photographic examples of each bottom type mapped are also included. Twenty-one distinct benthic habitat types within eight zones were mapped directly into a geographic information system (GIS) using visual interpretation of ortho-rectified aerial photographs. Benthic features were mapped that covered an area of 1600 km^2 in Puerto Rico and 490 km^2 in the U.S. Virgin Islands. In Puerto Rico, 49 km^2 of unconsolidated sediment, 721 km^2 of submerged vegetation, 73 km^2 of mangroves, and 756 km^2 of coral reef and colonized hardbottom were mapped. In the U.S. Virgin Islands, 24 km^2 of unconsolidated sediment, 161 km^2 of submerged vegetation, 2 km^2 of mangroves, and 300 km^2 of coral reef and hard bottom were mapped.

Available at: http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

Kendall, M.S., C,R. Kruer, K.R. Buja, J.D. Christensen, E. Diaz, R.A. Warner, and M. E. Monaco. 2004. A characterization of the shallow-water coral reefs and associated habitats of Puerto Rico. Gulf and Caribbean Research 16: 177-184.

We mapped bottom types and shelf zones of 1600 km^2 or about one fourth of Puerto Rico's insular shelf from the shoreline to the shelf edge. Overall map accuracy for these bottom types is estimated as 93.6% correct. Maps were produced through visual interpretation of benthic features using orthorectified aerial photographs within a Geographic Information System with customizable software. The maps are one component of an integrated mapping and monitoring program underway by NOAA and its partners in the US Coral Reef Task Force to assess all US reef ecosystems. Maps are currently being used to enhance coastal research and management activities in Puerto Rico such as fisheries assessments and designation of important fish habitats.

Keywords: Aerial photographs, Benthic environment, Coastal zone management, Continental shelves, Coral reefs; Fishery management, Fishery resources, GIS, Habitat; Mapping, Marine fisheries, Remote sensing, Shallow water

Kendall, M.S. and K.A. Eschelbach. 2006. Spatial analysis of the benthic habitats within the limited use zones around Vieques, Puerto Rico. Bulletin of Marine Science 79(2): 389-400.

We used a geographic information system (GIS) to analyze overlap between two preexisting spatial datasets, benthic habitat maps and marine zoning boundaries, to provide a spatial inventory of the benthic habitats around Vieques Island, Puerto Rico. We calculated the length of shoreline, area, and diversity of bottom habitats within and outside of the three limited-use areas offshore to a distance of 3 nmi around Vieques. Of note, 95% of the shoreline of Vieques, 100% of the mangroves and mud bottom, 96% of the macroalgae, nearly half of the coral reef/hard bottom, and higher diversity of benthic habitats were within the limited-use areas. The distribution of these features is the combined result of the island's geological, ecological, oceanographic, and ownership history.

Full article available at: http://www.ingentaconnect.com/content/umrsmas/bullmar

Matos, C.A., Garcia, J.R., and Diaz, E. 2002. Status of the Coral Reefs of Puerto Rico. pp. 119-130. In: D.D. Turgeon, R.G. Asch, B.D. Causey, R.E. Dodge, W. Jaap, K. Banks, J. Delaney, B.D. Keller, R. Speiler, C.A. Matos, J.R. Garcia, E. Diaz, D. Catanzaro, C.S. Rogers, Z. Hillis-Starr, R. Nemeth, M. Taylor, G.P. Schmahl, M.W. Miller, D.A. Gulko, J.E. Maragos, A.M. Friedlander, C.L. Hunter, R.S. Brainard, P. Craig, R.H. Richond, G. Davis, J. Starmer, M. Trianni, P. Houk, C.E. Birkeland, A. Edward, Y. Golbuu, J. Gutierrez, N. Idechong, G. Paulay, A. Tafileichig, and N. Vander Velde. 2002. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2002. National Oceanic and Atmospheric Administration/National Ocean Service/National Centers for Coastal Ocean Science, Silver Spring, MD. 265 pp.

