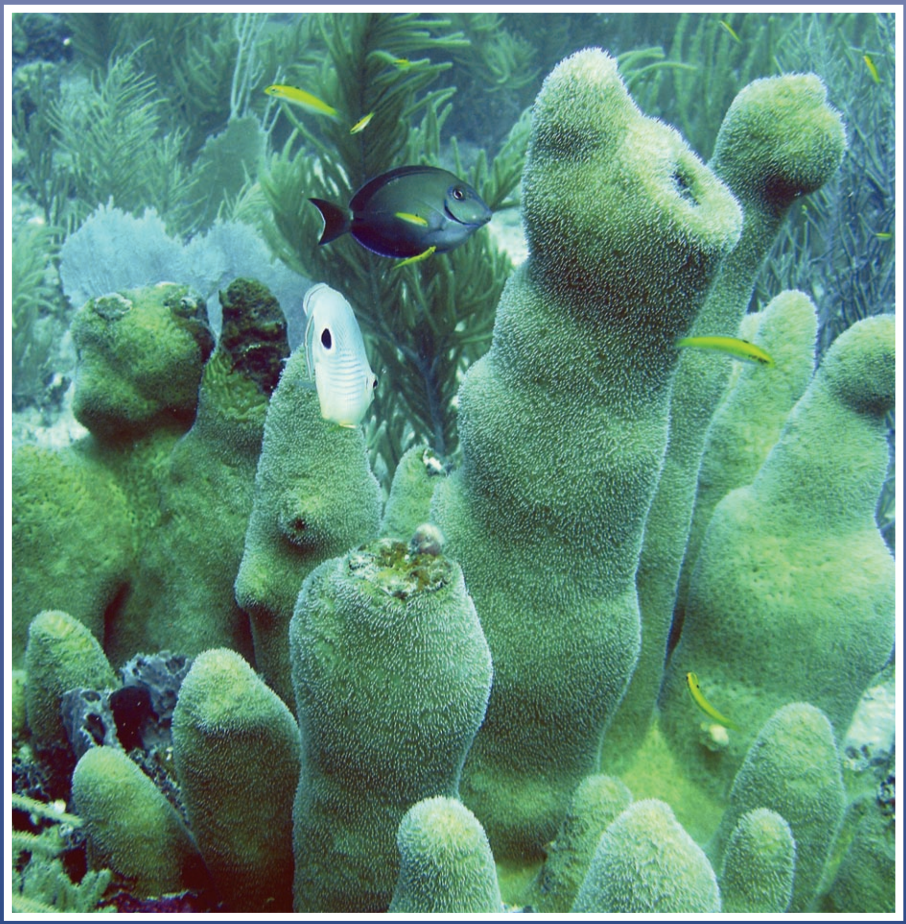
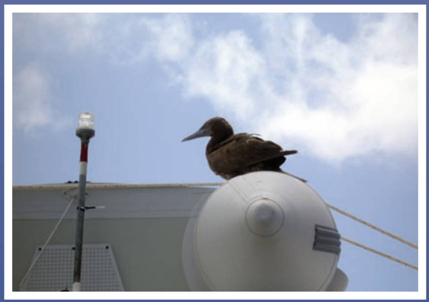
An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico

Part I: Historical Data Synthesis

by
Laurie J. Bauer, Charles Menza, Kimberly A. Foley, and Matthew S. Kendall
NOAA/NOS/NCCOS/CCMA Biogeography Branch
November 2008





NOAA Technical Memorandum NOS NCCOS 86
In Partnership with NOAA's Office of Response and Restoration

Citation:

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. Prepared by National Centers for Coastal Ocean Science (NCCOS) Biogeography Branch in cooperation with the Office of Response and Restoration. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 86. 121 pp.

An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico
Part I: Historical Data Synthesis

Biogeography Branch
Center for Coastal Monitoring and Assessment (CCMA)
NOAA/NOS/National Centers for Coastal Ocean Science
1305 East-West Highway (SSMC-4, N/SCI 1)
Silver Spring, MD 20910

NOAA Technical Memorandum NOS NCCOS 86

November 2008

Authors:
Laurie J. Bauer
Charles Menza
Kimberly A. Foley
Matthew S. Kendall

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Carlos M. Gutierrez Secretary	Conrad C. Lautenbacher, Jr. Administrator	John H. Dunnigan Administrator

ABOUT THIS DOCUMENT

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 (COAST) Branch. This work will build upon previous efforts by presenting new data on benthic habitats, assocated 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.

Funding for this project was provided by NOAA's Office of Response and Restoration, Coral Reef Conservation Program, and Center for Coastal Monitoring and Assessment. For more information on this work and other Biogeography Branch projects, please see:

http://ccma.nos.noaa.gov/about/biogeography/
and
http://ccma.nos.noaa.gov/ecosystems/coralreef/vieques.html

Direct questions or comments to:

Mark E. Monaco, Ph.D.
Biogeography Branch Lead
National Oceanic and Atmospheric Administration
1305 East West Highway
SSMC4, N/SCI-1
Silver Spring, MD 20910
Phone: (301) 713-3028 x160

EXECUTIVE SUMMARY

From the 1940s until 2003, portions of the island of Vieques, a municipality within the Commonwealth of Puerto Rico, were used by the US Navy as a base and training facility, resulting in development and zoning history that differ in comparison to other Caribbean islands. The majority of former Navy lands are now under the jurisdiction of the Department of the Interior's Fish and Wildlife Service as a National Wildlife Refuge, while a smaller percentage of land was transferred to the Vieques municipality and the Puerto Rico Conservation Trust. An analysis of the distribution and status of the marine resources is timely in light of the recent land transfer, increases in development and tourism, and potential changes in marine zoning around the island. To meet this need, NOAA's Biogeography Branch, in cooperation with the Office of Response and Restoration and other local and regional partners, conducted Part I of an ecological characterization to integrate historical data and research into a synthesis report. The overall objective of this report is to provide resource managers and residents a comprehensive characterization of the marine resources of Vieques to support research, monitoring, and management. For example, knowledge of the spatial distribution of physical features, habitats, and biological communities is necessary to make an informed decision of the establishment and placement of a marine protected area (MPA).

Image. Indigo hamlet (*Hypoplectrus indigo*) and other reef fish. Photo: Biogeography Branch.

The report is divided into chapters based on the physical environment (e.g., climate, geology, bathymetry), habitat types (e.g., reefs and hardbottom, seagrasses, mangroves) and major faunal groups (e.g. fish, turtles, birds). Each section includes five subsections: an overview, description of the relevant literature, methods of analysis, information on the distribution, status and trends of the particular resource, and a discussion of ecological linkages with other components of the Vieques marine ecosystem and surrounding environment.

The physical environment of Vieques is similar to other islands within the Greater Antilles chain, with some distinctions. The warm, tropical climate of Vieques, mediated by the northeasterly trade winds, is characterized by a dry season (December-April) and a rainy season (May-November), the latter of which is characterized by the occasional passage of tropical cyclones. Compared to mainland Puerto Rico, Vieques is characterized by lower elevation, less annual precipitation, and higher average temperatures. The amount of annual precipitation also varies spatially within Vieques, with the western portion of the island receiving higher amounts of rainfall than further east. While the North Equatorial Current dominates the circulation pattern in the Greater Antilles region, small scale current patterns specific to Vieques are not as well characterized. These physical processes are important factors mitigating the distribution and composition of marine benthic habitats around Vieques.

In general, the topography of Vieques is characterized by rolling hills. Mt. Pirata, the tallest point at 301 m, is located near the southwest coast. In the absence of island wide sedimentation measurements, information on land cover, slope, precipitation, and soil type were used to estimate relative erosion potential and sediment delivery for each watershed. While slope and precipitation amount are the primary driving factors controlling runoff, land use practices such as urban development, military activity, road construction, and agriculture can increase the delivery of pollution and sediments to coastal waters. Due to the recent land transfer, increased development and tourism is expected, which may result in changes in the input of sediments to the coastal environment.

North of Vieques, the bathymetry is generally uniform and shallow (<30 m), while the south and east coasts are characterized by a shelf slope dropoff that is closer to shore. The south coast includes numerous lagoons and embayments, including two bioluminescent bays (Puerto Ferro and Puerto Mosquito).

Principal marine habitats around Vieques include coral reefs and hardbottom, submerged vegetation (seagrass and algae), and mangroves. The most recent benthic habitat map of Vieques includes 72 km^2 of mapped reef and hardbottom, about 80% of which is located offshore of former military areas. The south side of the island contains about twice the amount of mapped reef/hardbottom habitat as the north side. Recent surveys conducted offshore of civilian and former military areas have identified approximately 50 species of coral. Although long-term reef monitoring studies are lacking, there are indications that Vieques reefs have experienced a decline in coral cover, especially *Acropora sp.*, in recent decades. The effect of military activity on

Vieques reefs has been subject to debate and the extent of damage from bombing and training purposes has not been thoroughly quantified. Other potential stresses to coral health include damage from hurricanes, coral bleaching, and diseases.

The nearshore (within 3 nautical miles) waters of Vieques include ~116 km^2 of mapped submerged aquatic vegetation habitat, approximately two-thirds of which is seagrass. The most extensive stretch of seagrass habitat is located in the shallow region along the north and northwest coasts and extends west to the main island of Puerto Rico. Additional seagrass areas are located in the bays, lagoons, and coastal areas on the south shore. Seagrass beds may include a mix of species *Thalassia testudinum*, *Halodule wrightii*, *Syringodium filiforme*, and *Halophila decipiens* and are usually intermixed with macroalgae.

Mangrove forests are distributed throughout Vieques for a total of 4.4 km^2. Locations with the largest areal coverage include lagoons on the northwest tip and the bays of the south coast, including the Bioluminescent Bays of Puerto Mosquito and Puerto Ferro. While comparisons with previous mapping efforts indicate that some areas have experienced a decline in mangrove coverage, overall losses appear to be less than in mainland Puerto Rico and elsewhere in the Caribbean. Anthropogenic threats to healthy mangrove systems in Vieques include sedimentation from upland erosion, construction of roads that bisect mangrove habitat, and blockage of outlets of mangrove lined bays to the ocean.

The fish community of Vieques is diverse and is similar to communities found around the main island of Puerto Rico and the US Virgin Islands. Much of the available fish data for Vieques were collected by the military or its contractors on shallow reefs, although recent investigations have included previously less-studied areas such as the western side of the island and seagrass and lagoon habitats. These studies identified many species not previously reported in Vieques, documented differences among fish assemblages in diverse habitat types and identified important habitats for the Vieques fisheries.

Vieques has a mixed fishery comprised of commercial, recreational and subsistence segments. Fishery datasets for reef fish, conch, and spiny lobster show high variability among landings, landing values and number of fishermen and no clear temporal patterns. Occurrence of two commercially important species, spiny lobster (*Panulirus argus*) and conch (*Strombus gigas*) was low in recent biological assessments. However, data on the spatial distribution of most invertebrate species is presently inadequate.

Four species of sea turtles are found within the territorial and federal waters surrounding Vieques: green (*Chelonia mydas)*, hawksbill (*Eretmoshelys imbricata*), loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*). All but loggerhead sea turtles regularly nest on the beaches of Vieques, but the island is not considered a major nesting ground. The greatest densities of sea turtles sighted around the island are observed near Mosquito Pier, off the eastern and western shores, and close to Sun Bay (Ensendada Sombe). While nesting beaches are distributed over much of the island, the greatest densities of turtle species and nests are found on a few beaches, particularly on the eastern end of the island in the undeveloped lands formerly owned by the Navy.

Eight species of marine mammals have been identified around Vieques, including dolphins, whales, and the West Indian manatee. Few data exist on the abundance and distribution of cetaceans around Vieques, while several studies have provided information on the spatial distribution and environmental factors which affect manatees. The greatest densities of manatees occur in the area northwest of Vieques in the lee of Mosquito Pier and along the south coast near protected bays.

At least 16 species of seabirds are known to occur on Vieques. Much of the available information is concentrated on the Caribbean Brown Pelican (*Pelicanus occidentalis*) and the Roseate Tern (*Sterna dougalli*). Several major seabird nesting, roosting, and feeding sites have been identified, including Cayo Conejo, <0.5 km off of the southeast coast. This nesting site comprises the majority of the nesting pelican population in all of Puerto Rico.

Where research has been deficient, gaps in data collection and future research needs were identified. The recent departure of the Navy will likely result in changes in land development, tourism, and the existing marine zoning, all of which have the potential to impact the marine resources of Vieques. This document, in combination with Part II of this assessment, will serve as a foundation with which to monitor future changes.

RESUMEN EJECUTIVO

Desde los 1940's hasta el 2003, secciones de la isla de Vieques, una municipalidad del Territorio de Puerto Rico que fue utilizada por la marina Estadounidense como base y sede de entrenamiento, lo cual resultó en una baja urbanización e incluso en una historia especial y muy diferente en comparación con otras islas del Caribe. La mayoría de las antiguas tierras de la Marina están ahora bajo la jurisdicción del Servicio de Pesca y Vida Silvestre del Departamento del Interior y son un Refugio Nacional de Vida Silvestre, mientras que un menor porcentaje de tierras fue transferido a la Municipalidad de Vieques y al Fideicomiso de Conservación de Puerto Rico. Un análisis de la distribución y estado de los recursos marinos es oportuno dada la reciente transferencia de tierras, el aumento en la construcción y el turismo, y el potencial de establecer áreas marinas protegidas (AMP) alrededor de la isla. Para responder a esta necesidad, la sección de Biogeografía de NOAA, en cooperación con la Oficina de Respuesta y Restauración y otros socios locales y regionales condujeron una primera caracterización ecológica en un reporte que integra además datos históricos e investigaciones previas. El objetivo general de este reporte es el proveer a los manejadores de recursos y residentes una caracterización detallada de los recursos marinos de la isla de Vieques como base para futura investigación, monitoreo y manejo. Por ejemplo, el conocimiento de la distribución espacial de su fisiografía, hábitats y comunidades biológicas es necesario para hacer decisiones informadas acerca del establecimiento y localización de AMPs.

El reporte está dividido en capítulos que tratan el ambiente físico (clima, geología, batimetría), tipos de hábitats (arrecifes y fondos duros, pastos marinos, manglares), y grupos fáusticos importantes (peces, tortugas y aves). Cada sección incluye cinco subsecciones: un resumen, una descripción de la literatura relevante, métodos de análisis, información de la distribución, estado y tendencias de los recursos estudiados, y una discusión de las relaciones ecológicas otros ecosistemas marinos y ambientes circundantes.

El ambiente bio-fisico de Vieques es similar al de otras islas de las Antillas Mayores con algunas particularidades. El clima cálido tropical de Vieques, influenciado por los vientos del noreste, se caracteriza por una estación seca (Diciembre-Abril) y una estación lluviosa (Mayo-Noviembre), este último afectado por el paso ocasional de ciclones tropicales. Comparado frente a la isla mayor de Puerto Rico, Vieques se caracteriza por su baja elevación y temperaturas promedio más elevadas. La cantidad anual de precipitación varía espacialmente en Vieques, con su porción oeste recibiendo mayores cantidades de lluvia que la otra porción este. La Corriente Ecuatorial Norte domina los patrones de circulación en la región de las Antillas Mayores, pero patrones de corrientes a menor escala específicos de Vieques no son del todo conocidos. Estos son dos procesos físicos que influyen en la distribución y composición de los hábitats bénticos alrededor de Vieques.

En general, la topografía de Vieques está caracterizada por colinas con el Monte Pirata, localizado cerca de la costa suroeste, siendo el punto más alto con 301 metros. Ante la falta de mediciones de sedimentación, información sobre la cobertura de suelo, pendientes, precipitación y tipo de suelo fueron usados para estimar el potencial relativo de erosión y la cantidad de aportes de sedimentos en cada cuenca. Mientras las pendientes y precipitación actúan como fuerzas primarias de las escorrentías, el uso del suelo y el desarrollo urbano, la actividad militar, la construcción de vías y la agricultura pueden incrementar la cantidad de sedimentos que llegan a la zona costera. Se espera que se den mayores construcciones y turismo dada la reciente transferencia de tierras, y que estas puedan generar cambios en los aportes de sedimentos en los ambientes costeros.

Hacia el norte de Vieques la batimetría es generalmente uniforme y somera (<30 m), pero el sur y este tienen una plataforma con pendiente pronunciada muy cerca de la costa. La costa sur incluye numerosas lagunas y bahías, incluyendo dos bio-luminiscentes (Puerto Ferro y Puerto Mosquito).

Los principales hábitats marinos alrededor de Vieques incluyen arrecifes de coral y fondos duros, vegetación sumergida (pastos marinos y algas) y manglares. El mapa más reciente de hábitats bénticos de Vieques incluye 72 km^2 de áreas cartografiadas con corales y fondos duros, con cerca del 80% localizados afuera de las antiguas zonas militares. El costado sur de la isla contiene cerca del doble de corales y fondos duros comparado con el costado norte. Estudios recientes realizados tanto en antiguas zonas militares marinas como en zonas civiles han identificado aproximadamente 50 especies de coral. A pesar de no tener monitoreos de largo plazo, hay indicaciones que los arrecifes de Vieques han reducido su cobertura de coral vivo, especialmente de *Acropora sp*. en décadas recientes. El efecto de las actividades militares sobre los arrecifes de Vieques ha sido debatido, pero la extensión del daño de los bombardeos y los entrenamientos no han sido cuantificados rigurosamente. Otros tensores potenciales incluyen los daños y alteraciones a la salud del arrecife causado por huracanes, blanqueamiento y otras enfermedades.

Dentro de las primeras 3 millas náuticas, las aguas de Vieques incluyen ~116 km^2 de hábitats de vegetación acuática, con aproximadamente dos terceras partes de pastos marinos. El rodal más extenso de pastos marinos se encuentra en la región somera del norte-noreste y se extiende al oeste hasta la isla principal de Puerto Rico. Áreas adicionales de pastos están en bahías, lagunas y zonas costeras de la costa sur. Las praderas de pastos marinos tienen seis especies *Thalassia testudinum*, *Halodule wrightii*, *Syringodium filiforme*, y *Halophila decipiens* mezcladas con macroalgas.

Los manglares de Vieques ocupan un área de 4.4 km^2. Las áreas con mayor cobertura de manglar incluyen las lagunas de la punta nor-oeste y las bahías del sur, incluyendo las bio-luminiscentes de Puerto Mosquito y Puerto Ferro. Comparado con mapas anteriores, los manglares parecen estables, con pérdidas menores al 1%, aunque algunas áreas específicas pueden tener mayores reducciones. Las amenazas antropogénicas a la salud de los manglares en Vieques incluyen sedimentación de tierras altas, construcción de vías los atraviesan y el taponamiento de los canales que los comunican con las bahías y el océano.

La comunidad de peces de Vieques es diversa y similar a otras encontradas en las islas de Puerto Rico y las Islas Vírgenes Americana. Mucha de la información de peces para Vieques fue tomada por los militares o sus contratistas en los arrecifes someros, aunque estudios recientes se han extendido a otras áreas poco estudiadas del costado oeste de la isla y de los hábitats de pastos marinos y lagunas. Estos estudios han hecho muchos nuevos registros, documentado diferencias entre las asociaciones de especies en hábitats diversos y localizado hábitats importantes para las pesquerías de Vieques.

Vieques tiene una pesquería multi-específica de especies comerciales, recreacionales y de subsistencia. Series de datos pesqueros de peces arrecifales, carrucho y langosta espinosa muestran gran variabilidad en los desembarcos, números de pescadores y no tienen tendencias claras. Hay dos pesquerías importantes, la langosta espinosa (*Panulirus argus*) y el carrucho (*Strombus gigas*) pero que mantienen bajas abundancias de acuerdo a análisis poblacionales recientes. Los datos de la distribución espacial de la mayoría de los invertebrados es desconocida en la actualidad.

Cuatro especies de tortugas se encuentran en las aguas territoriales y federales alrededor de Vieques: verde (*Chelonia mydas*), carey (*Eretmoshelys imbricata*), cabezona (*Caretta caretta*) y el tinglar (*Dermochelys coriacea*). Con excepción de la cabezona, todas las tortugas anidan regularmente en las playas de Vieques, a pesar de que la isla no es considerada como un sitio de desove destacado. Las mayores densidades de avistamientos de tortugas han sido observadas cerca del muelle Mosquito, afuera de las playas del este y el oeste y cerca de Ensenada Sombe. Las playas de anidaje están a lo largo de la isla, pero las que tienen mayor densidad de especies y de nidos están pocas playas, particularmente aquellas del la punta este de la isla en tierras sin desarrollos, antiguamente pertenecientes a la Marina.

Ocho especies de mamíferos marinos han sido reportadas alrededor de Vieques, incluyendo delfines, ballenas y el manatí del oeste. Se tiene poca información sobre la abundancia y distribución de los cetáceos en Vieques, pero varios estudios han reportado la distribución espacial y los factores ambientales que afectan los manatíes. Las máximas densidades de manatíes ocurren en el noroeste de Vieques en el costado protegido del muelle Mosquito y a lo largo de la costa sur cerca de bahías protegidas.

Al menos 16 especies de aves marinas se saben ocurren en Vieques. Mucha de la información disponible está concentrada en el pelicano café caribeño (*Pelicanus occidentalis*) y la gaviota roseate (*Sterna dougalli*). Se han localizado sitios importantes como zonas de anidamiento, descanso y alimentación como el Cayo Conejo <0.5 km afuera del sureste de Vieques. Este sitio soporta la mayor colonia anidante de pelícanos en todo Puerto Rico.

Vacíos de información y necesidad de futuras investigaciones fueron identificadas. La reciente retirada de la Marina probablemente resultara en cambios en el desarrollo de las tierras, el turismo y la zonificación de las zonas marinas, todos ellos con el potencial de impactar los recursos marinos de Vieques. Este documento en combinación con la Parte II de esta investigación sentará las bases para monitorear los cambios futuros.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AFWTF – Atlantic Fleet Weapons Training Facility
ANOVA – Analysis of variance
ANOSIM – Analysis of similarity
ATG – Air-to-ground
ATSDR – Agency for Toxic Substances and Disease Registry
CA – Civilian Area
CCFHR – Center for Coastal Fisheries and Habitat Research
CCMA – Center for Coastal Monitoring and Assessment
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CFMC – Caribbean Fisheries Management Council
CITES – Convention on the International Trade in Endangered Species
COAST – Coastal Oceanographic Assessment, Status and Trends
CSC – Coastal Services Center
DNER – Department of Natural and Environmental Resources
DOI – US Department of the Interior
DON – US Department of the Navy
EMA – Eastern Maneuver Area
EQB – Environmental Quality Board
ESA – Endangered Species Act
FKNMS – Florida Keys National Marine Sanctuary
FWS – US Fish and Wildlife Service
GEODAS – GEOphysical Data System
GIS – Geographic Information System
GMI – Geo-Marine, Inc.
ICON – Integrated Coral Observing Network
km – Kilometers
kts – Knots
LIA – Live Impact Area
LIDAR – Light Detection and Ranging
m – Meters
mb – Millibars
NASD – Naval Ammunition Support Detachment
NCCOS – National Center for Coastal Ocean Science
NCDC – National Climate Data Center
NCRI – National Coral Reef Institute
NDBC – National Data Buoy Center
NDC – National Data Center
NEC – North Equatorial Current
nm – nautical miles
NMFS – National Marine Fisheries Service
NOAA – National Oceanic and Atmospheric Administration
NPL – National Priorities List
ORR – Office of Response and Restoration
PECA – Punta Este Conservation Area
PR – Puerto Rico
RAWS – Remote Automated Weather Station
ROMS – Regional Ocean Model System
ROTHR – Relocatable Over the Horizon Radar
SEDAR – Southeast Data, Assessment, and Review
SEFSC – Southeast Fishery Science Center
SRCC – Southeast Regional Climate Center
SST – Sea Surface Temperature
USDA – US Department of Agriculture
USVI – US Virgin Islands
VNWR – Vieques National Wildlife Refuge
WRI – World Resources Institute

CHAPTER 1: INTRODUCTION

The following report is Part I of a two-part series that provides an ecological characterization of the marine resources of Vieques, Puerto Rico. The overall objective of this work is to provide natural resource managers with a spatially comprehensive characterization of marine habitats and resources surrounding Vieques. As the first phase of this assessment, this document integrates previously existing data and descriptions from published reports and assessments into a synthesis report. In Part II, newly collected data on fish, benthic habitats, and contaminant concentrations in sediments and coral are analyzed and interpreted relative to the status of other nearby regions in the US Caribbean.

Vieques is an island municipality of the Commonwealth of Puerto Rico that is located approximately 11 km southeast of the main island of Puerto Rico in the Caribbean Sea (Figure 1.1). The island is approximately 35 km long and 7.2 km wide at its widest point with a land area of approximately 133.5 km^2. The island and surrounding waters are characterized by a diversity of terrestrial, estuarine, and marine habitats, including two of Puerto Rico's three bioluminescent Bays. The municipality includes two principal towns located on opposite sides of the mid-section of the island, Isabel Segunda on the north shore and Esperanza on the south coast. The 2000 Census estimated the population of the Vieques municipality at 9,106 (DOI 2007).

The history of human habitation and development in Vieques are unique compared to other islands in the Caribbean and are important factors when considering the present distribution and condition of the marine resources. Until the 1800s, Vieques was inhabited by native tribes and later by small Spanish, English, Dutch, and French settlements (Langhorne 1987). As Spain exerted greater control and colonization of the island in the early to mid-1800s, much of the land was cleared for sugar cane, and the sugar industry flourished into the early 1900s. Along with the rest of Puerto Rico, Vieques was ceded to the Unites States in 1898 following the Spanish-American War.

Between 1941 and 1947, the United States annexed approximately two-thirds of the land on Vieques for use by the Navy as a base and training facility (Figure 1.2). The Naval Ammunition Support Detachment (NASD), located on the west end of the island, was comprised of approximately 33 km^2 and was used primarily for storage of ammunition. The municipality of Vieques (Civilian Area; CA), including the towns of Isabel Segunda and Esperanza, lay between the NASD and eastern Navy zones. Going from west to east, the remaining Navy lands were the Eastern Maneuver Area (EMA), Atlantic Fleet Weapons Training Facility (AFWTF), and the Live Impact Area (LIA, formerly the Air Impact Area) for a total of approximately 59 km^2. A 0.5 km^2 conservation zone (Punta Este Conservation Area; PECA) lay at the very eastern tip of the island. Training activities conducted within the EMA, AFWTF, and LIA, collectively known as the "Inner Range," include air, sea, and maneuver warfare, air-to-ground (ATG) bombing, amphibious landings, and artillery training operations, among others. ATG activities were primarily localized to the LIA. Locations of amphibious assault training activities included Green Beach, Yellow Beach, Blue Beach, Red Beach, and Purple Beach. Detailed information about prior Naval activities in Vieques can be found in a number of sources (DON 1979; DON 1986; DON 2001; GMI 2003; CH2M HILL 2004; GMI 2005).

Naval activities ceased in 2003 as controversy over the Navy's presence in Vieques escalated. The 2008 distribution of land ownership is shown in Figure 1.3. In 2001, 17 km^2 of former Navy lands on western Vieques were transferred to the municipality, 3.2 km^2 to the Puerto Rico Conservation Trust, a private, non-governmental organization (http://www.fideicomiso.org), and 12.5 km^2 to the Department of the Interior (DOI 2007). The Navy retained about 0.4 km^2 for its Relocatable Over the Horizon Radar (ROTHR) facility. In 2003, the eastern Navy lands, totaling 59 km^2, were also transferred to the Department of the Interior. The lands under jurisdiction of the DOI's Fish and Wildlife Service make up the Vieques National Wildlife Refuge (Figure 1.3; DOI 2007). Public access is currently restricted in a large part of the eastern refuge lands due to remnant hazards from Naval activity (e.g. unexploded ordnance). In 2005, the former Navy areas of Vieques were added to the National Priorities List (NPL or "Superfund"), legislation which requires the Navy to undertake activities needed to identify and clean-up contaminated areas by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (Federal Register 7182-7189 2005).

Image 1.1. Esperanza harbor, Vieques. Photo: Biogeography Branch.

Prior marine zoning included two restricted areas, on the west and south sides of the island, and a "danger zone" which encompassed the east end of the island and includ-

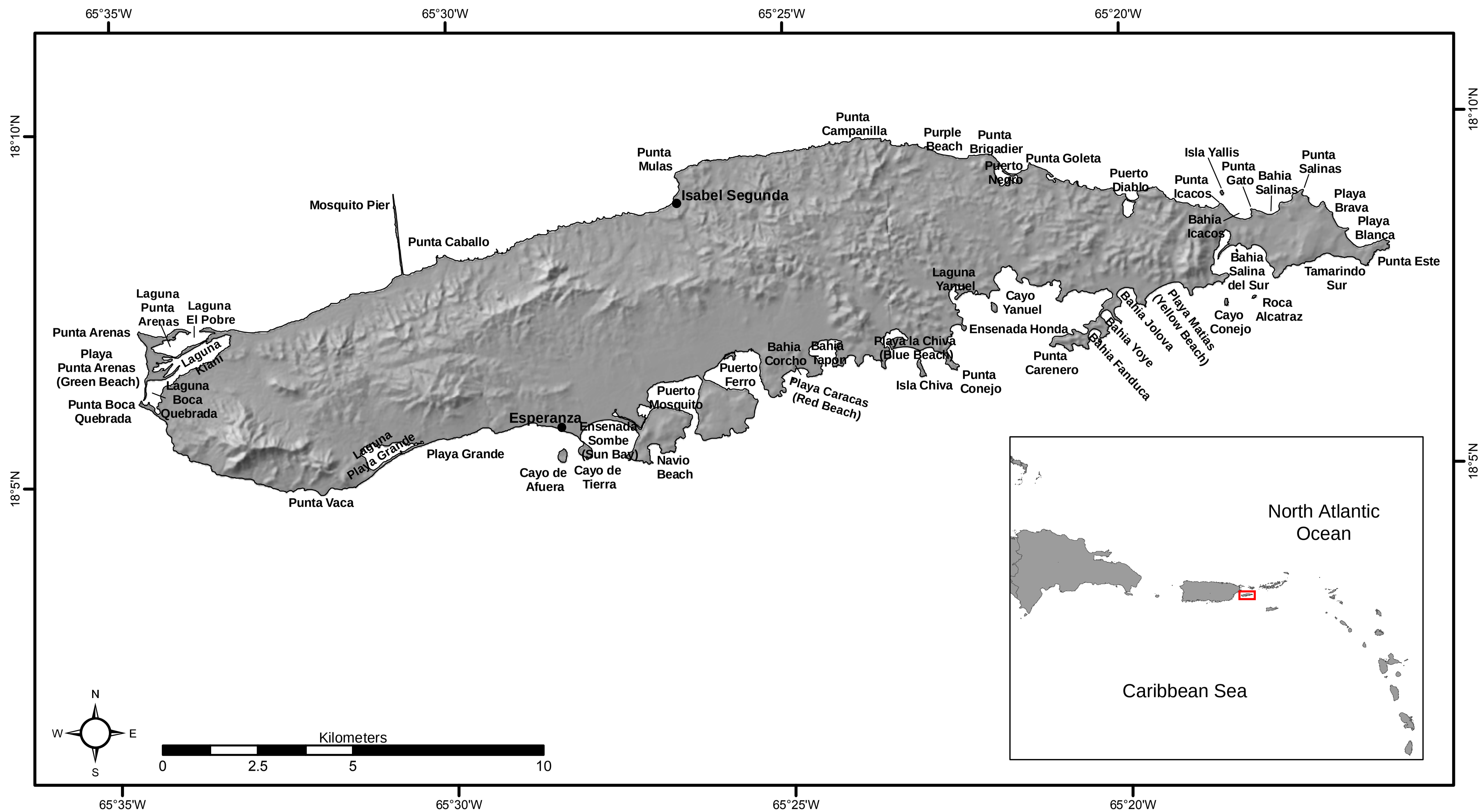


Figure 1.1. Location of Vieques, Puerto Rico. The digital elevation model (DEM) used here and throughout the document was adapted from NOAA's Summit-to-Sea database (NOAA and WRI 2006) and is a subset of the U.S. Geological Survey's National Elevation Dataset.

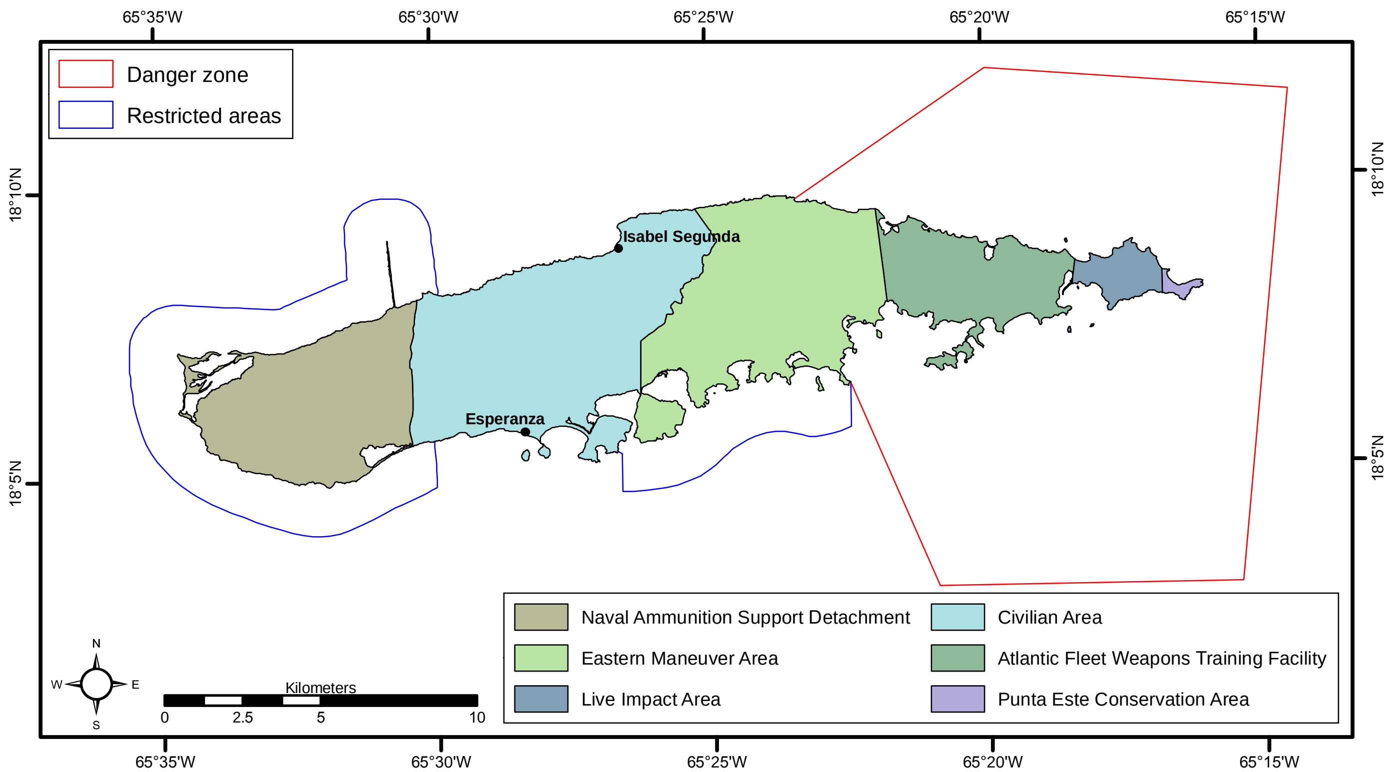


Figure 1.2. Former land ownership in Vieques from 1941 to land transfer in 2001 and 2003. Boundaries were provided by Geo-Marine, Inc.

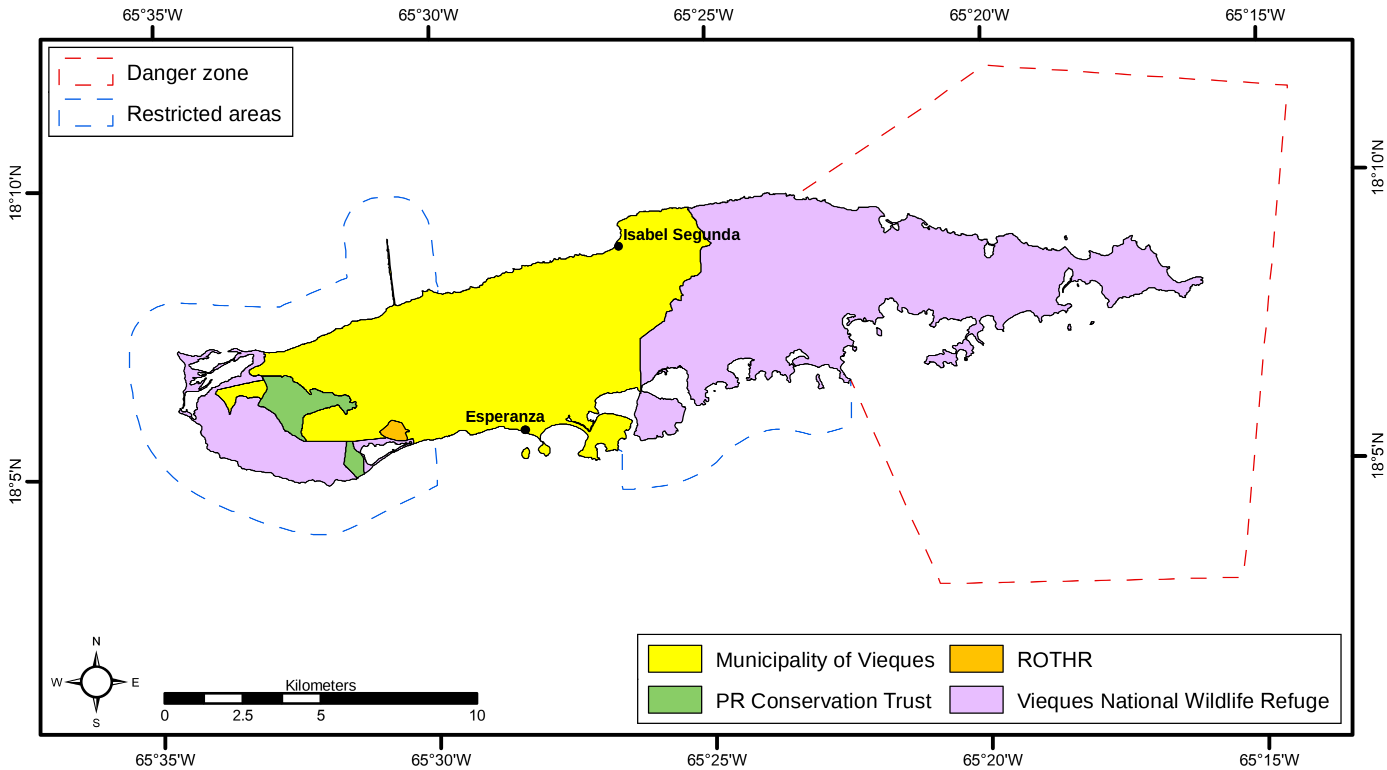


Figure 1.3. Land ownership distribution in Vieques as of 2008. Boundaries were provided by William Hernandez (US Fish and Wildlife Service). ROTHR= Relocatable Over the Horizon Radar.

ed the Live Impact Area (Figure 1.2). These areas were zoned with various levels of restricted access due to their uses and proximity to Navy activities (Code of Federal Regulations 2001a; Code of Regulations 2001b). The Danger Zone was open to navigation at all times except when firing and bombing practices were being conducted (Code of Federal Regulations 2001a). In the two restricted areas, access was prohibited at all times except for authorized personnel (Code of Federal Regulations 2001b). Although firing has ceased, the Navy is currently engaged in a Superfund program to remove all terrestrial unexploded ordnance (UXO) which often necessitates open detonation or "blow-in-place" of unexploded ordnance. Currently, access is mainly restricted to the LIA and PECA where most of the UXO safety concerns are located. As of 2008, there are no plans or authorized removal of underwater unexploded ordnance by the Navy (J. Noles, personal communicattion).

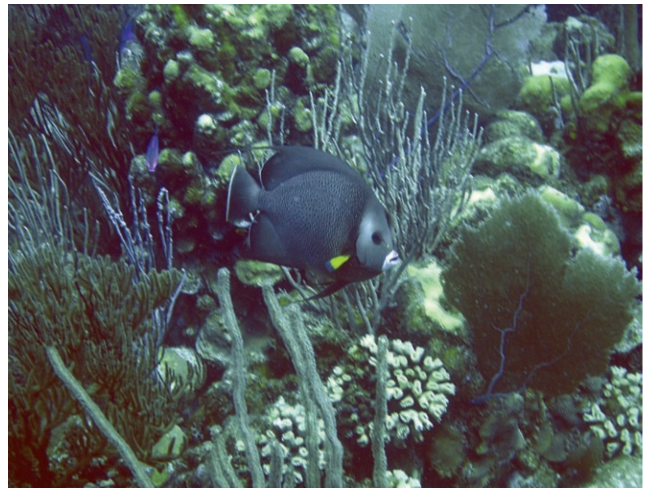


Image 2. Gray angelfish (*Pomacanthus arcatus*) amongst the Vieques coral reef ecosystem. Photo: Biogeography Branch.

A comprehensive report of the distribution and status of the marine resources of Vieques is timely in light of the recent land transfer, increases in development and tourism, and potential changes in marine zoning around the island. Within the last three decades, numerous reports have been published on the terrestrial and marine resources of Vieques. These reports include Environmental Impact Statements (e.g. DON 1979; DON 1986) and other studies commissioned by the Navy (e.g., GMI 2003). Accordingly, of the prior studies, most effort was devoted to Navy-occupied areas in order to evaluate and observe the impact of Navy activities on natural resources. Less attention was focused on civilian areas. Few studies have focused on the entirety of the island, and fewer still have provided a comprehensive assessment of multiple biological resources at the island scale (e.g., EQB 1972). The present characterization is not designed to replace any of these documents, rather it is meant to build upon this previous work by integrating information from the many disparate studies into a comprehensive assessment. The reader will be referred to original documents for further information. Although information regarding current land cover and land use patterns will be discussed in context of the links to marine habitats and resources, the main focus of this report is on the marine ecosystem. A thorough treatment of terrestrial resources within the Vieques Fish and Wildlife Refuge is provided in the recent Comprehensive Conservation Plan/Environmental Impact Statement (DOI 2007).

This report represents Part I of an Ecological Characterization of the Marine Resources of Vieques and contains an integrated summary of data collected before 2007 on Vieques. The report is divided into chapters based on the physical environment (e.g., climate, geology, bathymetry), habitat types (e.g., reefs and hardbottom, seagrasses, mangroves) and major faunal groups (e.g., fish, turtles, birds). The spatial scope of the study area is three nautical miles from shore, although a slightly wider scope of inference is considered when Vieques-specific data is lacking. Each section includes five subsections: 1) an overview, 2) description of the relevant literature, 3) methods of any new analysis, 4) information on the distribution, status and trends of the particular resource, and 5) a discussion of ecological linkages with other components of the Vieques ecosystem and surrounding environment. The reader will be referred to the full references for further information when appropriate. Finally, the last chapter will summarize key data gaps and include recommendations for further monitoring.

Part II of the ecological characterization will build upon the present report by presenting new data on benthic habitats, associated biological communities, nutrients, and contaminant concentrations in coral and sediments. Anticipated data products include orthorectified satellite imagery of Vieques, habitat maps delineated from the imagery at a finer scale than those presently available (Kendall et al. 2001), and population estimates of fish assemblages derived from new field surveys. This new information will provide a baseline from which to monitor changes in the distribution of resources over time and to design future research and monitoring studies. Together, these two volumes will provide a comprehensive characterization on the spatial distribution and status of the marine resources of Vieques.