The report-prepared under the U.S. Coral Reef Task Force's National Action Plan-provides a scientific baseline for subsequent reports on the health of U.S. coral reef ecosystems. NOAA and others involved in coral reef protection and management will use the report to evaluate coral reef conservation and management practices and help shape future actions and priorities concerning management and protection of these unique and valuable resources. Under the Coral Reef Conservation Act (Public Law 106–562, U.S.C. 6401 et seq.), enacted in December 2000, the Secretary of Commerce is responsible for helping to preserve, sustain, and restore the condition of coral reef ecosystems. The Act authorizes funds for the Secretary to establish a new Coral Reef Conservation Program and to fund a National Program to map, assess, and monitor coral reef ecosystems and conduct research, restoration, public outreach efforts and remove grounded vessels, fishing gear, or marine debris. Presidential Executive Order 13089 in 1998 established the United States Coral Reef Task Force, comprised of 11 federal agencies, governors of seven states and territories, and presidents of the Pacific Freely Associated States of Palau, the Marshall Islands, and Micronesia. That task force adopted a National Action Plan calling, among other things, for preparation and distribution of this biennial national report.

Full report available at: http://coastalscience.noaa.gov/documents/status_coralreef.pdf

Menza, C, C. Caldow, C. Jeffrey and M. Monaco. 2008. Analysis of Sample Frames and Subsampling Methods for Reef Fish Surveys. NOAA Technical Memorandum NOS NCCOS 72. 19 pp.

The National Oceanic and Atmospheric Administration's Biogeography Branch has conducted surveys of reef fish in the Caribbean since 1999. Surveys were initially undertaken to identify essential fish habitat, but later were used to characterize and monitor reef fish populations and benthic communities over time. The Branch's goals are to develop knowledge and products on the distribution and ecology of living marine resources and provide resource managers, scientists and the public with an improved ecosystem basis for making decisions. The Biogeography Branch monitors reef fishes and benthic communities in three study areas: (1) St. John, USVI, (2) Buck Island, St. Croix, USVI, and (3) La Parguera, Puerto Rico. In addition, the Branch has characterized the reef fish and benthic communities in the Flower Garden Banks National Marine Sanctuary, Gray's Reef National Marine Sanctuary and around the island of Vieques, Puerto Rico. Reef fish data are collected using a stratified random sampling design and stringent measurement protocols. Over time, the sampling design has changed in order to meet different management objectives (i.e. identification of essential fish habitat vs. monitoring). There are two aspects of the sampling design which are now under consideration and are the focus of this report: first, the application of a sample frame, identified as a set of points or grid elements from which a sample is selected; and second, the application of subsampling in a two-stage sampling design. To evaluate these considerations, the pros and cons of implementing a sampling frame and subsampling are discussed. Particular attention is paid to the impacts of each design on accuracy (bias), feasibility and sampling cost (precision). Further, this report presents an analysis of data to determine the optimal number of subsamples to collect if subsampling were used.

Available at: http://ccma.nos.noaa.gov/publications/NCCOSTM72.pdf

Monaco, M.E., J. Waddell, A. Clarke, C. Caldow, C.F.G. Jeffrey and S. Pittman. 2008. Status of the Coral Reefs Ecosystems in the U.S. Caribbean and Gulf of Mexico: Florida, Flower Garden Banks, Puerto Rico, Navassa and USVI. pp. 225-238. In: Wilkinson, C. (ed.). Status of Coral Reefs of the World: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Center, Townsville, Australia. 557 pp.

This chapter covers coral reef areas under the jurisdiction of the USA in the Wider Caribbean: Florida; Flower Garden Banks; Puerto Rico; U.S. Virgin Islands; and Navassa. The following information is condensed from six chapters of The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008.

Keywords: GCRMN, coral reef monitoring, management, resources, status reports

Available at: http://ccma.nos.noaa.gov/stateofthereefs.

Pait, A.S., C.F.G. Jeffrey, C. Caldow, D.R. Whitall, S.I. Hartwell, A.L. Mason, and J.D. Christensen. In press. Chemical contamination in southwest Puerto Rico: a survey of contaminants in the coral *Porites astreoides.* Caribbean Journal of Science.