LITERATURE CITED

CH2M HILL. 2004. Draft Final Closure Plan Open Burn/Open Detonation Site Former Atlantic Fleet Weapons Training Facility Vieques, Puerto Rico. Prepared for Department of the Navy, Atlantic Division Naval Facilities Engineering Command. CTO Task Order 039, LANTDIV CLEAN III Program, Virginia Beach, VA.

Code of Federal Regulations 2001a. Caribbean Sea and Vieques Sound, in vicinity of Eastern Vieques; bombing and gunnery target area. Title 33- Navigation and Navigable Waters, Volume 3, Chapter 2- Corps of Engineers, Department of the Army, Part 334- Danger Zone and Restricted Area Regulations. Section 334.1470.

Code of Federal Regulations 2001b. Vieques Passage and Atlantic Ocean, off east coast of Puerto Rico and coast of Vieques Island; naval restricted areas. Title 33- Navigation and Navigable Waters, Volume 3, Chapter 2- Corps of Engineers, Department of the Army, Part 334- Danger Zone and Restricted Area Regulations. Section 334.1480.

DOI (U.S. Department of the Interior). 2007. Final Comprehensive Conservation Plan/Environmental Impact Statement for Vieques National Wildlife Refuge, Vieques, Puerto Rico. Fish and Wildlife Service, Southeast Region, Atlanta, GA.

DON (U.S.Department of the Navy). 1979. Draft Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

DON (U.S. Department of the Navy). 1986. Environmental Assessment of Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range, Vieques, Puerto Rico. Prepared by Ecology and Environment, Inc.

DON (U.S. Department of the Navy). 2001. Biological Assessment for Continuing Training Activities on the Inner Range Vieques, Puerto Rico. Contract No. N622470-95-D-1160, CTO 0015.

EQB (Environmental Quality Board). 1972. Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Rico, Office of the Governor.

GMI (Geo-Marine, Inc.). 2003. Reef ecosystem baseline assessment survey and monitoring, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia. 341 pp.

GMI (Geo-Marine, Inc.). 2005. An assessment of the condition of coral reefs off the former Navy bombing ranges at Isla de Culebra and Isla de Vieques, Puerto Rico. Prepared for the Department of Defense, Legacy Resource Management Program, Arlington, Virginia, and US Army Corps of Engineers, Huntsville, Alabama. 76 + ix pp.

Kendall, MS, CR Kruer, KR Buja, JD Christensen, M Finkbeiner, RA Warner and ME Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (online). http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

Langhorne, E. 1987. Vieques: History of a Small Island. The Vieques Conservation and Historical Trust. Vieques, PR. 90 + A4 pp.

NOAA (National Oceanic and Atmospheric Administration) and WRI (World Resources Institute). 2006. Summit to Sea Characterization of Coastal Watersheds (Puerto Rico and US Virgin Islands). http://ccma.nos.noaa.gov/ecosystems/coralreef/summit_sea.html.

CHAPTER 2: CLIMATE AND CURRENTS

2.1 OVERVIEW

Like the rest of the Greater Antilles island chain, mainland Puerto Rico and its associated islands of Vieques and Culebra experience minimal variations in seasonal temperatures and humidity. Vieques is characterized by a relatively low lying terrain and low elevation hills and has therefore a drier, more arid climate similar to both the southwest coast of the mainland and the nearby island of Culebra (Frank 1972). Average daily high and low temperatures are generally consistent on Vieques throughout the year and range between 29-32 ºC and 19-22 ºC, respectively. The only major seasonal pattern experienced is a dry (December-April) versus rainy (May-November) season. The rainy months correspond with the tropical hurricane season. During the rainy season, Vieques is occasionally affected by tropical cyclones; from 1851-2006, 30 tropical cyclones have passed within 25 nm of Vieques for an average of one storm every five years.

Image 2.1. Rainbow following an afternoon storm on Vieques. Photo: Biogeography Branch.

Northeasterly trade winds move moist air from the Atlantic Ocean over the Greater Antilles, maintaining the warm and humid climate characteristic of a tropical marine environment. While the north shore is more exposed to the tradewinds, it is somewhat protected due to the shallow shelf and position behind the U.S. Virgin Islands and Culebra to the north. Although the southern coastal area is more protected from the northeast prevailing winds, the shore lies much closer to the insular shelf and faces the more open fetch and deep waters of the Caribbean Sea.

Circulation patterns in the Caribbean Sea are highly variable, both spatially and temporally. Variability is a function of bottom topography, wind forcing, current width and wind shear (Gyory et al. 2004). The dominant circulation pattern in the wider region is the westward flowing Caribbean Current, which is strongest in the southern part of the Caribbean Sea (Richardson 2005). At the local scale, coastal currents around the Caribbean islands of Puerto Rico and the US Virgin Islands are predominately influenced by the local wind patterns and tidal regime (Capella et al. 2003).

2.2 SOURCES OF DATA

The majority of the historical data compiled on climate patterns in the region focuses either solely on the mainland of Puerto Rico or combines Vieques and Culebra along with the mainland in the analysis (e.g., Daly et al. 2003). Few datasets address climate patterns specific to Vieques. Historical climatological data is available from the National Climatic Data Center for two stations that were previously maintained on Vieques (http://www.ncdc.noaa.gov/oa/ncdc, Accessed: 1-28-08). Data are available for station 669763, located near Esperanza, from 1955-1976, and for 669766, located near Isabel Segunda, from March 1983 – January 1994 (Figure 2.1). The data include daily precipitation totals and daily minimum, maximum, and mean air temperature. A Remote Automated Weather Station (RAWS) owned by the Fish and Wildlife Service is currently located in the eastern portion of the refuge north of Red Beach. Observations are recorded at hourly intervals and include air temperature, precipitation, wind speed, wind direction, dew point, solar radiation, and relative humidity. Daily and monthly summary data are available from the Western Regional Climate Center (http://www.raws.dri.edu/index.html) from mid-2005 to present. In addition, the detailed hourly observations are available from April 2007-present through MesoWest of the University of Utah (http://www.met.utah.edu/mesowest/).

Although no maritime data buoys are located around Vieques, the National Data Buoy Center (NDBC) maintains three buoys nearby: Lime Tree Bay, St Croix (LTBV3), Charlotte Amalie, St Thomas (CHAV3) and San Juan, PR (SJNP4) (Figure 2.1). Data were available from LTBV3 and CHAV3 for 2005 through 2007. Data from SJNP4 were available for 2005 through September 2007. The data included the following parameters: wind direction (degree), wind speed (m/s), wind gusts (m/s) and atmospheric pressure. The nearest Integrated Coral Observing Network (ICON, formerly CREWS) station is located in Salt River Bay, St. Croix (SRV12). A thorough analysis of this dataset was completed by Kendall et al. (2005).

Historical information on the tracks and intensity of hurricanes from 1851-2006 was obtained from NOAA's Coastal Services Center (http://maps.csc.noaa.gov/hurricanes, Accessed: 1/28/2008).

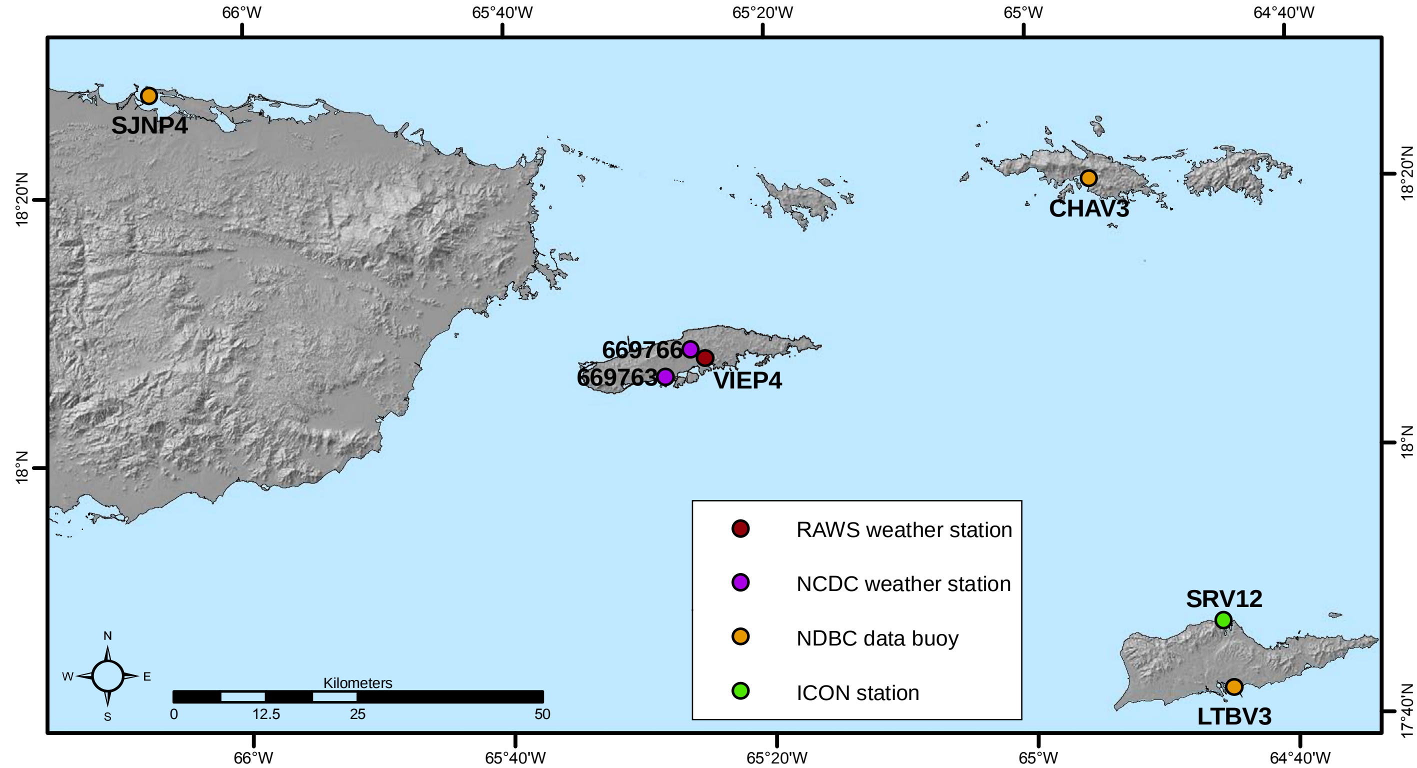


Figure 2.1. Locations of current and former weather stations on Vieques (Source: RAWS and NCDC) and National Data Buoys near Vieques, Puerto Rico. Data from three local buoys were used: SJNP4, CHAV3, LTBV3 (Source: NDBC).

Sea surface temperature data is collected in the northern Caribbean by the Advanced Very High Resolution Radiometer (AVHRR), a sensor carried aboard the NOAA polar-orbiting satellites. Seasonal and interannual patterns in sea surface temperature were assessed using the AVHRR data set for years 1985-2006 by V. Ransibrahmanakul et al., NOAA/CCMA (unpublished data). Profiles of sea surface temperature and degree heating weeks in the greater Puerto Rico – US Virgin Islands region were created for the time period. Degree heating weeks are a measure of cumulative thermal stress. If the current temperature of a reef site exceeds the maximum expected summertime temperature by one degree Celsius for one week, then the site receives a rating of 1 DHW. If the current temperature at the site is two degrees Celsius above the maximum expected summertime temperature or one degree above for a period of two weeks, the site would receive a rating of 2 DHWs, and so on.

There are limited data available on current patterns specific to the island of Vieques and a lack of discrete measurements. Large scale investigations include a study by Richardson (2005), in which 212 drifters were deployed in the Caribbean Current to investigate cyclonic patterns within the region. General surface current patterns around Vieques have been described by GMI (2003) based on information from the US Naval Atlantic Meteorology and Oceanography Detachment. Capella et al. (2003) offer the only other published study of regional data applicable to Vieques. The study was conducted to the north of Vieques, between Culebra and Vieques as part of an open aquaculture program maintained by Snapperfarm, Inc.

2.3 METHODS

The Vieques NCDC datasets were combined and analyzed across all years to compute the mean monthly minimum and maximum temperatures and mean monthly total precipitation. These data were compared to the RAWS temperature and precipitation time series for 2006-2007 and to those reported by Daly et al. (2003). The RAWS hourly wind observations from April 2007-March 2008 were used to estimate average and diel patterns in wind speed and wind direction for this year. To suppliment this data set, historical data from the regional NDBC data buoys were used to calculate average wind direction, wind gusts, and atmospheric pressure to determine general regional patterns.

Atlantic hurricane tracks were plotted in ArcGIS (v9.2, ESRI) for display. Hurricanes that passed within 25 nautical miles of Vieques were extracted to determine the frequency of the passage of hurricanes within close vicinity of the island.

Available literature, observations, and models were used to describe general current patterns around Vieques.

2.4 DISTRIBUTION, STATUS AND TRENDS

Minimum and maximum daily temperatures on Vieques exhibit small seasonal variation (Figure 2.2). Average highs vary from 29ºC in January and February to 31-32ºC in the summer months. Similarly, mean lows only vary by approximately three degrees between the winter and summer months. There are generally two seasons recognized in the Caribbean, a wet season from May to November and a dry season from December to April. Rainfall on Vieques is elevated during these months (Figure 2.2a). Historically, the highest rainfall amounts have occurred in October and November, while February and March receive the lowest mean rainfall totals. Storm events as well as hurricanes and tropical storms are most frequent during the months of June-November. Although uncommon, occasional cold fronts during the dry season can cause heavy precipitation. Excluding years with missing data, total annual rainfall averaged 107.1 (±5.8 SE) cm and ranged between 65.7 cm (1967) and 182.5 cm (1969). Data from 2006-2007 reflects both the general trend from the historical dataset and the year-to-year variability (Figure 2.2b).

Compared to mainland Puerto Rico, elevations are lower on Vieques; therefore there is less annual rainfall and higher average temperatures (Frank 1972; Daly et al. 2003). In addition, rainfall patterns on Vieques are not consistent across the island due to the influence of the easterly trade winds and differences in elevation across the island. The data from the NCDC and RAWS weather stations, which were located in the middle of the island, does therefore not capture the spatial differences between the eastern and western extremes.

Daly et al. (2003) used information on elevation and coastal proximity in combination with available precipitation and temperature data for Puerto Rico, Vieques and Culebra to predict spatial variation in rainfall across the Commonwealth. The results of this study highlighted the difference in the amount of rainfall received between the eastern and western portions of Vieques. In general, the amount of precipitation increases from east to west.

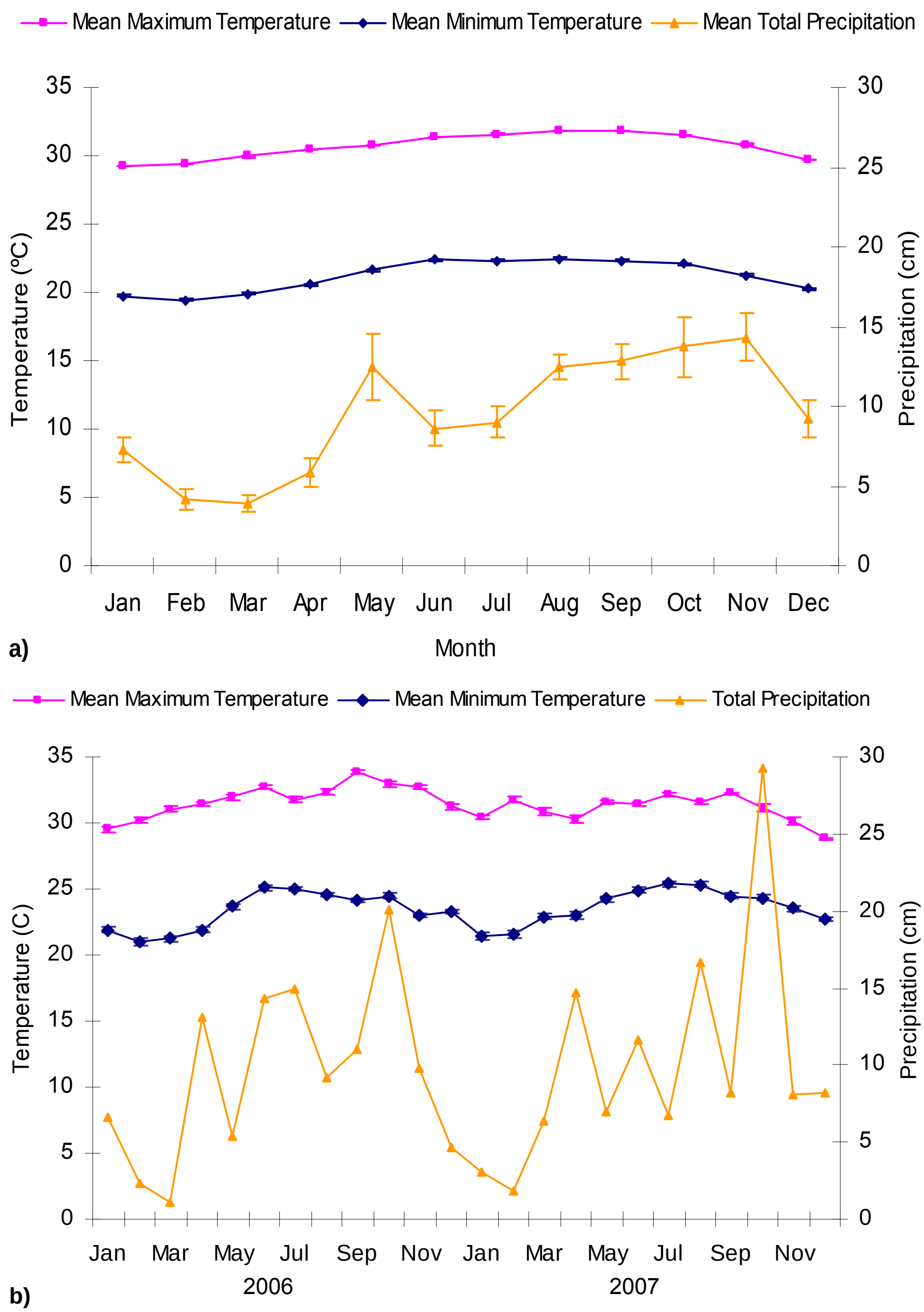


Figure 2.2. a) Mean (± standard error) monthly minimum and maximum air temperature and total precipitation for NCDC weather stations formerly located on central Vieques. Data used to compute monthly means includes years 1955-1976 and 1983-1994 (Source: NCDC). b) Mean monthly minimum and maximum temperatures and total precipitation for 2006-2007 recorded at the RAWS station in the western VNWR (Source: RAWS).

Table 2.1. Summary statistics for 2005-2007 data from NBDC buoys in San Juan, Puerto Rico and the US Virgin Islands and the RAWS weather station on Vieques (standard error noted in parentheses). The 2007 summary statistics for the Vieques station were calculated using hourly data collected from April 1, 2007-March 31, 2008.

Location	Buoy/ Station	Average Wind Direction (deg)			Average Wind Speed (kts)			Average Wind Gusts (kts)			Average Atmospheric Pressure (in.)		
		2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
San Juan, PR	SJNP4	111 (8.2)	106 (3.1)	130 (5.3)	0.8 (<0.1)	1.8 (0.1)	4.1 (0.1)	27.7 (1.2)	3.6 (0.13)	5.1 (0.3)	60.4 (6.3)	27.3 (0.10)	27.5 (0.4)
Charlotte Amalie, USVI	CHAV3	108 (5.5)	106 (0.3)	100 (3.9)	0.8 (0.1)	1.7 (<0.1)	2.0 (0.1)	27.6 (4.5)	3.3 (<0.1)	3.9 (0.2)	55.6 (10.0)	27.3 (<0.1)	27.6 (0.4)
Lime Tree Bay, USVI	LTBV3	93 (0.4)	109 (0.2)	110 (0.3)	3.2 (<0.1)	3.3 (<0.1)	3.5 (<0.1)	5.9 (<0.1)	5.3 (<0.1)	7.1 (<0.1)	27.2 (<0.1)	27.7 (0.1)	27.6 (0.2)
Vieques, PR	VIEP4	NA	NA	90 (0.7)	NA	NA	6.6 (<0.1)	NA	NA	11.8 (<0.1)	NA	NA	NA

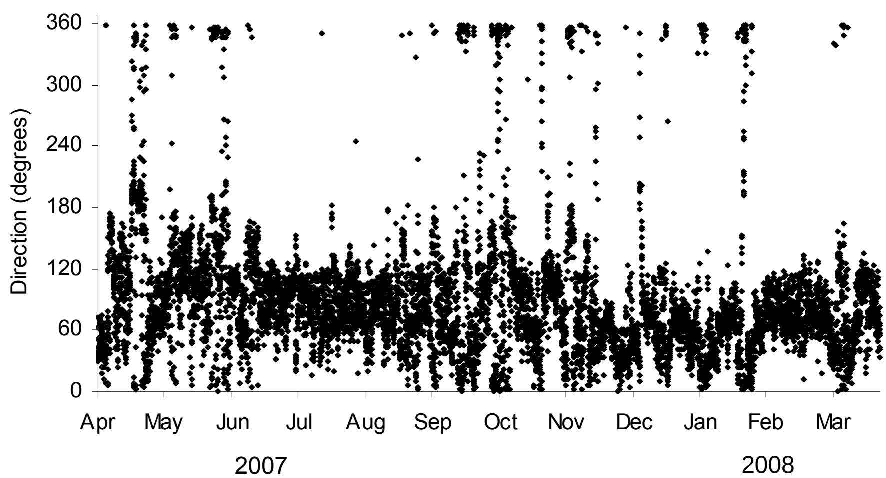


Figure 2.3. Wind direction plotted from raw RAWS data from April 2007 to March 2008.

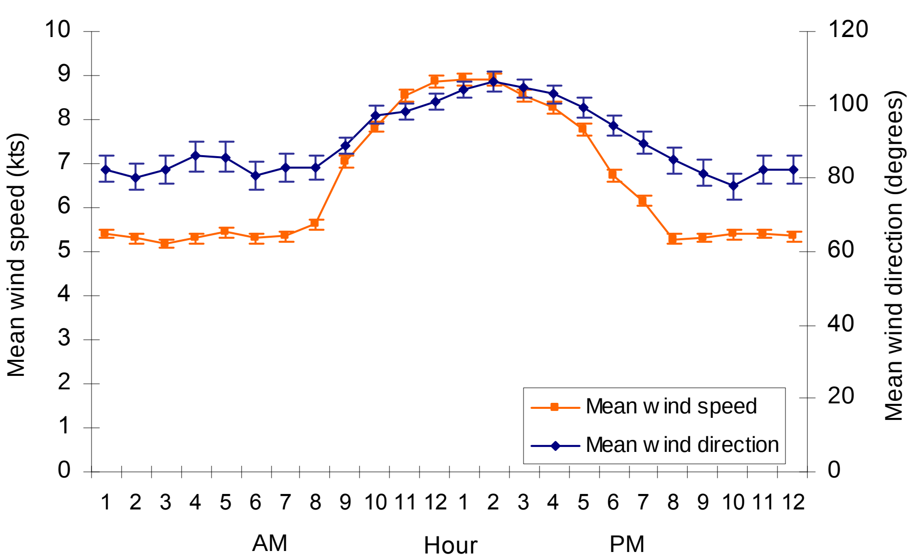


Figure 2.4. Mean hourly wind speed and direction over the course of a 24 hour period, based on RAWS data pooled from April 2007 to March 2008.

This finding is in agreement with previous work by GMI (1996), who found that the eastern end of the island received an average of 64 cm compared to an average of 125 cm on the western end of the island. The east-west gradient in precipitation is partly attributed to differences in topography. The highest elevations occur at the western part of the island, which includes Monte Pirata, the tallest point on Vieques (elevation = 301 m). The primary effect of the elevation difference was determined to be degree of cloud cover and the precipitation rates across the island (Daly et al. 2003). Higher precipitation on the western end is also influenced by the atmospheric heating and cloud formation over land as winds blow from east to west. In addition to the highlighted elevation differences, Daly et al. (2003) found climate patterns to be influenced by proximity to the shoreline and reported precipitation rates and temperature as inversely proportional, as rainfall decreased along an inland to coastal gradient. Consequently, the low lands remain relatively dry, particularly along the coastal zones.

Local winds are predominately from the east throughout the year, with occasional wind events from the north and west (Table 2.1; Figure 2.3). There was a high degree of variability in the wind speeds both temporally and spatially, and distinct seasonal patterns were not discernible at any of the stations. In comparison to the regional buoys, average wind speeds and gusts at the Vieques station in 2007 were slightly higher (Table 2.1). Wind speeds were generally stronger in Lime Tree Bay compared to Charlotte Amalie and San Juan. Average wind gusts were elevated in Charlotte Amalie and San Juan in 2005, despite low average wind speeds and elevated atmospheric pressure (Table 2.1). Variations in wind speed and direction among these stations may be attributed to factors such as location of the buoy/station in a protected versus eposed area, or leeward versus windward placement of instrumentation.

Diel changes in wind speed and direction were observed at the Vieques RAWS station in 2007 (Figure 2.4). In general, wind speed was lowest in the pre-dawn hours, increased following sunrise, and reached maximum intensity mid-day before decreasing in the evening. Winds blew more strongly out of the east-southeast during the day but shifted slightly to the northeast at night. Similar hourly patterns in wind speed have also been observed at the ICON station in nearby Salt River Bay (Kendall et al. 2005).

From 1851-2006, the center (eye) of 30 tropical cyclones has passed within 25 nm of Vieques for an average of one storm every five years (Table 2.2, Figure 2.5). Nearly half of the storms (14 of 30) have occurred in September, while an additional nine have occurred in August. Recent storms of note include Tropical Storm Jeanne (2004), Hurricane Georges (1998), Hurricane Hugo (1989), and Tropical Storm Frederick (1979). The strongest of these, Hurricane Hugo, passed over Vieques as a category four hurricane in September, 1989 with sustained winds up to 120 mph. Although a 25 nm buffer was considered here for brevity and to highlight storms that have directly impacted Vieques, depending on the hurricane size and intensity, it is likely that Vieques has also been impacted by tropical systems whose tracks occur further away. When the search radius is expanded, a tropical cyclone has passed within 50 nm of Vieques an average of every three years, and within 100 nm every 1-2 years.

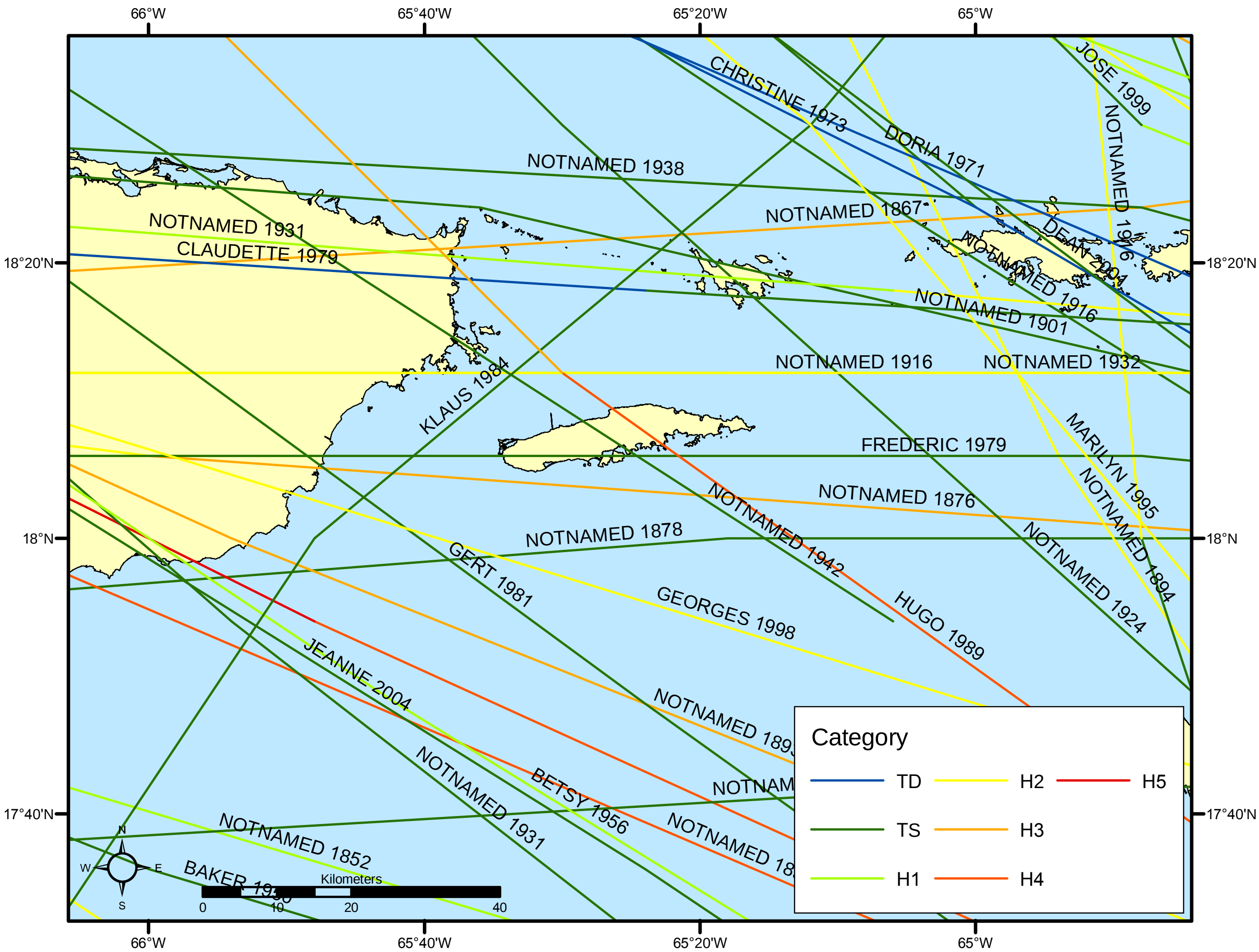


Figure 2.5. Historical tropical storm tracks around the waters of Vieques (Source: NOAA CSC). TD=Tropical Depression, TS=Tropical Storm, H1=Category 1 Hurricane, H2=Category 2 Hurricane, H3=Category 3 Hurricane, H4=Category 4 Hurricane, H5=Category 5 Hurricane.

Sea surface temperature around Vieques and the PR-USVI region typically only varies by a few degrees between the winter and summer months (Figure 2.6). However, periodically anomalously high sea surface temperatures (SST) have occurred for extended periods of time, usually in late summer and fall. Observed coral bleaching events often coincide with these periods of high SST, most recently in 2005. Due to the lack of regular coral monitoring in Vieques, the frequency of bleaching events around the island's reefs has not been determined. Hence, a more regional context was considered here to highlight observed bleaching events in nearby islands that are likely to have affected Vieques. At least seven mass bleaching events have been reported in Puerto Rico and the USVI since 1985, four of which occurred between 1998 and 2006.

The nearshore currents around Vieques are influenced by both the prevailing trade winds and tidal flow. The longshore surface currents to the north and south of the island flow in a east/NE to west/SW direction at approximately 10 cm/s (GMI 2003). Capella et al. (2003) also documented a west-southwest circulation pattern in the region north of Vieques. Flood and ebb tidal currents vary in speed and direction around different portions of the island (GMI 2003). North of Vieques, between Vieques and Culebra, reported typical tidal flow peaks of 10-20 cm/s in the region with a mean vector velocity of 5 cm/s (Capella et al. 2003), but may be stronger (>50 cm/s) in the Vieques Passage and off of the eastern end of the island (GMI 2003). Tidal height is estimated in Vieques at 30-40 cm above and below mean low water (MLW) (Capella et al. 2003). In addition, a greater-Caribbean drifter study indicated the presence of an eastward current of > 30 cm/s along the southwest coast of Vieques, continuing across the Vieques Passage towards mainland Puerto Rico (Richardson 2005).

Table 2.2. Tropical cyclones that have passed within 25 nautical miles of Vieques (Source: NOAA CSC). TD=Tropical Depression, TS=Tropical Storm, H1=Category 1 Hurricane, H2=Category 2 Hurricane, H3=Category 3 Hurricane, H4=Category 4 Hurricane, H5=Category 5 Hurricane.

Year	Month	Name	Wind (knots)	Category
1867	October	Not Named	100	H3
1876	September	Not Named	100	H2-H3
1878	November	Not Named	60	TS
1893	August	Not Named	100	H3
1894	October	Not Named	85	H2
1899	August	Not Named	125	H4
1901	September	Not Named	50	TS
1916	July	Not Named	45	TS
1916	August	Not Named	85	H1-H2
1924	August	Not Named	40	TS
1928	September	Not Named	140	H4-H5
1931	August	Not Named	35	TS
1931	September	Not Named	85	H1-H2
1932	September	Not Named	95	H2
1933	September	Not Named	40	TS
1938	August	Not Named	55	TS
1942	November	Not Named	35	TS
1949	September	Not Named	35	TS
1956	August	Betsy	80	H1
1971	August	Doria	25	TD
1973	September	Christine	30	TD
1979	July	Claudette	35	TD-TS
1979	September	Frederick	45	TS
1981	September	Gert	50	TS
1984	November	Klaus	50	TS
1989	September	Hugo	120	H3-H4
1995	September	Marilyn	95	H2
1998	September	Georges	90	H2
2001	August	Dean	45	TS
2004	September	Jeanne	60	TS

An extensive sand deposit (Escollo de Arenas) is located off the northwest corner of Vieques at Punta Arenas where the longshore transport converges along the north and west shores (Rodriguez and Trias 1989). The sand wedge has a maximum thickness of 7 meters and is continuously migrating northeastward (Zeigler and Giese 1971). Murray et al. (1977) explain how large volumes of sediment will tend to accumulate to the lee of high speed current zones, such as along Punta Arenas where Garcia et al. (2001) reported current speeds of approximately 1 knot (~50 cm/sec). Given the high current flows along the northwest corner of the island at Escollo de Arenas and through the Vieques channel, there is increased potential for suspension of sediments and turbid conditions in this region, leading to a shift of internal sand waves within the sand wedge (Ziegler and Giese 1971). Despite the high flow conditions, the sand wedge is relatively stable with minimal changes in the internal structure (Ziegler and Giese, 1971; see Chapter 3: Geology and Land Cover).

2.5 ECOLOGICAL LINKAGES

Precipitation rates directly impact the marine environment as associated runoff transfers land based sediment, nutrients and pollutants into coastal waters. This is of particular concern on Vieques due to the opening of formerly closed areas for public access and the anticipated increase in coastal development following the departure of the Navy in 2003 (see Chapter 3: Geology and Land Cover). Turbid conditions in near shore waters can lead to stress on corals in particular, and the new development coupled with high rain events may lead to

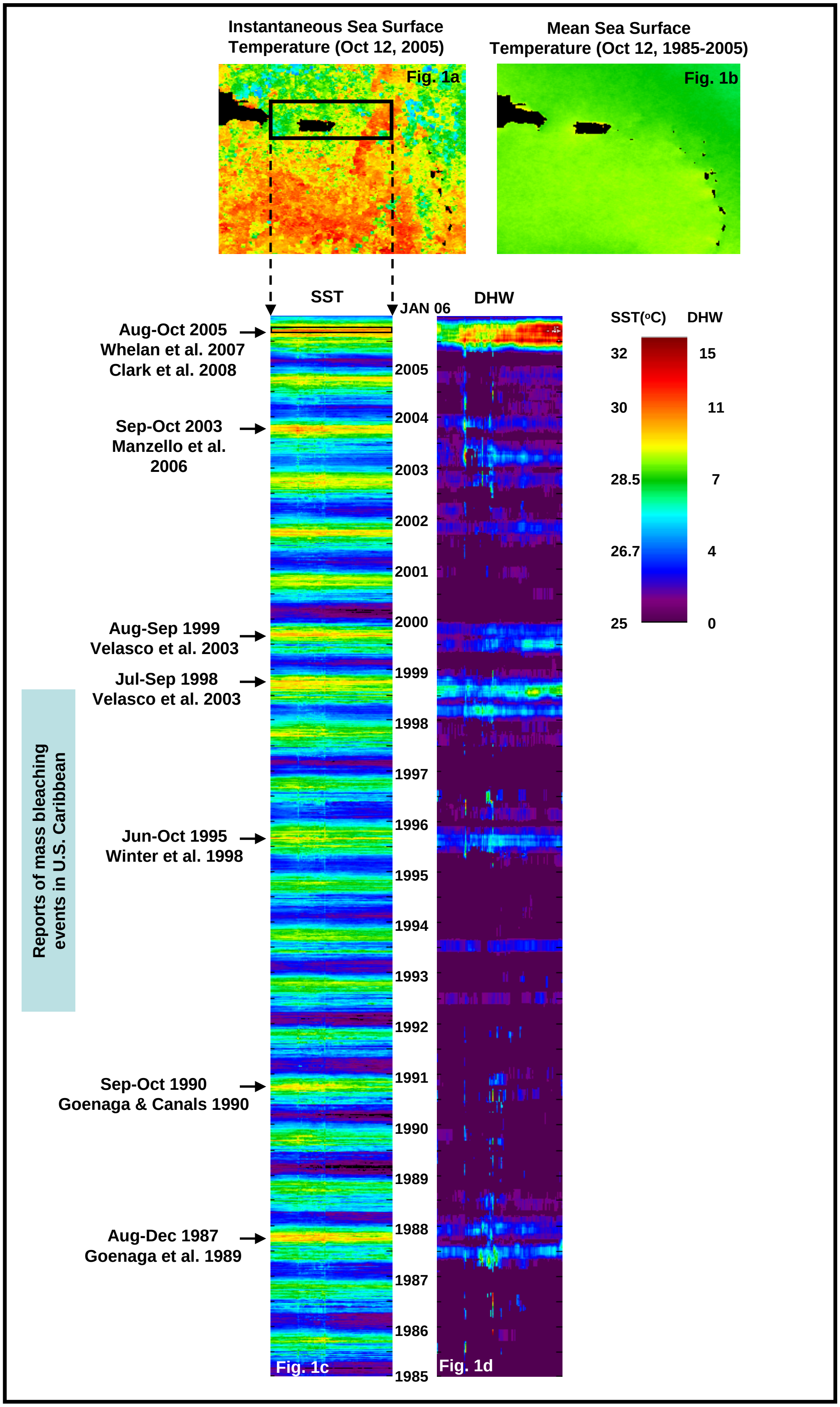


Figure 2.6. Seasonal and interannual patterns in sea surface temperature and the relationship to regional coral bleaching events. a) Instantaneous SST on October 12, 2005, which coincided with a mass bleaching event recorded in St Croix, USVI. b) Mean SST for October 12 from 1985-2005. c) Profile of sea surface temperature from 1985-2005 and coincidence of extended periods of warm SST with observed bleaching events in the US Caribbean. d) Degree heating weeks (DHW) during this time period. (Source: V. Ransibrahmankul, D. Pirhalla, S. Pittman, and K. Casey, NOAA/CCMA).

increased coastal runoff and added sedimentation in near shore waters. Persistent turbid conditions, caused by increased sediment loading, can also degrade near shore seagrass beds (Vincente et al. 1980).

The mean monthly rainfall on Vieques correlates with two distinct seasons and the dramatic increase in rainfall during the rainy season highlights the impact of large rain events (Figure 2.1; Daly et al. 2003). Localized heavy rains are most frequently associated with extreme storm events, such as tropical storms and hurricanes. Hurricane Hugo impacted Vieques in September 1989 and is considered the primary cause of extensive blowouts in seagrass beds along the coast (Vincente 1989; Uhrin et al. unpublished report; see Chapter 6: Seagrass and Algae). Seagrass recovery was seen within a year following the hurricane in some areas (Vincente et al. 1991), but several areas still remain uncolonized and therefore hinder the buffering benefits of the beds for the coast, as well as diminish important food resources for marine grazers and juvenile fishes (see Chapter 6: Seagrass and Algae).

Climate patterns directly affect the marine environment and associated marine fauna. As atmospheric temperatures increase surface water temperatures, marine fauna are introduced to a high stress environment, particularly in shallow waters that heat rapidly. Increased sea surface temperatures (SST) have been more frequent in recent years and have been linked to mass coral bleaching events in the Caribbean (Figure 2.6). Although a comprehensive assessment of bleaching prevalence in Vieques has not been conducted, McGarrity and Deslarzes (2006) reported coral bleaching as the most prevalent coral malady in Vieques, accounting for 78% of all coral maladies reported from each of their 18 sampling sites around the island (see Chapter 5: Coral Reefs and Hardbottom).

Hurricanes and tropical storms also alter marine habitats through storm surge and high wave energy. The high wave energy associated with these extreme weather events can turn over large mounding corals and break large branching corals which is destructive to the federally listed species, *Acropora palmata* (see Chapter 5: Coral Reefs and Hardbottom). Such storms can significantly alter the coastline and associated marine habitats. In addition, high amounts of coastal runoff due to heavy rain lead to increased water turbidity.

Physical processes are important in shaping coral reef systems, in controlling growth rates of corals, as well as the formation of new coral colonies through fragmentation during storm events (Hubbard et al. 1981). Thus, it is important to understand the impact of low and high energy current patterns on the marine ecosystem, which requires discrete measurements to create accurate models. The available information on currents does not provide enough detail to use in conjunction with research being conducted at a much finer scale. This is particularly important as coastal development expands around Vieques, which could potentially increase the sediment loading into the coastal waters. Detailed information on the direction and speed of nearshore currents will improve predictions of the distribution of sediment plumes.

In addition, knowledge of the fine scale current flow around Vieques would provide insight into the sink or source potential for fish and coral larvae around the island. This is particularly important in light of declining grouper stocks in Vieques (Matos-Caraballo et al. 2006). Having flow models for Vieques could predict the flow of larvae to certain geographic regions of the island so that better management decisions could be made regarding fishing closures or marine protected areas. It is currently difficult to make further inferences regarding local fish and coral stocks from the existing broad scale current models. Discrete measurements and a finer scale, more island focused model would be valuable to validate such predictions and management decisions. This data would also offer baseline information to better assess the impacts of extreme events such as hurricanes (*see* Chapter 2: Climate and Currents) and aid research efforts currently conducted by NOAA's Center for Coastal Fisheries and Habitat Research (CCFHR, see Chapter 6: Seagrass and Algae) towards the protection and management of degrading seagrass beds and associated fauna along the northwest coast of Vieques.

LITERATURE CITED

Capella JE, DA Alston, A Cabarcas-Núñez, H Quintero-Fonseca and R Cortés. 2003. Oceanographic Considerations for offshore Aquaculture on the Puerto Rico-U.S. Virgin Island Platform. pp. 247-261. In: CJ Bridger and BA Costa-Pierce, editors. Open Ocean Aquaculture: From Research to Commercial Reality. The World Aquaculture Society Baton Rouge, LA, USA.

Clark, R., C Jeffrey, K Woody and Z Hillis-Starr. In review. Spatial and Temporal Patterns of Coral Bleaching around Buck Island Reef National Monument, St. Croix, US Virgin Islands. Bulletin of Marine Science.

Daly, C, EH Helmer and M Quinones. 2003. Mapping the Climate of Puerto Rico, Vieques and Culebra. International Journal of Climatology 23:1359-1381.

DON 1985. Soil erosion control plan for the Atlantic Fleet Weapons Training Facility, Vieques, Puerto Rico. Ecology and Environment, Inc. 311 pp.

Frank, K. 1972. Section I: Climate. In: Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Rico, Office of the Governor.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2001. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 108 pp.

GMI (Geo-Marine, Inc.). 1996. Land Use Management Plan for US Naval Facilities, Vieques, Puerto Rico. Prepared for Department of Navy, US Naval Station, Roosevelt Roads, and Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

GMI (Geo-Marine, Inc.). 2003. Reef ecosystem baseline assessment survey and monitoring, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

Goenaga C and M Canals. 1990. Island-wide coral bleaching in Puerto Rico. Caribbean Journal of Science 26: 171-175.

Gyory, J, AJ Mariano and EH Ryan. 2004. The Caribbean Current. http://oceancurrents.rsmas.miami.edu/caribbean/caribbean.html. University of Miami, Florida, USA.

Hubbard DK, JL Sadd and HH Roberts. 1981. The Role of Physical Processes in Controlling Sediment Transport Patterns on the Insular shelf of St Croix, U.S Virgin Islands. pp. 399-410. In: Proceedings of 4th International Coral Reef Symposium, Vol. 1. Manilla, Philippines.

Kendall, MS, LT Takata, O Jensen, Z Hillis-Starr and ME Monaco. 2005. An Ecological Characterization of the Salt River Bay Historical Park and Ecological Preserve, U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS 14. 116 pp.

Manzello D, JC Hendee, D Ward and Z Hillis-Starr. 2006. An evaluation of environmental parameters coincident with the partial bleaching event in St Croix, US Virgin Islands 2003. pp. 709-717. Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan.

Matos-Caraballo, D, JM Posada and BE Luckhurst. 2006. Fishery-Dependent Evaluation of a Spawning Aggregation of Tiger Grouper (*Mycteroperca tigris*) at Vieques Island, Puerto Rico. Bulletin of Marine Science 79 (1): 1-16.

McGarrity, CJ and KJP Deslarzes. 2006. Preliminary data on juvenile corals and coral maladies on reefs off civilian and former military locations at the islands of Culebra and Vieques, Puerto Rico. pp. 1160-1164. In: Proceedings of 10th International Coral Reef Symposium. Okinawa, Japan.

Murray AP, HA Robers, DM Conlon and GM Rudder. 1977. Nearshore Current Fields around coral islands; Control on sediment accumulation and reef growth. pp. 53-59. Proceedings of 3th International Coral Reef Symposium, Vol. 2. Miami, FL.

Ranisbrahmankul, R., D. Pirhalla, S. Pittman, and K. Casey. NOAA/NOS/NCCOS Center for Coastal Monitoring and Assessment. Personal communication.

Richardson, PL. 2005. Caribbean Current and eddies as observed by surface drifters. Deep Sea Research II 52: 429-463.

Rodriguez, RW and JL Trias. 1989. Maps showing characteristics of the Escollo de Arenas sand and gravel deposit, Vieques Island, Puerto Rico. Department of the Interior, U.S. Geological Survey. Map MF-2108.

Uhrin, AV, MS Fonseca and J Kenworthy. Unpublished report. Recovery of Seagrass Blowout Formations in Southeastern Puerto Rico. NOAA, Center for Coastal Fisheries and Habitat Research. http://mapping.orr.noaa.gov/website/portal/vieques/pdfs/ViequesBlowoutProject.pdf.

Velasco AT, E Weil, and A Bruckner. 2003. Climate change and coral reef bleaching in Puerto Rico: Efforts and challenges. In: Proceedings of the Coral Reef, Climate and Bleaching Workshop, Oahu, Hawaii.

Vincente, VP, LR Almodovar, JA Rivera and D Corales. 1980. An ecological evaluation of the seagrasses in Guayanilla Bay. Science-Ciencia 7(4): 76-88.

Vincente, VP, S Slander, M Barreto, J Saliva, P Torres and D Corales. 1991. An ecological evaluation of some marine and terrestrial systems at Ceiba and Vieques Island after Hurricane Hugo: Fiscal Year 1990-91. US Fish and Wildlife Service, Caribbean Field Office, Boquerón, Puerto Rico.

Whelan, KRT, J Miller, O Sanchez and M Patterson. 2007. Impact of the 2005 coral bleaching event on *Porites porites* and *Colpophyllia natans* at Tektite Reef, US Virgin Islands. Coral Reefs 26: 689-693.

Winter, A, RS Appeldoorn, A Bruckner, EH Williams and C Goenaga. 1998. Sea surface temperatures and coral reef bleaching off La Parguera, Puerto Rico (northeastern Caribbean Sea). Coral Reefs 17: 377-382.

Ziegler, JM and GS Giese. 1971. Geology and Hydrodynamics of Punta Arenas Shoal. pp.33-38. In: Transactions of the 5th Caribbean Geological Conference, Geology Bulletin No. 5. Queens College Press.

CHAPTER 3: GEOLOGY AND LAND COVER

3.1 OVERVIEW

As the North American Plate subducted under the Puerto Rico trench along the northern edge of the Caribbean Plate, tectonic activity deposited ash and magma on the shelf that formed the island foundations of mainland Puerto Rico, Vieques and Culebra (Brink 2005). As volcanic activity subsided, leaving igneous rock, limestone accreted on the igneous rock and formed the base of the coral reef communities (O'Connell et al. 2007).

Image 3.1. Rocky shoreline on Vieques. Photo: A. Mason.

The topography of Vieques is characterized by rolling hills in the western region of the island, rugged peaks in the east and areas of lower elevation along the coast which include bays, lagoons and alluvial plains (DON 1996). Although the terrain is gentler in slope, the highest elevation, Monte Pirata (301 m), is found in the western region of the island. The eastern region has a maximum elevation of 150 m at Cerro Matias (DOI 2007). Since it is volcanic in origin, there are relict fault lines present in both the west and central portions of the island.

Vieques' landscape has undergone various stages of human development dating from the first record of occupation (ca. 200 BC, Langhorne 1987; see Chapter 1: Introduction). Although the island was reportedly characterized by dense climax forest when inhabited by Native Americans (Langhorne 1987), timber harvesting and widespread clearing for sugarcane in the 19th century removed the majority of the native forest. By 1972, it was estimated that approximately 80% of the native vegetation had been modified, and as a result various sections of the island were in different degrees of succession, ranging from pasture/rangeland to secondary growth of thorn scrub and woodland (Woodbury 1972).

The most recent land cover map was analyzed in relation to recent and former land ownership. Due in part to island-wide variations in precipitation, the vegetation shifts from a moist to dry community assemblage moving from west to east. The western third of the island is composed largely of moist and dry forest. Grassland and pasture becomes a larger proportion of the landscape east of Mosquito Pier. Urban development is largely restricted to the municipalities of Isabel Segunda on the north side and Esperanza on the south coast. The eastern portion of Vieques is composed largely of dry forest, dry woodland/shrubland, and grassland/pasture.

Although streams are ephemeral in nature, six watersheds have been identified on Vieques. Due to spatial variations in land cover, elevation, soil type, and climate, the relative rates of erosion and sediment delivery are not uniform across the island. Modeled potential sediment delivery is highest on the southwest coast, north central coast, and the bay of Ensenada Honda. This information can be used to identify regions of concern for further study, but discrete sedimentation measurements and further study on the coastal hydrodynamics are needed to fully assess the input and distribution of terrestrial sediment and pollutants in the marine environment.

3.2 SOURCES OF DATA

Few geological investigations have been conducted on Vieques. The data that are available focus primarily on the origin and geologic components of the island mass as well as soil classifications. The Department of the Navy (1996) conducted investigations on the marine geology both south of Roosevelt Roads on the east coast of mainland Puerto Rico and around Vieques Island to characterize the geological origins of the continental shelf. In addition, the Commonwealth of Puerto Rico conducted a geologic survey in 1972 as part of a complete investigation to catalogue the natural resources of Vieques (Groves 1972). The distribution of subsurface geology types is available from GMI (2003a). McIntosh Marine (year unknown) conducted an island wide study to locate and identify relic fossils to gain more information about the formation of the island and its geological history.

The island soils were classified in an investigation conducted by Boccheciamp (1977) into four primary soil associations where each group contained several subcategories similar to those found along the eastern coast of mainland Puerto Rico. In response to increased soil erosion rates, the Department of the Navy (1985) released a report identifying methods to reduce erosion of the young infertile soils that dominate the island's soil complex. The goal of the project was to prevent further adverse environmental impacts within the Atlantic Fleet Training Facility (AFWTF) by suggesting alternative methods of military activities.

Studies of Escollo de Arenas, a large sand deposit off the northwest coast of Vieques, have been conducted by Ziegler and Giese (1971), Rodriguez and Trias (1989), and Rodriguez et al. (1994).

The most recent land cover analysis of Vieques was completed as part of the USGS Puerto Rico Gap Analysis Project (PRGAP 2006). Land cover was delineated for the entire Puerto Rico Commonwealth using Landsat 7 ETM+ scenes collected between 1999 and 2003. Six major land cover classes were described, including forest (except mangrove), woodland and shrubland, mangrove, grassland/pasture/agriculture, urban and barren, and water. A land cover accuracy assessment of these main groups resulted in an overall accuracy of 84.92% and a kappa value of 0.8 (Gould et al. 2007). These six classes were further divided into 70 units using information on biogeoclimatic zones, topography, and soil moisture. Of the 70 units classified for all of Puerto Rico, 29 are present in Vieques.

Additional land cover data (Geo Cover, MDA Federal) was utilized as part of NOAA and the World Resources Institute's Summit to Sea Characterization of Coastal Watersheds in Puerto Rico and the US Virgin Islands (NOAA and WRI 2006; WRI and NOAA 2006). In this study, land cover information was combined with data on topographic slope, soil types, and precipitation to estimate the relative erosion potential and sediment loading potential for all individual watersheds in Puerto Rico, including Vieques. This information was calculated for 1990 and 2000 to estimate potential changes in sediment loading. The main outflow points within each watershed were also identified. In addition, the Summit-to-Sea data includes an estimate of the threat to benthic habitats from land-based sources of sediment, or the potential sediment plumes from the main outflow points. This continuous surface was calculated using the point density tool (ArcGIS Spatial Analyst) with sediment delivery at the outflow points as the input and a kernel radius of 5 km. All data are relative and cannot be expressed in absolute numbers, but this information represents the most current and thorough estimate of potential sediment loading in Vieques waters, and can be used to identify areas of concern for further study and analysis.

3.3 METHODS

Available literature and spatial data were used to describe the distribution of geology and soils of Vieques.

The PRGAP (2006) data was used to quantify the area of land cover types in Vieques. The PRGAP land cover grid was chosen over the 2000 Geo Cover land cover data because it is the most recent dataset and contains more detailed classifications. In addition, portions of Vieques were not able to be delineated in the Geo Cover map due to cloud cover. Land cover types were compared among zones of former (NASD, CA, EMA, AFWTF, LIA, PECA) and current (DOI [Vieques NWR, East and West], PRCT, ROTHR, Vieques municipality) ownership. In this analysis the 29 detailed land cover classes present in Vieques were condensed into 15 broader classes to show those of most interest for potential marine impacts (Table 3.1). This modification was a compromise in that the groupings provide more detail than the six broad classes originally identified in the PRGAP project, but allow for more meaningful interpretation than the detailed classification.

The following Summit-to-Sea data for Vieques watersheds were extracted and plotted in ArcGIS: relative erosion potential (2000), relative sediment delivery by watershed (2000), percent change in relative sediment delivery from 1990 to 2000, and relative threat to benthic habitats (i.e. estimated sediment plumes). Since numeric data are relative, watersheds were ranked from low to high in terms of potential sediment delivery. In addition, Summit-to-Sea watershed values were ranked across all Puerto Rico watersheds (n=132) to assess how Vieques watersheds rank in comparison to the rest of the Commonwealth.

3.4 DISTRIBUTION, STATUS, AND TRENDS

The geologic structure on Vieques is shown in Figure 3.1. The bedrock underlying Vieques is igneous, or more specifically is formed from the fusion of volcanic deposits (Sommer et al. 1964). Late Cretaceous andesite is the major component of the volcanic rock on the island. Along the coastline, this bedrock has been exposed due to the weathering and erosion of the upper soil layers, while a mixture of gravel and sand have collected into the alluvial plains from formerly flowing rivers (Sommer 1964; ATSDR 2003). The alluvial plain deposits in this region are comprised of sand, silt and clay (GMI 2003a). In the western end of the island, quartz diorite plutonic rocks dominate the composition, while the northern and southern coasts are characterized by a

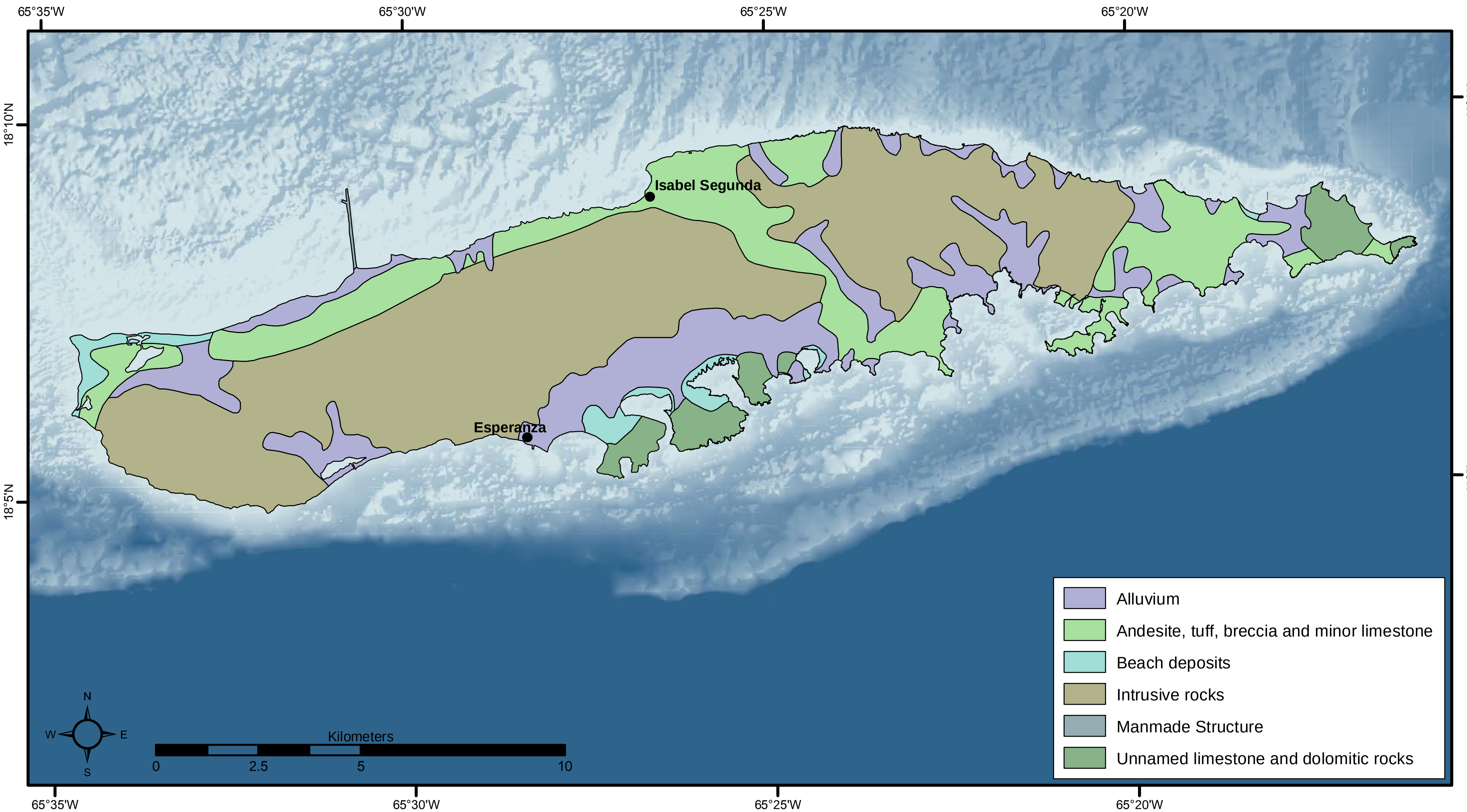


Figure 3.1. Geological structure on Vieques (Source: Integrated Natural Resources Management Plan, GMI 2003a, based on Miller et al. 1999).

combination of alluvial and dune deposits (DON 1985). Specifically along the northwestern coast the beach and dune deposits are comprised of a mixture of calcite, quartz, portions of volcanic rock and small portions of magnetite (GMI 2003a). In addition, portions of the southern coast have ancient marine deposits, from when the island was submerged, of limestone, sandstone, siltstone, and other sedimentary rocks (ATSDR 2003).

Fossil coral reefs were found at Punta Este, within the former Navy Live Impact Area (LIA) and at Fossil Cliff along the northern coast near Isabel Segunda (McIntosh Marine Inc., year n/a). These areas were found to contain fossils predating Caribbean species and are primarily composed of species that are now found only in the Pacific Ocean (i.e.*Trachyphyllia sp*. and *Pocillopora)* (McIntosh Marine Inc., year n/a).

Boccheciamp (1977) conducted investigations of the soil composition of eastern Puerto Rico and identified 11 major soil associations in the region, four of which occur on Vieques: (1) Descalabrado-Guayama (2) Coamo-Guamani-Vives, (3) Swamps-Marshes, and (4) Panudra-Rock land-Patillas. Within these associations, there are 25 detailed soil map units on Vieques (Boccheciamp 1977). CH2MHILL (2001) investigated the soils of Vieques for the Department of the Navy and describe a fifth “Mixed” soil category that is comprised of nine separate soil components and accounts for 20% of the island’s soil composition. The subcategories described by Boccheciamp (1977) showed that the soil composition in Vieques was similar to that found along the eastern coast of mainland Puerto Rico. The soil composition has been greatly altered through the varying land use activities over time, including timber harvesting, farming of livestock and several forms of agriculture, dominated by sugarcane production (DOI 2007).

An extensive sand wedge exists along the northwestern edge of Vieques at Punta Arenas. This sand wedge, Escollo de Arenas, sits atop a broad platform between mainland Puerto Rico and Vieques (Figure 3.2) and was formed from the long shore transport of sediment from adjacent beaches (Rodriguez and Trias 1989). The shoal extends northwest approximately 7 km into the Vieques Passage and covers nearly 4 km^2 (Kendall and Eschelbach 2006). Well developed sand waves or bedforms extend the length of the deposit as a result of tidal currents (Rodriguez and Trias 1989). While there have been minimal changes in the overall geometry of the sand wedge or the composition of the deposition (Zeigler and Giese 1971), a large volume of sediment from the shoal was dispersed into adjacent seagrass beds during Hurricane Hugo (Rodriguez et al. 1994).

The current distribution of vegetation types in Vieques is a function of the island’s geologic history, climate, and land use practices (DOI 2007). Removal of native species for the early 19^{th} century timber industry, followed by extensive clearing and sugarcane farming have altered the vegetation communities on Vieques. Agriculture

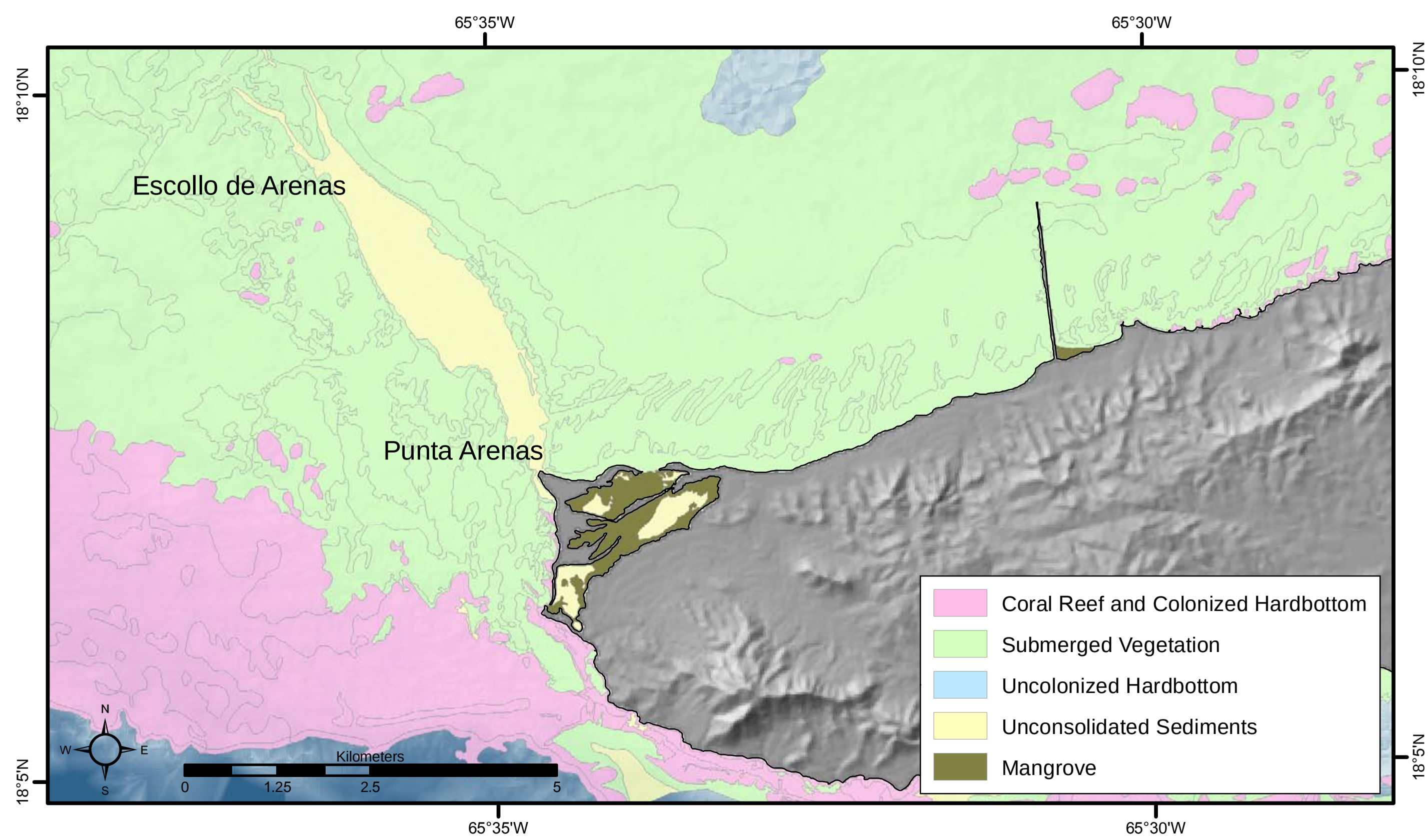


Figure 3.2. Escollo de Arenas off Punta Arenas, Vieques and the associated benthic habitats within that region (Source: Kendall et al. 2001).

Image 3.2. Vegetation near Mt. Pirata. Photo: Biogeography Branch.

shifted to livestock during the mid-20th century, and even during the Navy occupation, portions of the eastern Navy lands were used for grazing. Consequently, no original forest is thought to remain on Vieques; woodlands are primarily secondary growth forests or scrub, and about 20% of the 830 documented plant species on the island are exotic (DOI 2007).

Most of the island is characterized as sub-tropical arid, while the southwest portion is more humid and classified as sub-tropical moist and receives more rainfall (see Chapter 2: Climate and Currents). The spatial differences in climatic patterns are reflected in the distribution of the vegetation types. Dry forest covers approximately 40% of Vieques and is the primary cover type on the far west coast and east of Isabel Segunda and Esperanza (Figure 3.3, Table 3.1). Dry forests are primarily mature secondary semi-deciduous forests that can be further categorized by soil type and elevation (PRGAP 2006). Throughout much of central and eastern Vieques, the dry forest is intermixed with dry shrubland and woodland, whereas dry shrubland and woodland predominate on Punta Este. Shrubland is composed primarily of drought resistant, often thorny scrub plants, primarily *Acacia sp.* and mesquite, *Prosopis juliforis* (DON 1979).

Moist forest, which covers approximately 28 km^2, or 21% of Vieques, is located exclusively on the western half of Vieques and is the characteristic habitat of the hilly southwest coast, including Mt. Pirata, the highest point on the island. The primarily evergreen moist forest is the most diversified vegetation complex and contains many of the rare and endemic species on the island, including the federally endangered species *Eugenia woodburyana* (Woodbury's stopper), *Goetzea elegans* (mata buey), and *Calyptranthes thomasiana* (Thomas' lidflower) (DOI 2007). Other common species include *Cocothrinax alta* (slender palm fan), *Bursera simaruba* (almacigo), *Savia sessiliflora* (amansa guapo), *Krugiodendron ferreum* (leadwood), *Chrysophyllum argenteum* (bastard redwood), and *Ceiba pentandra* (kapoktree) (DOI 2007; DON 1979). Extensive information on plant species present in Vieques can be found in DOI (2007), DON (1979) and Woodbury (1972).

Grassland and pasture is widely dispersed and comprises 16.1 km^2, or approximately 12% of the land in Vieques. This cover type is intermixed with moist forest, moist shrubland/woodland, and urban areas in the central and western portions of the island, as well as large sections in the eastern third. Inland water bodies are primarily limited to salt ponds surrounded by mangroves and salt/mudflats. A few small freshwater ponds are located in the former LIA.

Table 3.1. Area of land cover types in Vieques (adapted from PRGAP 2006).

Cover type	Area (km^2)	% of total
Moist forest	27.9	20.9
Dry forest	53.9	40.4
Moist shrubland and woodland	7.2	5.4
Dry shrubland and woodland	15.9	11.9
Grassland/pastures	16.1	12.1
Mangrove and shrubland	3.1	2.3
Wetlands	0.2	0.1
Salt and mudflats	2.0	1.5
Rocky cliffs and shelves	0.6	0.4
Urban (High-density)	0.5	0.3
Urban (Low-density)	2.3	1.7
Artificial barrens	0.9	0.7
Beaches	1.7	1.3
Freshwater	0.1	0.1
Saltwater	1.2	0.9
Total	133.5	100

Due to the gradient in cover types and land practices moving east to west, areas of former and present land ownership vary in their composition of vegetative cover and non-vegetative cover (Figure 3.4a,b). The former PECA is approximately two-thirds dry shrubland and woodland, followed by grasslands/pastures, rocky cliffs, salt and mudflats, and beaches. Moving west through the former LIA, AFWTF, and EMA, which comprise the remaining portion of the eastern VNWR, dry shrubland and woodland continues to be prevalent, although grassland/pasture and dry forest also comprise a large percentage of these areas. Artificially barren areas identified in the LIA include former target areas; due to the cessation of firing practices, these areas may have since become vegetated. Moving westward from Punta Este, the coastline transitions from primarily rocky cliffs on the eastern tip to an alternating mixture of sheltered sandy beaches and exposed rocky cliffs. Mangrove/shrubland and wetlands line many of the bays and coves on the south shore (see Chapter 8: Mangroves). The municipality, being in the center of the island, includes a mix of dry and moist forest, woodland and shrubland, agriculture, and low

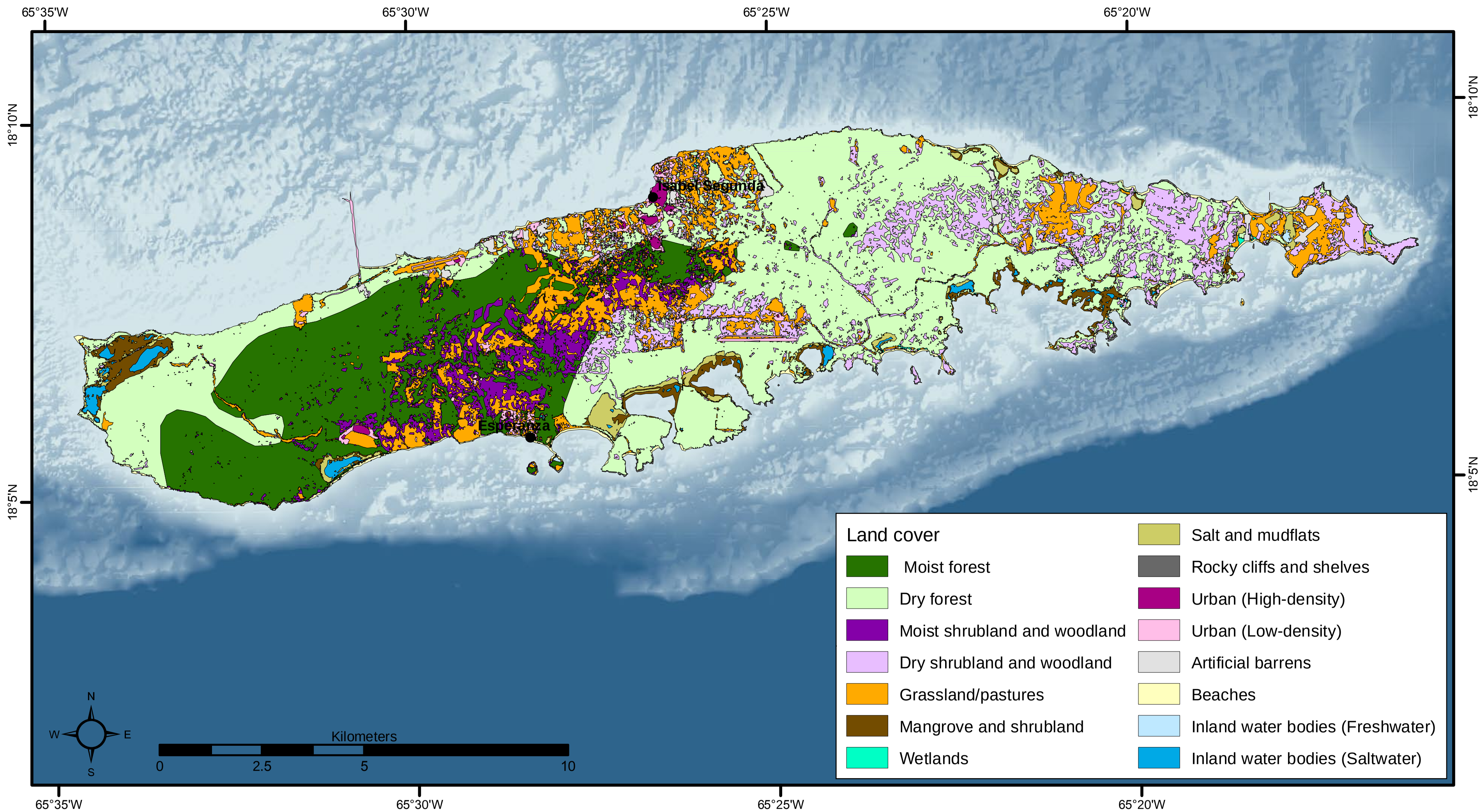


Figure 3.3. Distribution of land cover types on Vieques (adapted from PRGAP 2006).

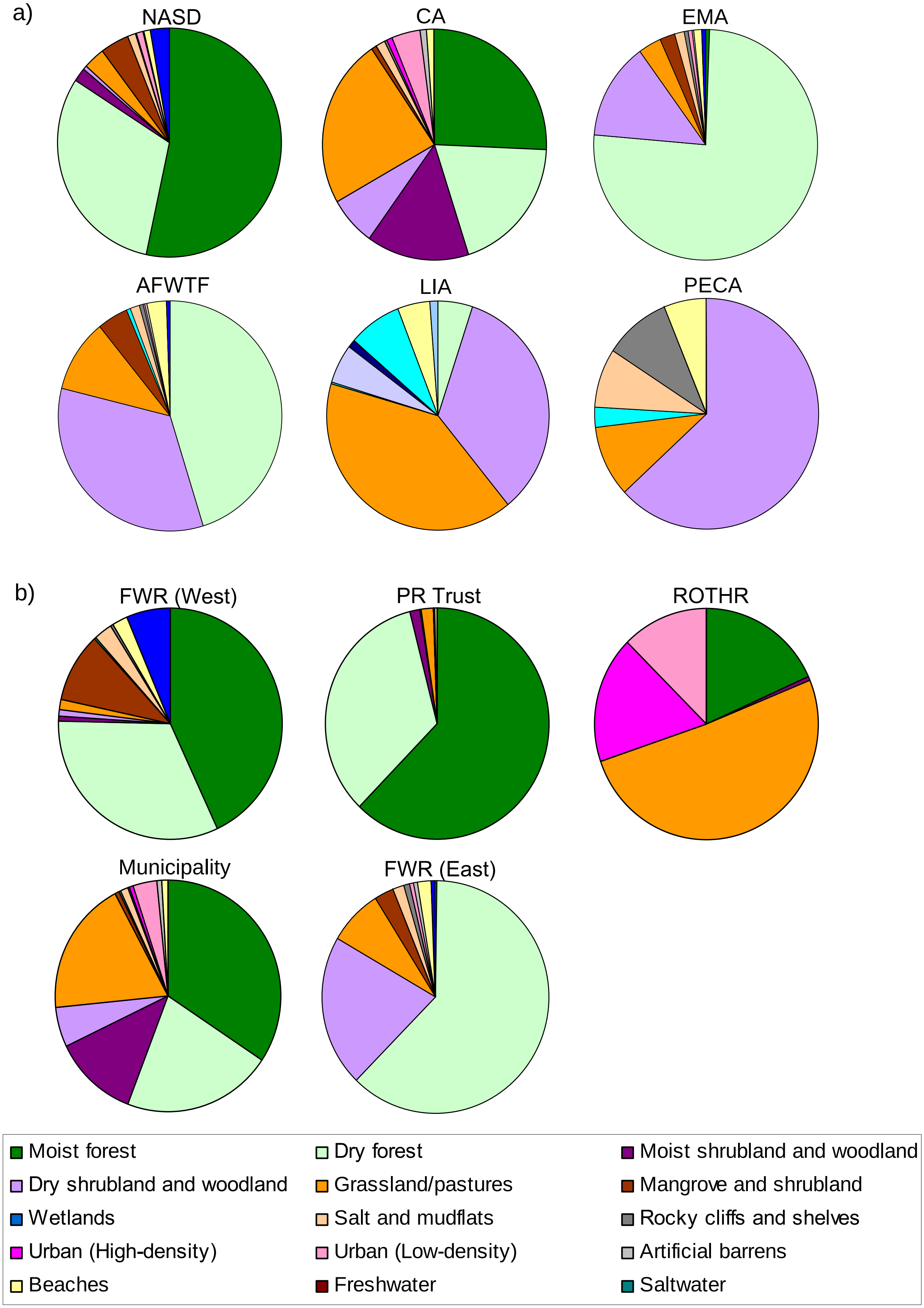


Figure 3.4. Proportion of land cover types within a) former and b) current land use boundaries.

Table 3.2. Rankings of Vieques watersheds (shown in Figures 3.5 and 3.6) in terms of modeled relative erosion potential and sediment delivery, out of all watersheds in Puerto Rico (n=133). Data from NOAA and WRI's (2006) Summit-to-Sea model.

Basin ID	Area	Mean Relative Erosion Potential (1990)	Mean Relative Erosion Potential (2000)	Change in Mean REP (1990-2000)	Potential Sediment Delivery (1990)	Potential Sediment Delivery (2000)	Change in PSD (1990-2000)
A	66	103	105	87	90	90	82
B	83	23	35	93	57	62	89
C	79	52	56	31	67	67	43
D	48	69	72	67	56	60	59
E	90	35	46	48	71	72	55
F	72	37	51	85	58	63	81

and high density urban development. The western VNWR and Puerto Rico Conservation Trust area are dominated by moist and dry forest.

Six watersheds have been identified in Vieques (Table 3.2; Figure 3.5; NOAA and WRI 2006) but waterflow is ephemeral and there are no permanent streams on the island. Primary outflow points identify where the main outflow from each watershed is located, but drainage is not necessarily restricted to these locations. The outflow point associated with the watershed with the highest potential sediment delivery is located near Esperanza, followed by Ensenada Honda, Laguna Playa Grande, east of Punta Mulas/Isabel Segunda, Punta Campanilla, and east of the NW mangrove complex. The watershed-specific potential sediment delivery is related to a number of factors, including soils, precipitation, land cover and elevation (NOAA and WRI 2006). In general, potential sediment delivery is highest in the three watersheds on the south side of Vieques (Figure 3.6). The largest output occurs near the municipality of Esperanza in the largest watershed on the island in terms of area (watershed D). This watershed also contains a high proportion of agriculture, which has a high relative erosion rate. The outflow near Laguna Playa Grande in the southwest region (watershed B) occurs in an area of greater relief and amount of precipitation. In contrast, watershed A contains little urban or agriculture area, and a high percentage of forest, which has a lower relative erosion rate.

Although absolute estimates of amount of erosion and sediment delivery are not available, the relative estimates were used to compare Vieques watersheds with the Commonwealth as a whole. The 133 watersheds of the entire Commonwealth were ranked in terms of Relative Erosion Potential and Potential Sediment Delivery from 1 (highest values) to 133 (lowest values). Relative to all watersheds in Puerto Rico, in general the Vieques watersheds rank in the middle third with respect to watershed size, relative erosion potential, potential sediment delivery to the outflow point, and 1990-2000 change in the Relative Erosion Potential and Potential Sediment Delivery (Table 3.2). All watersheds ranked lower in Relative Erosion Potential and Potential Sediment Delivery in 2000 compared to 1990. This could be attributed to differences in the scale of development in Vieques compared to the main island. The Geo Cover 2000 land cover in Vieques did not change appreciably from 1990, with the exception of less cloud cover/unknown areas.

Watershed C, located in the north central side of the island, ranked 31st out of 133 watersheds in Puerto Rico in change in relative erosion potential between 1990 and 2000. This watershed also experienced the largest percent increase in Potential Sediment Delivery over the ten year period (14%) among the six Vieques watersheds. However, it should be noted that the general area was less obscured by clouds in the later imagery, so it is possible that this increase may be at least partially due to the ability for more land cover (primarily agriculture and shrub/scrubland) to be mapped in this watershed in 2000 compared to 1990.

The potential threat of land based sediment and pollution on benthic habitats of Vieques is a function of the magnitude of the potential sediment loading and the distance from the outflow points (Figure 3.6). In the absence of quantitative data on currents and other hydrologic factors, this is akin to the location and extent of potential sediment plumes stemming from Vieques watersheds. However, as the general current pattern around Vieques runs from east to west (see Chapter 2: Climate and Currents), it is possible that plumes spread more westward from outflow points rather than in equal directions as considered here. Note that the ranking scale devised here is relative to Vieques only and can only be used to compare habitats around Vieques in comparison to each other. In addition, different benthic habitats (i.e., seagrass, coral reef and hardbottom) may vary in their susceptibility to sedimentation. Areas with the highest relative susceptibility to land based sediment and pollution are located in three primary locations: south of the island from Punta Vaca east to Navio Beach, north of the island from Punta Mulas east to Punta Goleta, and Ensenada Honda (Figure 3.6). Areas with low relative sedimentation threat in 2000 include the east end and northwest regions of Vieques. Potential changes in

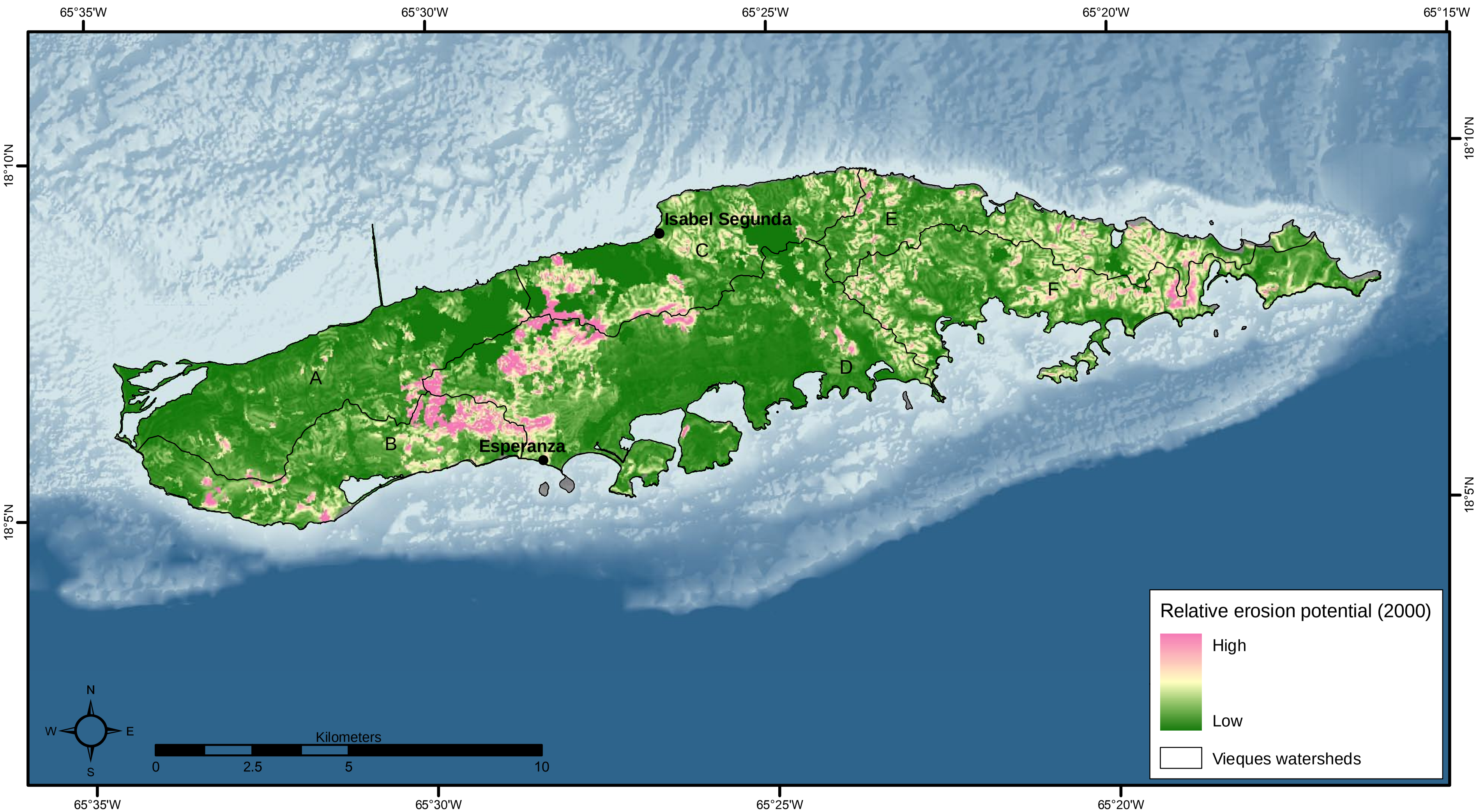


Figure 3.5. Relative erosion potential in Vieques based on 2000 land cover, slope, precipitation, and soil type. Source: NOAA and WRI (2006).