Coral tissues (Porites astreoides) from eight sites in southwest Puerto Rico were analyzed for approximately 150 chemical contaminants as part of a larger project to characterize environmental contamination and assess linkages between contamination and coral condition. The concentration of PAHs (polycyclic aromatic hydrocarbons) and PCBs detected in the coral tissues was comparable to concentrations found in adjacent sediments. However, the concentration of a chemical contaminant (e.g., PAHs) found in the coral tissues at a site was often different from what was found in the sediments. The levels of PCBs and DDT in coral tissues appeared higher just outside of Guanica Bay, and there was some evidence of a downstream concentration gradient for these two contaminant classes. The trace elements copper, zinc and nickel were frequently detected in coral tissues, and the concentration in the corals was usually comparable to that found in adjacent sediments. Chromium was an exception in that it was not detected in any of the coral tissues analyzed.

Pait, A.S., C.F.G. Jeffrey, C. Caldow, D. R. Whitall, S. I. Hartwell, A. L. Mason, and J. D. Christensen. 2009. Chemical Contaminants in the Coral *Porites astreoides* from Southwest Puerto Rico. NOAA Technical Memorandum NOS NCCOS 91. Silver Spring, MD. 40 pp.

This report presents an initial characterization of chemical contamination in coral tissues (*Porites astreoides*) from southwest Puerto Rico. It is the second technical report from a project to characterize chemical contaminants and assess linkages between contamination and coral condition. The first report quantified chemical contaminants in sediments from southwest Puerto Rico. This document summarizes the analysis of nearly 150 chemical contaminants in coral tissues. Although only eight coral samples were collected, some observations can be made on the correlations between observed tissue and sediment contaminant concentrations. The concentrations of polycyclic aromatic hydrocarbons (PAHs), typically associated with petroleum spills and the

combustion of fossil fuels, and polychlorinated biphenyls (PCBs) in the coral tissues were comparable to concentrations found in adjacent sediments. However, the concentration of a chemical contaminant (e.g., PAHs) in the coral tissues at a particular site was not a good predictor of what was in the adjacent sediments. In addition, the types of PAHs found in the coral tissues were somewhat different (higher ratios of alkylated PAHs) than in sediments. The levels of PCBs and DDT in coral tissues appeared higher just outside of Guanica Bay, and there was evidence of a downstream concentration gradient for these two contaminant classes. The trace elements copper, zinc and nickel were frequently detected in coral tissues, and the concentration in the corals was usually comparable to that found in adjacent sediments. Chromium was an exception in that it was not detected in any of the coral tissues analyzed. Additional work is needed to assess how spatial patterns in chemical contamination affect coral condition, abundance and distribution.

Available at: http://ccma.nos.noaa.gov/publications/nccostechmemo91.pdf

Pait, A.S., D.R. Whitall, C.F.G. Jeffrey, C. Caldow, A.L. Mason, J.D. Christensen. 2008. Chemical contamination in southwest Puerto Rico: An assessment of organic contaminants in nearshore sediments. Marine Pollution Bulletin 56(3): 580-587.

Organic chemical contaminants were quantified in sediments of southwest Puerto Rico as part of a larger project to assess linkages between contaminants and coral reef ecosystem condition. The study area included the nearshore waters adjacent to the town of La Parguera and east to Guanica Bay. Surficial sediments were collected and analyzed from 43 sites. Overall, concentrations of organic contaminants in the study area were fairly low, with most sites below the national median values from NOAA's National Status and Trends (NS&T) Program. Elevated levels of contaminants were seen at the two sites sampled in Guanica Bay. Polycyclic aromatic hydrocarbons (PAHs) detected in the sediments were a mix of low and high molecular weight compounds. Concentrations of polychlorinated biphenyls (PCBs) and organochlorine pesticides were somewhat elevated adjacent to the town of La Parguera. At the sites in Guanica Bay, the Effects Range-Median (ERM) concentration was exceeded for total PCBs.

Keywords: southwest Puerto Rico, La Parguera, organic contaminants, PAHs, PCBs

Available at: http://www.sciencedirect.com

Pait, A.S., Whitall, D.R., Jeffrey, C.F.G., Caldow, C., Mason, A.L., Lauenstein, G.G. and Christensen, J.D. 2008. Chemical contamination in southwest Puerto Rico: An assessment of trace and major elements in nearshore sediments. Marine Pollution Bulletin 56(11): 1949-1956.