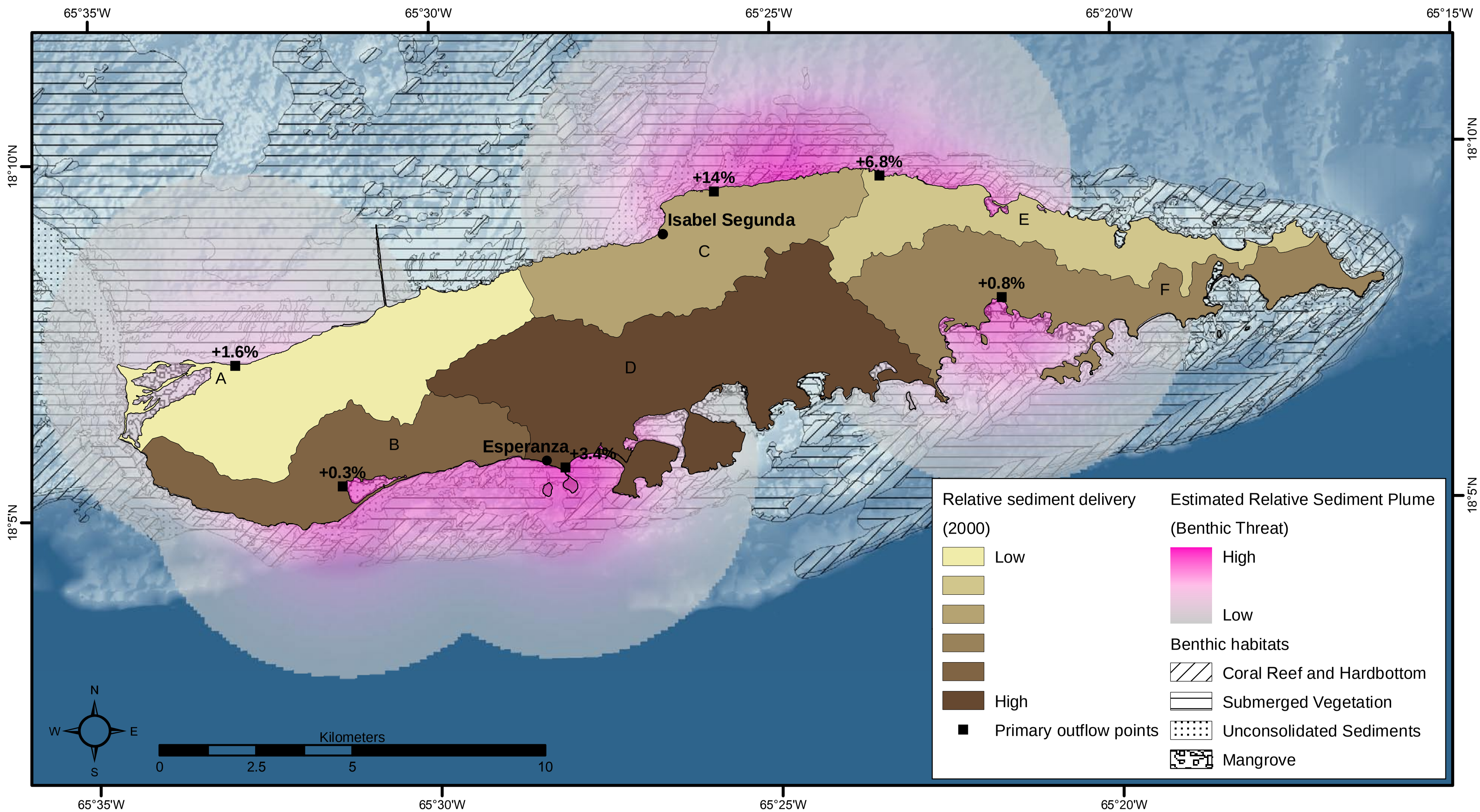


Figure 3.6. Relative sediment delivery by watershed, location of major outflow points, and relative threat to benthic habitats. The percent change in potential sediment delivery from 1990-2000 is labeled at each outflow point. Adapted from NOAA and WRI (2006). Benthic habitat data from Kendall et al. (2001).

sediment delivery may have occurred since this time; for example, land is routinely cleared on the eastern end of the island to search for unexploded ordnance.

3.5 ECOLOGICAL LINKAGES

The distribution of marine habitats is directly related to the marine geology of the island. The bedrock around the island of Vieques is the foundation that supports development of coral reefs and associated marine fauna. Calcareous sediment is the primary component of the beaches on Vieques, which is of particular significance given that sea turtles nest there and are particular about the texture and composition of the sand for proper nesting conditions and egg development (see Chapter 10: Sea Turtles).

Land use practices such as urban development, military activity, road construction, and agriculture can increase the delivery of pollution and sediments to coastal waters. As a result of the long standing history of farming and agriculture on the island of Vieques (ASTDR 2001), the top layers of soil are relatively infertile and unstable and therefore have high erosion rates. Coupled with an increase in coastal development and associated land clearing, suspended sediments pose added stresses to the nearshore reefs, seagrass communities and other associated marine fauna. Factors that influence the distribution and direction of sediment plumes include the type of sediment, grain size, currents, circulation patterns, waves, and storm events. Although only sedimentation associated with land cover and land use are considered here, sedimentation may also arise from human alterations of the seafloor (e.g., dredging, firing and bombing exercises).

Sedimentation can negatively impact coral reefs and other marine habitats in several ways. Sediments can smother corals and reduce light available for photosynthesis, and over time, persistent sedimentation has been associated with lower coral growth rates, reduced coral recruitment, less live coral cover, lower species diversity, and reduced rates of reef accretion (Rogers 1990; Dodge and Vaisnys 1977). Coral species differ in their tolerance and response to siltation, and hence nearshore turbid areas impacted by sedimentation often significantly differ in coral community composition compared to clearer, offshore waters (Sanders and Baron-Szabo 2005). In turn, alterations in coral community structure affect the diversity and abundance of associated reef fishes and invertebrates (Rogers 1990; Vazquez-Dominguez 2003). The concurrent input of nutrients from sewage and fertilizers from terrestrial runoff can compound the effects of sedimentation by stimulating algal growth (Edinger and Risk 1994). Mangrove and seagrass habitats serve as a buffer to reefs by trapping sediments; however, excessive terrestrial runoff has also been linked to the decline of seagrass beds. Increased turbidity from suspended sediments and algal growth stemming from nutrient enrichment reduces the light available for seagrasses (Burkholder et al. 2007). In addition, sediment can serve as a vector for transporting sediment-associated contaminants to the marine environment, which can have harmful effects on corals (Pait et al. 2007).

Military activities have altered the rates of soil erosion and sedimentation through road construction, clearing and grading activities and training exercises with artillery deployment (DON 1985). Ordnance deployment in particular has fractured underlying bedrock and burned overlying vegetation. Recovery of vegetation appeared stronger in areas of volcanic rock rather than in areas of limestone, due to a thicker soil layer (DON 1985). To quantify sedimentation changes related to militarily activity, Raymond (1978) collected sediment samples at Bahia Salina and Bahia Icacos and found that the levels of terrigenous sediments were low and therefore rates of coastal runoff did not pose significant threats to local coral reefs.

Although recent, spatially comprehensive data on sediment loading to Vieques systems is not available, the Summit-to-Sea analysis (NOAA and WRI 2006) identifies areas where further study is warranted. In the absence of island-wide sedimentation measurements, information on land cover, slope, precipitation, and soil type were used to estimate watershed-specific relative erosion potential and sediment delivery. Although the few sedimentation studies that have been conducted on Vieques have focused on military areas where in-water bombing activity took place (Rogers et al. 1978; GMI 2003b), results from NOAA and WRI (2006) indicate that areas located outside the Live Impact Area are also susceptible to sedimentation. In addition, the information provides a framework with which to monitor changes in land cover and associated erosion potential over time. Due to the recent land transfer, increased development and tourism is anticipated, which may result in changes in the input of sediments to the coastal environment.

LITERATURE CITED

ATSDR (Agency for Toxic Substances and Disease Registry). 2001. Focused Public Health Assessment, Drinking Water Supplies and Groundwater Pathway Evaluation, Isla de Vieques Bombing Range, Vieques, Puerto Rico. http://www.atsdr.cdc.gov/HAC/PHA/vieques/vie_p1.html.

ATSDR (Agency for Toxic Substances and Disease Registry). 2003. Petitioned Public Health Assessment, Soil Pathway Evaluation, Isla de Vieques Bombing Range, Vieques, Puerto Rico. http://www.atsdr.cdc.gov/HAC/PHA/isladevieques/idv_toc.html.

Boccheciamp, RA. 1977 Soil survey of Humacao area of eastern Puerto Rico. US Department of Agriculture, Soil Conservation Service. 103 pp.

Brink, U. 2005. Vertical motions of the Puerto Rico Trench and Puerto Rico and their cause. Journal of Geophysical Research 110: 1-16.

Burkholder, JM, DA Tomasko and BW Touchette. 2007. Seagrasses and eutrophication. Journal of Experimental Marine Biology and Ecology 350: 46-72.

CH2MHILL. 2001. Final description of current conditions report Atlantic Fleet Weapons Training Facility Vieques Island, Puerto Rico. Prepared for the Department of the Navy Atlantic Division Naval Facilities Engineering Command. Tampa, FL 34 pp.

Dodge, RE and JR Vaisnys. 1977. Coral populations and growth patterns: responses to sedimentation and turbidity associated with dredging. Journal of Marine Research 35: 715–730.

DOI (US Department of the Interior). 2007. Final Comprehensive Conservation Plan/Environmental Impact Statement for Vieques National Wildlife Refuge, Vieques, Puerto Rico. Fish and Wildlife Service, Southeast Region, Atlanta, GA.

DON (US Department of the Navy). 1985. Soil Erosion Control Plan for the Atlantic Fleet Weapons Training Facility Vieques, PR. Ecology and Environment, Inc.

DON (US Department of the Navy). 1996. Soil Erosion Control Plan for the Atlantic Fleet Weapons Training Facility Vieques, PR. Ecology and Environment, Inc.

DON (US Department of the Navy). 1979. Draft Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

Edinger, EN and MJ Risk. 1994. Oligocene-Miocene extinction and geographic restriction of Caribbean corals: roles of turbidity, temperature, and nutrients. Palaios 9: 576-598.

GMI (Geo-Marine, Inc.). 2003a. Navy Lands on Vieques: Integrated Natural Resources Management Plan, Plan Years: 2003-2012. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

GMI (Geo-Marine, Inc.). 2003b. Reef ecosystem baseline assessment survey and monitoring, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

Gould, W, C Alarcón, B Fevold, ME Jiménez, S Martinuzzi, G Potts, M Solórzano and E Ventosa. 2007. Puerto Rico Gap Analysis Project- Final Report. USGS, Moscow, ID, and the USDA Forest Service International Institute of Tropical Forestry, Río Piedras, PR. 159 pp. + 8 appendices.

Groves, K. 1972. Section 2: Geology. In: Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Rico, Office of the Governor.

Kendall, MS, CR Kruer, KR Buja, JD Christensen, M Finkbeiner, RA Warner and ME Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (online). http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html. 45 pp.

Kendall, MS and KA 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.

Langhorne, E. 1987. Vieques: History of a Small Island. The Vieques Conservation and Historical Trust. Vieques, PR. 90 + A4 pp.

McIntosh Marine, Inc. Year unknown. A brief description of Fossil Assets at Vieques, Puerto Rico. Vero Beach, FL.

Miller, JA, RL Whitehead, SB Gingerich, DS Oki and PG Olcott. 1999. Ground Water Atlas of the United States; Segment 13 Alaska, Hawaii, Puerto Rico and the U.S. Virgin Islands. Hydrologic Investigations Atlas 730-N. United States Geological Survey, Reston, Virginia.

NOAA (National Oceanic and Atmospheric Administration) and WRI (World Resources Institute). 2006. Summit to Sea Characterization of Coastal Watersheds (Puerto Rico and US Virgin Islands). http://ccma.nos.noaa.gov/ecosystems/coralreef/summit_sea.html.

O'Connell, S, TC Ku and A Martini. 2007. The hydrodynamics and biogeochemistry of Bioluminescent Bays, Vieques, Puerto Rico. 20th Annual Keck Symposium.

Pait, AS, DR Whitall, CFG Jeffrey, C Caldow, AL Mason, JD Christensen, ME Monaco and J. Ramirez. 2007. An Assessment of Chemical Contaminants in the Marine Sediments of Southwest Puerto Rico. NOAA Technical Memorandum NOS NCCOS 52. Silver Spring, MD. NOAA/NOS/Center for Coastal Monitoring and Assessment. 116 pp.

PRGAP (Puerto Rico GAP Analysis Project). 2006. PRGAP Landcover. USDA Forest Service, International Institute of Tropical Forestry, Rio Piedras, Puerto Rico. http://gapanalysis.nbii.gov/portal/server.pt.

Raymond, W. 1978. Marine sediment of a Naval bombing range. Ocean Research and Survey, Inc. Fort Lauderdale, FL.

Rodriguez, RW and JL Trias. 1989. Maps showing characteristics of the Escollo de Arenas sand and gravel deposit, Vieques Island, Puerto Rico. Department of the Interior, U.S. Geological Survey. Map MF-2108.

Rodriguez, RW, RMT Webb and DM Bush. 1994. Another look at the impact of Hurricane Hugo on the shelf and coastal resources of Puerto Rico, USA. Journal of Coastal Research 10(2): 278-296.

Rogers, CS. 1990. Responses of coral reefs and reef organisms to sedimentation. Marine Ecology Progress Series 62: 185-202.

Rogers, CS, G Cintron and C Goenaga. 1978. The impact of military operations on the coral reefs of Vieques and Culebra. Report to the Department of Natural Resources, San Juan, Puerto Rico.

Sanders, D and RC Baron-Szabo. 2005. Sclerectinian assemblages under sediment input: their characteristics and relation to the nutrient input concept. Paleogeography, Paleoclimatology, Paleoecology 216: 139-181.

Sommer, SE, EE Angino and DW Hood. 1964. Mineralogy and Geochemistry of Recent Sediments, Vieques Passage, Puerto Rico. Texas A&M Research Foundation, Office of Naval Research Technical Report 64-12T.

Vázquez-Domínguez, E. 2003. Diversity and distribution of crustaceans and echinoderms and their relation with sedimentation levels in coral reefs. Revisita de Biología Tropical 51(1): 183-193.

WRI (World Resources Institute) and NOAA (National Oceanic and Atmospheric Administration). 2006. Land-based sources of threat to coral reefs in the US Virgin Islands. http://pdf.wri.org/usvi_atlas_web.pdf.

Woodbury, RO. 1972. Section VII: Vegetation. In: Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Riso, Office of the Governor.

Ziegler, JM and GS Giese. 1971. Geology and Hydrodynamics of Punta Arenas Shoal. pp. 33-38. In: Transactions of the 5th Caribbean Geological Conference, Geology Bulletin No. 5. Queens College Press.

CHAPTER 4: BATHYMETRY

4.1 OVERVIEW

The island platform on which Puerto Rico lies is bound by two deep trenches, the Puerto Rico Trench to the north and the Muertos Trench to the south. Additional bathymetric features are situated between the two trenches east of the main island of Puerto Rico. The ~4500 m deep Virgin Islands Trough, which lies north of the Muertos Trench, separates Vieques Island, St. John and St. Thomas in the north from St. Croix to the south. The Sonda de Vieques, which lies between Vieques and Culebra, is a relatively flat shallow region that rarely exceeds 30 meters in depth.

An inventory of available bathymetry data for the seafloor surrounding Vieques was conducted. Two types of bathymetry data are available for this region, LIDAR (LIght Detection And Ranging) data and NOAA hydrographic survey data. Due to more extensive coverage, the hydrographic survey data was used to create a comprehensive bathymetry map of the coastal area around Vieques out to approximately three nautical miles. The accuracy of the interpolated map was assessed with observed depths from a May 2007 field survey. Overall, there was a strong relationship between the predicted and field depths. Potential changes in the bathymetry were assessed by comparing the interpolated map with the newer LIDAR data collected on the eastern end of the island.

The seafloor topography surrounding Vieques differs markedly between the north and south shore. North of the island, the seafloor is generally uniform and shallow (<30 m), interrupted only by patch reefs and a shallow shoal, the Escollo de Arenas. The south shore is characterized by an east-west oriented coral reef and a steep slope or wall at the edge of the insular shelf. This wall is closest to shore on the southwest side of the island where it is a mere 1-2 km from shore. West of the town of Esperanza, the shoreline is marked by numerous shallow bays less than 10 m in depth. On the southeastern half of the island, a nearshore barrier reef formation is separated from an offshore reef formation by a <30 m deep trough.

4.2 SOURCES OF DATA

The available data sources for the bathymetry around Vieques include NOAA hydrographic survey soundings and LIDAR (LIght Detection And Ranging) bathymetry data.

Depth soundings, in the form of point data, were obtained from the GEOphysical DAta System (GEODAS, http://www.ngdc.noaa.gov/mgg/geodas/geodas.html), which is a compilation of all NOAA hydrographic survey data. Soundings data available from Vieques were from surveys conducted from 1902-1982. The majority was collected between 1962-1976, while ~25% of the data was collected before 1910. Further details about bathymetric surveys conducted during the late 1960s in southeastern Puerto Rico are provided by Starr and Bassinger (1971). All soundings data is adjusted to mean low water by GEODAS. The spacing of points was not uniform among surveys and some areas had been surveyed more than once; hence density of points per square kilometer varied across the study area. Density was highest in Vieques Sound between eastern Puerto Rico and Vieques and in nearshore areas around most of the island, ranging from 75 to over 500 points per km^2. Beyond the inner shelf slope on the south side, especially past the 50 m contour, the point density drops precipitously (<10 points per km^2). Density also tended to be lower (<75 points per km^2) northeast of the island beyond the first 2-3 km offshore. The data was primarily collected by a Digital Echo Sounder during surveys post-1960, however, it is assumed that survey depths collected in the early 1900s were measured by lead lines.

LIDAR bathymetry data was collected around Vieques by the US Army Corps of Engineers and Joint Airborne LIDAR Bathymetry Technical Center of Expertise (JALBTCX) using the Scanning Hydrographic Operational Airborne Bathymetry LIDAR System (SHOALS) in 2000 (see JALBTCX 2000 for data collection methods). The purpose of the survey was to characterize the existing bathymetry of the eastern end of Vieques. Soundings were spaced approximately across a 4x4 m grid and were adjusted to low mean water. Although the point density was much higher and the data was collected more recently than the GEODAS hydrographic survey data, the coverage of the LIDAR dataset was limited to the eastern half of Vieques and did not include some of the offshore reefs. As such, the point soundings of the hydrographic survey data, which provided coverage of the entire survey area, were used to generate a bathymetric surface for the study area. However, the LIDAR data was examined to investigate potential changes in bathymetry on the east end since the hydrographic surveys were conducted. The hydrographic survey data in this area was collected in the 1960s-70s on the northern side, but in 1917 on south side.

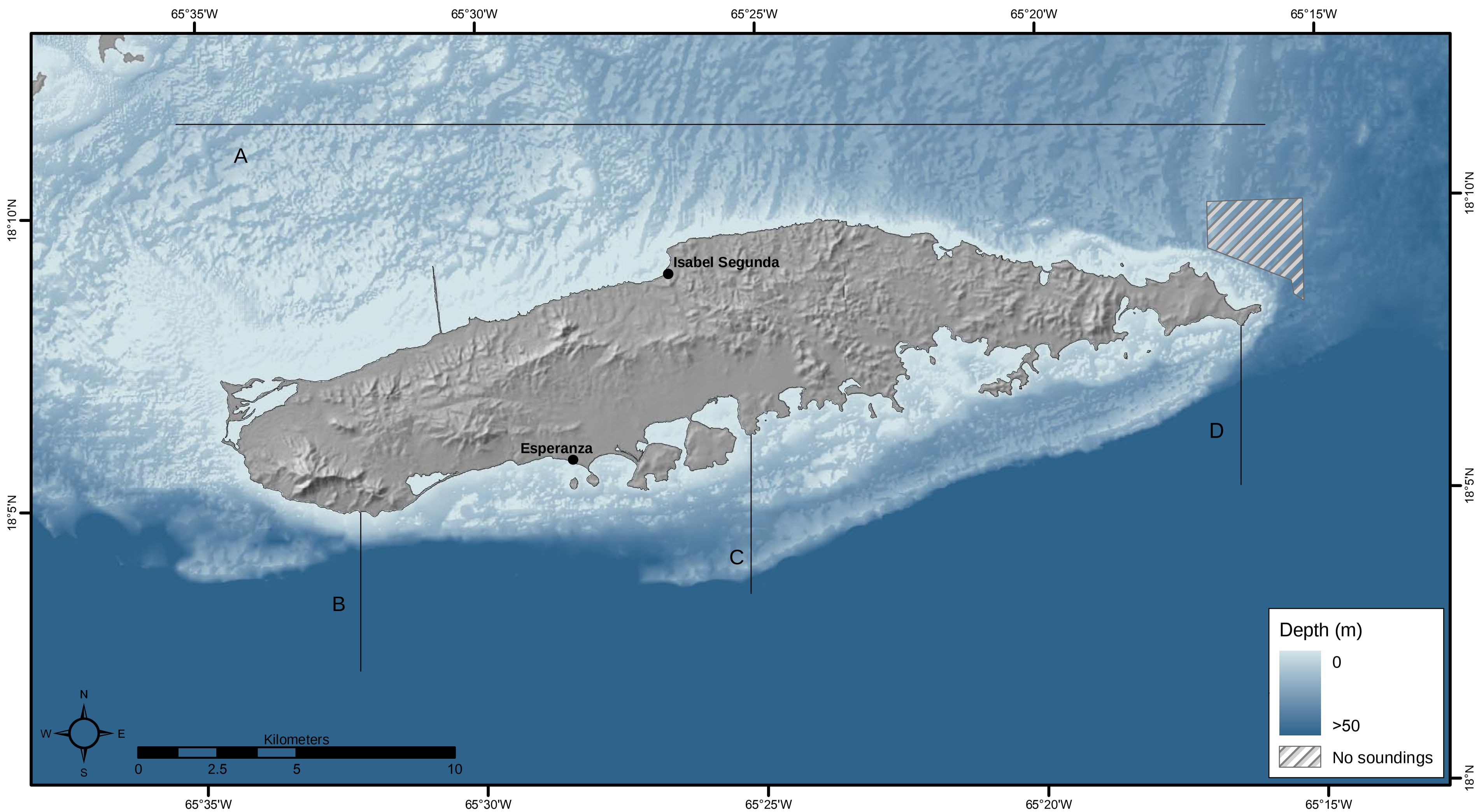


Figure 4.1. Bathymetry map around Vieques generated from GEODAS data. Bathymetric profiles of lines A-D are shown in Figure 4.2. No sounding data were available in the gray shaded section and the interpolated depth in this area is coarse and unreliable.

4.3 METHODS

Prior to analysis, outliers and individual points or tracklines that were suspected to be erroneous were removed from the GEODAS data. Soundings data were interpolated using a triangulated irregular network (TIN) in ArcGIS (3D-Analyst extension). The method involves automated creation of a network of non-overlapping triangles from all combinations of three nearest points. Each triangle is given an average depth value based on the measured depths at each vertex of the triangle. The shoreline derived from the 1999 aerial photography (Kendall et al. 2001) was fixed at zero depth and reef crests from benthic habitat maps (Kendall et al. 2001) were used as hard fills with a value of 1 m since they are barely submerged features. The resulting TIN file was converted to a 25 m grid using a natural neighbor interpolation for analysis and display. Example two-dimensional bathymetric profiles were created for the north side (west-east) and south side (north-south) to highlight spatial differences in the nearshore bathymetry. Depth values collected in the field by NOAA's Coastal Oceanographic Assessment, Status, and Trends (COAST) Branch during recent field surveys were used to conduct an accuracy assessment of the interpolated bathymetry map. Depth was measured at 124 sites as part of COAST sampling during a May 2007 field survey (COAST, unpublished data). The measured depth at these locations was compared to the expected depth from the bathymetry map using regression analysis (JMP v6).

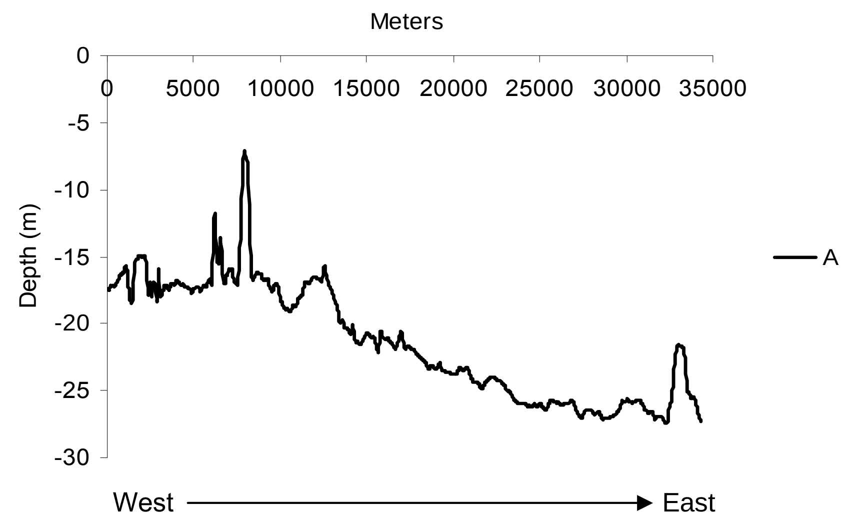
In addition, topographic complexity was calculated from the bathymetric data using the neighborhood statistics function within Spatial Analyst in ArcGIS 9.2. In this analysis, a standard deviation of water depth was calculated within a 75 x 75 m moving window on each bathymetric cell. The calculated standard deviation is assigned to the center of the neighborhood and results in an estimate of the standard deviation of the bathymetry at a scale of 25 m for the entire region. Due to the sparseness of the point data beyond the inner shelf edge, topographic complexity is only displayed out to the 50 m contour.

The SHOALS LIDAR data was also interpolated for the area where data was collected (the eastern half of the island) and converted to a 4 m grid (i.e., the approximate spacing of data collection) for analysis and display. To investigate potential areas of bathymetric change in the time between collection of the GEODAS (1902-1982) and LIDAR (2000) datasets, 100 random points were generated (HawthsTools v3.23) within the area of overlap between the two data sets. The estimated bathymetry value beneath each point was extracted and compared for both bathymetry layers using correlation analysis.

4.4 DISTRIBUTION, STATUS AND TRENDS

The modelled bathymetry around Vieques is shown in Figure 4.1. The water depth extending north of Vieques all the way up to Culebra is generally uniform and shallow (<30 m), although there is a gradual decreasing trend in depth going from west to east (Figure 4.2). In particular, a shallow shoal less than 5 m in depth extends northwest from Punta Arenas. This feature, called the Escollo de Arenas, is noticeable in aerial images and is composed of sand and gravel deposits (Rodriguez and Trias 1989; see Chapter 3: Geology and Land Cover).

The seafloor southwest of Vieques experiences a much steeper drop-off close to shore. This is reflected in profile B, where the inner shelf edge occurs ~1 km off-



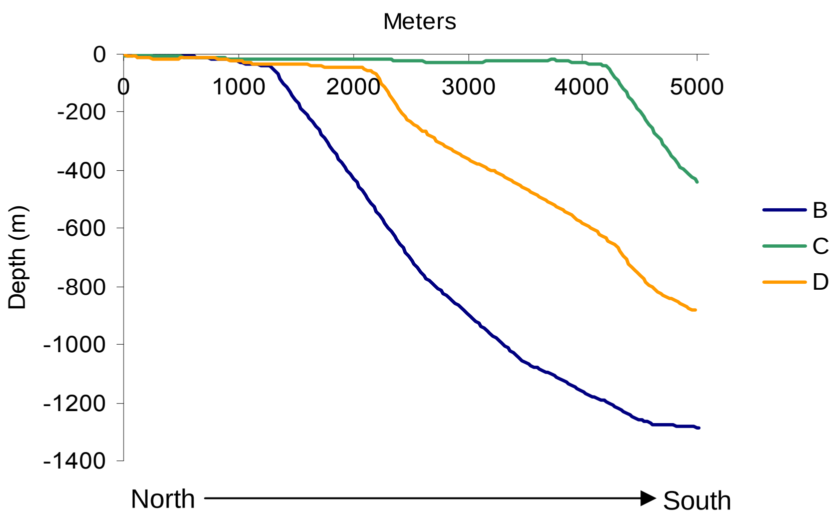


Figure 4.2. Bathymetric profiles (A-D) corresponding to lines in Figure 4.1.

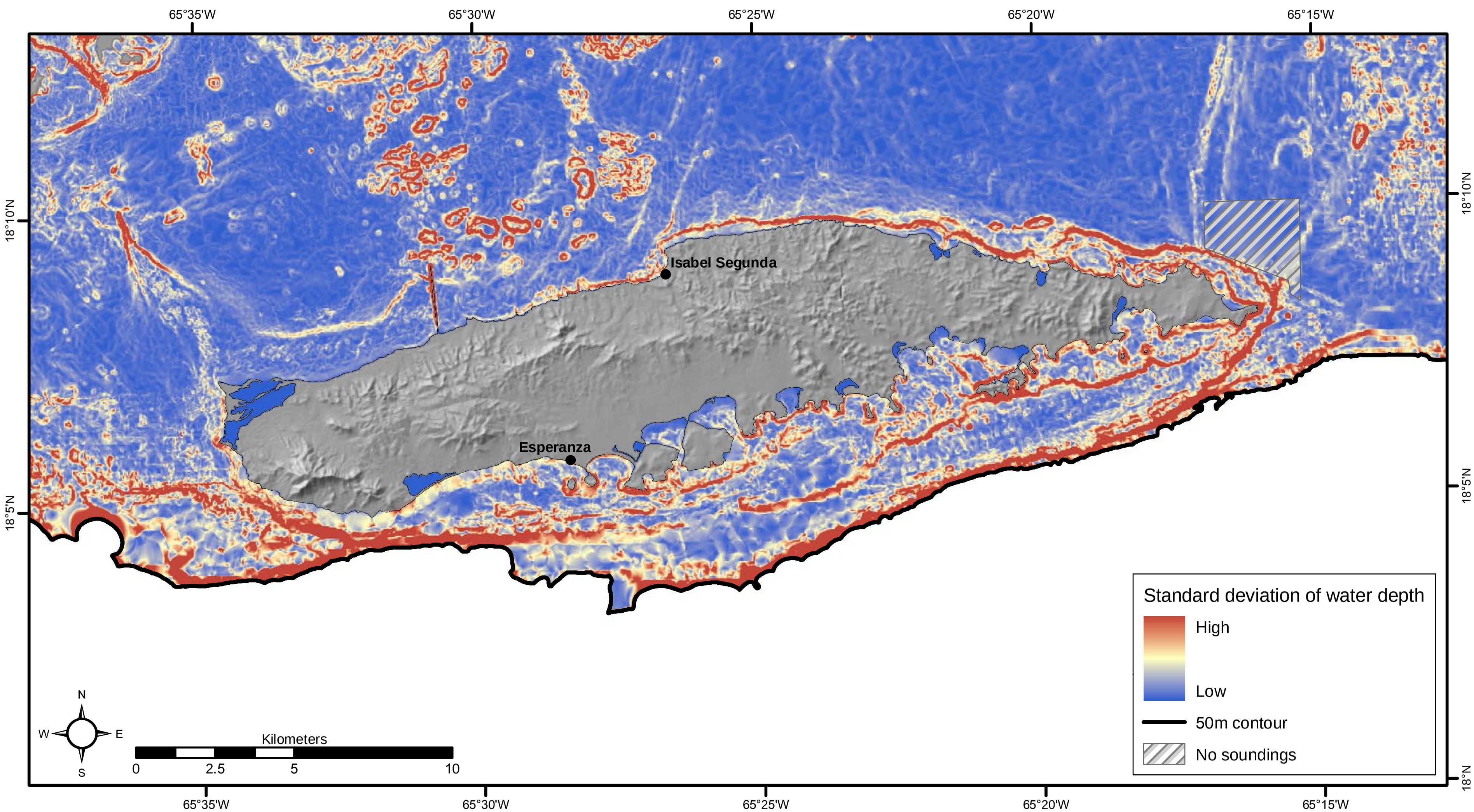


Figure 4.3. Topographic complexity of bathymetry out to the 50 m contour.

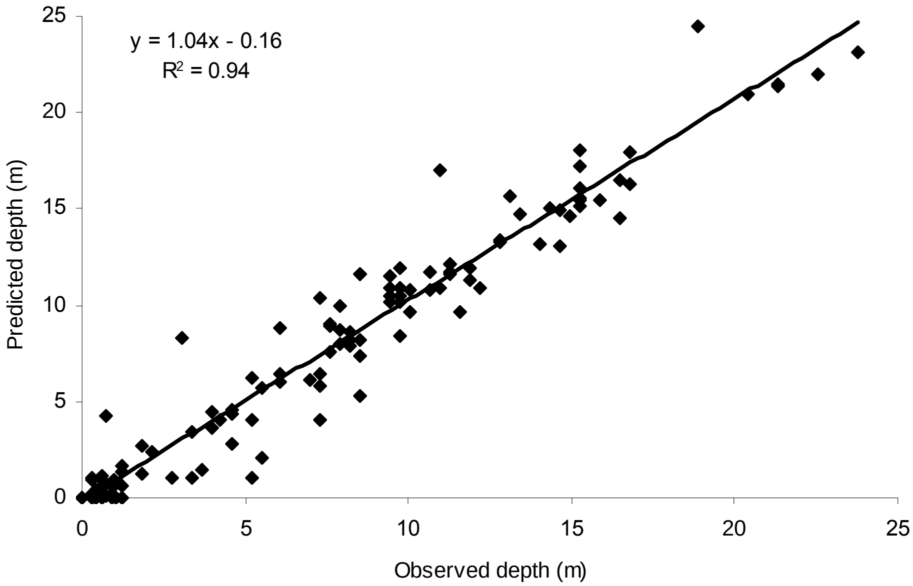


Figure 4.4. Results of regression analysis for predicted depth versus observed depth at 124 sites surveyed during May 2007 field survey. The line represents the fit of the regression equation.

shore (Figure 4.2). Further east on the southern shore, there are numerous shallow bays that are less than 10 m deep. Offshore of the bays, the bottom slopes down to around 20 m before a shallow ridge rises further offshore. This ridge, which becomes progressively narrower heading from east to west, is marked by the presence of a series of coral reefs (Chapter 5: Reefs and Hardbottom). Seaward of the reefs, the bathymetry drops off precipitously. At profile C, water depth is <30 m until the shelf edge occurs approximately 4 km offshore. Offshore of the eastern tip of the island, the edge occurs closer to the coast (e.g., profile D). Physiographic complexity is highest in these areas where bathymetry changes rapidly and where other reef formations (e.g., patch reefs on the north shore) are present (Figure 4.3).

The accuracy assessment of the bathymetry map resulted in a high fit (R^2 = 0.94) between the predicted and observed bathymetry values from the field data (Pr< 0.001, Figure 4.4). The difference between the two values was within 1 meter at 63% of the sites, and within 2 meters at 85% of the sites. The largest discrepancies were observed at sites on the east end of the island, and areas where there is a high degree of slope (Figure 4.5). In addition, the predicted depths tended to be greater than the observed depths at some patch reefs on the north shore. Several factors could be responsible for the difference in the interpolated depths and field values, including the resolution of the interpolated bathymetry map (25 x 25 m). The predicted depth at a point is the depth value for the 25 x 25 m cell in which the point is located; however, it is likely that depth varies significantly within a cell in areas of high slope and complexity. Other potential factors include the accuracy of the GEODAS data, changes in the bathymetric profile since the data was collected, or errors in geographic position during the field survey. In addition, it is important to note that the majority of the sample locations were on reef/hardbottom habitat, therefore the dataset is not representative of all bottom types around Vieques. However, it would be expected that reef and hardbottom would be more variable than softbottom habitat due to higher physiographic complexity. In addition, the accuracy assessment focused only on relatively shallow depths (<25 m). Anomalous features in the bathymetry and topographic complexity in areas outside of the assessment area cannot be verified. For example, numerous straight lines extend north from the northeastern end of the island and may be an artifact of low sounding density and the TIN process.

The soundings from which the map was created are over 25 years old, and the oldest are 100 years old, although early 1900s data comprised only 25% of the total data. Bathymetry can change over time due to natural processes such as erosion, deposition and sediment transport as well as anthropogenic factors such as dredging and filling and military activity. For instance, changes in the appearance of the Escollo de Arenas were noted following Hurricane Hugo (Rodriguez et al. 1994; see Chapter 3: Geology and Land Cover). Air to ground exercises in the Live Impact Area would likely displace sediment and produce craters in the seafloor, although these would be at a finer scale than can be captured with a 25 m grid. Hence, the comparison of the bathymetry map derived from the older GEODAS data with a layer derived from newer LIDAR data was conducted to investigate potential changes in bathymetry. It should be noted that the analysis and interpretation is limited to the extent of the LIDAR data on eastern half of the island.

There was a very strong correlation between the interpolated depth derived from the LIDAR and GEODAS datasets at the 100 random locations (Rho = 0.99, Pr<0.0001; Figure 4.6). For 79% of the locations, the difference was ≤1 meter and the deviation only exceeded 2 meters at 6 sites. The points with the greatest difference tended to be located in shallow nearshore bays, or south and east of the island where slope and topographic complexity are high (Figure 4.7). For instance, at two points in Ensenada Honda, the GEODAS derived depth for the underlying grid cells exceeded the LIDAR derived depth by 6.5 and 3.4 m, respectively. Conversely, the LIDAR derived depth exceeded GEODAS by nearly 5 m in a cell southwest of Punta Este. Overall, the LIDAR depth exceeded the GEODAS depth 70% of the time, even though the difference was generally small (<1 m). Whether these differences represent actual changes in the bathymetry, or are the result of the methods

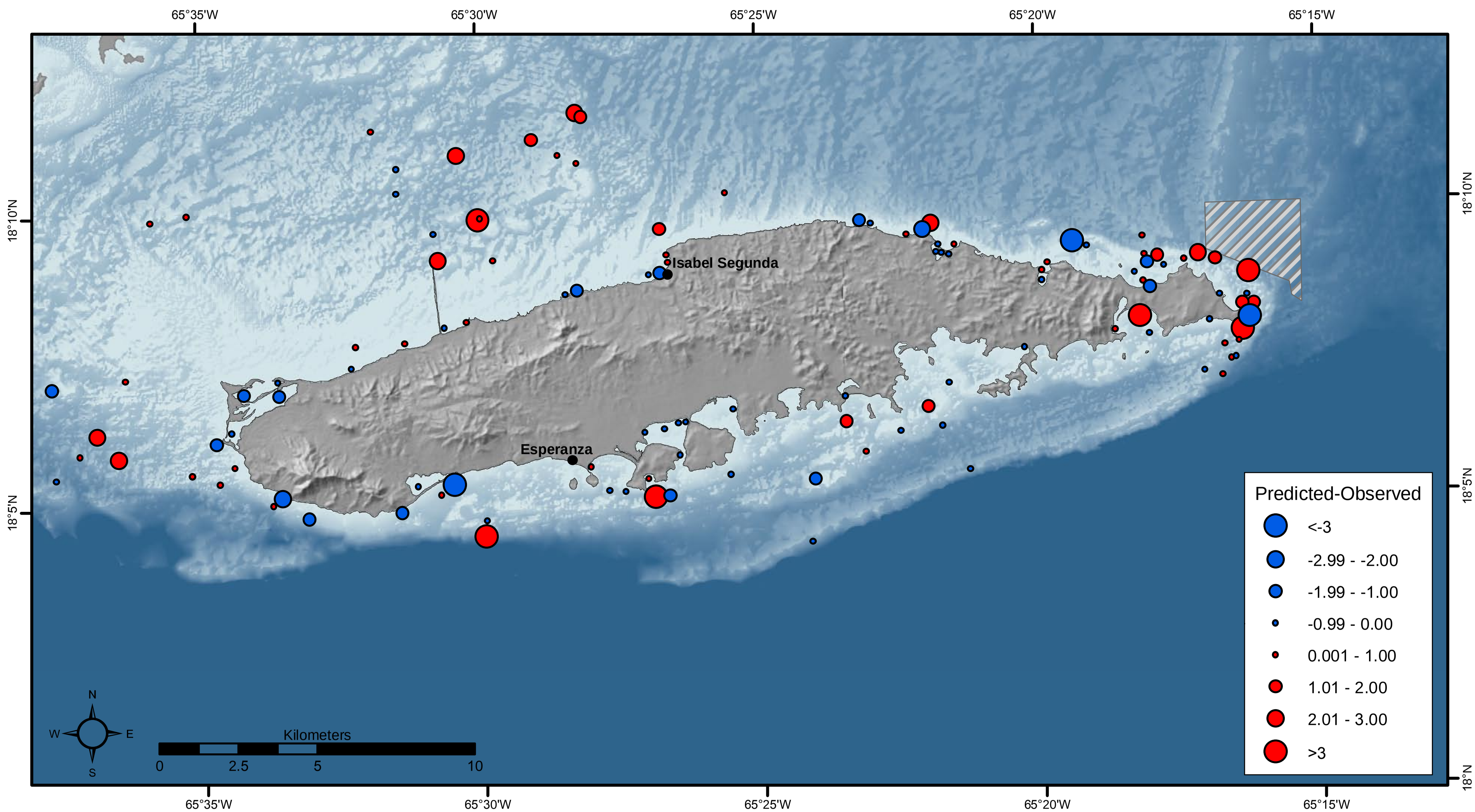


Figure 4.5. Comparison of predicted and observed depth at 124 field survey locations. The bubbles correspond to the magnitude of the difference between the predicted and observed depth values at that location.

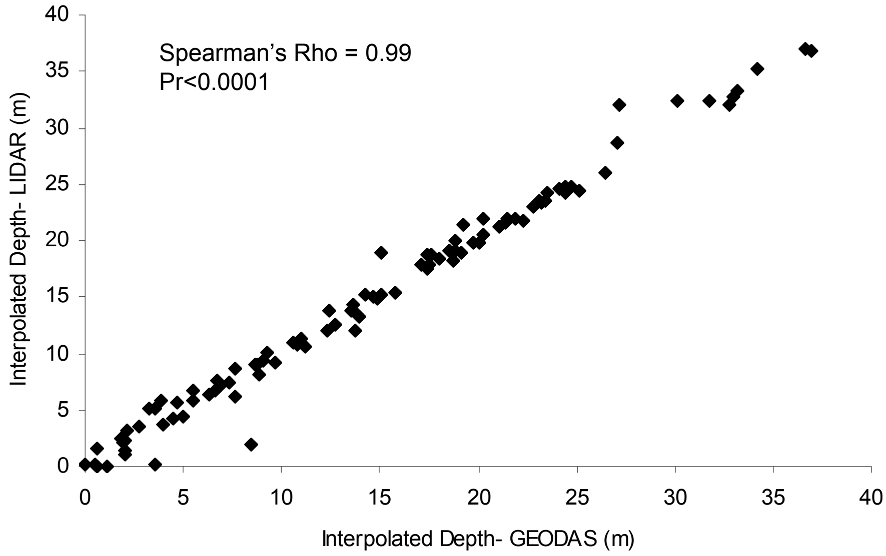


Figure 4.6. Correlation of GEODAS depth and LIDAR depth.

used to collect and map the data is unknown. One advantage of the LIDAR dataset is the density of data points (4 x 4 m), which allows for the creation of a fine-scale grid. In contrast, the spacing between points in the GEODAS set was typically much greater, and is particularly sparse beyond the inner shelf edge. Even inshore, occasional small gaps exist where no point data is available. On slopes, the relief can change quickly over a short distance; it's possible that the available ship sounding data may not be sufficiently spaced to accurately capture small scale patterns in the bathymetry profile. Further, out of concern for surface navigation, NOAA hydrographic survey data is typically "shoal-biased," i.e., the data is cleaned and selectively includes shallow over deep points in order to preserve shoal features (Calder 2006). In contrast, LIDAR data is not shoal-biased and can sometimes include false bottom readings due to water column interference (Intelmann 2006). In addition, the GEODAS data were collected by a variety of methods (e.g., lead lines, digital echo soundings) and the geo-positional accuracy and quality of the data is not always known.