This paper presents a spatial characterization of trace and major elements in the 35 sediments adjacent to coral reefs and hardbottom substrates in southwest Puerto Rico. Overall, the levels of trace and major elements in the sediments were fairly low. A pattern seen in the study area included higher concentrations of trace elements in the embayments and behind the emergent reefs, while offshore sites tended to have lower concentrations. Sediment concentrations of chromium, nickel and copper were below the

NS&T national median in most of the sediment samples taken in the study area. At the two sites sampled in Guanica Bay, levels of both chromium and nickel were above the ERM value for these trace elements, indicating they may be having adverse impacts on biota. The results presented provide important baseline information that can be used to assess future changes in contaminants in the study area, and ultimately to begin to understand linkages between contaminants and coral reef condition in southwest Puerto Rico.

Keywords: southwest Puerto Rico, La Parguera, trace elements, metals, coral reef ecosystems, pollution

Available at: http://www.sciencedirect.com

Pittman, S.J., C. Caldow, S. Davidson Hile, and M.E. Monaco. 2006. Explaining patterns in abundance of juvenile fish using Caribbean mangroves: a multi-scale seascape approach. First International Symposium on Mangroves as Fish Habitat. Poster Presentation, Miami, Florida, April 19-21, 2006.

Mangroves are often considered an important resource for many species of fish, supporting high densities of juveniles including many commercially important species. Typically, these species use mangroves as part of a chain of interlinked resources through daily home ranges and to support developmental shifts ("ontogenetic stepping stones"). Considerable spatial variability is found in the patterns of abundance from one area to another. This study applies a landscape ecology approach to explore the influence of seascape composition on the abundance of fish using mangroves in southwestern Puerto Rico. We quantified within-patch structure (1 m^2 quadrat) and seascape structure (50, 100, 300, 500 m) using landscape metrics applied to NOAA's benthic habitat map. Results indicate that the amount of seagrass surrounding mangroves explains more of the variability in fish abundance than fine-scale mangrove structure. Fish community composition is significantly different in mangroves with high adjacent seagrass cover than mangroves with little or no seagrass cover. This has important implications for resource protection, restoration efforts, and water quality management.

Poster presentation available at:
http://ccma.nos.noaa.gov/publications/biogeography/mangrove_poster_Man-Sym.pdf

Pittman, S.J., C. Caldow, S.D. Hile, and M.E. Monaco. 2007. Using seascape types to explain the spatial patterns of fish in the mangroves of SW Puerto Rico. Marine Ecology Progress Series 348: 273-284.

Many of the most abundant fish species using mangroves in the Caribbean also use other habitat types through daily home range movements and ontogenetic habitat shifts. Few studies, however, have considered the structure of the surrounding seascape when explaining the spatial distribution of fish within mangroves. This study develops an exploratory seascape approach using the geographical location of mangroves and the structure of the surrounding seascape at multiple spatial scales to explain the spatial patterns in fish density and number of species observed within mangroves of SW Puerto Rico. Seascape structure immediately surrounding mangroves was most influential in

determining assemblage attributes and the density of juvenile *Haemulon flavolineatum*, which were significantly higher in mangroves with high seagrass cover (>40%) in close proximity (<100 m) than mangroves with low (<40%) or no adjacent seagrasses. Highest mean density of juvenile *Ocyurus chrysurus* was found in offshore mangroves, with high seagrass and coral reef cover (>40 and >15%, respectively) in close proximity (<100 m). In contrast, juvenile *Lutjanus griseus* responded at much broader spatial scales, and with highest density found in extensive onshore mangroves with a large proportion (>40%) of seagrass within 600 m of the mangrove edge. We argue that there is an urgent need to incorporate information on the influence of seascape structure into a wide range of marine resource management activities, such as the identification and evaluation of critical or essential fish habitat, the placement of marine protected areas and the design of habitat restoration projects.

Keywords: Seascape structure, Mangroves, Seagrasses, Coral reef ecosystems, Spatial scale, Fish, Puerto Rico, Caribbean

Available at:
http://uvi.academia.edu/documents/0023/3835/Pittmanetal2007b_MEPS.pdf

Pittman, S.J., J.D. Christensen, C. Caldow, C. Menza, and M.E. Monaco. 2007. Predictive mapping of fish species richness across shallow-water seascapes in the Caribbean. Ecological Modelling 204: 9-21.

Effective management of coral reef ecosystems requires accurate, quantitative and spatially explicit information on patterns of species richness at spatial scales relevant to the management process. We combined empirical modelling techniques, remotely sensed data, field observations and GIS to develop a novel multi-scale approach for predicting fish species richness across a compositionally and topographically complex mosaic of marine habitat types in the U.S. Caribbean. First, the performance of three different modelling techniques (multiple linear regression, neural networks and regression trees) was compared using data from southwestern Puerto Rico and evaluated using multiple measures of predictive accuracy. Second, the best performing model was selected. Third, the generality of the best performing model was assessed through application to two geographically distinct coral reef ecosystems in the neighbouring U.S. Virgin Islands. Overall, regression trees outperformed multiple linear regression and neural networks. The best performing regression tree model of fish species richness (high, medium, low classes) in southwestern Puerto Rico exhibited an overall map accuracy of 75%; 83.4% when only high and low species richness areas were evaluated. In agreement with well recognized ecological relationships, areas of high fish species richness were predicted for the most bathymetrically complex areas with high mean rugosity and high bathymetric variance quantified at two different spatial extents (≤0.01 km^2). Water depth and the amount of seagrasses and hard-bottom habitat in the seascape were of secondary importance. This model also provided good predictions in two geographically distinct regions indicating a high level of generality in the habitat variables selected. Results indicated that accurate predictions of fish species richness could be achieved in future studies using remotely sensed measures of topographic complexity alone. This integration of empirical modelling techniques with spatial technologies provides an important new tool in support of ecosystem-based management for coral reef ecosystems.

Keywords: Bathymetric complexity, Coral reef ecosystems, Caribbean, Fish species richness, Predictive modeling, Seascape structure

Available at:
http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VBS-4MYMP45-2&_user=3615566&_coverDate=05%2F24%2F2007&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1366918597&_rerunOrigin=google&_acct=C000060967&_version=1&_urlVersion=0&_userid=3615566&md5=b40c355fab1e4a1030875efb4b7c7b04

Pittman, S.J., B. Costa, and T. Battista. 2009. Using Lidar bathymetry and boosted regression trees to predict the diversity and abundance of fish and corals. J. Coast. Res. S53: 27-38.

Coral reef ecosystems are topographically complex environments and this structural heterogeneity influences the distribution, abundance and behavior of marine organisms. Airborne hydrographic lidar (Light Detection and Ranging) provides high resolution digital bathymetry from which topographic complexity can be quantified at multiple spatial scales. To assess the utility of lidar data as a predictor of fish and coral diversity and abundance, seven different morphometrics were applied to a 4 m resolution bathymetry grid and then quantified at multiple spatial scales (i.e., 15, 25, 50, 100, 200 and 300 m radii) using a circular moving window analysis. Predictive models for nineteen fish metrics and two coral metrics were developed using the new statistical learning technique of stochastic gradient boosting applied to regression trees. Predictive models explained 72% of the variance in herbivore biomass, 68% of parrotfish biomass, 65% of coral species richness and 64% of fish species richness. Slope of the slope (a measure of the magnitude of slope change) at relatively local spatial scales (15-100 m radii) emerged as the single best predictor. Herbivorous fish responded to topographic complexity at spatial scales of 15 and 25 m radii, whereas broader spatial scales of between 25 and 300 m radii were relevant for piscivorous fish. This study demonstrates great utility for lidar-derived bathymetry in the future development of benthic habitat maps and faunal distribution maps to support ecosystem-based management and marine spatial planning.