Given the age and spacing of the GEODAS data set, an island-wide comprehensive LIDAR dataset would be useful for updating the Vieques bathymetry dataset out to 60 m depth, the general limit of mapping with LIDAR. This data could be combined with deep-water technologies such as multibeam to provide a comprehensive fine-scale bathymetric layer for the Vieques region. The general agreement of the GEODAS derived bathymetry layer with the field data and the LIDAR-derived layer on the eastern end suggests that the island

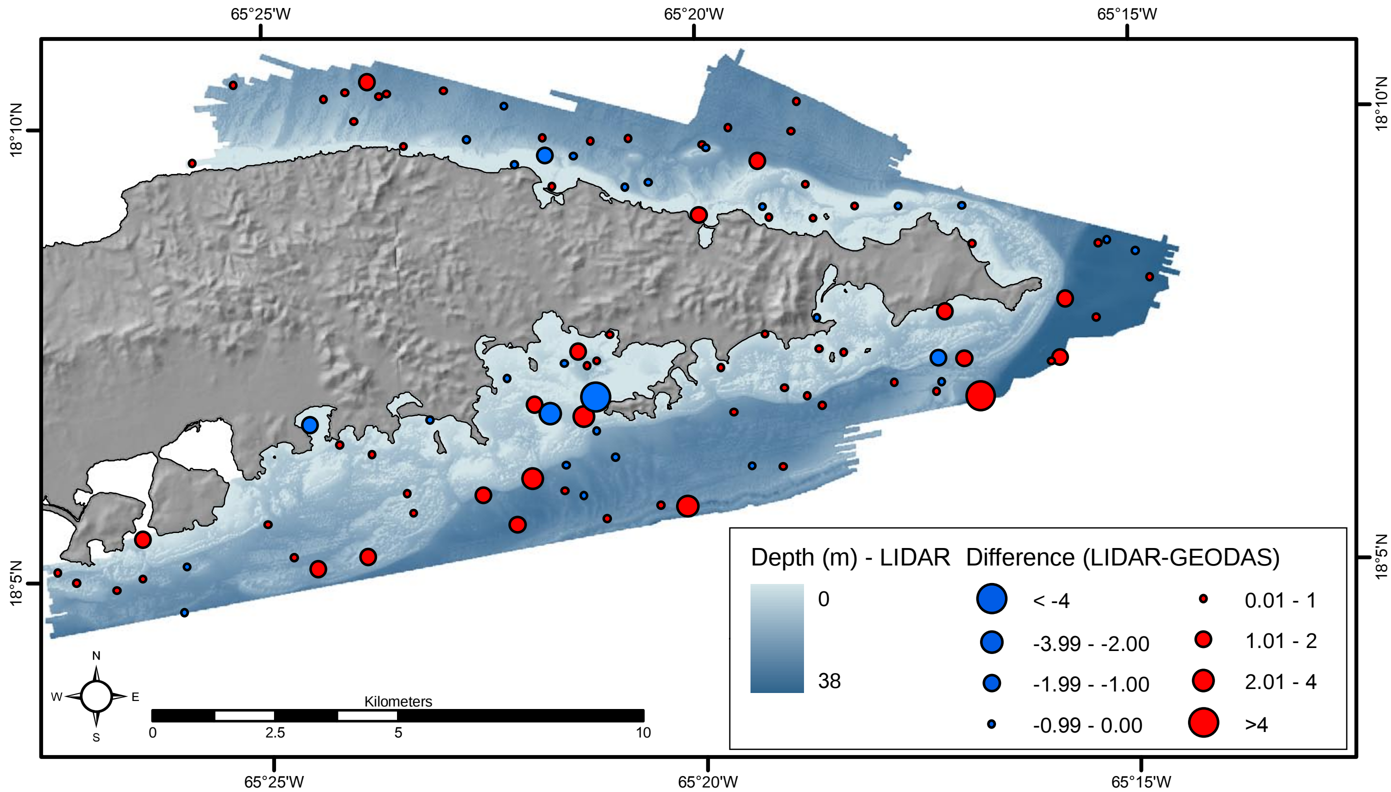


Figure 4.7. Bathymetry map around Vieques (east end only) generated from LIDAR data. The locations of 100 random points are displayed. The bubbles correspond to the difference in predicted depth values at that location.

wide bathymetry layer derived here is a useful planning product for the depths tested (<30 m), especially where slope and rugosity are low. However, for many modeling applications (e.g., fish habitat utilization), a finer-scale bathymetry map is needed.

4.5 ECOLOGICAL LINKAGES

Bathymetric information provides a foundation for spatial analyses such as habitat suitability modeling and will aid in interpretation of aerial imagery for benthic habitat mapping. In addition, the bathymetry map derived here will improve field operations as it will be useful for stratifying and planning research and monitoring surveys. However, the map should not be used for navigation. For instance, the map will be useful for planning SCUBA surveys, as dives are generally limited to depths <30 m. Knowledge of the complexity at greater depths can be used to select locations to conduct field surveys with alternative technologies such as Autonomous Underwater Vehicles (AUV) and Remotely Operated Vehicles (ROV).

The bathymetry around Vieques is shaped by broad and fine scale current patterns in the region. The east to west long shore drift on the north side of the island results in the deposition of sediment northwest of the island. Formation of the Escolla de Arenas is influenced by the convergence of westward and northward longshore currents in conjunction with tidal currents (Chapter 2: Climates and Currents; Rodriguez and Trias 1989). At the same time, water depth and bathymetric features influence the flow and direction of waves, currents and sediments. The contrasting bathymetric profiles on the north and south sides of Vieques are reflected in the distribution of benthic habitats and associated biological communities. Seagrass communities (see Chapter 6: Seagrass and Algae), which are generally limited to shallow depths and protected, low-energy regions, are widespread northwest of Vieques where depth is shallow and conditions are relatively calm. In contrast, hardbottom habitats are typified by higher topographic complexity than seagrass and other softbottom habitats (Pittman et al. 2007). For example, the areas of highest complexity around Vieques highlight slopes and areas of reef and hardbottom (see Chapter 5: Reefs and Hardbottom). These features include numerous patch reefs north of Vieques, and barrier reefs extending along the inner slope wall on the south side of the island. Caribbean islands are typically characterized by higher coral accretion and higher fringing reef development on the higher energy, windward side of islands (Roberts et al. 1992). The differences in topographic complexity between the eastern and western portions of the island are reflective of this trend. In turn, there is a positive relationship between topographic complexity and fish species richness at both fine (Gratwicke and Speight 2005) and broad scales (Pittman et al. 2007; see Chapter 8: Fish).

LITERATURE CITED

Calder, B. 2006. On the uncertainty of archive hydrographic data sets. IEEE Journal of Oceanographic Engineering 31(2): 249-265.

Gratwicke, D, and MRS Speight. 2005. The relationship between habitat complexity and fish species richness and abundance in shallow tropical marine habitats. Journal of Fish Biology 66: 650-667.

Intelmann, SS. 2006. Comments on the hydrographic and topographic LIDAR acquisition and merging with multibeam sounding data acquired in the Olympic Coast National Marine Sanctuary. Marine Sanctuaries Conservation Series ONMS-06-05. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Program, Silver Spring, MD. 18 pp.

JALBTCX (Joint Airborne LIDAR Bathymetry Technical Center of Expertise). 2000. Vieques, Puerto Rico DVD. http://shoals.sam.usace.army.mil/.

Pittman, SJ, JD Christensen, C Caldow, C Menza and ME Monaco. 2007. Predictive mapping of fish species richness along shallow-water seascapes in the Caribbean. Ecological Modelling 204: 9-21.

Roberts, HH, PA Wilson and A Lugo-Fernández. 1992. Biologic and geologic responses to physical processes: examples from modern reef systems of the Caribbean-Atlantic region. Continental Shelf Research 12(7-8): 809-834.

Rodriguez, RW and JL Trias. 1989. Maps showing characteristics of the Escollo de Arenas sand and gravel deposit, Vieques Island, Puerto Rico. Department of the Interior, U.S. Geological Survey. Map MF-2108..

Rodriguez, RW, RMT Webb and DM Bush. 1994. Another look at the impact of Hurricane Hugo on the shelf and coastal resources of Puerto Rico, USA. Journal of Coastal Research 10(2): 278-296.

Starr, RB and RG Bassinger. 1971. Marine geophysical observations of the eastern Puerto Rico – Virgin Islands region. Transactions of the Fifth Caribbean Geological Conference, Geological Bulletin 5: 25-3.

CHAPTER 5: CORAL REEFS AND HARDBOTTOM

5.1 OVERVIEW

Coral reefs represent an important component of the marine ecosystem of Puerto Rico and Vieques. Since the 1970s, several surveys of benthic communities on Vieques reefs have been conducted, often with the intent to investigate the effects of military activities on reef condition. Accordingly, many surveys were restricted to small portions of the island (e.g., the former military range or the civilian area), and in general, Vieques has received comparatively less study than other areas of Puerto Rico and the US Virgin Islands (Asch and Turgeon 2003).

Image 5.1. Fire coral and other reef organisms. Photo: Biogeography Branch.

The distribution of the types of reef/hardbottom habitat varies geographically. Approximately 80% of the mapped reef/hardbottom area around Vieques is offshore of the former military zones, and the south side of the island contains about twice the amount of reef/hardbottom habitat as the north side. Approximately 50 species of coral have been documented in recent (2000-present) surveys on Vieques reefs. Commonly observed species include *Montastrea annularis, M. cavernosa*, *Siderastrea siderea*, *Porites porites*, *P. asteroides*, *Millepora sp.*, and *Diploria labyrinthiformis. Acropora palmata*, which was dominant in earlier studies (ca. 1970s), presently constitutes only a minor member of the coral community. Stresses to coral health include coral bleaching and diseases, although the extent of these maladies in comparison to the wider Caribbean has not been quantified.

The effects of military activity on Vieques reefs are debated and have not been thoroughly quantified. While some studies suggest widespread destruction, others have documented minimal, localized damage and have argued that military presence has been beneficial to reefs due to curbed commercial/residential development and fishing compared to other Caribbean islands. Due to the lack of long-term monitoring studies of reefs over the period of Navy presence, there is insufficient data to address changes in reef communities due to military activity, hurricanes, and other natural and anthropogenic factors. However, similar to elsewhere in the Caribbean, there is evidence of widespread decline in coral cover on reefs around the island.

5.2 SOURCES OF DATA

Several benthic mapping efforts have been conducted to quantify the spatial distribution of reef and hardbottom around Vieques (Reid and Kruer 1998; Kendall et al. 2001; GMI 2003; Hernandez-Cruz et al. 2006). The most recent spatially comprehensive map was completed by NOAA's Biogeography Branch based on 1999 aerial photography (Kendall et al. 2001). Within the coral reef/hardbottom main category, seven detailed habitat types were delineated with a minimum mapping unit of 1 acre (4048 m^2). The detailed habitat types for reef/hardbottom include colonized bedrock, colonized pavement, colonized pavement w/ sand channels, linear reef, patch reef (aggregated), patch reef (individual), and scattered coral/rock in unconsolidated sediment (Kendall et al. 2001).

Several field surveys pertaining to reef/hardbottom habitat and associated benthic communities have been conducted since the 1970s and were usually restricted to small portions of the island (e.g., the former military range or the civilian area). These studies range from qualitative descriptions of specific reefs to quantitative data collection of variables such as percent cover and coral species diversity, or measurements of coral growth. A brief summary of the methods and findings are included here to provide a comprehensive overview of past research (Table 5.2), but the reader is referred to the original documents for full detail.

Recent surveys of the coral reefs in Vieques include Hernandez-Delgado (2000), Garcia-Sais et al. (2001), GMI (2003), Garcia-Sais et al. (2004), and GMI (2005). In 2001, the U.S. Navy commissioned a baseline assessment of the coral reefs on the eastern end of Vieques (GMI 2003; Riegl et al. 2008). Scientists from the National Coral Reef Institute (NCRI) and Geo-Marine, Inc. (GMI) established 18 permanent transects, all located within the former military zone (12 LIA, 6 EMA). Data were collected on coral species, percent cover, and abundance using a phototransect method and *in situ* coral counts. In the summer of 2006, scientists from NCRI revisited the permanent sites to assess changes in the benthic composition (D. Gilliam, personal communication). In addition, Garcia-Sais (2001) established 12 permanent sites in the western half of Vieques in 2001, six of which were re-surveyed in 2004.

5.3 METHODS

The available benthic habitat maps from NOAA (Kendall et al. 2001) were used to display and quantify the spatial distribution of hardbottom types around Vieques.

Previous reports have argued that reef development is highest offshore of areas occupied by the Navy (DON 1979; DON 1986), however until recently, this had not been quantified. Kendall and Eschelbach (2006) demonstrated that approximately half of the coral reef and hardbottom habitats mapped around Vieques are located within the former restricted areas and Danger Zone (See Chapter 1: Introduction, Figure 1.2). Building upon this, we used a similar method to look more closely at spatial distribution patterns of reef/hardbottom in relation to former and current land use configurations. For instance, military activities were not homogenous within the Danger Zone, as evidenced by the known distribution of ordnance locations and in-water ordnance hits (GMI 2003). To determine how the area of reef and hardbottom varies in regards to land use patterns, the waters around Vieques were divided into sections based on historical land use prior to the Navy's departure in 2001 (western portion) and 2003 (eastern portion). First, a 3 nm buffer was generated around the island in ArcGIS v9.2. Former land use was used to divide the marine area into 12 regions by manually drawing lines from shore on both the north and south side of the island. As described in the Introduction (Chapter 1), the six *former* land use zones were defined, from west to east, as the Naval Ammunition and Support Detachment (NASD), Civilian Area (CA), the Eastern Maneuver Area (EMA), the western portion of the Atlantic Fleet Weapons Training Facility (AFWTF), the Live Impact Area (LIA), and the Punta Este Conservation Area (PECA). The total mapped two-dimensional area, the number of polygons, and total area of the polygons for each detailed reef/hardbottom habitat type was calculated within each section using XTools Pro v3.0. In addition, the proportion of reef/hardbottom within each zone as a percent of the total was calculated.

A similar procedure was followed to quantify the amount of reef/hardbottom habitat offshore of *current* land use configurations, which includes eastern and western sections of the Vieques National Wildlife Refuge (VNWR), an expanded Vieques Municipality, and land under jurisdiction of the Puerto Rico Conservation Trust (PRCT). The PRCT parcels are intermixed with the western VNWR and only a small segment is directly adjacent to the coast, therefore this was included with the southern portion of the western VNWR.

In situ reef survey sites were plotted in ArcGIS to show the distribution of field efforts (Antonius and Weiner 1982; DON 1986; Garcia-Sais et al. 2001; GMI 2003; Garcia-Sais et al. 2004; GMI 2005). Although GPS coordinates were not available for Antonius and Weiner's (1982) and DON's (1986) survey locations, the location of the sites was approximated from maps published in these reports. Comparisons in variables such as percent coral cover from different studies is challenging due to differences in survey methodologies, the type of data collected, and differences in sampling locations. Common methodologies that have been used in Vieques to estimate coral cover include the linear point transect method (Antonius and Weiner 1982; DON 1986; GMI 2005), the phototransect method (GMI 2003; Riegl et al. 2008) and the linear chain transect method (Garcia et al. 2001; Garcia et al. 2004). Few comparative methodology studies have addressed all of these techniques over the same reef tract, but several researchers have observed similar results in percent coral cover when comparing plot and plotless methods (Dodge et al. 1982; Rogers and Miller 2001; Nadon and Stirling 2006). The differences in methodology may be most important when individual sites exhibit spatial heterogeneity (Dodge et al. 1982) or when coral cover is low, as some studies indicate a decrease in precision and accuracy of some methods with decreasing coral cover (Nadon and Stirling 2006; Lam et al. 2006). With these limitations in mind, coral percent cover data for six surveys conducted from 1978 to 2004 were compiled for qualitative comparison (Antonius and Weiner 1982; DON 1986; Garcia et al. 2001; Garcia et al. 2004; GMI 2003; GMI 2005). The mean percent cover (+/- SE) across all sites within a survey was calculated, however, only summary information was available from DON (1986), preventing the calculation of standard error. Information from published reports were also used to generate a coral species inventory for Vieques, and to describe the general reef community in Vieques.

5.4 DISTRIBUTION, STATUS AND TRENDS

The seven mapped hardbottom and reef types found around Vieques differ in regards to geographic location, relief, and biotic cover (Kendall et al. 2001; Kendall and Eschelbach 2006). Colonized bedrock refers to exposed bedrock contiguous with the shoreline that is covered by macroalgae, coral and other invertebrates. Linear reefs (often referred to as fringing or barrier reefs) constitute coral formations that are oriented parallel to and follow the contour along the shore or shelf edge. Colonized pavement is flat, low-relief carbonate rock colonized by macroalgae, hard corals, gorgonians, and other sessile invertebrates. Colonized pavement with

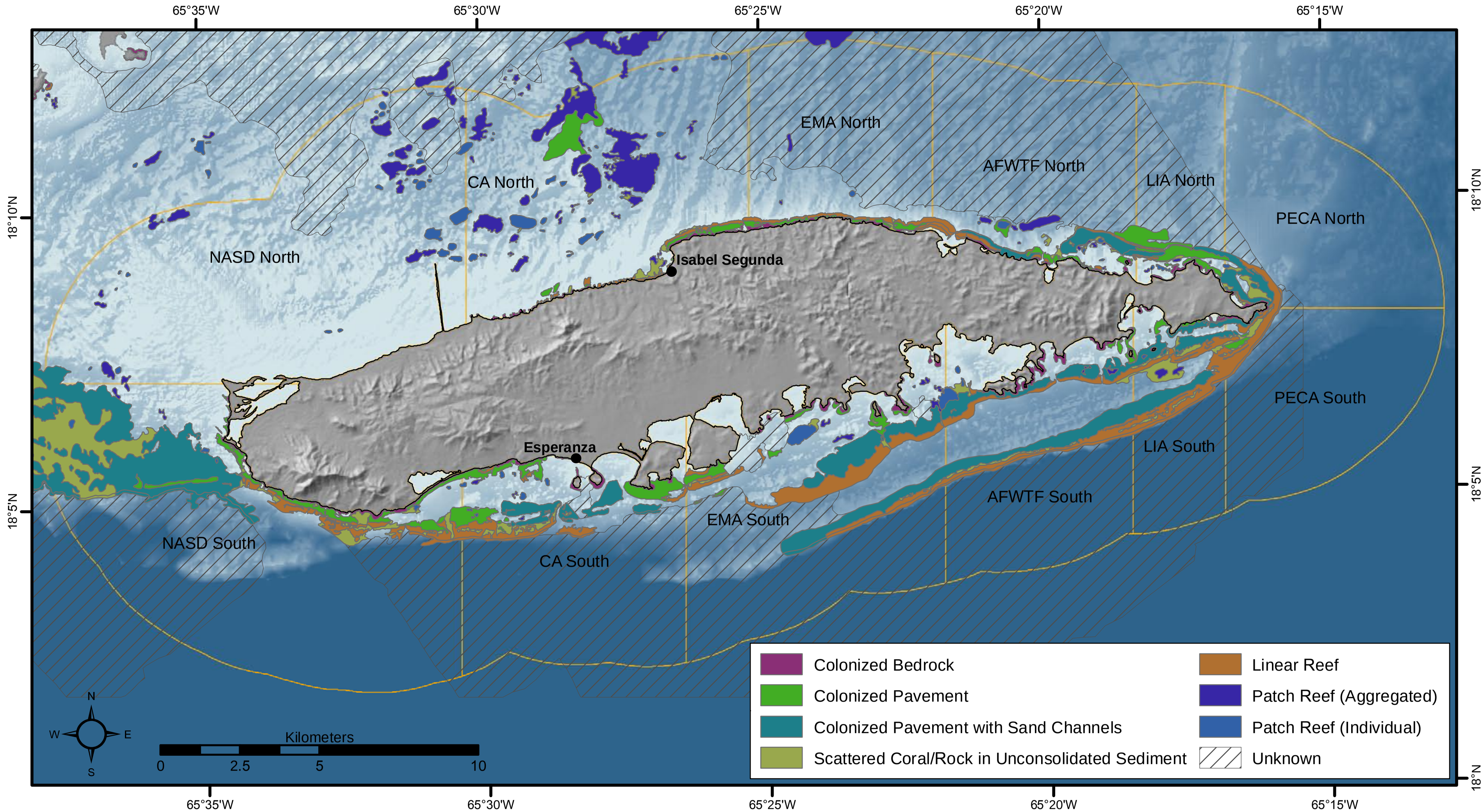


Figure 5.1a. Distribution of reef/hardbottom habitat around Vieques relative to historical land use. Benthic habitat data from Kendall et al. (2001).

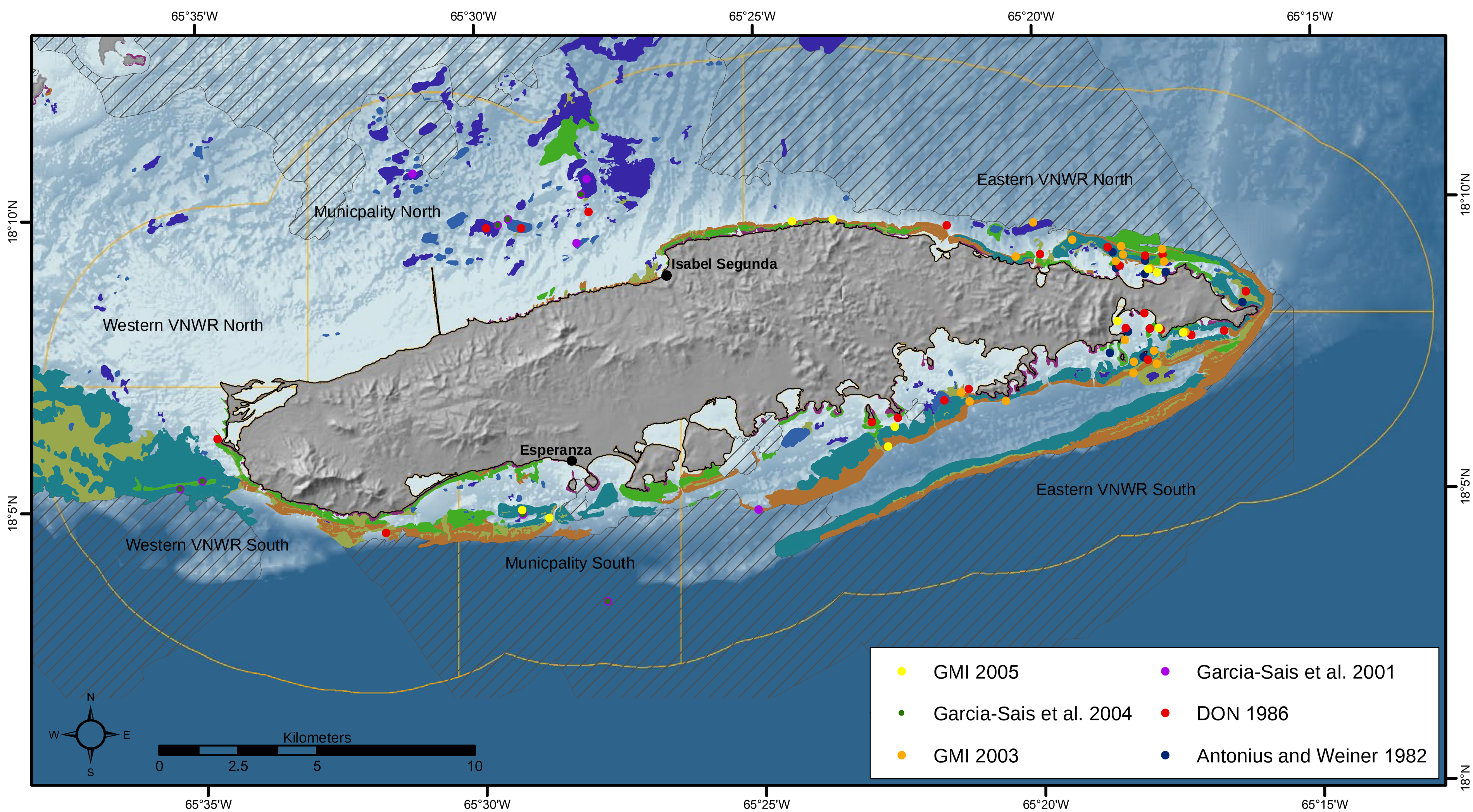


Figure 5.1b. Distribution of reef/hardbottom habitat around Vieques relative to current land use. Recent field monitoring sites are displayed. Benthic habitat data from Kendall et al. (2001).

sand channels is habitat with alternating sand and colonized pavement formations that are oriented perpendicular to the shore or bank/shelf escarpment. This habitat type generally occurs in areas exposed to moderate wave surge. Patch reefs are separated from other coral formations by other habitat types such as sand or seagrass. Distinctive patch reefs that are equal or greater in size to the minimum mapping unit (MMU) were mapped as individual patch reefs, while clustered patch reefs that are individually smaller than the MMU or too close together are delineated as aggregated patch reefs. Scattered coral/rock in unconsolidated sediment refers to habitat that is characterized by rocks and small coral heads scattered in sand or seagrass bottom.

The total area of reef and hardbottom habitat within the 3 nm area around Vieques able to be mapped was 71.97 km^2, with over two thirds of the area on the south side (50.86 km^2) of the island (Table 5.1). Numerous patch reefs are present in the shallow waters north of Vieques, particularly between Mosquito Pier and Isabel Segunda from 1-8 km offshore (Figure 5.1a). East of Mosquito Pier, a thin line of mixed hardbottom is present adjacent to the coast. The two colonized pavement habitats become more extensive east of Puerto Diablo. The eastern tip of the island is characterized by extensive linear reef formations; these reefs begin ~1.5 km northwest of Punta Este and extend along the southern side of the island adjacent to shore. On the south side extending west from Tamarindo Sur, a deeper channel dominated by submerged vegetation separates nearshore and offshore hardbottom formations (see Chapter 6: Seagrass and Algae). Colonized pavement with sand channels outlines the shoreward side of both linear reef formations. Smaller patches of hardbottom are present outside the entrances to several bays, including Puerto Mosquito, and surround the islands of Isla Chiva, Cayo Yanuel, Cayo Conejo, and Roca Alcatraz. West of Esperanza, a line of fringing reef extends offshore to the 30 m contour. The formations may continue further offshore, but 30 m was the detection limit for mapping with aerial photography in this area (Kendall et al. 2004). The fringing reef is bordered shoreward by other hardbottom types, including scattered coral/rock in unconsolidated sediment and colonized pavement. Westward, this mixed formation merges with a thinner line of colonized bedrock and pavement that runs parallel to shore. This line of colonized bedrock, pavement, and fringing reef becomes narrower as it extends around the western end of the island and ceases around Green Beach. Only small patches of hardbottom are present north of here, as seagrass habitat is the dominant habitat type north and northwest of Vieques and is nearly contiguous to the main island of Puerto Rico (Chapter 6: Seagrass and Algae). South of the submerged vegetation, a mix of colonized pavement with sand channels and scattered coral/rock in unconsolidated sediment extends west of the island for several kilometers.

In context of historical land use configurations, approximately 80% of the mapped reef/hardbottom habitat was located within the zones offshore from the former military areas (Table 5.1a, Figure 5.1b). In comparison, approximately two-thirds of the land was under military designation. In addition, the combined reef/habitat area in the southern zones was approximately twice that in the northern zones combined. The zone with the highest area of hardbottom habitat is south of the former NASD, however this is primarily composed of colonized pavement with sand channels and scattered coral/rock in unconsolidated sediment. The majority of patch reefs are located on the north side of the former NASD and CA, while most linear reef is located south of the island. The amount of reef and hardbottom habitat located offshore of the Vieques municipality is slightly higher under current land use configurations (24%, Table 5.1b) as the area considered encompasses additional patch reefs on the north side near Mosquito Pier (Figure 5.1b).

There are a few limitations to the current benthic habitat map of Vieques, particularly in regards to reef and hardbottom habitat. The minimum mapping unit, one acre, precludes mapping of fine-scale features such as small patch reefs. In addition, small portions of the nearshore south coast could not be mapped due to cloud cover. Much of the area offshore was not mappable due to water depth (see Chapter 4: Bathymetry) and will have to be mapped using sonar. Another recent mapping analysis (GMI 2003), which was aided by hyperspectral imagery and LIDAR in addition to the aerial photography, indicates there is additional reef cover outside the entrance to Puerto Ferro, one of the areas that had been obstructed by clouds in the 1999 photograph. To fill in some of these gaps, Part II of this characterization will include updated fine-scale benthic habitat maps derived from a new set of high-resolution IKONOS satellite imagery.

As mentioned previously, the depth limits of mapping with aerial photography prevent the mapping of deeper reefs (>30 m depth), yet such reefs do exist offshore of Vieques (Garcia et al. 2004), elsewhere in Puerto Rico (Singh et al. 2004) and the US Virgin Islands (Menza et al. 2007; Armstrong et al. 2006). Although acoustic sonar and underwater imaging technologies are increasingly being utilized to characterize and map deep reef habitats, they are considerably less studied than shallow nearshore reefs (Menza et al. in press). Coral cover on mid-shelf reefs in the region is often quite high (Menza et al. 2007), and some of these reefs are known to support large aggregations of fish (Armstrong et al. 2006). Coral cover on insular shelf reefs south of St. John and St. Thomas has been observed to increase with depth and distance from shore (Menza et al. 2008). The nearby Hind Bank conservation district is also characterized by high coral cover (>70% at some reefs), primarily *Montastrea annularis* (Armstrong et al. 2006). It is likely that deep reefs in the Vieques region would harbor similar characteristics to those in the USVI and southwest PR, but to date, investigations have not been conducted on reefs ≥30 m depth in this area, with the exception of Black Jack Reef, located ~3.5 km south of Sun Bay (Garcia-Sais et al. 2001, 2004).

Table 5.1. Area of reef and hardbottom (in km²) within 3 nm around Vieques, separated by proximity to a) former and b) current land use.

a)	NASD North	NASD South	CA North	CA South	EMA North	EMA South	AFWTF North	AFWTF South	LIA North	LIA South	PECA North	PECA South	Total
Colonized bedrock	0	0.47	0.34	0.41	0.28	0.53	0.23	0.57	0.17	0.11	0.07	0.07	3.25
Colonized pavement	0	1.86	1.61	1.73	0.40	0.89	0.62	0.16	1.33	0.22	0.01	0.14	8.97
Colonized pavement w/ sand channels	0.35	10.07	0	1.78	0	4.46	1.18	3.61	0.30	2.03	0.89	0.20	24.87
Linear reef	0	1.70	0.48	1.42	0.60	3.54	0.72	2.13	0.14	2.19	0.45	1.05	14.42
Patch reef (aggregated)	1.87	0.09	5.20	0.06	0.25	0.25	0.46	0.06	0.03	0.13	0	0	8.42
Patch reef (individual)	0.94	0.11	0.81	1.15	0.03	0.47	0.12	0.18	0.06	0.02	0.01	0	3.90
Scattered coral/rock in unconsolidated sediment	<0.01	5.42	0.42	0.51	0.05	0.27	0.22	0.50	0.05	1.06	0.38	0.26	9.13
Total area reef/ hardbottom	3.16	19.72	8.85	6.05	1.62	10.41	3.55	7.22	2.09	5.76	1.83	1.71	71.97
Percent of island-wide total	**4.4**	**27.4**	**12.3**	**8.4**	**2.3**	**14.5**	**4.9**	**10.0**	**2.9**	**8.0**	**2.5**	**2.4**	**100**

b)	Western VNWR North	Western VNWR South	Municipality North	Municipality South	Eastern VNWR North	Eastern VNWR South	Total
Colonized bedrock	0	0.47	0.34	0.41	0.76	1.28	3.25
Colonized pavement	0	1.86	1.61	1.73	2.37	1.41	8.97
Colonized pavement w/ sand channels	0.35	10.07	0	1.78	2.38	10.30	24.87
Linear reef	0	1.70	0.48	1.42	1.91	8.91	14.42
Patch reef (aggregated)	0.51	0.09	6.57	0.06	0.75	0.45	8.42
Patch reef (individual)	0.06	0.11	1.69	0.15	0.22	0.66	3.90
Scattered coral/rock in unconsolidated sediment	<0.01	5.42	0.42	0.51	0.71	2.09	9.13
Total area reef/ hardbottom	0.91	19.72	11.10	6.05	9.09	25.10	71.97
Percent of island-wide total	**1.3**	**27.4**	**15.4**	**8.4**	**12.6**	**34.9**	**100**

A recent meta-analysis indicates that live coral cover in the Caribbean has declined by 80% over the last three decades (Gardner et al. 2003). Although long-term monitoring data is not available for Vieques, significant declines in coral cover have been documented on reefs in the US Virgin Islands (Edmunds 2002; Rogers and Miller 2006). Factors attributed to this decline include pollution, nutrient loading, sedimentation, disease, overfishing, and hurricane damage (Bruckner et al. 2005). Often multiple factors are linked to the decline (e.g., corals may fail to recover from hurricane mortality due to colonization of macroalgae and lack of herbivory, Rogers and Miller 2006). *Acropora palmata* (elkhorn coral) and *A. cervicornis* (staghorn coral), which were formerly dominant reef builders in shallow and intermediate fore reef communities, respectively, have been devastated by white-band disease (Aronson and Precht 2001). In Puerto Rico, recovery from the initial 1980s outbreak has been limited and Acroporid populations have declined significantly at locations island-wide where they were formerly abundant (Weil et al. 2002). Both species have recently been listed as threatened under the Endangered Species Act (ESA). Although trends in coral cover on reefs in Vieques have not been as well documented as elsewhere in the Caribbean, several studies suggest changes in the coral community and a general decline in coral cover, particularly *A. palmata*, over the same time period. For example, Hernandez-Cruz et al. (2006) examined a series of photographs of Bahia Salina del Sur from 1937-2000 and detected the decline of two healthy *A. palmata* reefs starting in the 1970s.

As previously mentioned, the lack of long-term monitoring data in Vieques makes it difficult to evaluate historical trends in reef and hardbottom habitat. Little information is available about reefs and hardbottom in Vieques prior to the 1970s. As part of a 1972 report by the Environmental Quality Board, Torres and Pearl (1972) provided a qualitative description of reef formations in Vieques, which to our knowledge was the first report documenting *in situ* observations of reef communities (Table 5.2). In 1978, litigation was brought against the US Navy to cease bombing (Barcela v. Brown, see DON 1980), in part due to claims by fishermen that bombing activity was harming coral reefs and fish populations. Several assessments of reefs within the firing range followed, often with the intent of assessing impacts of military activities on reef condition (Antonius and Weiner 1982; Rogers et al. 1978) or coral growth (Dodge 1981; Macintyre et al. 1983).

Image 5.2. *Acropora palmata*. Photo: Biogeography Branch.

Several factors prohibit comparison of metrics such as percent coral cover over time, including differences in survey methods and survey locations among data sources (Table 5.2). DON (1986) surveyed 12 sites in close proximity to those in the LIA surveyed by Antonius and Weiner (1982) as well as 11 additional sites outside of the LIA. Five of the 11 new sites were located on the western half of the island. Mean coral cover decreased by approximately 15% from 1978 to 1985 (Table 5.3). There is a 16-20 year gap between the 1985 survey and recent studies. The sites surveyed by Garcia-Sais et al. (2001, 2004) were located primarily offshore of civilian areas (Figure 5.1b). No major changes in the benthic community were detected three years after the baseline survey (Garcia-Sais et al. 2004). Curiously, GMI (2003, 2005) detected a much lower amount of coral cover than those conducted by Garcia-Sais et al. (2001, 2004), even though these were conducted during similar time periods (Table 5.3). For instance, mean percent coral cover was 24.4 (±3.8 SE)% and 28.0 (±2.0 SE)% at sites surveyed by Garcia-Sais et al. (2001) and Garcia-Sais et al. (2004), respectively. In contrast, the estimates of mean coral cover, 5.5 (±0.9 SE)% and 9.2 (±2.1 SE)%, respectively, were much lower in the other studies (GMI 2003, 2005). These differences may be in part due to differences in study location and survey method. The GMI/NCRI surveys were conducted primarily on the eastern end, although some sites in the latter survey were located in the civilian area. In contrast, the surveys conducted by Garcia-Sais et al. (2001, 2004) were conducted primarily in civilian and non-target areas on the western half of the island.

In addition to decline in overall coral cover, there appears to have been a shift in the coral species community since the 1970s. The decline in *Acropora* detected by Hernandez-Cruz et al. (2006) is supported by the comparison of recent field data to older reports. As part of a 1972 report by the Environmental Quality Board, Torres and Pearl (1972) provided a qualitative description of reef formations in Vieques (Table 5.2). While no quantitative data was collected, *A. palmata* formations were observed at numerous reefs on both the north and south side of the island. In 1978, half of the reef-building corals seen by Antonius and Weiner (1982) were *A. palmata*. In contrast, live *Acropora*, particularly *A. palmata*, was not often encountered in recent surveys, although dead rubble was often noted (McGarrity and Deslarzes 2006; Riegl et al. 2008).

Forty-seven species of coral have been documented in recent field surveys around Vieques (Table 5.4). Although recent surveys were conducted in different geographic locations, the most common species were simi-

Table 5.2. A summary of prior field studies of reefs/hardbottom in Vieques, in chronological order.

Citation	Time of survey	Location(s)	Number of sites	Technique	Data collected
Torres and Pearl 1972	1972	Island-wide	N/A	Aerial survey, diving survey	Qualitative description of reefs (species present, relative size and extent)
Rogers et al. 1978	Feb.-July 1978	Eastern end (Bahia Icacos, Bahia Salinas, Bahia Salina del Sur)	4	Four 10 m diversity transects per site	Coral: species diversity, percent cover; Qualitative descriptions of military damage
Dodge 1981	May-July 1978	North and south of the LIA; Mosquito Reef	15	Collection of *Montastrea annularis* samples	Mean growth rates and variances for *M. annularis* for 1970-1977
Macintyre et al. 1983	May 1978	Bahia Salina del Sur	1	Collection of 3 cores of *Acropora palmata*	Growth rates of *A. palmata*
Antonius and Weiner 1982, DON 1979, DON 1980	Spring-Fall 1978	Eastern end, including Live Impact Area	12	100 m point transects (1m intervals); qualitative site descriptions	Substrate type, animal/plant species/ military debris, as percentage of total sample points (10,100)
Raymond and Dodge 1980	May 1980	North and south of the LIA	10	Visual inspection; phototransect at one site	Qualitative observations of storm damage; percent cover at site of phototransect
DON 1986	January 1985	Island wide, majority of sites in Navy zones	24	100 yd point transects (0.5 yd intervals), collection of *M. annularis* samples	Species list of hard corals, percent coverage of main cover groups, *M. annularis* growth rates
Hernandez-Delgado 2000	N/A	Civilian area	4	Rover diving method	Coral: species richness; relative reef condition using rapid diagnostic method
Porter 2000	August 1999	Live Impact Area, Ensenada Honda	7	Qualitative surveys, 40 m^2 species inventory transects at 3 locations	Coral: Number of colonies per m^2, species richness, species diversity
Garcia-Sais et al. 2001	July 2001	Civilian area and western end	12	Chain transect method, video transect method; permanent sites marked (10)	Coral: percent cover, density (colonies per m^2), species richness, species diversity, evenness; Sponges/Algae/Enc. Gorgonians: percent cover; Gorgonians: Number; Rugosity
Garcia-Sais et al. 2004	July 2004	Civilian area and western end, Black Jack Reef	7 (6 sites from 2001)	Chain transect method, video transect method	Coral: percent cover (species level), species richness; Sponges/Algae/Enc. Gorgonians: percent cover; Gorgonians: Number; Rugosity
GMI 2003, Riegl et al. 2008	July 2001	Eastern Maneuver Area and Live Impact Area	18 (12 LIA, 6 EMA)	Phototransects (30 m^2); in-situ coral colony counts for entire 30 m^2; permanent sites established	Analyzed with coral point count software; Coral: percent cover, species richness, species diversity, incidence of injury and disease; Algae/gorgonians/sponges: percent cover
GMI 2002	Nov. 2001	USS Killen wreck, barge in Bahia Salina del Sur, Bahia Jolova	3	Photographs of entire barge deck, phototransects at other two sites	Coral: percent cover, number of colonies, species diversity; Algae/gorgonians/ sponges: percent cover
GMI 2005, McGarrity and Deslarzes 2006, Deslarzes et al. 2006	2003	Civilian area, EMA, LIA	11 (2 CA, 4 EMA, 5 LIA)	Linear point transect method (10 m, 0.2 m intervals)	Coral: percent cover, species richness, juvenile coral abundance; topographic complexity

Table 5.3. Mean (±SE) percent coral cover on coral reef sites from six published field studies. Further details on locations and field methods are displayed in Table 5.2 and Figure 5.1b. Only summary data was available from DON (1986); therefore a standard error could not be calculated.

Reference	Survey method	n	Mean percent cover (± SE)
Antonius and Weiner 1982	Point transects	12	47.0 (±4.1)%
DON 1986	Point transects	24	31.3%
GMI 2003	Photo transects	18	5.5 (±0.9)%
GMI 2005	Linear point transects	11	9.2 (±2.1)%
Garcia et al. 2001	Chain transects	10	24.4 (±3.8)%
Garcia et al. 2004	Chain transects	6	28.0 (±2.0)%

lar among surveys. In GMI/NCRI's 2001 survey, conducted on the east end of the island, the five most numerically abundant coral species, *Porites porites, Millepora alcicornis*, *Montastrea annularis*, *Porites astreoides,* and *Siderastrea siderea* (in order of decreasing importance), accounted for 61.5% of all encountered corals (GMI 2003; Riegl et al. 2008). Similarly, the most abundant taxa observed by GMI (2005), which included reefs in both military and civilian areas, were *M. annularis*, *Millepora spp.*, *D. labyrinthiformis*, and *P. porites*. *M. annularis* accounted for the highest mean percent cover in surveys by Garcia-Sais et al. (2001 and 2004), followed by *M. cavernosa*, *Millepora spp., P. asteroides*, *S. siderea*, *C. natans*, and *P. porites*. Mean Shannon diversity, calculated from abundance counts of coral species, ranged from 1.5 (Garcia-Sais et al. 2001) to 1.9 (GMI 2003).

Results from Riegl et al. (2008) also indicate that coral species composition at Vieques reefs may be related to depth, although no significant differences were found in statistical tests. Shallow sites (depth = 5 m) were dominated by *Millepora sp.*, while *Porites sp., D. strigosa,* and *Siderastrea sp.* were more common at medium depth sites (depth = 7 m). Deep locations (depth = 15 m) were characterized by *Montastrea sp.* This species zonation pattern is similar to other reefs in the region (Garcia-Sais et al. 2005). Reef sites on the south side of the island exhibited slightly higher coral species diversity than reefs on the north side, but no differences in species composition, diversity, or coral cover were observed between reefs inside or outside of the military target zone (Riegl et al. 2008). Observations of the habitat functional value of sunken targets in Bahia Salina del Sur and Bahia Jolova (USS Killen and two barges) indicate that coral species have colonized these artificial reefs (GMI 2002).

The impact of military activities on coral reefs has been a subject of debate. While some studies report widespread damage from bombing, others have concluded that damage is minimal and have argued that Navy ownership has afforded Vieques reefs protection from other human activities (e.g., tourism, coastal development). Based on point transects and comparisons with similar data from the U.S. Virgin Islands, Antonius and Weiner (1982) concluded that minimal damage had occurred on reefs. In contrast, an investigation by Rogers et al. (1978) conducted during the same time period concluded that there was widespread damage to reefs in the Live Impact Area from military operations. Observations of impacts were qualitative in nature and included fracturing of reef structure due to direct hits or blasts, abrasion by steel and rock fragments, and indirect damage from deposition of sediments. A more recent study (GMI 2005) found that reefs in former military areas to be of similar condition to the civilian areas, although the two sites with the lowest condition were located in the military target area. Other studies have concluded that while damage was not widespread, there has been damage to specific reefs within the Live Impact Area (e.g., Roca Alcatraz, fringing and patch reefs within Bahia Salina del Sur and Bahia Icacos) that were located near targets (DON 1980; Macintyre et al. 1983; DON 1986).