Keywords: Topographic complexity, terrain morphometrics, seascapes, predictive modeling, fish species richness, spatial scale, Puerto Rico

Available at: http://www.bioone.org/doi/pdf/10.2112/SI53-004.1

Pittman, S.J., S.D. Hile, C.F.G. Jeffrey, R. Clark, K. Woody, B.D. Herlach, C. Caldow, M.E. Monaco, R. Appeldoorn. 2010. Coral reef ecosystems of Reserva Natural La Parguera (Puerto Rico): Spatial and temporal patterns in fish and benthic communities (2001-2007). NOAA Technical Memorandum NOS NCCOS 107. Silver Spring, MD. 202 pp.

The report provides a spatial and temporal characterization of the fish and benthic communities of southwestern Puerto Rico, primarily within the La Parguera Natural Reserve. The reserve is a multi-use area that spans the continental shelf from the extensive mangrove forests fringing the shoreline to the complex shelf edge coral reefs that support a diverse and productive fish community. The coral reef ecosystem of La

Parguera supports a locally important fishery, as well as recreational activities such as boating, snorkeling and diving. The data and synthesis in this report are intended to provide essential baseline biological information to support future management decision making. The project is a component of NOAA's Caribbean Coral Reef Ecosystem Monitoring (CREM) project of NOAA's Coral Reef Conservation Program (CRCP) and was conducted through an ongoing multi-agency collaboration between NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch (CCMA-BB), the University of Puerto Rico and the Puerto Rico Government's Department of Natural and Environmental Resources (DNER).

Available at: http://ccma.nos.noaa.gov/news/feature/laparguera.html

Zitello, A.G., D.R. Whitall, A. Dieppa, J.D. Christensen, M.E. Monaco and S.O. Rohmann. 2008. Characterizing Jobos Bay, Puerto Rico: A Watershed Modeling Analysis and Monitoring Plan. NOAA Technical Memorandum NOS NCCOS 76. 81 pp.

This characterization of Jobos Bay, Puerto Rico represents a progress report on an ongoing partnership between the U.S. Department of Agriculture (USDA) and the National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment (CCMA). The Conservation Effects Assessment Project (CEAP) Special Emphasis Watershed at Jobos Bay originated from a long-standing collaboration between NOAA and USDA on the U.S. Coral Reef Task Force. The objective of this cooperative effort is to quantify the environmental effects of agricultural conservation practices on coral reef ecosystems. The Jobos Bay watershed was chosen because it has a large percentage of agricultural land use and is host to a NOAA National Estuarine Research Reserve (NERR). With the assistance of Jobos Bay NERR staff, USDA and NOAA continue to conduct *in situ* monitoring efforts on the watershed and in the estuary that will enhance the understanding of ecosystem responses to conservation practices. The report consists of two components: a discussion of sediment and pollutant predictions in the Jobos Bay watershed from a spatially-explicit modeling approach; and a description of the monitoring efforts conducted by NOAA in the estuary. The watershed modeling analysis provides an initial screening of areas on the landscape that may exert the greatest stress on the coral reef ecosystem from sedimentation and pollution. The monitoring plans described in this report will be carried out before and after conservation practices are implemented on the watershed. The results will allow USDA and NOAA to assess the effectiveness of selected conservation practices and make recommendations for other agricultural operations in tropical regions.

Available at: http://ccma.nos.noaa.gov/publications/CEAPHiRes.pdf

Web Sites of CCMA projects that support identification of EFH in Puerto Rico:

Caribbean Essential Fish Habitat by Kendall
http://ccma.nos.noaa.gov/products/biogeography/efh/carib-efh/index.shtml

Seafloor Characterization of the U.S. Caribbean
http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_nps.html

Caribbean Coral Reef Ecosystem Monitoring Project
http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish.html

Coral Reef Ecosystem Studies (CRES) — U.S. Caribbean Component
http://ccma.nos.noaa.gov/ecosystems/coralreef/cres.html

An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico
http://ccma.nos.noaa.gov/ecosystems/coralreef/vieques.html

United States Department of Commerce

Gary Locke
Secretary

National Oceanic and Atmospheric Administration

Jane Lubchenco
Undersecretary of Commerce for Oceans and Atmosphere and Administrator

National Ocean Service

David Kennedy
Acting Assistant Administrator