Although the extent of damage is not thoroughly established, recent efforts have highlighted the area of highest concern. A map of known in-water ordnance hits, areas containing ordnance, and areas containing concentrated ordnance, primarily located within the LIA, can be found in GMI (2003). GMI (2003) overlapped these areas with known coral coverage from NOAA's benthic habitat map (Kendall et al. 2001) to calculate the amount of reef/hardbottom habitat that is potentially impacted by ordnance. It was estimated that 1722 m^2 of habitat was potentially impacted by known in-water ordnance hits (1989-1999 only), and that an additional 0.9 km^2 and 0.8 km^2 of reef/hardbottom habitat are located within areas potentially containing ordnance and potentially containing concentrated ordnance, respectively (GMI 2003).

Damage from military activities can be difficult to distinguish from storm damage (Antonius and Weiner 1982), as shallow water reefs are susceptible to storm damage from wave action. Numerous hurricanes and tropical storms have passed nearby Vieques (see Chapter 2: Climate and Currents). Storm damage was reported to be high on reefs within the Naval training range of Vieques after the 1979 Hurricanes David and Frederick (Raymond and Dodge 1980). Hurricane David passed approximately 120 miles south of Vieques with winds of 165 mph, while Frederick was a tropical storm when it passed over the island. Damage consisted of broken and overturned coral with branching corals, especially *A. palmata*, with the south side of Vieques most severely affected. Raymond and Dodge (1980) returned to reefs first assessed by Antonius and Weiner (1982) in the spring of 1980 and noted that shallow reefs that had formally been dominated by large *A. palmata* or *Porites porites* colonies had been reduced to rubble. A 1985 survey reported minimal recovery of *A. palmata* at most southern reefs, and reported that coral cover (as percentage of all point counts) at sites in the target range was lower than at sites outside the target range on both the north (28% vs. 37%) and south (26% vs. 34%) sides of Vieques (DON 1986).

Hurricane Hugo passed directly over Vieques in 1989, causing extensive storm surge, coastal flooding, and damage to buildings (Rodriguez et al. 1994). Although damage to reefs was extensive east of Culebra, Rodriguez et al. (1994) noted only minor storm damage to reefs south of Vieques and in the Vieques passage. Vincente et al. (1989, 1991) also qualitatively assessed damage to underwater habitats following Hurricane Hugo. Observed effects on reefs included sediment abrasion, burial, and breakage, but damage was variable and more noticeable on shallow reefs. Garcia-Sais et al. (2001) also noted extensive mechanical damage to *Acropora* on a shallow northern reef (outside the military zone) that was consistent with hurricane damage. Overall, assessments of hurricane effects on Vieques reefs have been primarily qualitative in nature, but these accounts indicate that hurricanes may have significant effects on local reefs. Further, other factors, including disease and predation following storms, may inhibit the recovery of corals following hurricane disturbance (Lugo et al. 2000). Pre and post-hurricane quantitative surveys would be needed to determine the change in benthic composition and percent cover, and to monitor recovery over time.

Similar to reefs elsewhere in the Caribbean, Vieques reefs appear to be stressed by bleaching events, such as the one that occurred in 2005, and various diseases. Coral bleaching accounted for 78% of observed maladies by McGarrity and Deslarzes (2006). Coral diseases observed at Vieques reefs include Aspergillosis, black-band disease, red-band disease, white-band disease, and white-plague (McGarrity and Deslarzes 2006). In comparison to Culebra, McGarrity and Deslarzes (2006) observed fewer incidences of disease and bleaching at Vieques, however a compre-

Table 5.4. List of hard coral species observed in recent (post-2000) surveys around Vieques. Sources: GMI 2003 (a), GMI 2005 (b), Garcia-Sais et al. 2001 (c), Garcia-Sais et al. 2004 (d), Hernandez-Delgado 2000 (e).

Scientific Name	Common Name	Reference
Acropora cervicornis	Staghorn coral	a,b,c,d,e
Acropora palmata	Elkhorn coral	a,b,e
Agaricia agaricites	Lettuce coral	a,c,d,e
Agaricia fragilis	Fragile saucer coral	c
Agaricia grahamae	Graham's sheet coral	c,d
Agaricia humilis	Lowrelief lettuce coral	a,e
Agaricia lamaracki	Lamarck's sheet coral	a
Colpophyllia natans	Boulder brain coral	a,b,c,d,e
Dendrogyra cylindrus	Pillar coral	a,b,c,d,e
Dichocoenia stokesii	Elliptical star coral	a,b,d,e
Diploria clivosa	Knobby brain coral	a,b,c,e
Diploria labyrinthiformis	Grooved brain coral	a,b,c,d,e
Diploria strigosa	Symmetrical brain coral	a,b,c,d,e
Eusmilia fastigiata	Smooth flower coral	a,b,c,d
Favia fragum	Golfball coral	a,b,e
Helioseris cucullata	Sunray lettuce-leaf coral	a
Isophyllia sinuosa	Sinuous cactus coral	a,c,d,e
Isophyllastrea rigida	Rough star coral	b,d,e
Leptoseris cucullata	Sunray lettuce coral	d,e
Madracis decactis	Ten-ray star coral	a,c,d,e
Madracis mirabilis	Yellow pencil coral	a
Manicina areolata	Rose coral	a,e
Meandrina meandrites	Maze coral	a,b,c,d,e
Millepora alcicornis	Fire coral	a,c,d,e
Millepora squarrosa	Box fire coral	d,e
Millepora complanata	Blade fire coral	e
Montastrea annularis	Boulder star coral	a,b,c,d,e
Montastrea cavernosa	Great star coral	a,b,c,d,e
Montastrea faveolata	Boulder star coral	a,b
Montastrea franksi	Boulder star coral	a,b
Mussa angulosa	Spiny flower coral	d
Mycetophyllia aliciae	Knobby cactus coral	d,e
Mycetophyllia danaana	Lowridge cactus coral	a,e
Mycetophyllia ferox	Rough cactus coral	d,e
Mycetophyllia lamarkiana	Ridge cactus coral	a,c,d,e
Oculina diffusa	Diffuse ivory bush coral	a,b,e
Porites astreoides	Mustard hill coral	a,b,c,d,e
Porites branneri	Blue crust coral	a,b
Porites porties	Finger coral	a,b,c,d,e
Porites furcata	Branched finger coral	c
Scolymia cubensis	Artichoke coral	a,d
Scolymia lacera	Atlantic mushroom coral	e
Siderastrea radians	Lesser starlet coral	a,b,c,d,e
Siderastrea sidereal	Massive starlet coral	a,b,c,d,e
Stephanocoenia michelinii	Blushing star coral	a,b,d
Stephanocoenia intersepta	Blushing star coral	e
Stylaster roseus	Rose lace coral	e

hensive comparison of the condition of Vieques reefs to the wider Caribbean has not been conducted.

In summary, the available data and literature suggest that Vieques reefs are similar in composition and have followed a similar trajectory to those elsewhere in the Caribbean.

5.5 ECOLOGICAL LINKAGES

The distribution and composition of reefs and hardbottom around Vieques has been influenced by numerous factors, including the island's geologic history, bathymetry, currents and oceanographic conditions, and climate. The influence of anthropogenic factors, such as land ownership and subsequent variation in the degree of development and types of activities are also factors.

Image 5.3. Bleached *Siderastrea*. A pencil is shown for scale. Photo: Biogeography Branch

Nutrient and sediment levels further influence reef ecosystem health and function. The magnitude of sedimentation in Vieques has been addressed in several reports due to the potentially negative effects on coral growth (GMI 2003; GMI 2005). The amount of sediment originating from terrestrial sources reaching the bays and coast of Vieques has likely changed over the years due to alterations in plant cover and land practices (see Chapter 3: Geology and Land Cover). Most of the land in Vieques was cleared in the 19th century to grow sugar cane. Much of the land that now encompasses the VNWR is now reforested, albeit primarily by non-native species. The higher amount of non-vegetated land in the former target zone is evidenced by the presence of numerous craters in aerial imagery. Additionally, as cleanup activities continue, brush and other vegetation is removed to search for unexploded ordnance. Turbidity at reefs has been found to be higher in Vieques than in Culebra (Rogers et al. 1978; GMI 2005) but sedimentation rates at reefs in the former LIA are less than St. Croix (GMI 2003). Factors that influence erosion and sediment delivery, such as elevation and precipitation, are not universal across the island, resulting in varying erosion potential and sediment delivery among Vieques watersheds (NOAA and WRI 2006; see Chapter 3: Geology and Land Cover). An estimate of the potential threat of sediment delivery and land based sources of pollutants to coral ecosystems, derived by NOAA and WRI (2006), indicates that the vulnerability of reef/hardbottom and other habitat to sediment/pollutants varies spatially. The areas with the highest threat are located near primary outflow points with the greatest discharge, on the south coast near and west of Esperanza, and on the north coast adjacent to and east of Isabel Segunda.

Coral reefs comprise an important component of the tropical seascape in Vieques. Mangroves and seagrass beds help to trap and stabilize coastal sediments; the clearer water that results promotes the development of offshore reefs. In turn, reefs provide protection by dissipating the force of currents and waves. The prevalence of all of these habitat types on the south shore of Vieques in particular is testament to this interaction. In concert with submerged vegetation and mangroves, reef and hardbottom support multiple life stages of numerous commercially and ecologically important fish and invertebrate species (see Chapters 8: Fish and 9: Mobile Invertebrates).

LITERATURE CITED

Antonius, A and A Weiner. 1982. Coral reefs under fire. PSZNI: Marine Ecology 3(3): 255-277.

Armstrong, RA, H Singh, J Torres, RS Nemeth, A Can, C Roman, R Eustice, L Riggs and G Garcia-Moliner. 2006. Characterizing the deep insular shelf coral reef habitat of the Hind Bank marine conservation district (U.S. Virgin Islands) using the Seabed autonomous underwater vehicle. Continental Shelf Research 26: 194-205.

Aronson, RB and WF Precht. 2001. White-band disease and the changing face of Caribbean coral reefs. Hydrobiologia 460: 25-38.

Asch, RG and DD Turgeon. 2003. Detection of gaps in the spatial coverage of coral reef monitoring projects in the US Caribbean and the Gulf of Mexico. Revisita de Biología Tropical 51(Suppl. 4): 127-140.

Bruckner, A, K Buja, L Fairey, K Gleason, M Harmon, S Heron, T Hourigan, C Jeffrey, J Kellner, R Kelty, B Leeworthy, G Liu, S Pittman, A Shapiro, A Strong, J Waddell and P Wiley. 2005. Threats and stressors to U.S.

coral reef ecosystems. pp. 12-44. In: Waddell, JE (ed.), The State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522 pp.

DON (U.S. Department of the Navy). 1979. Draft Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

DON (U.S. Department of the Navy). 1980. Final Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

DON (U.S. Department of the Navy). 1986. Environmental Assessment of Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range, Vieques, Puerto Rico. Prepared by Ecology and Environment, Inc.

Deslarzes, KJP, R Nawojchik, DJ Evans, CJ McGarrity and P Gehring. 2006. The condition of former military training areas at Isla de Culebra and Isla de Vieques, Puerto Rico: preliminary results. pp. 1152-1159. In: Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan.

Dodge, RE. 1981. Growth characteristics of reef building corals within and external to a naval ordnance range: Vieques, PR. Proceedings of the 4th International Coral Reef Symposium, Manilla, Vol. 2: 241-248.

Dodge, RE, A Logan and A Antonius. 1982. Quantitative reef assessment studies in Bermuda: A comparison of methods and preliminary results. Bulletin of Marine Science 32(3): 745-760.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2001. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 108 pp.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2004. Monitoring of coral reef communities from Isla de Vieques, Puerto Rico, 2004. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 122 pp.

Garcia-Sais, JR, R Appeldoorn, A Bruckner, C Caldow, JD Christensen, C Lilyestrom, ME Monaco, J Sabaater, E Williams and E Diaz. 2005. The State of the Coral Reef Ecosystems of the Commonwealth of Puerto Rico. pp. 91-134. In J. Waddell (ed.), The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522 pp.

Gardner, TA, IM Côté, JA Gill, A Grant and AR Watkinson. 2003. Long-term region-wide declines in Caribbean corals. Science 301: 958-960.

GMI (Geo-Marine, Inc.). 2002. Ex-USS Killen site investigation and biological characterization, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Commander, Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

GMI (Geo-Marine, Inc.). 2003. Reef ecosystem baseline assessment survey and monitoring, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

GMI (Geo-Marine Inc.). 2005. An assessment of the condition of coral reefs off the former Navy bombing ranges at Isla de Culebra and Isla de Vieques, Puerto Rico. Prepared for the Department of Defense, Legacy Resource Management Program, Arlington, Virginia, and US Army Corps of Engineers, Huntsville, Alabama.

Hernández-Cruz, LR, SJ Purkis and BM Riegl. 2006. Documenting decadal spatial changes in seagrass and *Acropora palmata* cover by aerial photography analysis in Vieques, Puerto Rico: 1937-2000. Bulletin of Marine Science 79(2): 401-414.

Hernandez-Delgado, EA. 2000. Effects of anthropogenic stress gradients in the structure of coral feed fish and epibenthic communities. PhD Dissertation, Department of Biology, University of Puerto Rico, San Juan, Puerto Rico.

Kendall, MS, CR Kruer, KR Buja, JD Christensen, M Finkbeiner, RA Warner and ME Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (online). http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

Kendall, MS, CR Kruer, KR Buja, JD Christensen, E Diaz, RA Warner and ME Monaco. 2004. A characterization of the shallow-water coral reefs and associated benthic habitats of Puerto Rico. Gulf and Caribbean Research 16(2): 177-184.

Kendall, MS and KA 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.

Lam, K, PKS Shin, R Bradbeer, D Randall, KKK Ku, P Hodgeson and SG Cheung. 2006. Journal of Experimental Marine Biology and Ecology 333: 115-128.

Lugo, AE, CS Rogers and SW Nixon. 2000. Hurricanes, coral reefs, and rain forests: resistance, ruin, and recovery in the Caribbean. Ambio 29(2): 106-114.

Macintyre, IG, B Raymond and R Stuckenrath. 1983. Recent history of a fringing reef, Bahia Salina del Sur, Vieques Island, Puerto Rico. Atoll Research Bulletin 268, Smithsonian Institution, Washington DC.

McGarrity, CJ and KJP Deslarzes. 2006. Preliminary data on juvenile corals and coral maladies on reefs off civilian and former military locations at the islands of Culebra and Vieques, Puerto Rico. pp. 1160-1164. In: Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan.

Menza, C, M Kendall, C Rogers and J Miller. 2007. A deep reef in deep trouble. Continental Shelf Research 27(17): 2224-2230.

Menza, C, M Kendall and S. Hile. 2008. The deeper we go the less we know. Revista de Biologia Tropical 56(Suppl. 1): 11-24.

Nadon, M and G Stirling. 2006. Field and simulation analyses of visual methods for sampling coral cover. Coral Reefs 25:177-185.

NOAA (National Oceanic and Atmospheric Administration) and WRI (World Resources Institute). 2006. Summit to Sea Characterization of Coastal Watersheds (Puerto Rico and US Virgin Islands). http://ccma.nos.noaa.gov/ecosystems/coralreef/summit_sea.html.

Porter, JW. 2000. The effects of naval bombardment on the coral reefs of Isla Vieques, Puerto Rico. Submitted to King and Spaulding, Atlanta, Georgia. 38 pp.

Raymond, WF and RE Dodge. 1980. 1979 hurricane damage to coral reefs of Vieques. Report to the Commander, Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

Reid, JP and CR Kruer. 1998. Mapping and characterization of nearshore benthic habitats around Vieques Island, Puerto Rico. Report to US Navy. US Geological Survey/BRD, Sirenia Project, Gainesville, Florida. 11 pp.

Riegl, BM, RP Moyer, B Walker, K Kohler, D Gilliam and RE Dodge. 2008. A tale of germs, storms, and bombs: geomorphology and coral assemblage structure at Vieques (Puerto Rico) compared to St. Croix (US Virgin Islands). Journal of Coastal Research 24(4): 1008-1021.

Rodriguez, RW, RMT Webb and DM Bush. 1994. Another look at the impact of Hurricane Hugo on the shelf and coastal resources of Puerto Rico, USA. Journal of Coastal Research 10(2): 278-296.

Rogers, CS, G Cintron and C Goenaga. 1978. The impact of military operations on the coral reefs of Vieques and Culebra. Report to the Department of Natural Resources, San Juan, Puerto Rico.

Rogers, CS and J Miller. 2001. Coral bleaching, hurricane damage, and benthic cover on coral reefs in St. John, US Virgin Islands: A comparison of surveys with the chain transect method and videography. Bulletin of Marine Science 69(2): 459-470.

Rogers, CS and J Miller. 2006. Permanent 'phase shifts' or reversible declines in coral cover? Lack of recovery of two coral reefs in St. John, US Virgin Islands. Marine Ecology Progress Series 306: 103-114.

Singh, H, R Armstrong, F Gilbes, R Eustice, C Roman, O Pizarro and J Torres. 2004. Imaging coral I: imaging coral habitats with the SeaBED AUV. Subsurface Sensing Technologies and Applications 5(1): 25-42.

Torres, F and W Pearl. 1972. Section 11: Marine Resources. In: Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Rico, Office of the Governor.

Vincente, VP, FH López, F. Vilella and S Slander. 1989. Qualitative post-hurricane habitat and population assessments at Ceiba and Vieques Island, Puerto Rico. US Fish and Wildlife Service, Caribbean Field Office, Boquerón, Puerto Rico.

Vincente, VP, S Slander, M Barreto, J Saliva, P Torres and D Corales. 1991. An ecological evaluation of some marine and terrestrial systems at Ceiba and Vieques Island after Hurricane Hugo: Fiscal Year 1990-91. US Fish and Wildlife Service, Caribbean Field Office, Boquerón, Puerto Rico.

Weil, E, EA Hernandez-Delgado, AW Bruckner, AL Ortiz, M Nemeth and H Ruiz. 2002. Distribution and status of Acroporid coral (Scleractinia) populations in Puerto Rico. In Bruckner, AW (ed.). NOAA Technical Memorandum NMFS-OPR-24. Silver Spring, MD.

CHAPTER 6: SEAGRASS AND ALGAE

6.1 OVERVIEW

Four species of tropical seagrasses are found in the Caribbean, all of which occur in the waters around Vieques: *Thalassia testudinum* (turtle grass), *Halodule wrightii* (shoal grass), *Syringodium filiforme* (Manatee grass) and *Halophila decipiens* (paddle grass) (Hemminga and Duarte 2000; Garcia-Sais et al. 2001; Kenworthy et al. 2007). Seagrass beds are characteristically monospecific, while other beds may contain several species. Within beds containing multiple species, the highest biomass is attributed to the apex species (Hemminga and Duarte 2000). Of the four species in Vieques, *T. testudinum* is the apex species, *S. filiforme* is the second most abundant species while *H. wrightii* is the fastest growing species (Burke et al. 2007; Duarte 1991). While several species of algae have been reported from the waters around Vieques (Torres and Pearl 1972; Garcia et al. 2001) there are currently no studies providing a comprehensive list of all algal species. The majority of the local surveys were conducted on reef habitat or aimed at investigating only seagrass distribution. Algae is more ubiquitous than seagrass since it can colonize on both hard and soft bottom substrate**.**

Seagrasses and algae are important to Vieques for several reasons, including their function as nursery habitat for many reef fishes in the coastal zones, their role in sediment capture and retention, their exploitation as a food source for grazers and their ability to reduce coastal storm effects (Littler et al. 1989). Natural and anthropogenic impacts are altering this ecosystem. Natural events in Vieques include high energy storms (e.g.hurricanes), grazing pressure from marine organisms and the associated bioturbation; while anthropogenic activities include propeller scarring, sediment mining, coastal development and past military impacts (Ziegler and Giese 1971; Zieman 2000; Fourqurean et al. 2001).

The history of military activities around Vieques has resulted in scientific studies assessing potential impacts on submerged aquatic vegetation (SAV). These studies have focused on the densest areas of seagrass beds along the northwest corner of the island surrounding Escollo de Arenas in the Vieques Passage and around Mosquito Pier along the north coast. Zieman (2000) reported the seagrass communities of Vieques to be productive and healthy and that naval impacts were restricted to two primary locations around the island at Bahia Icacos and Bahia Salinas, but each showed signs of recovery.

6.2 SOURCES OF DATA

The spatial distribution of SAV around Vieques has been estimated in several recent benthic mapping assessments (Reid and Kruer 1998; Kendall et al. 2001; Kendall and Eschelbach 2006; Shapiro and Rohmann 2006; Hernandez-Cruz et al. 2006).

A recent comprehensive assessment of SAV around the island of Vieques was conducted by Kendall and Eschelbach (2006) as part of an island wide spatial assessment using benthic habitat maps created by NOAA's Biogeography Branch (Kendall et al. 2001) and the former marine zoning areas around Vieques (see Chapter 1: Introduction, Figure 1.2). Detailed habitat types for SAV include both seagrass and macroalgae and the degree of coverage (continuous vs. patchy).

Image 6.1. Vieques seagrass community. Photo: CCFHR.

Shapiro and Rohmann (2006) used a combination of LANDSAT imagery and NOAA benthic habitat maps (Kendall et al. 2001) to estimate change in SAV coverage in the Vieques Passage between 1985 and 2000. SAV locations were verified from the benthic habitat maps of Kendall et al. (2001) to confirm that SAV areas in the LANDSAT imagery concurred with SAV designated zones on the habitat maps. Hernandez-Cruz et al. (2006) used aerial photography to investigate changes in SAV cover within Bahia Salina del Sur between 1937 and 2000. While these studies focused on specific areas rather than island-wide, they offer insight into the patterns of change and recolonization of SAV over time relative to environmental and anthropogenic impacts and focus on insular shelf regions of high seagrass density.

Torres and Pearle (1972) assessed the marine benthic communities around Vieques focusing on seagrass cover determined by aerial photographs and verified with *in situ* surveys on SCUBA. Algal samples were collected at 10 sites to compile a species composition inventory and estimate total coverage of algal classes for the coral reef sites.

Additional studies were conducted by Zieman (1978, 1985, 2000) to evaluate the seagrass community of Vieques in Bahia Icacos, Bahia Salinas, and Bahia Salina del Sur on the eastern end as well as west of Mosquito Pier. Seagrass beds were assessed using a combination of underwater surveys and examination of historical aerial photographs. Data include information on seagrass species distribution and depth ranges around the island based on core samples. The cores provided a quantitative sample of standing crop and root material, which were used to estimate total biomass (Zieman 1978). In addition, military impacts on the seagrass community were qualitatively surveyed.

NOAA's Center for Coastal Fisheries and Habitat Research (CCFHR) is currently conducting two separate studies relating to submerged vegetation around Vieques. The first study adapted a seagrass recovery model from the Florida Keys National Marine Sanctuary (FKNMS) in an effort to predict the recovery period for seagrass beds in Vieques. Biomass losses were from physical disturbances (e.g. hurricanes) and herbivorous grazers within the visible blowouts to the northeast of Punta Arenas (Burke et al. 2007). To do this, CCFHR conducted Braun-Blanquet surveys (Fourqurean et al. 2001) and collected 15 cm diameter sediment cores among three sites: Puerto Ferro (n=25), Puerto Mosquito (n=25) and along the NW coast of Vieques between Escollo de Arenas and Mosquito Pier (n=20). Braun Blanquet sampling among these sites only generated relative measurements of coverage, so the core samples were used to generate estimates of shoot density and biomass using the plant material in the core.

The objective of the second CCFHR study is to characterize the fish community and soft and hardbottom habitats around Vieques in an effort to define locations for marine protected areas (MPAs). Habitat assessments were conducted using the Braun-Blanquet method to estimate percent cover and density of seagrass and macroalgae at the same sites where fish censuses were conducted (Burke et al. 2007). The fish and habitat surveys were conducted in four locations: Bahia Holiday, Ensenada Honda, Puerto Negro, and southwest Vieques. Each zone was further subdivided into three cross shelf classifications based on depth contours (inner, middle, outer). Only preliminary analysis of the data for both studies was available at the time of this report (Burke et al. 2007). A complete analysis will be presented in a future CCFHR technical report (J. Burke and J. Kenworthy, personal communication).

Garcia-Sais et al. (2001, 2004) conducted monitoring surveys on coral reefs around Vieques. Twelve sites were surveyed in 2004 in the western half of Vieques, and six of these sites were re-surveyed in 2004 (see Chapter 5: Coral Reefs and Hardbottom, Figure 5.1b). Algae were identified to the species level.

6.3 METHODS

Recent benthic habitat maps were used to describe the spatial distribution of SAV around Vieques (Kendall et al. 2001). Results from Shapiro and Rohmann (2006) and Hernandez-Cruz et al. (2006) were used to highlight temporal changes in seagrass communities in Vieques Passage and Bahia Salina del Sur, respectively.

Survey locations from recent seagrass and macroalgae surveys (Garcia-Sais et al. 2001, 2004; Burke et al. 2007) were plotted in ArcGIS to show the distribution of sampling efforts. Preliminary results from CCFHR's seagrass recovery survey (Burke et al. 2007) were used to describe general patterns in seagrass types and density in the surveyed areas. Estimates of seagrass shoot density were provided for northwest Vieques, Puerto Mosquito, and Puerto Ferro (Burke et al. 2007).

Data from Garcia-Sais et al. (2001, 2004) was used to generate a graph illustrating the mean coverage (m^2) of the various classes of algae on reefs surveyed during each of the sampling events (2001 and 2004).

An algal species inventory for Vieques was generated using data from Torres and Pearl (1972), Zieman (2000), and Garcia-Sais et al. (2001, 2004).

6.4 DISTRIBUTION, STATUS AND TRENDS

Seagrasses require specific environmental conditions for optimal growth including sufficient substrate for rhizome root development, water immersion, and sufficient light penetration for photosynthesis (Hemminga and Duarte 2000). For this reason, seagrass distribution around Vieques is not uniform and is a function of the varying environmental conditions around the coast (see Chapter 2: Climate and Currents) as well as varying geologic features of the shelf (see Chapter 3: Geology and Land Cover).

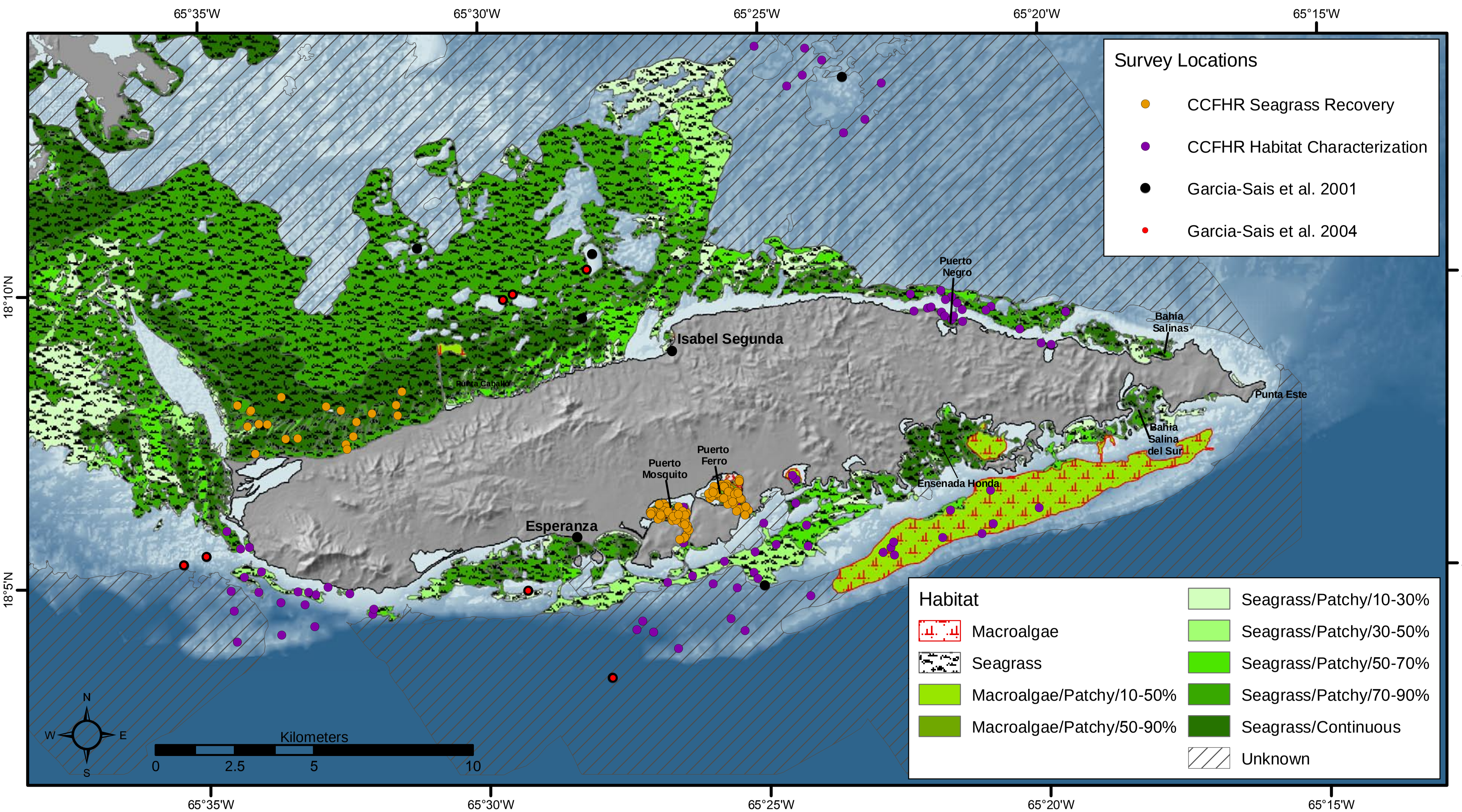


Figure 6.1. Distribution of submerged aquatic vegetation around Vieques, Puerto Rico (Source: Kendall et al. 2001) and location of recent seagrass and algae field surveys.

Submerged aquatic vegetation covers a large portion of the near shore waters of Vieques. From the spatial assessment conducted by Kendall and Eschelbach (2006), 116.4 km^2 of SAV was estimated among the 255 km^2 mapped area within 3 nm of Vieques. The broad classification of SAV included both seagrass and macroalgae, where seagrass alone covered 92.7 km^2 and macroalgae covered 23.7 km^2 of the inventoried area (Kendall and Eschelbach 2006). Thus, SAV accounted for 46% of the benthic habitat around the near shore waters of Vieques when compared to estimates of 59.3 km^2 and 75.2 km^2 of unconsolidated sediment and coral reef habitat, respectively. The largest expanse of seagrass is located north of the island from the midpoint west to the main island of Puerto Rico (Figure 6.1). Additional seagrass areas are located in the bays, lagoons, and coastal areas on the south shore. Small areas of mapped macroalgae are interdispersed with seagrass in shallow areas, particularly in lagoons, but the largest expanse of macroalgae is located southeast of the island in a deeper (20-30 m) channel where seagrass is absent.

Zieman (1978) found standing crop and biomass of Vieques seagrass beds comparable to other regions of the Caribbean. Comparison of aerial photographs from 1978 to those from 1985 revealed similar seagrass distribution in the northwest region, near Escollo de Arenas, with blowouts continuously present among the dense seagrass beds as a result of herbivorous grazing and hurricane impact. Biomass (per m^2) was not observed to change between 1978 and 1985 (Zieman 2000). Zieman (2000) qualitatively assessed military artillery impacts and determined it to be more prevalent in Bahia Icacos (northeast) within the former Live Impact Area (LIA) relative to sample sites in Bahia Salina del Sur (southeast).

Shapiro and Rohmann (2006) analyzed SAV coverage from 1985-2000 within a 660 km^2 study area around Escollo de Arenas and estimated 27.7 km^2 of SAV area change over the 15 year period. Within this 27.7 km^2, 18.6 km^2 was determined as area gain and 9.15 km^2 was lost. The most notable gain was seen along the west shore of mainland Puerto Rico while the highest losses were noted in the shallow waters north of Escollo de Arenas. Gains were seen in deeper water while losses were noted in shallow water and attributed to strong currents, sediment loading and poor water quality (Shapiro and Rohmann 2006). Estimated new growth included >13 km^2 of SAV in dense (70-90%) seagrass beds near the shores of mainland PR and along the north edge of Escollo de Arenas (Shapiro and Rohmann 2006).

Following verification, 90% of the estimated changes in SAV by Shapiro and Rohmann (2006) matched SAV classified areas in the benthic habitat map of Kendall et al (2001). An estimated biomass gain of 5% (0.3 km^2) and a loss of 20% fell within unknown habitat classified areas of the map. It is important to map these remaining unclassified regions to properly monitor and manage the SAV community of Vieques.

Hernandez et al. (2006) estimated that seagrass coverage increased ~85% in Bahia Salina del Sur since 1937 due to a combination of environmental factors, such as the protected location of the bay, recolonization following hurricane impacts and a reduction in herbivorous grazers. While this study and Shapiro and Rohmann (2006) examined long time periods to estimate change, they focused on specific study areas rather than an island wide assessment.

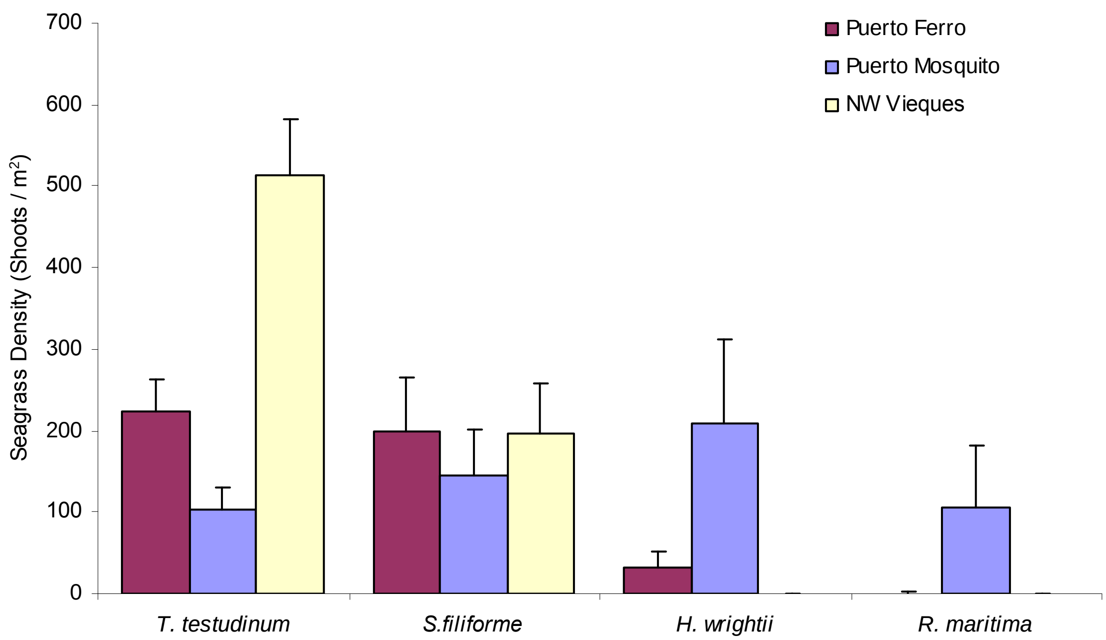


Figure 6.2. Mean density (±SE) estimates for seagrass species from select sites within Puerto Ferro, Puerto Mosquito and along the NW coast of Vieques as part CCFHR's seagrass recovery study (Source: Burke et al. 2007).

Depth is a primary factor controlling seagrass growth and distribution. Zieman (1985) found that *H. wrightii* dominated the community within a depth range of 5-6 meters and grew in predominately monotypic beds. At 6.6-8.8 m depth, *T. testudinum* dominated, and beyond 8.8 m the macroalgae *Caulerpa sp.* dominated the system. Zieman (1985) noted one deep water seagrass bed in Bahia Icacos composed of *Halophila sp.* at 9.1 m depth. *S. filiforme* and *H. wrightii* dominated the vegetative community off the eastern end of the island (former LIA). On the shallow flats of Bahia Icacos to the northeast, *T. testudinum* dominated with patches of *S. filiforme* and *H. wrightii* interspersed, while characteristically deeper beds were comprised of sparse *S. filiforme* and *H. wrightii* and lacked any *T. testudinum* (Zieman 1985). Along the south coast in Bahia Salina del Sur the seagrass beds were characterized primarily by lush *T. testudinum* where there were no military impacts and *H. wrightii* and *S. filiforme* in impacted areas (Zieman 1985). Along the northwest coast there is an expansive climax community of *T. testudinum* interspersed with *Halimeda sp.* patches around Mosquito Pier and Escollo de Arenas (Zieman 1985).

In addition, Zieman (1985) qualitatively assessed military impact craters and determined those noted in 1985 photos were the result of new (post-1978) excavation from artillery deployment and that all craters seen in the 1978 photos had recovered. Unfortunately, there is no estimate of total area of crater damage since not all craters were measured and only information on presence/absence or inconsistent count data is available. Therefore, it is hard to assess an absolute area of damage, but the results do show potential for relatively rapid recovery, particularly given the cessation of military operations.

Seagrass density estimates from sample cores from CCFHR's seagrass recovery study in Puerto Mosquito, Puerto Ferro, and northwest Vieques are shown in Figure 6.2. Density of *T. testudinum* and *S. filiforme* estimates were nearly equal in Puerto Ferro. *H. wrightii* was in very low density within Puerto Ferro but highest in density among the four seagrass species in Puerto Mosquito. *H. wrightii* was absent from NW Vieques. Concurrent with Zieman (2000), T. *testudinum* was nearly 2x the density of any other seagrass species along the NW coast of Vieques. *H. decipens* was found in low density within Puerto Ferro and Puerto Mosquito and absent from sites along the north coast. *Ruppia maritima* (widgeon grass), which typically grows in fresh or brackish water, was found at a density of approximately 100 shoots per m^2 in Puerto Mosquito but was largely absent from the other study areas.

Macroalgae is a more ubiquitous class of SAV and occurs not only in close association with seagrass, but also colo-

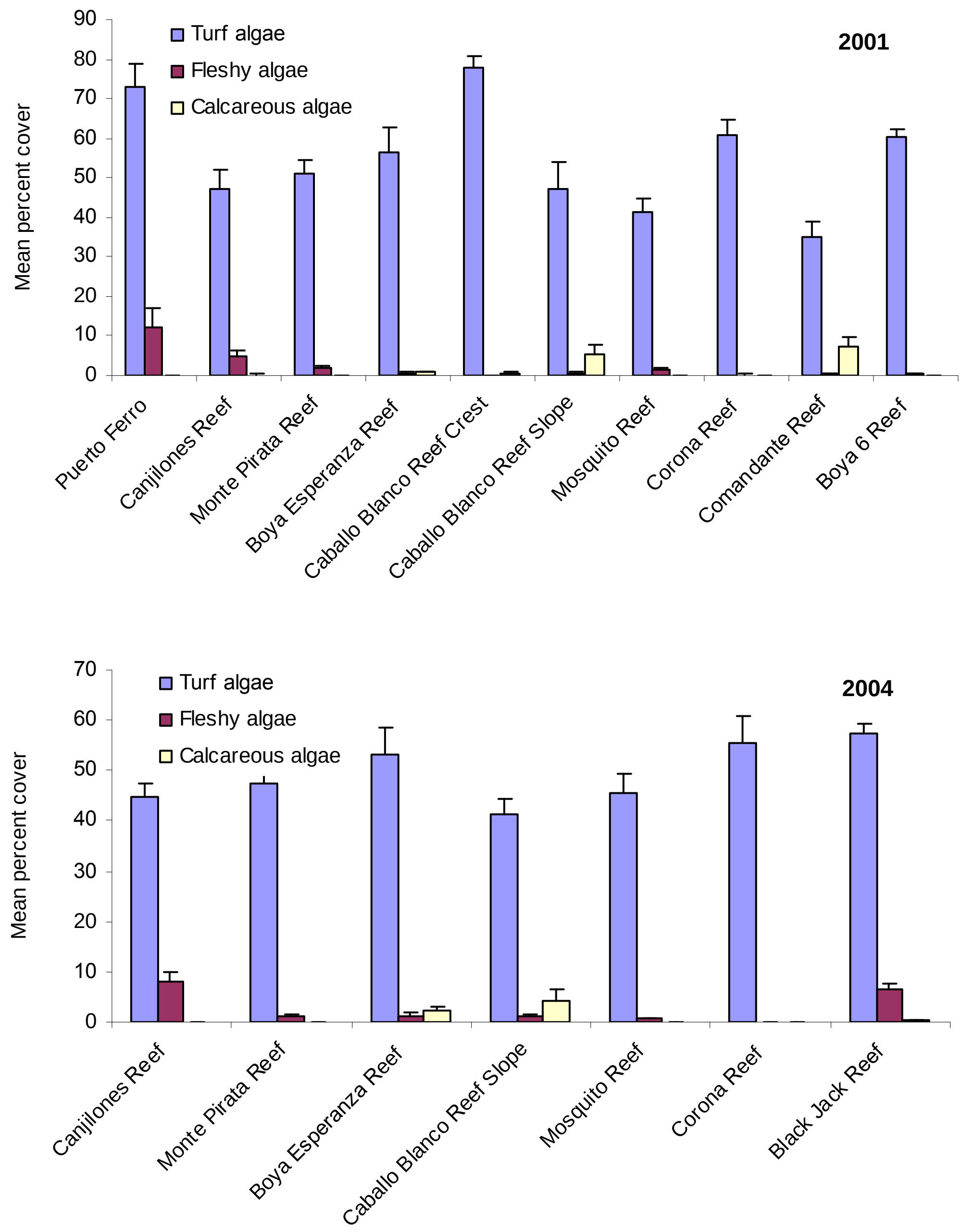


Figure 6.3. Major algal percent composition around reefs of Vieques (Source: Garcia-Sais et al. 2001, 2004). Error bars represent standard error.

Table 6.1. List of marine algal species distribution observed in the waters of Vieques. Sources: Garcia-Sais et al. 2001 (a), Torres and Pearl 1972 (b)., and Zieman 2000 (c).

Scientific name	Locations	References cited
Amphiroa sp.	Playa Grande north central, North of Punta Martineau	a,b
Anadyomene	Playa Grande north central	b
Avrainvillea sp.	Punta Arenas, Comandante Reef, West of Rompeolas, West of Rompeolas 1	a
Avrainvillea nigricans	Desembarcadero Mosquito Western side	b
Cladocera debilis	Punta Arenas	a
Dictyota sp.	West of Rompeolas	a
Dictyopteris justii	Playa Grande north central	b
Dictyosphaeira cavernosa	Playa Grande north central, West of Rompeolas	a,b
Gracileria	Laguna Kiania	b
Halimeda sp	Desembarcadero Mosquito Western side, Corona Reef, North of Punta Martineau, Bahia Icacos	a,b,c
Halimeda discoidea	Punta Arenas, Comandante Reef, North of Punta Martineau	a
Halimeda incrassata	Esperanza 1, Esperanza 2	a
Halimeda monile	Punta Arenas, Esperanza 3, West of Rompeolas, West of Rompeolas 1	a
Halimeda opuntia	West of Rompeolas, West of Rompeolas 1	a
Hypnea sp.	Laguna Kiania	b
Jania sp.	Corona Reef, Comandante Reef, West of Rompeolas	a
Lobophora variegata	Comandante Reef	a
Padina sp.	West of Rompeolas, West of Rompeolas 1	a
Penicillus sp.	Punta Arenas, Esperanza 2, North of Punta Martineau, bahia Icacos	a,c
Penicillus capitatus	Desembarcadero Mosquito Western side, West of Rompeolas	a,b
Penicillus capitatus	Esperanza 3, Corona Reef. Comandante Reef, West of Rompeolas 1	a
Penicillus dumetosus	West of Rompeolas	a
Pocockiella variegata	Desembarcadero Mosquito Western side	b
Sargassum	Playa Grande north central	b
Syridia	Laguna Kiania	b
Turbinaria	Playa Grande north central	b
Udotea sp.	Punta Arenas, Esperanza 3, Corona Reef, Comandante Reef, North of Punta Martineau, Bahia Icacos	a,c
Udotea cyanthiformis	West of Rompeolas, West of Rompeolas 1	a
Udotea flabellum	Desembarcadero Mosquito Western side, Esperanza 2	a,b
Udotea flabellum	Esperanza1, Esperanza 2	a
Valonia sp. (ventricosa)	Punta Arenas. Esperanza 2, West of Rompeolas	a

nizes hard bottom habitats such as coral reefs. Table 6.1 lists the algal species documented in Vieques, the reported location and data source (Torres and Pearl 1972; Zieman 2000; Garcia-Sais et al. 2001).

Unfortunately, given the variety of sampling strategies used by most studies and the varying array of sites surveyed, it is not possible to discern whether the algae colonized soft bottom or hard bottom habitat in all studies. Within soft bottom areas the most common algal species included: *Udotea, Halimeda* and *Penicillus* (Zieman 2000). Garcia-Sais et al (2001) conducted habitat specific surveys and include data that differentiates by whether the algae was on hard or soft bottom habitat. Garcia-Sais et al. (2001) only made observations on species occurrences and algal coverage was reported according to major algal groups. Three taxa that were commonly observed included: *Lobophora sp.*, *Amphiroa sp.* and *Dictyota sp.* (Figure 6.3). Turf algae remained the dominant algal cover class which did not significantly change from 2001 to 2004. It remains dominant due to its resistance to currents and wave action (Garcia-Sais et al. 2004).

6.5 ECOLOGICAL LINKAGES

Submerged aquatic vegetation (SAV) is an important habitat for a variety of marine fauna, providing a food resource or structural refuge for many species. Seagrass beds are noted as highly productive marine systems (Fourqurean et al. 2001) and are a critical food source for sea turtles, manatees, and many species of reef fish (see Chapter 8: Fish, Chapter 10: Sea Turtles and Chapter 11: Marine Mammals). In addition, seagrass beds are an important link in nutrient cycling on coral reef ecosystems. Fish that migrate off of reefs to feed in seagrass transfer nutrients and organic matter back to reefs through excrement (Meyer and Schultz 1985). Spatial estimates report 46% (92.7 km^2) of the nearshore habitat of Vieques is comprised of SAV, relative to 29.5% (75.2 km^2) of coral reef habitat (Kendall and Eschelbach 2006). There are still areas of unknown habitat and these estimates may be low due to limitation of prior mapping activities, therefore there is a need to have a more accurate map in order to fully assess the SAV community.

The community structure of the seagrass beds may shift in response to impacts (natural and anthropogenic) as new species colonize impact craters or blowout areas following disturbance (Zieman 1985; Zieman 2000). With the closure of the Navy base in 2003 and the elimination of further artillery impacts, bomb craters will eventually be colonized by the fast growing seagrass species *H. wrightii* and *S. filiforme*, and perhaps over time by the apex species, *T. testudinum* (Zieman 2000).

The most prevalent qualitative observance of natural disturbance in seagrass beds around the island was noted near Punta Arenas along the northwest corner of Vieques. This impact was attributed to grazing by the endemic West Indian manatee (*Trichechus manatus)*, although some blowouts still persist from the impact of Hurricane Hugo (Kenworthy et al. 2007; see Chapter 2: Climate and Currents). The West Indian manatee is most common in the northwest region of the island because of the high abundance of seagrass in the region (see Chapter 11: Marine Mammals). In addition to manatees, there are several other prominent grazers on seagrass such as urchins, including the long-spined urchin (*Diadema antillarium)*, Queen conch (*Strombus gigas)*, green sea turtle (*Chelonia mydas)* and many species of herbivorous fishes (Garcia-Sais et al. 2001). In other areas of the island, Zieman (1985) noted that *T. testudinum* was most prevalent seagrass species in Bahia Icacos, Bahia Salina del Sur and along the northwest corner near Punta Arenas. Seagrass distribution estimated by Kendall and Eschelbach (2006) correlates well with the manatee sighting data provided in Chapter 11: Marine Mammals. The overlap is most noticeable in the northwest corner, west and south coastal regions of the island.

While the algal community has remained relatively stable since 2001 (Garcia-Sais et al. 2004) there is concern that as coastal development increases, there will be additional sediment loading or pollutant runoff into near shore habitats. These changes could lead to an indirect increase in algal cover as coral reef communities deteriorate and algal species colonize the unhealthy reefs (Shapiro and Rohmann 2006). As military cleanup efforts are implemented in the LIA, extractive methods or detonation of relic ordnance in the water is likely to further impact existing seagrass communities and could pose added stress to the already impacted community. Therefore it is pertinent to continue monitoring efforts in Vieques and periodically update maps to properly identify all SAV resources including both seagrass and algal communities.

LITERATURE CITED

Burke, JS, WJ Kenworthy, BP Degan, GD Carlo, JB Landry and JC Taylor. 2007. Preliminary results of a survey of coastal fishes and their habitat around the island of Vieques. CCFHR, Beaufort, NC. Unpublished report.

Duarte, CM. 1991. Seagrass depth limits. Aquatic Botany 40(4): 363–377.

Fourqurean, JW, A Willsie, CD Rose and LM Rutten. 2001. Spatial pattern in seagrass community composition and productivity in South Florida. Marine Biology 138: 341-354.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2001. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 108 pp.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2004. Monitoring of coral reef communities from Isla de Vieques, Puerto Rico, 2004. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 122 pp.

Hemminga MA and CM Duarte 2000. Seagrass Ecology. Cambridge University Press, 298 pp.

Hernández-Cruz, LR, SJ Purkis and BM Riegl. 2006. Documenting decadal spatial changes in seagrass and *Acropora palmata* cover by aerial photography analysis in Vieques, Puerto Rico: 1937–2000. Bulletin of Marine Science 79(2): 401-414.

Kendall, MS and KA 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.

Kendall, MS, CR Kruer, KR Buja, JD Christensen, M Finkbeiner, RA Warner and ME Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (online). http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

Kenworthy, J et al. 2007. Calibration of seagrass injury and disturbance recovery models and fishery habitat utilization in southeastern Puerto Rico and Vieques Island. Cruise Report: NF-07-07-SEAS, April 27-May 06, 2007.

Littler, DS, MM Littler, KE Bucher and JM Norris. 1989. Marine Plants of the Caribbean: A Field Guide From Florida to Brazil. Smithsonian Institution Press, Washington, DC.

Meyer, JL and ET Schultz. 1985. Migrating haemulid fishes as a source of nutrients and organic matter on coral reefs. Limnology and Oceanography 30(1): 146-156.

Reid, JP and CR Kruer. 1998. Mapping and characterization of nearshore benthic habitats around Vieques Island, Puerto Rico. Report to US Navy. US Geological Survey/BRD, Sirenia Project, Gainesville, Florida. 11 pp.

Shapiro, AC and SO Rohmann. 2006. Mapping Changes in Submerged Aquatic Vegetation using Landsat Imagery and Benthic Habitat Data: Coral Reef Ecosystem Monitoring in Vieques Sound Between 1985 and 2000. Bulletin of Marine Science 79(2): 375-388.

Torres, F and W Pearle. 1972. Section 11: Marine Resources. In: Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Rico, Office of the Governor.

Ziegler, JM and GS Giese. 1971. Geology and Hydrodynamics of Punta Arenas Shoal. pp.33-38. In: Transactions of the 5th Caribbean Geological Conference, Geology Bulletin No. 5. Queens College Press.

Zieman, JC. 1978. The seagrass communities of Vieques, Puerto Rico. A report for EG&G. Consultants and the U. S. Department of Justice. 42 pp.

Zieman, JC. 1985. An Evaluation of the Condition of the Seagrass Beds of Vieques, PR. A Report for Ecology and Environment, Inc.

Zieman, JC. 2000. An preliminary evaluation of the condition of the seagrass beds Vieques, Puerto Rico. Geo-Marine, Inc. Contract #: N62470-91-D-1160, Contract Task Order 0022 February.

CHAPTER 7: MANGROVES

7.1 OVERVIEW

Two types of mangrove forests are present in Vieques, basin and fringing. Basin forests are well developed in the northwest corner of the island while both basin and fringe forests are abundant on the south shore. The majority of mangrove forests are found in these two geographic regions. Only a small acreage of mangrove forest is found on the northeast and southwest shores. The most recent island-wide map estimates a total mangrove area of approximately 4.1 km^2 in 1999 (Kendall and Eschelbach 2006).

Comparisons with previous mapping efforts indicate that some areas have experienced a decline in mangrove coverage. These include the lagoon at Playa de la Chiva, Bahia Mosquito, and Laguna Boca Quebrada. However, overall losses appear to be less than on mainland Puerto Rico and elsewhere in the Caribbean. Total island-wide coverage has been relatively stable in the last few decades. Anthropogenic threats to healthy mangrove systems in Vieques include sedimentation from upland erosion, construction of roads that bisect mangrove habitat, and blockage of outlets of mangrove lined bays to the ocean.

7.2 SOURCES OF DATA

The most current island-wide map of mangrove extent was completed by NOAA's Biogeography Branch based on 1999 aerial photography (Kendall et al. 2001). In addition to this recent map, primary literature, technical reports, and prior maps were compiled to address historical changes in mangrove distribution, species composition, and health in relation to the present status. There have been several previous efforts to map the area of mangroves in the former Navy lands (GMI 2002; GMI 2003), the Bioluminescent Bays (Mitchell 2003), and for the whole island of Vieques (Fram 1972; Lewis 1981; Reid and Kruer 1998). In addition, a mangrove/shrubland category was included in a recent land cover map of Vieques (PRGAP 2006; see Chapter 3: Geology and Land Cover).

7.3 METHODS

The available marine benthic habitat maps were used to describe the spatial distribution of mangroves on Vieques. A map was generated using delineations from NOAA's benthic habitat map (Kendall et al. 2001) to show the most recent extent of mangroves. The mapped area of mangroves was compared to the historical record to estimate potential changes in the area of mangrove coverage over time.

Image 7.1. Red mangrove (*Rhizophora mangle*). Photo: A. Mason.

7.4 DISTRIBUTION, STATUS AND TRENDS

Four mangrove species are found in the greater Caribbean, all of which occur on Vieques: *Rhizophora mangle* (Red Mangrove), *Laguncularia racemosa* (White Mangrove), *Avicennia germinans* (Black mangrove), and *Conocarpus erectus* (Button Mangrove) (Lugo and Snedaker 1974; Proctor 1994). These species are spatially stratified by distance to shore and elevation. Red mangrove is typically found in the lower intertidal zones and is characterized by arching prop roots that are usually partly submerged in tidal water or mud. The remaining three species typically dominate the mangrove community further inland where tidal flushing is less. Black mangrove can tolerate a wide range of salinities and is recognized by a series of root-like structures called pneumatophores that project up from the soil around the tree. White mangroves lack prop roots or pneumatophores and grow in brackish to salty mud that is intermittently affected by tides. Button mangrove is generally found on the landward side of mangrove forests and serves as an intermediate species between tidal and dryland forests. In general, there is an inverse relationship between soil salinity and mangrove tree size, and mortality increases above a salinity threshold of about 65 ppt (Cintron et al. 1978).

There are five main types of mangrove forest in all of Puerto Rico that are identified based on the topography and the pattern of water circulation: fringe, riverine, overwash, basin, and dwarf forests (Lugo and Snedaker 1974). Two of these types, fringe and basin forests, primarily constitute the mangrove forests in Vieques. Fringe forests occur along the seaward edge of protected shorelines, with red mangroves generally lining the seaward edge of the fringe system. Moving inland, elevation typically increases and there is reduced turbulence and tidal flushing, resulting in an increasing salinity gradient and shift in species composition. An example of this typical zonation pattern is seen at the fringe forest in Bahia Mosquito, which is characterized by continuous *R. mangle* fringing the bay followed landward by a line of *A. germinans* (Mitchell 2003).

Basin forests occur in inland areas along drainage depressions. Salinity varies seasonally depending upon precipitation and connection to the ocean. In Vieques, the basin forests occur as fringes of mangroves lining inland coastal lagoons. Lagoons may be permanently open to the ocean, have an ephemeral connection to the ocean (i.e., open during the wet season and closed during the dry season) or may be closed. Species composition of mangrove forests varies and may be dependent on the extent of tidal flushing, rainfall, freshwater input, and soil salinity. The dominant mangrove species in 28 areas in the former eastern Navy lands have been documented in recent field studies (GMI 2002). While some lagoons are monotypic (e.g., composed solely of red, buttonwood or black mangroves), others are composed of multiple species.

Mangroves are best developed on the northwest and south coasts of Vieques. Island wide, mangroves cover a total of approximately 4.1 km^2, constituting 5.7% of the total mangrove acreage in Puerto Rico (Kendall et al. 2001; Table 7.1; Figure 7.1). Note that this map does not identify individual species, or differentiate between open and closed canopies. Basin forests in the lagoons on the northwest corner of the island (Laguna Kiani, Laguna El Pobre, Laguna Punta Arenas, and Laguna Boca Quebrada) account for 1.2 km^2, or approximately one-third of the total mangrove area in Vieques. Approximately 0.9 km^2 of mangroves are located along the shores of Ensenada Honda (including Cayo Yanuel). Mangroves fringe the coastline of numerous other south shore bays, including Bahia Mosquito (0.4 km^2 including the open lagoon extending west from the bay), Puerto Ferro (0.4 km^2), Bahia Salina del Sur (0.2 km^2), and Bahia Tarpon (0.2 km^2). Basin lagoon forests are present in Laguna Playa Grande (0.2 km^2), north of Playa de la Chiva (0.2 km^2), and Laguna Yanuel (0.1 km^2). Smaller areas are located on the north side in Puerto Negro (0.1 km^2), Puerto Diablo (0.1 km^2), adjacent to Mosquito Pier (0.1 km^2) and east of Punta Goleta (0.02 km^2). The majority of mangrove areas in Vieques are located within the Vieques Fish and Wildlife Refuge, while the mangroves in Bahia Mosquito and Puerto Ferro are located within the Bahias Bioluminiscentes de Vieques Natural Reserve.

It is important to note that Figure 7.1 only includes mangrove complexes that are tidally influenced and larger than 1 acre, which is the minimum mapping unit (MMU) at which the benthic habitat mapping was conducted (Kendall et al. 2001). From a different set of 1999 aerial photography, GMI (2002) also mapped mangroves within the former eastern Navy lands (i.e., east of Bahia Mosquito). They identified several small inland water bodies, most of which had no visible surface connection to the ocean, that were also lined with mangroves. For consistency, the GMI (2002) mangrove delineations were not included in Figure 7.1 because the mapping was conducted at a different scale (MMU unknown), and because the assessment was only conducted on the eastern half of the island. However, a map showing the locations of the additional inland mangrove areas is available in GMI (2002, 2003). In addition, the GMI (2002) report provides supporting field data for the mangroves complexes surveyed in the study area.

Table 7.1. Total estimated mangrove area in Vieques from published sources.

Year	Total mangrove area (km^2)	Source	Method
1936	4.5	Lewis 1981	Aerial photography
1941	3.9	Fram 1972	US Geological Survey Map
1972	3.3	Fram 1972	Aerial photography, field study
1981	3.7	Lewis 1981	Aerial photography, field studies
1994	4.5	Reid and Kruer 1998	Aerial photography, MMU = 1 acre
1999	4.1	Kendall et al. 2001	Aerial photography, MMU = 1 acre
1999-2003	3.1	PRGAP 2006	Landsat imagery, Raster pixel size = 225 m^2

PRGAP (2006) estimated 3.1 km^2 of mangrove/shrubland on Vieques, which is much lower than the estimate by Kendall et al. (2001). However, it should be noted that another category, salt and mudflats, also potentially contain mangroves (PRGAP 2006). In addition, the mapping was conducted using a different set of imagery, scale, and mapping methods. The large difference in the estimated mangrove area between two maps produced around the same time indicates that multiple factors, such as the source imagery, classification methods, and MMU, influence the total area mapped.

The distribution and extent of mangrove forests in Vieques has been estimated from historical aerial photos dating back to 1936, preceding Navy activity in Vieques (Table 7.1). The extent of mangroves prior to when the

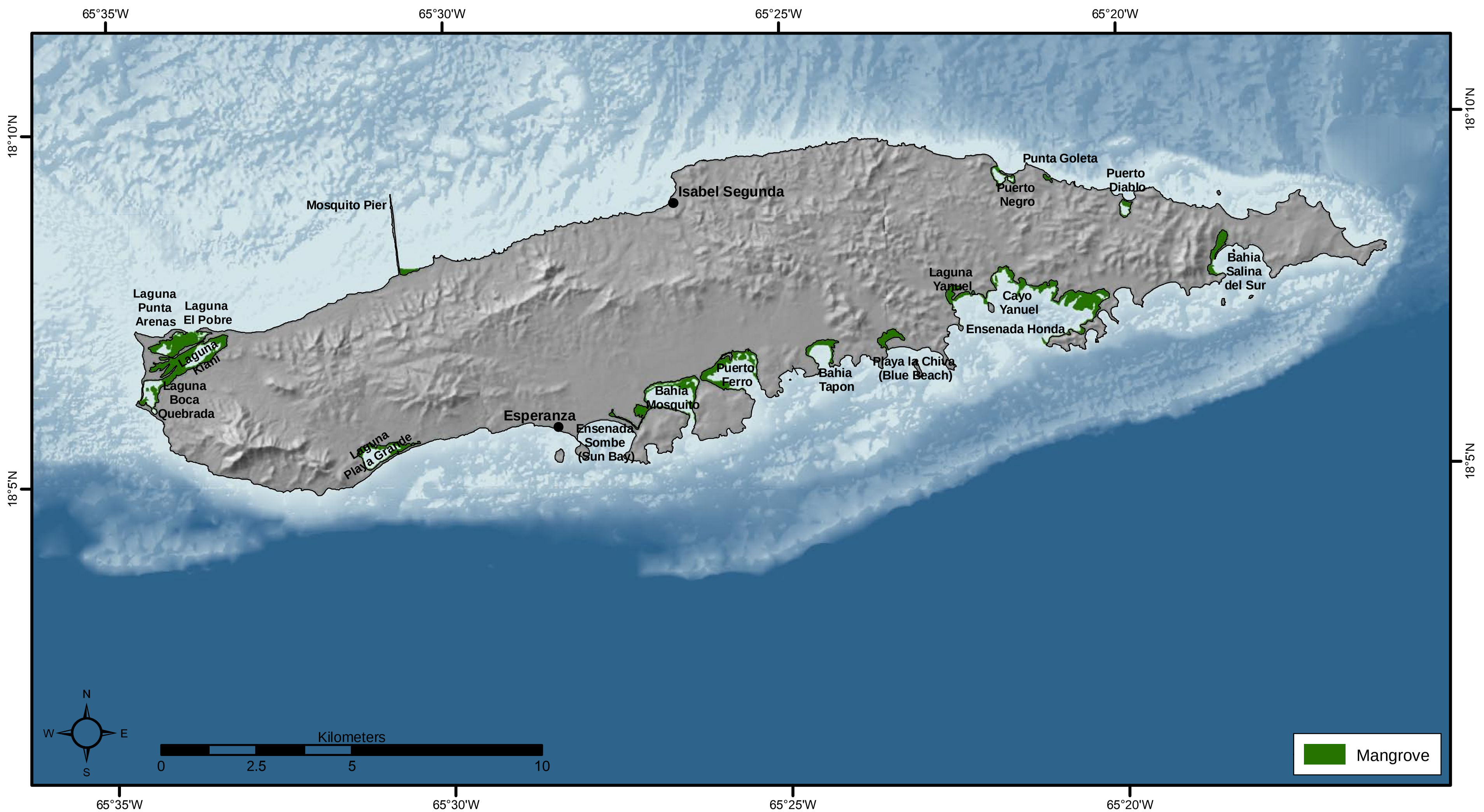


Figure 7.1. Distribution of mangroves in Vieques (Source: Kendall et al. 2001).

land was cleared for agriculture in the late 19th and early 20th centuries is unknown. Analysis of aerial photography from 1936 and 1949 estimate the island-wide coverage at 4.5 (Lewis 1981) and 3.9 (Fram 1972) km^2, respectively. Fram (1972) documented a 16% decline in mangrove coverage between 1949 and 1972. Similarly, in a separate study, Lewis (1981) estimated the decline in mangrove cover from 1936 to 1981 at 18%. Different lagoons and bays experienced varying degrees of change. For instance, a large area of mangroves in Laguna Boca Quebrada in the northwest tip were stressed or dead in 1981, which was attributed to a blocked connection to the ocean and a prolonged 1960s drought, resulting in fluctuating salinity and water levels (Lewis 1981). Cattle damage was also identified as a factor. Restricted flow continues to be a problem in Laguna Boca Quebrada (GMI 1996; DOI 2007), and much of the area that was identified as dead mangrove in 1981 was most recently mapped as a mud flat (Kendall et al. 2001), indicating that mangroves in this lagoon have not recovered. Other lagoons with restricted flow include the lagoon behind Playa la Chiva, and Laguna Puerto Diablo (GMI 1996; GMI 2002). In addition, bombing damage has been observed at several small mangrove stands in inland lagoons on the eastern end of the island (Lewis 1981; GMI 2002).

Mangroves are a conspicuous component of Bahia Mosquito and Puerto Ferro, the bioluminescent bays on the south shore. Although the current extent of mangrove in Bahia Mosquito is lower than historical levels, the mangrove community fringing the bay and the adjacent tidal forest to the west comprise one of the largest mangrove systems on the south shore of Vieques. In 1941, this complex was estimated to cover 0.8 km^2 (Fram 1972). When the area was resurveyed in 1972, the mangroves in the western half of the tidal lagoon were largely dead, accounting for a loss of 0.3 km^2 or 40% (Fram 1972). Today, a fringe of black mangroves lines the outside of this basin but red mangrove is restricted to the eastern portion of the basin close to the inlet (Mitchell 2003). Wetland and salt flats cover most of the remainder of the area.

Despite the apparent decline in mangrove coverage in some localities, the results of recent mapping efforts (Reid and Kruer 1994; Kendall et al. 2001; PRGAP 2006) indicate that total mangrove coverage on Vieques is presently similar to levels observed in the earliest photographs. Compared to Lewis (1981), mangrove coverage in 1999 was smaller in Laguna Playa Grande but has otherwise increased or remained steady in the other major lagoons and bays (Kendall et al. 2001). Interestingly, the lagoons in the northwest tip, which experienced decline through the 1980s, overall had higher mangrove cover in 1999 compared to the 1941 map by Fram (1972). GMI (2002) documented a further decline in mangrove coverage at the lagoon at Playa de la Chiva and Puerto Ferro, but for most surveyed areas (eastern former Navy lands only), mangroves were deemed to be in good condition and had experienced little change in coverage compared to previous estimates. Some of the differences between the studies may be attributed to actual growth and/or death of mangroves but may also result from differences in mapping methods, photo quality, and photo interpretation. No attempts were made to distinguish between sparse, open and closed canopies in any previous maps, which should be a priority in future mapping efforts. In addition, detailed species zonation has not been mapped for any areas outside of Bahia Mosquito and Puerto Ferro. The use of high resolution satellite imagery (e.g., IKONOS, QuickBird) has improved the ability to map mangrove forest species composition (Wang et al. 2004a,b). Updated maps of mangrove distribution for the entire island of Vieques are needed to provide resource managers with a detailed assessment of current mangrove forest distribution and composition.

The rate of disappearance of mangrove habitat in Vieques appears to be less than elsewhere in Puerto Rico and the greater Caribbean (see review by Ellison and Farnsworth 1996). It has been estimated that Puerto Rico had lost nearly 85% of its original mangroves by 1975 (Lugo and Cintron 1975). Reasons cited for the decline include increased development of heavy industry in the 1960s, dredge and fill operations, oil pollution, changes in drainage, and sedimentation. The lack of widespread industry and coastal development in Vieques may in part explain the incongruity in magnitude of mangrove loss in comparison with the rest of the commonwealth.

7.5 ECOLOGICAL LINKAGES

In conjunction with coral reefs/hardbottom and seagrass, mangroves represent an important component of the marine ecosystem in Vieques. Mangroves export a high amount of organic material to the coastal environment in the form of leaves, twigs, flowers, and seedlings. This detritus is decomposed by bacteria, fungus and protozoa, which is in turn consumed by crustaceans, mollusks, and small fish. Due to this high organic input and protective prop root structure, mangroves provide important habitats for juvenile stages of many fish and invertebrate species, including those which are commercially and ecologically important (see Chapter 8: Fish). Further, fish movement patterns link mangroves with coral reefs and submerged vegetated habitats (Sheaves 2005). It has been shown that fish density and the number of species in mangroves is related to the complexity of the surrounding seascape (Pittman et al. 2007). In particular, the amount of seagrass in close proximity to mangrove habitats was an important determinant of the spatial distribution of some fish species in Southwest Puerto Rico (Pittman et al. 2007).

A diverse assemblage of epiphytic organisms grow on submerged prop roots, including molluscs, sponges, bryozoans, hydroids, annelids, tunicates, and algae, of which many species have been documented in Vieques mangroves (DON 1979). Mangrove systems also provide habitat and food for numerous species of wading and sea birds, including the endangered Caribbean Brown Pelican (see Chapter 12: Seabirds). In addition, mangroves stabilize shorelines, reduce coastal erosion and protect low-lying coastal areas from waves and storms.

Compared to other areas of Puerto Rico and the Caribbean, the mangrove system in Vieques is largely intact, but still faces threats from anthropogenic activities. Current stressors include cattle grazing, road construction, and deposition of sediment by upland erosion, the latter two of which can lead to the restriction or blockage of tidal flow or freshwater drainage (Lewis 1981; GMI 1996; GMI 2002). Natural stressors include hurricanes and salt buildup in the soil due to high evaporation rates, especially during periods of drought as streams in Vieques are predominantly ephemeral. There is little information on the effects of hurricanes on mangroves in Vieques, although GMI (2002) speculated that damage from Hurricane Hugo and/or Georges may be in part responsible for the decrease in mangrove coverage in the lagoon behind Bahia de la Chiva. However, fringe forests in Vieques are largely located in bays that are relatively well protected, hence they may receive less storm associated wave action than more exposed systems. In addition to wind and wave damage, hurricanes may have additional effects on mangrove succession (Cintron et al. 1978). For example, waves and currents from storms may deposit large amounts of debris in front of fringes or tidal outlets, reducing water circulation. This may have negatively affected mangrove forests after Hurricane Hugo, as openings of some lagoons were reportedly closed after the storm (GMI 1996), but specific impacts and degree of recovery have not been documented. Conversely, mangrove systems may expand in size following hurricanes when fresh seawater and rain inundate inland hypersaline lagoons.

LITERATURE CITED

Cintron, G, AE Lugo, DJ Pool and G Morris. 1978. Mangroves of arid environments in Puerto Rico and adjacent islands. Biotropica 10(2):110-121.

DOI (U.S. Department of the Interior). 2007. Final Comprehensive Conservation Plan/Environmental Impact Statement for Vieques National Wildlife Refuge, Vieques, Puerto Rico. Fish and Wildlife Service, Southeast Region, Atlanta, GA.

DON (U.S. Department of the Navy). 1979. Draft Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

Ellison, AM and EJ Farnsworth. 1996. Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends, and future predictions. Biotropica 28(4A): 549-565.

Fram, MJ. 1972. Section 9: Tidal Forests. In: Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Rico, Office of the Governor.

GMI (Geo-Marine, Inc.). 1996. Rare, threatened, and endangered species habitat inventory of Navy lands in Vieques, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA.

GMI (Geo-Marine, Inc.). 2002. Mangrove forest health and status, Vieques Island. Draft report. Prepared for Commander, Atlantic Division, Naval Facilities Engineering Command, Norfolk, VA.

GMI (Geo-Marine, Inc.). 2003. Navy Lands on Vieques: Integrated Natural Resources Management Plan, Plan Years: 2003-2012. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

Kendall, MS and KA 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.

Kendall, MS, CR Kruer, KR Buja, JD Christensen, M Finkbeiner, RA Warner and ME Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (online). http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

Lewis III, RR. 1981. Mangrove Forests of Vieques, PR, Volume 1: Management Report. Report by Mangrove Systems, Inc. to the U.S. Navy.

Lugo, AE and SC Snedaker. 1974. The ecology of mangroves. Annual Review of Ecology and Systematics 5: 36-64.

Lugo, AE and G Cintron. 1975. The mangroves of Puerto Rico and their management. In G Walsh, S Snedaker, and H Teas (Eds.). Proceedings of the International Symposium on Biology and Management of Mangroves. Institute of Food and Agricultural Sciences, University of Florida, Gainesville. pp. 825-846.

Mitchell, LE. 2003. Developing a GIS of the bioluminescent bays on Vieques, Puerto Rico. National Geospatial-Intelligence Agency NGA PA 04-201.

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

Proctor, GR. 1994. Vieques Mangrove Forest Manual. Department of Natural and Environmental Resources, San Juan, PR.

PRGAP (Puerto Rico GAP Analysis Project). 2006. PRGAP Landcover. USDA Forest Service, International Institute of Tropical Forestry, Rio Piedras, Puerto Rico. http://gapanalysis.nbii.gov/portal/server.pt.

Reid, JP and CR Kruer. 1998. Mapping and characterization of nearshore benthic habitats around Vieques Island, Puerto Rico. Report to US Navy. US Geological Survey/BRD, Sirenia Project, Gainesville, Florida. 11 pp.

Sheaves, M. 2005. Nature and consequences of biological connectivity in mangrove systems. Marine ecology Progress Series. 302: 293-305.

Wang, L, WP Sousa and P Gong. 2004a. Integration of object-based and pixel-based classification for mapping mangroves with IKONOS imagery. International Journal of Remote Sensing. 25 (24): 5655-5668.

Wang, L, WP Sousa, P Gong and GS Biging. 2004b. Comparison of IKONOS and QuickBird images for mapping mangrove species on the Caribbean coast of Panama. Remote Sensing of Environment. 91: 432-440.

CHAPTER 8: FISH

8.1 OVERVIEW

The fish community in the waters surrounding Vieques is similar to the communities found among the U.S. Virgin Islands and main island of Puerto Rico. The community is diverse with over 200 identified species. Damselfish (Pomacentridae), parrotfish (Scaridae), wrasses (Labridae), surgeonfish (Acanthuridae), grunts (Haemuliae), gobies (Gobiidae) and jacks (Carangidae) make up a majority of observed individuals.

Much of the fish data from around Vieques were collected by the military or its contractors among shallow reefs on the east end of the island. A primary rationale behind collection of this data was to determine if military activities impacted the fish community. Although several reports discussed the possibility that the military provided a de facto marine protected area on the eastern side of Vieques, or alternatively that military activities negatively affected fish communities, a clear difference among reefs inside and outside of the restricted zone has not been found.

Several studies have recently begun to expand the limited spatial scope of the military surveys, such as among deep reefs, seagrass beds and lagoons, and on the western side of the island. These studies identified many additional species, detailed differences among fish assemblages in diverse habitat types, and identified important habitats for Vieques fisheries. Several reports present evidence of differences among community structures among habitats on northern versus southern sides of the island, but the pattern is not consistent among studies.

Vieques has a mixed fishery comprised of commercial, recreational and subsistence segments. The most common gear types are SCUBA (e.g., spearfishing), hook and line, and traps. Targeted species are mainly grunts, groupers, snappers and migratory finfish, but as many as 180 species regularly enter the fishery. A recent comprehensive assessment of the fishery including species composition in landings is lacking. A fishery dataset from 1971 to 2006 shows high variability among landings, landing values and number of fishermen and no clear temporal patterns.

8.2 SOURCES OF DATA

As with many natural resources studied around Vieques, the majority of fish data come from military sources (DON 1979, 1986) and their affiliated contractors (GMI 2003, 2005; Evans et al. 2006). These data were collected to satisfy specific objectives related to the impacts of military use on the coral reef ecosystem. Consequently surveys have a spatial bias towards reefs in the Eastern Maneuver Area, Atlantic Fleet Weapons Training Facility and Live Impact Area. Over 90% of surveys by the military and its contractors were on shallow reefs located on the eastern side of the island (Figure 8.1).

Early studies by the Navy (DON 1979, 1986) used visual survey methods which did not incorporate a constant search area and emphasized the collection of data to make a species inventory and obtain relative abundance scores. More recent studies (e.g., GMI 2003, 2005; Evans et al. 2006) collected data using point counts standardized by area and time, thus providing the potential for different studies to be compared.

Image 8.1. Gray angelfish (*Pomacanthus arcuatus*). Photo: Biogeography Branch.

Garcia-Sais et al. (2001) supplemented Navy work with fish surveys on the western side of the island (Figure 8.1). Three years later they returned to six of the 24 sites initially surveyed in 2001 to assess temporal changes of the reef community (Garcia-Sais et al. 2004). In addition to shallow reefs, the areas surveyed by Garcia-Sais et al. (2001) included seagrass and deep reef habitats which were scarcely surveyed by the Navy. Garcia-Sais et al. (2001, 2004) employed a combination of visual survey methods; one with a constant search area and one without. The latter was used to acquire data on rare species (e.g., grouper, snapper) which require a large search area to increase the probability of detection.

Studies by the Navy (DON 1979, 1986; GMI 2003, 2005; Evans et al. 2006) and Garcia-Sais et al. (2001, 2004) collected data at non-random sites selected to be representative of particular reef habitats. This design is advantageous when few samples can be afforded, but prohibits integration of datasets and may not be representative of the community at large, because sites were selected and not random. Comparisons among such studies are difficult to interpret, because there is no way of knowing if a difference detected among communities represents differences among selected sites, chance or represented communities.

More recently, in collaboration with NOAA's Office of Response and Restoration, the Center for Coastal Fisheries and Habitat Research (CCFHR) conducted studies on Vieques' fish communities. Surveys by CCFHR were designed to identify important benthic habitats for shelf fisheries (Burke et al. 2007). Data was collected in three lagoons (Puerto Ferro, Puerto Mosquito, Puerto Negro), and five large areas distributed offshore around the island. Their dataset includes over 100 randomly selected sites on hard-bottom (i.e. reef, pavement) and soft-bottom (i.e. seagrass, sand) habitats and among three depth zones (inner shelf, mid shelf, outer shelf). In addition, they collected data using hydroacoustics which were used to examine changes in the spatial pattern of fish density over time and space.

All reports describing and comparing the reef fish community structure of Vieques have utilized abundance metrics. Community structure reported in this way may not accurately reflect ecosystem structure and function. A better estimator of ecosystem structure and function may be derived from biomass estimates. Fish biomass is derived from energy consumption and use, and is a suitable integrator of energy flow through the ecosystem. Biomass estimates are commonly made by visually estimating fish sizes and using known size to weight relationships. No study has quantified or examined the distribution of biomass in the reef fish community, but Garcia-Sais et al. (2001, 2004) and Burke et al. (2007) collected the necessary size frequency and identification data for biomass computation.

A long-term fishery-independent dataset is lacking, however the Caribbean Fisheries Management Council (CFMC) has compiled annual fish landings, landing values and number of fishermen in the Vieques fisheries since 1967. Data from 1983-2006 was provided by the National Marine Fisheries Service's Southeast Fishery Science Center (SEFSC). Data before 1983 was not provided by the SEFSC, but landings and species composition data from 1971-1976 was presented by DON (1979) and is used to supplement data provided by the SEFSC.

8.3 METHODS

All sources of data were used to produce a comprehensive inventory of reef fish species identified around the island (Appendix A). The inventory includes every species mentioned in text or recorded in tables, including those observed outside of survey search areas and in fishery landing statistics. Some species names were converted to taxonomic standards referenced by the American Fisheries Society (Nelson et al. 2004).

The variability in survey methodologies and sampling designs prohibits an integrated analysis of datasets among studies within a single spatial framework. Consequently, the spatial distribution of fish species cannot be assessed. Instead reported findings in each study are compiled and analyzed for consistent patterns over space and time.

The 20 most abundant species for each study were identified and compared. This community metric was first reported by DON (1979). Most studies did not provide these data, but it was easily computed using available density and total count information. Some reports did not provide sufficient information to compute ranks above 20, therefore an average rank was computed using a rank of 21 for species with ranks greater than 20.

Two datasets were available to identify changes in the fish community of Vieques over time. First, Garcia-Sais et al. (2001, 2004) present their results from data collected in 2001 and 2004 and their findings are summarized and discussed relative to the other datasets. Second, fishery-dependent data was examined for temporal changes through time. These data were not corrected for non-compliance (i.e., the proportion if fishers who did not report landings), because the only non-compliance estimates available were for Puerto Rico as a whole and it is unknown if these were valid for Vieques data (J. Bennett, personal communication).

8.4 DISTRIBUTION, STATUS AND TRENDS

At least 209 species of fish, representing 51 taxonomic families, have been identified in the waters surrounding Vieques (Appendix A). This number is likely an underestimate and further study is necessary to obtain a more rigorous species inventory. Bohlke and Chaplin (1968) and Randall (1983) report Caribbean reefs support

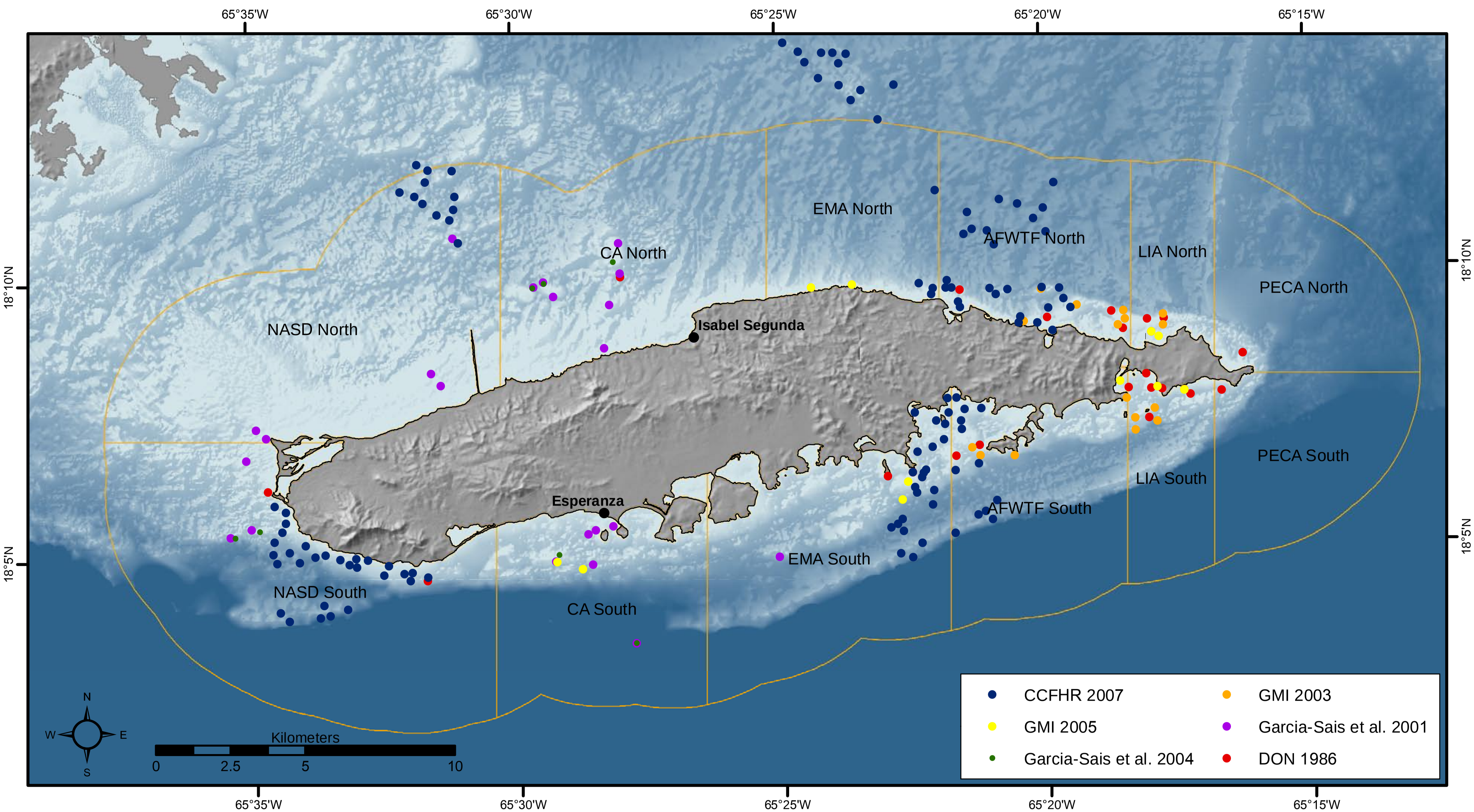


Figure 8.1. Location of reef fish surveys for studies around Vieques. LIA – Live Impact Area, EMA – Eastern Maneuver Area, CA – Civilian Area, NASD – Naval Ammunition Support Detachment, PECA – Punta Este Conservation Area.

over 500 species of fish. Further, although several survey methods were used to collect reef fish data, the vast majority employed diurnal visual observations in shallow reef habitats. Cryptic, rare, nocturnal, small, deep and pelagic species are underrepresented with these methods. In a comparison of measurement methods off St. Croix, Smith-Vaniz et al. (2006) showed that only 36% of species detected with an ichthyocide were also visually detected. To obtain an accurate species inventory of Vieques, alternative survey methods such as ichthyocides, trawl nets and gill nets are needed. Also, more surveys must be completed among unrepresented habitats, such as deep and offshore reefs, seagrass beds, mangroves, and at night.

The fish community structure in Vieques is similar to nearby Caribbean islands, such as St. Croix and Culebra (DON 1979, 1986; GMI 2003, 2005). Visual surveys have consistently shown damselfish (Pomacentridae), parrotfish (Scaridae), wrasses (Labridae) and surgeonfish (Acanthuridae) are the most abundant taxonomic families (DON 1979, 1986; Garcia-Sais et al. 2001, 2004). Grunts (Haemuliae), gobies (Gobiidae) and jacks (Carangidae) have also been noted for their contribution to total abundance (DON 1986; Garcia-Sais et al. 2001).

Garcia-Sais et al. (2004) describes the fish community to be “well balanced” in terms of trophic structure. The most abundant trophic groups are herbivores (e.g. parrotfish, damselfish), epibenthic invertebrate predators (wrasses, squirrelfish) and zooplanktivores (damselfish, wrasses). Piscivores (snappers, groupers, sharks) generally make up a small proportion of the community, but are still considered relatively common in western Vieques compared to other Puerto Rican coral reef ecosystems (Garcia-Sais et al. 2004).

The 20 most abundant species detected by six studies were all commonly referred to as “reef fish” (Table 8.1). Most of these species are not only abundant, but commonly sighted around the entire island and in diverse reef habitats. Coral reefs are prevalent in Vieques (see Chapter 5: Coral Reef and Hardbottom) and thus this assemblage has a large habitat area. Several of the most abundant species, such as the silversides, herrings, anchovies, *Coryphopterus personatus*/*hyalinus*, and scad are patchily distributed and relatively abundant in the few areas where they are found. Their vast numbers in these few areas overwhelm other species in overall species counts.

The large quantity of information for the reef fish assemblage is largely due to its relatively high diversity and abundance compared to other assemblages and the greater amount of effort devoted to surveying hard-bottom habitats. The few studies which surveyed seagrass, mangrove and lagoon habitats show that these habitats had lower species diversity and abundance than reef sites. For example, when compared to hard-bottom sites, DON (1979) reported 75% fewer species on seagrass and 78% fewer families among mangroves, and Burke et al. (2007) reported more than 60% fewer taxonomic families among lagoon sites.

Although many of the same species observed among seagrass, mangrove and lagoon habitats are also observed among hard-bottom habitats including reefs, community composition and structure are not identical (DON 1979, Garcia-Sais et al. 2001). Few of the most abundant species detected among soft-bottom sites (Table 8.2) were also abundant among hard-bottom sites and vice versa (Table 8.1). Size distribution of these species also likely varied among habitat types, but was not reported consistently among studies to enable analysis.

The fish community around Vieques is heterogeneous over a range of spatial scales. Not only does the community change among soft and hardbottom habitats as outlined above, but several reports reveal heterogeneity within benthic habitat types and at regional scales. Various studies conducted four principal comparisons to demonstrate spatial heterogeneity and assess the impact of military activities: among geographic regions (i.e. north vs. south), within habitats (i.e. within lagoons), among habitats (i.e. softbottom vs. hardbottom), and among islands (i.e. Vieques vs. Culebra).

In the majority of spatial comparisons, findings among studies were inconsistent. This variability may be attributed to differing survey methods or study sites, chance, or actual changes over space or time. For example, northern and southern reefs were compared by DON (1986), GMI (2003) and Burke et al. (2007). DON (1986) reported communities to the north and south of the island were similar in terms of abundance, species number and species diversity, while GMI (2003) detected community differences using the Bray-Curtis similarity index (ANOSIM, p-val=0.003). Burke et al. (2007) showed fish abundance among hard-bottom strata was relatively uniform among four regions distributed to the north and south of the island (SE, SW, WNW, NE) with the exception of the northwest region where abundance was significantly lower. In a similar analysis focused on soft-bottom strata, there were significant differences among study regions, but no obvious trend among northern and southern regions (Burke et al. 2007). In addition to abundance aggregated for all species, Burke et al. (2007) investigated abundances among trophic guilds. Their findings show diurnal reef predators, herbivores and zooplanktivores were higher among southern regions, whereas nocturnal soft-bottom predators and invertebrate browsers were higher among northern regions (Burke et al. 2007). The difference among northern and southern regions was attributed to different habitat morphology (i.e. habitat types and distribution; Burke et

Table 8.1. Abundance ranks of the 20 most abundant reef fish species among reefs from six studies. Blanks denote species with insufficient information for a rank. * The majority of studies reported data from reef habitats separately, but Burke et al. (2007) reported data from hard-bottom and soft-bottom habitats together.

Species Name	Common Name	DON 1979	DON 1986	Garcia-Sais et al. 2001	GMI 2003	Garcia-Sais et al. 2004	Burke et al. 2007*	Avg. Rank
Thalassoma bifasciatum	Bluehead wrasse	1	4	5	1	4	1	2.67
Scarus iserti	Striped Parrotfish	9	6	4	9	6	6	6.67
Acanthurus coeruleus	Blue Tang	2	1	16	5	16	3	7.17
Stegastes partitus	Bicolored Damselfish	19	15	2	2	8	8	10.71
Stegastes adustus	Dusky Damselfish	7	13	7	10	7		10.83
Acanthurus bahianus	Ocean Surgeonfish	5	11		4		5	11.17
Sparisoma aurofrenatum	Redband parrotfish		10	15	7	11	11	12.50
Coryphopterus personatus	Masked goby			1	20	1	14	13.00
Sparisoma viride	Stoplight Parrotfish	12	2	13		10		13.17
Chromis multilineata	Brown Chromis	8		6	3			13.33
Clepticus parrae	Creole fish			11		2		13.75
Chromis cyanea	Blue Chromis			9		3	10	14.17
Haemulon flavolineatum	French Grunt		8	10	16			15.20
Acanthurus chirurgus	Doctorfish	3	5					15.33
Halichoeres bivittatus	Slippery dick	13			6		13	15.83
Holocentrus adscensionis	Squirrelfish		9	14	12		19	16.00
Scarus taeniopterus	Princess Parrotfish	10	7				17	16.17
Haemulon aurolineatum	Tomtate			19		14	7	16.40
Ocyurus chrysurus	Yellowtail Snapper		12		14		12	16.83
Halichoeres garnoti	Yellowhead wrasse		20	20	13	12	16	17.00
Sparisoma rubripinne	Yellowtail Parrotfish	16	3					17.17
Halichoers maculipinna	Clown Wrasse	15			8	17		17.17
Caranx Ruber	Bar jack			19	15	19	9	17.33
Atherinidea, Clupidae & Engraulidadae	Silversides, herrings, anchovies	17					2	17.83
Stegastes planifons	Threespot Damselfish			3				18.00
Abudefduf saxatilis	Sergeant Major	6	18					18.00
Ophioblennius atlanticus	Redlip Blenny	4						18.17
Haemulon	Grunt						4	18.17
Inermia vittata	Boga					5		18.33
Haemulon plumieri	White grunt				11		15	18.33
Decapterus macarellus	Scad			8				18.83
Microspathodon chrysurus	Yellowtail Damselfish	11			18			18.83
Gobiosoma evelynae	Sharknose goby					9		19.00
Haemulon macrostomum	Spanish grunt			12				19.50
Coryphopterus lipernes	Peppermint goby					13		19.67
Haemulon sciurus	Bluestriped grunt		16				18	19.67
Halichoeres radiatus	Puddingwife	14						19.83
Bodianus rufus	Spanish hogfish		14					19.83
Chaetodon capistratus	Foureye butterflyfish		17			18		19.83
Scarus vetula	Queen parrotfish				17			20.33
Myripristis jacobus	Blackbar soldierfish			17				20.33
Stegastes leucostictus	Beaugregory	18						20.50
Lutjanus apodus	Schoolmaster		18					20.50
Malacoctenus macropus	Saddled blenny				19			20.67
Sparisoma radians	Bucktooth parrotfish					20		20.83
Pseudopeneus maculatus	Spotted goatfish						20	20.83

al. 2007). The north is characterized by relatively flat pavement while the south has more coral reefs and vertical relief.

Table 8.2. Ten most abundant fish species observed among seagrass sites by DON (1979) and Garcia-Sais et al. (2001). Abundance data provided in Garcia-Sais et al. (2001) was used to rank species from most abundant to least. Corresponding abundance data was not presented in DON (1979).

Species Name	Common Name	DON 1979	Sais et al. 2001
Haemulon sp.	Grunt		1
Haemulon sp. (juvenile)	Juvenile Grunt		2
Sparisoma radians	Bucktooth parrotfish	X	3
Halichoeres maculipinna	Clown wrasse		4
Decapterus macarellus	Scad		5
Haemulon sciurus	Bluestriped grunt		6
Sparisoma sp.	Parrotfish	X	7
Harengula sp.	Herring		8
Ocyurus chrysurus	Yellowtail snapper		9
Pseudupeneus maculatus	Spotted goatfish		10
Cryptotomus roseus	Slender parrotfish	X	
Halichoeres bivittatus	Slippery dick	X	
Halichoeres poeyi	Blackear wrasse	X	
Monocanthus ciliatus	Fringed filefish	X	
Scorpaena bergi	Goosehead scorpionfish	X	
Scorpaena inermis	Mushroon scorpionfish	X	
Sphoeroides spengleri	Bandtail puffer	X	
Xyrichthys martinicensis	Rosy razorfish	X	

Reefs on the eastern and western side of the island were also compared. Since the eastern side of the island was used for military training, these comparisons allowed an examination of the military's impact on the marine community, especially within the LIA. As with north-south comparisons, findings reported among studies were inconsistent. Among hard-bottom habitats, DON (1979) initially found higher abundances of fish and species diversity inside the LIA, later DON (1986) found the opposite and GMI (2003; ANOSIM, p=0.012) did not find any significant difference. Burke et al. (2007) did not find a difference among eastern and western study regions in hard-bottom strata, but did find eastern regions had almost twice the fish abundance of western regions in soft-bottom strata. Studies which showed significantly higher abundances on the eastern side of the island or LIA suggested the reason for these findings was lower fishing pressure imposed by military activities (DON 1979; Burke et al. 2007) and greater availability of reef habitat to the east (DON 1979). DON (1986) suggested the impacts of recent hurricanes and several different habitats were the reason diversity and abundance was higher outside the LIA.

Few comparisons have been made within specific benthic habitat types, but some significant differences have been found. GMI (2003) showed clear dissimilarities among fish communities at fringing, reef crest and deep reefs (9-21m). Fringing reefs possessed the highest species number (93), and almost 50% more species and 33% more individuals than reef crest or deep reefs. Burke et al. (2007) showed differences in fish abundance among shelf zones (i.e. inner, mid, outer). Fish abundance was greatest offshore in the northeast and southwest study regions, but most abundant inshore in the southeast study region. In addition, Burke et al. (2007) showed considerable differences among three lagoons. Puerto Negro had relatively low diversity and was dominated by yellowtail snapper, whereas Puerto Ferro and Puerto Mosquito had 3 to 4 times as many taxonomic families and a much more evenly distributed community.

Most studies suggest the fish community around Vieques is similar to other Caribbean islands (DON 1979, 1986; GMI 2003) in terms of abundance and diversity; however these findings generally come from coral reef habitats. Burke et al. (2007), the only study which has collected data in lagoons, documented differences among lagoons in Vieques and La Parguera, Puerto Rico. Burke et al. (2007) showed that the average density of gray snapper and schoolmaster snapper in three lagoons in Vieques were more than an order of magnitude greater than corresponding densities in La Parguera. Further, they found the lagoon in Vieques most similar in terms of water clarity to the lagoon in La Parguera had more than four times the density of yellowtail snapper. These species are commonly part of the fisheries off La Parguera and Vieques.

Much less is known of the temporal distribution of the fish community. In regard to daily patterns, Burke et al. (2007) showed considerable differences in the spatial pattern of fish between day and night using hydrocaoustics. Their findings reveal a shift from high densities over hard-bottom habitat during the day, to deeper soft-bottom habitats at night. These shifts are likely individuals moving from sheltered positions among reefs during the day to feed on epibenthic fauna over soft-bottoms at night.

Since a long-term monitoring dataset for Vieques is lacking, few comparisons across time periods have been made. GMI (2003) discussed general findings presented by the Navy (DON 1979, 1986) and compared these to their own. They examined a general community metric which would be relatively insensitive to changes in survey methodology. They concluded that there had not been a major shift in the dominance of the most abundant families between 1979 and 2001.

A temporal assessment by Garcia-Sais et al. (2001, 2004) on six reef sites over three years was inconclusive. They reported significant increases (44% to 670%) in the abundance of fish at all sites, but suggested improved visibility and weather conditions in 2004 augmented the number of reported fish. Further, much of the increase in abundance could be attributed to greater quantities of a single tiny species – the Masked goby (*Coryphopterus personatus*), which can be found in immense schools, and thus may not reflect a major shift in the fish community.

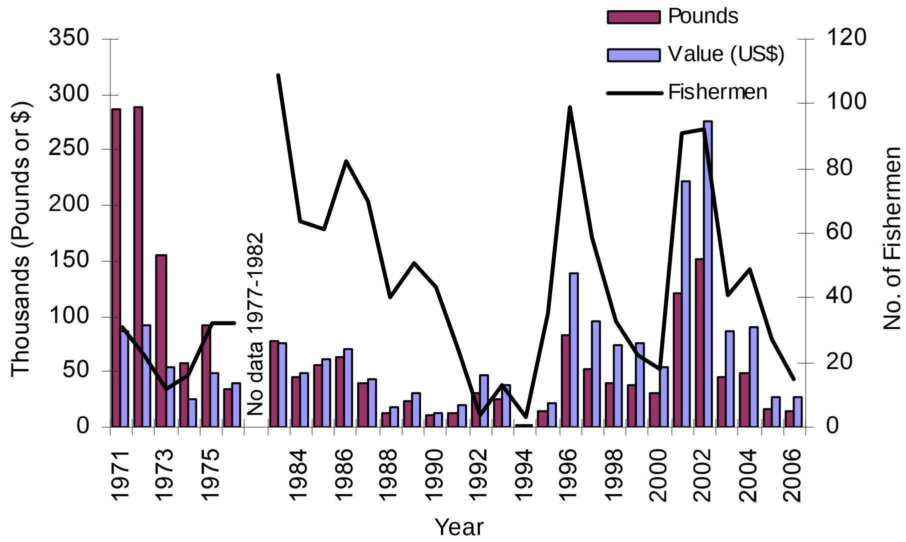


Figure 8.2. Commercial landings (lbs.), landing values ($US) and number of fishermen from the Vieques fishery from 1971-2006. Data provided by DON (1979; 1971-1976) and SEFSC (1983-2006).

The only available dataset to examine long-term temporal patterns in the fish community is fishery dependent. Fishery data presented by DON (1979; 1971-1976) and provided by the SEFSC (1983-2006) show great variability among fishery landing weights, landing values and number of fishermen (Figure 8.2). Fishery landings reached almost 300 thousand pounds in 1971 and 1972, but since then, have averaged less than 50 thousand pounds (Figure 8.2). Short term surges in landings occurred in 1996 and 2001-2002 and coincide with surges in the number of fishermen. Landing values (US$) are more stable than landing weights and correlate positively with the number of fishermen as well (Spearman's R=0.60). A general transition from pounds exceeding value to value exceeding pounds is apparent with the inflexion point occurring between 1975 and 1976. This transition indicates fishermen are obtaining more money per pound of fish now than they did in the early 70's.

The Vieques fisheries are described by DON (1979, 1986) and Shivlani (2007) as a mixed fishery (multiple species targeted in a single trip) comprised of commercial, recreational and subsistence segments. Using interviews with Vieques fishermen, DON (1986) reported approximately 80% of the islanders engaged in some type of fishing activity, and most of this was subsistence. It is unknown whether this statistic has changed over time. DON (1986) showed that 27% of fishermen, and 15% of total landing weight in Puerto Rico are from Vieques.

The most common gear types used to fish are SCUBA (e.g., spearfishing), hook and line, and traps. DON (1979, 1986) reported that traps were the principle type of fishing gear, but Shivlani's report (2007) more than 20 years later suggests traps are used less than SCUBA and hook and line. Agar et al. (2005) show a similar trend in fishing gear usage for all of Puerto Rico and suggests maintenance costs of trap gear are a factor.

Recent data on the species composition of fishery landings is deficient. The most recent report of species composition was in 1976 and is presented by DON (1979). In addition to the targeted species listed above, historical landings data (1971-1976) indicate parrotfish, goatfish, porgy, triggerfish, and hogfish were also important to the fishery in terms of landings and value. The most caught species of fish are generally absent from visual surveys of nearshore habitats and include pelagic or deep reef species, such as tuna, dolphin-fish, silk snapper and wahoo. Many other species reported in fishery landings but which generally make up a smaller proportion of the total catch, such as jacks, lane snapper, and barracuda, are commonly observed during visual surveys among coral reefs and seagrass beds (DON 1979, 1986; GMI 2003, 2005; Garcia-Sais et al. 2001, 2005).

Targeted fishery species are mainly grunts, groupers, snappers and migratory finfish, but as many as 180 species regularly enter the fishery in quantity (DON 1986). The primary fishing areas reported by DON (1979, 1986) are predominantly off the eastern, southeastern and northern coasts of Vieques. These areas coincide with the conch and lobster (see Chapter 9: Motile Invertebrates) and trap fishing areas delineated by fishermen in interviews with Shivlani (2007).

Several fish aggregation sites along the insular shelf edge are fished as well (Matos-Caraballo et al. 2006). One particular tiger grouper (*Mycteroperca tigris*) spawning aggregation site called "El Seco" has been well studied since 1982 (Sadovy et al. 1994). An assessment of fishery dependent data showed a considerable decline in landings (60%) and a shift in the sex ratio (4:1 to 12:1) from 1995 to 1998 (Matos-Caraballo et al. 2006). The site is considered to be unsustainably fished and a seasonal closure has been recommended (Matos-Caraballo et al. 2006).

The latest comprehensive assessment of the Vieques fishery was made by DON in 1986. DON's (1986) general conclusion was that the fishery had not changed substantially since 1978. A broader-scale fishery assessment was completed for the entire U.S. Caribbean by Appeldoorn et al. (1992). Using data mostly from Puerto Rico, the assessment reports significant changes in the fishery, including a decline in landings, and a shift in community composition. A recent assessment of the coral reef fisheries in Puerto Rico indicated that many stocks within the snapper-grouper complex were below spawning biomass levels considered to be sustainable (Ault et al. 2008). These regional changes are likely to reflect changes in Vieques as well.

Fishery management is shared by the Puerto Rico and U.S. federal governments. The Puerto Rico Department of Natural and Environmental Resources manage fish and essential habitats up to 9 nm from shore, while the areas outside of 9 nm and up to the edge of the U.S. exclusive economic zone are managed by the U.S. Secretary of Commerce and the Caribbean Fishery Management Council (CFMC). Many regulations are the same in these two areas, but some distinctions exist, such as the timing of and species included under seasonal fishing restrictions and types of gear allowed for fishing.

In 1985 a reef fish fishery management plan was put in place by CFMC for Puerto Rico and the U.S. Virgin Islands (CFMC 1985; 50 FR 34850). Several amendments followed (CFMC 1990, 1991, 1993, 2003). The primary management procedures included gear and capture method specifications, definition of stock assessment statistics, and size limits and capture/possession prohibitions for specific species (e.g. Nassau grouper).

8.5 ECOLOGICAL LINKAGES

The fish community around Vieques is made up of many species, with widely differing life histories, habitat requirements, and ecological niches. However the vast majority of species are supported by reefs for at least some portion of their lives. Reefs provide shelter, food and living space. A major reason for the abundance and diversity of fish is the prevalence of coral reef and hard-bottom habitats (see Chapter 5: Coral Reefs and Hardbottom).

Numerous environmental factors, such as reef rugosity (Friedlander and Parrish 1998; Gratwicke and Speight 2005), and the spatial pattern and connectivity of different reef habitats (Appeldoorn et al. 2003) are important determinants of species composition. These associations make reef fish inherently linked to processes that affect the physical structure, benthic composition and health of reefs.

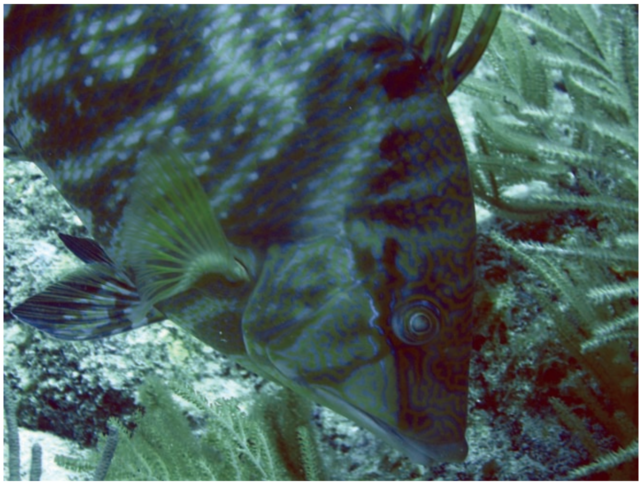


Image 8.2. Hogfish (*Lachnolmaimus maximus*). Photo: Biogeography Branch.

In addition to reef habitats, numerous fish species are supported by other habitats such as seagrass beds and mangroves. Seagrass habitats are used in a variety of ways by many species, even those commonly referred to as reef fish. For example some grunts are found among reefs during the day and migrate to seagrass beds at night to feed on epibenthic fauna (Ogden and Zieman 1977), a pattern documented at Vieques by Burke et al. (2007). In addition to diurnal movements to seagrass habitats, some juvenile surgeonfish and snappers use seagrass beds as nursery habitats (Faunce and Serafy 2007), and razorfish and some parrotfish are permanent residents relying on seagrass for camouflage and soft sediments for shelter.

Mangroves and lagoons function in much the way as seagrass (Burke et al. 2007; Faunce and Serafy 2007; Veirweij et al. 2007). Burke et al. 2007 found the lagoons of Vieques were dominated by juveniles. These fish were likely seeking shelter and feeding until they matured.

As the above information clearly outlines, multiple habitats are critical to the fish community. Fisheries are also dependent on multiple habitats, as many fish species migrate between multiple habitats on both a daily basis and ontogenetic habitat shifts. For instance, Mumby et al. (2004) reported biomass of several commercially important species is doubled in similar reef systems when adult reef habitat is connected to mangroves. Additionally, Pittman et al. (2007) demonstrated how the seascape structure surrounding mangroves influenced the spatial distribution and density of several haeumulid and lutjanid species.

Habitat loss due to anthropogenic and natural stressors such as coastal development, hurricanes and disease can have significant impacts on fish communities. Each essential habitat type and associated spatial connections are important to proper ecosystem functioning, community diversity and resilience, and fishery sustainability. Resource managers must consider these important ecological linkages to make sound management decisions.

LITERATURE CITED

Agar, J, M Shivlani, J Waters, M Valdés-Pizzini, T Murray and D Suman. 2005. U.S. Caribbean Fish Trap and Fishery Costs and Earnings Study. NOAA Technical Memorandum NMFS-SEFSC-534. 127 pp.

Appeldoorn, R, J Beets, J Bohnsack, S Boldlen, D Matos, S Meyers, A Rosario, Y Sadovy and W Tobias. 1992. Shallow water reef fish stock assessment for the U.S. Caribbean. NOAA Technical Memorandum NMFS-SEFSC-304. 70 pp.

Appeldoorn RS, A Friedlander, J Sladek Nowlis, P Usseglio and A Mitchell-Chui. 2003. Habitat connectivity in reef fish communities and marine reserve design in Old Providence-Santa Catalina, Colombia. Gulf and Caribbean Research 14:61–77.

Ault, JS, SG Smith, J Luo, ME Monaco and RS Appeldoorn. 2008. Length-based assessment of sustainability benchmarks for coral reef fisheries in Puerto Rico. Environmental Conservation 35:221-231.

Bohlke JE and CCG Chaplin. 1968. Fishes of the Bahamas and Adjacent Tropical Waters. Livingston Publ. Co., Wynnewood, PA. 771 pp.

Burke, JS, WJ Kenworthy, BP Degan, G Di Carlo, JB Landry and JC Taylor. 2007. Preliminary results of a survey of coastal fishes and their habitats around the island of Vieques. Unpublished report. CCFHR, Beaufort, NC.

CFMC (Caribbean Fisheries Management Council). 1985. Fishery management plan, final environmental impact statement, and regulatory impact review for the shallow-water reef fish fishery of Puerto Rico and the U.S. Virgin Islands. Caribbean Fishery Management Council, San Juan, Puerto Rico.

CFMC (Caribbean Fisheries Management Council). 1990. Amendment Number 1 to the Fishery Management Plan for the Shallow-Water Reef Fish Fishery, Preliminary Environmental Assessment and Regulatory Review. Caribbean Fishery Management Council, San Juan, Puerto Rico.

CFMC (Caribbean Fisheries Management Council). 1991. Regulatory amendment to the shallow water reef fish fishery management plan. Caribbean Fishery Management Council, San Juan, Puerto Rico.

CFMC (Caribbean Fisheries Management Council). 1993. Amendment Number 2 to the Fishery Management Plan for the Shallow-Water Reef Fish Fishery of Puerto Rico and the U.S. Virgin Islands. Caribbean Fishery Management Council, San Juan, Puerto Rico.

CFMC (Caribbean Fisheries Management Council). 2003. Comprehensive amendment to the fishery management plans of the U.S. Caribbean to address required provisions of the Magnuson-Stevens Fishery Conservation and Management Act. Caribbean Fishery Management Council, San Juan, Puerto Rico.

DON (Department of the Navy). 1979. Draft Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

DON (Department of the Navy). 1986. Environmental Assessment of Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range, Vieques, Puerto Rico. Prepared by Ecology and Environment, Inc.

Evans, D, R Nawojchik and KJP Deslarzes. 2006. The status of coral reef fish populations off former military ranges at the islands of Culebra and Vieques, Puerto Rico. pp. 1105-1109. In: Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan.

Faunce, CH and JE Serafy. 2007. Nearshore habitat use by gray snapper (*Lutjanus griseus*) and bluestriped grunt (*Haemulon sciurus*): environmental gradients and ontogenetic shifts. Bulletin of Marine Science 80: 473-495.

Friedlander, AM and JD Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Biology and Ecology 224: 1-30.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2001. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 108 pp.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2004. Monitoring of coral reef communities from Isla de Vieques, Puerto Rico, 2004. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 122 pp.

GMI (Geo-Marine, Inc.). 2003. Reef ecosystem baseline assessment survey and monitoring, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

GMI (Geo-Marine Inc.). 2005. An assessment of the condition of coral reefs off the former Navy bombing ranges at Isla de Culebra and Isla de Vieques, Puerto Rico. Prepared for the Department of Defense, Legacy Resource Management Program, Arlington, Virginia, and US Army Corps of Engineers, Huntsville, Alabama.

Gratwicke B and MR Speight. 2005. Effects of habitat complexity on Caribbean marine fish assemblages. Marine Ecology Progress Series 292: 301-310.

Matos-Caraballo, D, JM Posada and B Luckhurst. 2006. Fishery-dependent evaluation of a spawning aggregation of tiger grouper (*Mycteroperca tigris*) at Vieques Island, Puerto Rico. Bulletin of Marine Science 79: 1-16.

Mumby PJ, AJ Edwards, JE Arias-Gonzalez, KC Lindeman, PG Blackwell, A Gall, MI Gorczynska, AR Harborne, CL Pescod, H Renken, CCC Wabnitz and G Llewellyn. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427:533-536.

Nelson, JS, EJ Crossman, H Espinosa-Pérez, LT Findley, CR Gilbert, RN Lea and JD Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. American Fisheries Society, Special Publication 29, Bethesda, Maryland.

Ogden JC and JC Zieman. 1977. Ecological aspects of coral reef–seagrass bed contacts in the Caribbean. pp. 377–382. In: Proceedings of the 3rd International Coral Reef Symposium, Vol. 1. Miami, FL.

Randall, JE. 1983. Caribbean reef fishes. T.F.H. Publications, Inc. Jersey City, N.J. 350 pp.

Sadovy, Y, PL Colin and ML Domeier. 1994. Aggregation and spawning in the tiger grouper, *Mycteroperca tigris* (Pisces: Serranidae). Copeia 1994: 511-516.

Shivlani, M. 2007. Community studies to determine the feasibility and expectations of marine protected area (MPA) management in Vieques, Puerto Rico. Unpublished report. 38 pp.

Smith-Vaniz, WF, HL Jelks and LA Rocha. 2006. Relevance of cryptic fishes in biodiversity assessments: a case study at Buck Island Reef National monument, St. Croix. Bulletin of Marine Science 79: 17-48.

Verweij MC, I Nagelkerken, SLJ Wartenbergh, IR Pen and G van der Velde. 2006. Caribbean mangroves and seagrass beds as daytime feeding habitats for juvenile French grunts, *Haemulon flavolineatum*. Marine Biology 149(6): 1291–1299.

CHAPTER 9: MOTILE INVERTEBRATES

9.1 OVERVIEW

Motile invertebrates such as crabs, lobsters, jellyfishes, sea urchins, and conch make up important components of the marine and inter-tidal ecosystems around Vieques. Their jobs as predators, scavengers of decomposing material and filter-feeders are critical to energy and nutrient dynamics. In addition, some motile invertebrates such as lobsters and conch are fished and are important to the economy and culture of Vieques.

Several large-scale biological assessments of marine habitats and organisms have been conducted since 1979 around Vieques that provide information on motile invertebrates among a suite of other biological and environmental variables. Data provide an inventory and abundance estimates for several species, including the long-spine sea urchin (*Diadema antillarum*) and queen conch (*Strombus gigas*). At present, data on the spatial distribution of most invertebrate species is inadequate. The most recent survey of benthic infauna and zooplankton occurred in the 1970s and was not spatially comprehensive. While portnunid crabs and penaeid shrimps often comprise an important component of communities in the nearshore bays, available data are from surveys designed to sample fishes. Dedicated invertebrate surveys are needed to provide population estimates.

Occurrence of two commercially important species, spiny lobster (*Panulirus argus*) and queen conch (*S. gigas*) was low in recent biological assessments. In addition to the data from biological assessments, NOAA's Southeast Fisheries Science Center and the Fisheries Management Laboratory of the Puerto Rico Department of Natural and Environmental Resources (DNER) have monitored commercial landings of both *P. argus* and *S. gigas* in Puerto Rico, including Vieques, since 1983. Landings of both species have fluctuated over time, with the highest landings in Vieques recorded in 2002.

9.2 SOURCES OF DATA

Zooplankton data was collected by DON (1979) in June and September 1978 at 12 stations around Vieques. Seven stations were located in bays (including Puerto Mosquito and Puerto Ferro) and other nearshore locations in both military and non-military areas, while the remaining five locations were several kilometers offshore. Geographic coordinates were not available, but a map of station locations can be found in DON (1979). Collections were made using surface plankton tows and were meant to characterize the community composition and distribution. In the same report a survey of the benthic invertebrates that inhabit seagrass beds was also presented (Brook 1978). Benthic invertebrates within seagrass beds were collected at six sites over a range of depths (1-7 m) using a suction dredge.

Additional studies have surveyed macroinvertebrates in lagoons, seagrass, and coral reef habitats around Vieques. This information was often collected in conjunction with surveys of fish communities and/or coral and other benthic cover. Garcia-Sais et al. (2001), collected macroinvertebrate data at 24 hardbottom/reef and seagrass sites distributed around the western half of the island in 2001. Six of the 24 sites were revisited in 2004 to assess temporal changes. Taxonomic and abundance information was gathered at each site as part of a quantitative and qualitative baseline survey of organisms and habitats (Garcia-Sais et al. 2001, 2004). Later, GMI (2005) collected echinoderm data at eleven sites distributed among civilian, military non-target and military target areas on the eastern side of the island. The abundance of echinoderms was used along with various other biological and environmental variables to assess the impact of military training activities on fringing coral reefs (GMI 2005).


Image 9.1. Banded coral shrimp (*Stenopus hispidus*). Photo: Biogeography Branch.

NOAA's Center for Coastal Fisheries and Habitat Research (CCFHR) recently surveyed epibenthic faunal communities in the lagoons of Bahia Mosquito, Puerto Ferro, and Puerto Negro (Burke et al. 2007). Although the primary objective of the push net sampling was to survey juvenile fishes of commercial importance, macroinvertebrates were also recorded.

A May 2007 queen conch survey was designed by NOAA's Biogeography Branch and carried out by scientific divers from the Fish and Wildlife Service (FWS). Twenty-six sites were surveyed in seagrass habitat and were primarily located on the western half of the island (Figure 9.1).

In addition to the data from biological assessments, commercial landings of spiny lobster (*Panulirus argus*) and conch (*Strombus gigas*) for Vieques were provided by the National Marine Fisheries Service Cooperative Statistics Program at the Southeast Fisheries Science Center from 1983-2006 (Accumulated Landings System Tables provided by J. Bennett, NOAA-SEFSC, Nov. 19 2007). These data provide a valuable way to monitor the populations of these species over time and complement the analyses that are possible with data from biological assessments. While conch landings data include all conch species (e.g. *S. costatus*, *S. gigas*), *S. gigas* is the target species (J. Bennett, personal communication).

9.3 METHODS

At each survey location in the 2007 survey by NOAA/FWS, all queen conch (*Strombus gigas*) encountered within a 50 m x 4 m belt transect (2 m on either side) were counted and noted as mature or immature. Maturity was determined by the presence or absence of a flared lip; conch without a flared lip are classified as immature. When a flared lip is present, conch are labeled maturing, young adult, old adult, or very old adult, respectively (CFMC/CFRAMP 1999). Lip thickness was determined for all mature conch to the nearest mm following guidelines by Appledoorn (1998).

Reports from available biological assessments were used to produce an inventory of observed motile invertebrates (Table 9.1). Density data from each survey was converted to number of individuals per 100 m^2, and the mean density across surveys was calculated for both hardbottom and seagrass. Distribution patterns were examined for conch, lobster, and urchin species. Data were plotted in ArcGIS to show the distribution of field efforts and distribution of these species.

The 2003-2006 conch landings data were adjusted due to a change in reporting (SEDAR 2007). Conch landings were reported as meat weights, and in 2003, fishermen began removing the head and viscera prior to weighing conch (“cleaned weight”). Approximately 50% of fishermen were reporting cleaned weight in 2003, while all were thought to be reporting cleaned weight in 2004. Cleaned weight landings were converted to uncleaned weight using a conversion factor of 1.5 as recommended in the SEDAR 14 data workshop (SEDAR 2007). Landings data for conch in Vieques were not available in 1992 and 1994.

To examine temporal patterns, the total landings in pounds, the total value of spiny lobster and conch landed in Vieques, and the number of fishers were plotted from 1983-2006. These data were not corrected for non-compliance, because the only non-compliance estimates available were for Puerto Rico as a whole and it is unknown if these are valid for Vieques data (J. Bennett, personal communication).

9.4 DISTRIBUTION, STATUS AND TRENDS

Over 25 species or genera of motile invertebrates have been documented in Vieques in recent biological assessments (Table 9.1). This is by no means an exhaustive species list and the number of invertebrate species in the area is likely much higher. The majority of these sightings were limited to data from Garcia-Sais et al. (2001, 2004), whose sites were distributed largely offshore of non-military locations. Therefore, mean abundance estimates of most species are restricted to the western half of the island, while abundance of several echinoid species also incorporates data from the GMI (2005) survey, which includes sites on the eastern end of the island. Mean abundance for most species was low; density only exceeded one individual per 100 m^2 for three species/genera. For all three of these genera (*Astraea sp., Diadema antillarum, Echinometra sp.*) the mean abundance estimate was influenced by high counts at a few sites. For instance, *Astrea* was observed at only two locations, but was observed in high numbers at one of those locations. Two commercially important species of interest, *S. gigas* (queen conch) and *P. argus* (spiny lobster) were observed in low frequencies by Garcia-Sais et al. (2001 and 2004) (Figure 9.1, 9.2). In the recent NOAA/FWS 2007 conch survey, a conch was only observed within the survey transect at three locations out of 26 sites surveyed (5200 m^2 total). One of these three conch was mature, while the remaining two were classified as young adults. Elsewhere in Puerto Rico, queen conch densities are low and distribution is patchy (Appeldoorn 1991), hence the intensity of conch sampling around Vieques to date is likely insufficient to make inferences about the distribution or population size.

Five species of sea urchins have been documented in recent surveys in Vieques (Table 9.1). Sea urchins were more frequently observed by GMI (2005) than Garcia-Sais et al. (2001, 2004) (Figure 9.3). This finding could be influenced by differences in survey locations, field methodology, and year/season of sampling. *D. antillarum*

Table 9.1. Inventory of motile invertebrate species around Vieques. Data from four independent biological assessments. Sources: 1-Garcia-Sais et al. 2001 (10 hardbottom sites, 12 seagrass sites), 2 - Garcia-Sais et al. 2004 (7 hardbottom sites), 3-GMI 2005 (7 hardbottom sites), 4-2007 NOAA/FWS queen conch survey (26 seagrass sites).

Species Name	Common Name	Mean (±SE) Abundance Hardbottom (#/100m²)	Mean (±SE) Abundance-Seagrass (#/100m²)	Sources
Anomura sp.	Hermit crab	<1	0	1,2
Astraea sp.	Star snail	3 (±3)	0	1,2
Calappa sp.	Box crab	0	<1	1,2
Carpilus coralinus	Coral crab	<1	0	1,2
Clypeaster sp.	Sand dollar	0	<1	1,2
Cyphona gibbosum	Flamingo tongue	<1	0	1,2
Diadema antillarum	Long spine urchin	5 (±2)	0	1,2,3
Echinometra lucunter	Rock boring urchin	<1	0	1,2
Echinometra viridis	Reef urchin	<1	0	1,2
Echinometra sp.	Reef or rock boring urchin	4 (±3)	---	3
Eucidaris trubuloides	Slate pencil urchin	<1	0	1,2,3
Holothuria Mexicana	Sea cucumber	0	<1	1,2
Holothuria sp.	Sea cucumber	0	<1	1,2
Holothuria thomasi	Sea cucumber	<1	0	1,2
Isostichopous badiontus	Chocolate chip cucumber	<1	0	1,2
Lima scabra	Rough fileclam	<1	0	1,2
Lytechinus variegates	Variegated urchin	0	<1	1,2
Mithrax sp.	Spider crab	<1	0	1,2
Oreaster reticulates	Cushion sea star	0	1 (±0.4)	1,2
Panulirus argus	Spiny lobster	<1	<1	1,2
Panulirus guttatus	Rock lobster	<1	<1	1,2
Periclimenes pedersoni	Pederson cleaner shrimp	<1	0	1,2
Stenopus hispidus	Coral banded shrimp	<1	0	1,2
Stenorhincus seticornis	Arrow crab	<1	0	1,2
Strombus costatus	Milk conch	0	<1	1,2
Strombus gigas	Queen conch	<1	<1	1,2,4
Strombus sp.	Conch	0	<1	1,2
Tripneustes ventricosus	West Indian sea egg	<1	<1	1,2,3
Vasum muricatum	Caribbean vase	0	<1	1,2

was observed with greater frequency (16 out of 24 hardbottom locations) but the density per site varied widely. While the two *Echinometra* species were observed in low frequency and numbers by Garcia-Sais et al. (2001, 2004), *Echinometra sp.* were found at six out of the seven locations surveyed by GMI (2005). When urchins were present, the density was usually <10 individuals per 100 m^2 but sometimes occurred in greater numbers, with *Diadema antillarum* or *Echinometra sp.* the most commonly observed. Sites with the highest observed densities are highlighted in Figure 9.3. Four out of five sites with a *D. antillarum* density of >10 urchins/100 m^2 were located on the east end. GMI (2005) found no statistically significant differences in echinoid abundance among study sites, due primarily to high intra-site variability. Although once abundant in the greater Caribbean, a mass mortality of *D.antillarum* was observed in the 1980s and reduced populations dramatically (Levitan 1988; Lessios 1988). Although an increase in *D. antillarum* has been noted elsewhere in the Caribbean (e.g., Aronson and Precht 2000; Miller et al. 2003), temporal trends in urchin populations around Vieques are unknown due to lack of long-term datasets.

Other invertebrate species that were not documented in these recent studies have been noted in previous assessments. Other mollusk species that are known to occur off of Vieques include the octopus (*Octopus sp.*), coquina clam (*Donax denticulata*), oyster (*Ostrea rhizophorae*), and two snails (*Marisa cornuaretis* and *Tarebia granifera*) (Raffaele et al. 1973). Additional crustacean species found in nearshore marine habitats off Vieques include the freshwater shrimp (*Macrobrachium carcinus*), mole crab (*Emerita portoricensis*), beach crab (*Hippia cubensis*), ghost crab (*Ocypode quadrata*), land crab (*Cardisoma guanhumi*), fiddler crab (*Uca sp.*), and

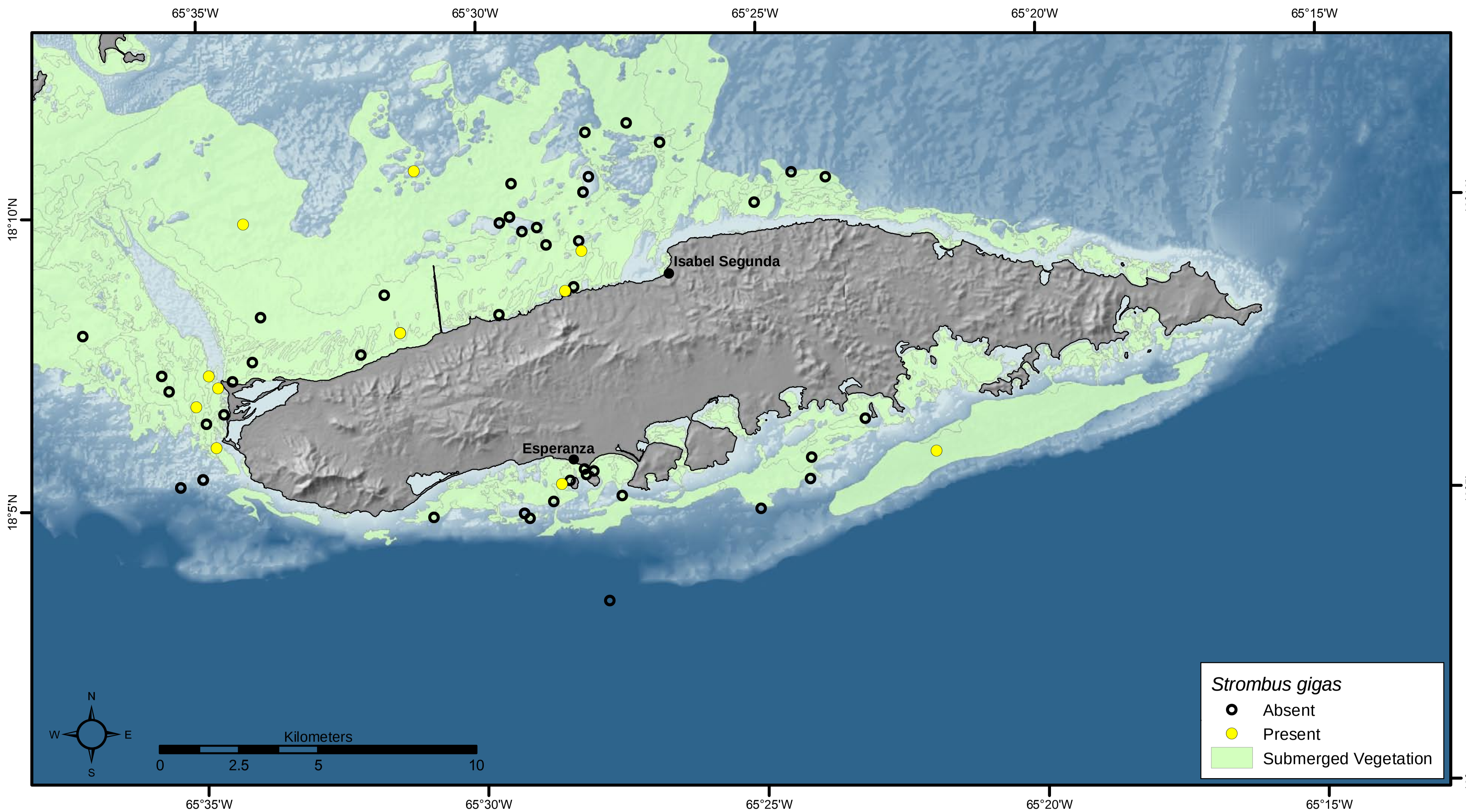


Figure 9.1. Presence of queen conch in recent biological assessments in Vieques (Garcia-Sais et al. 2001, 2004; NOAA/FWS 2007 survey).

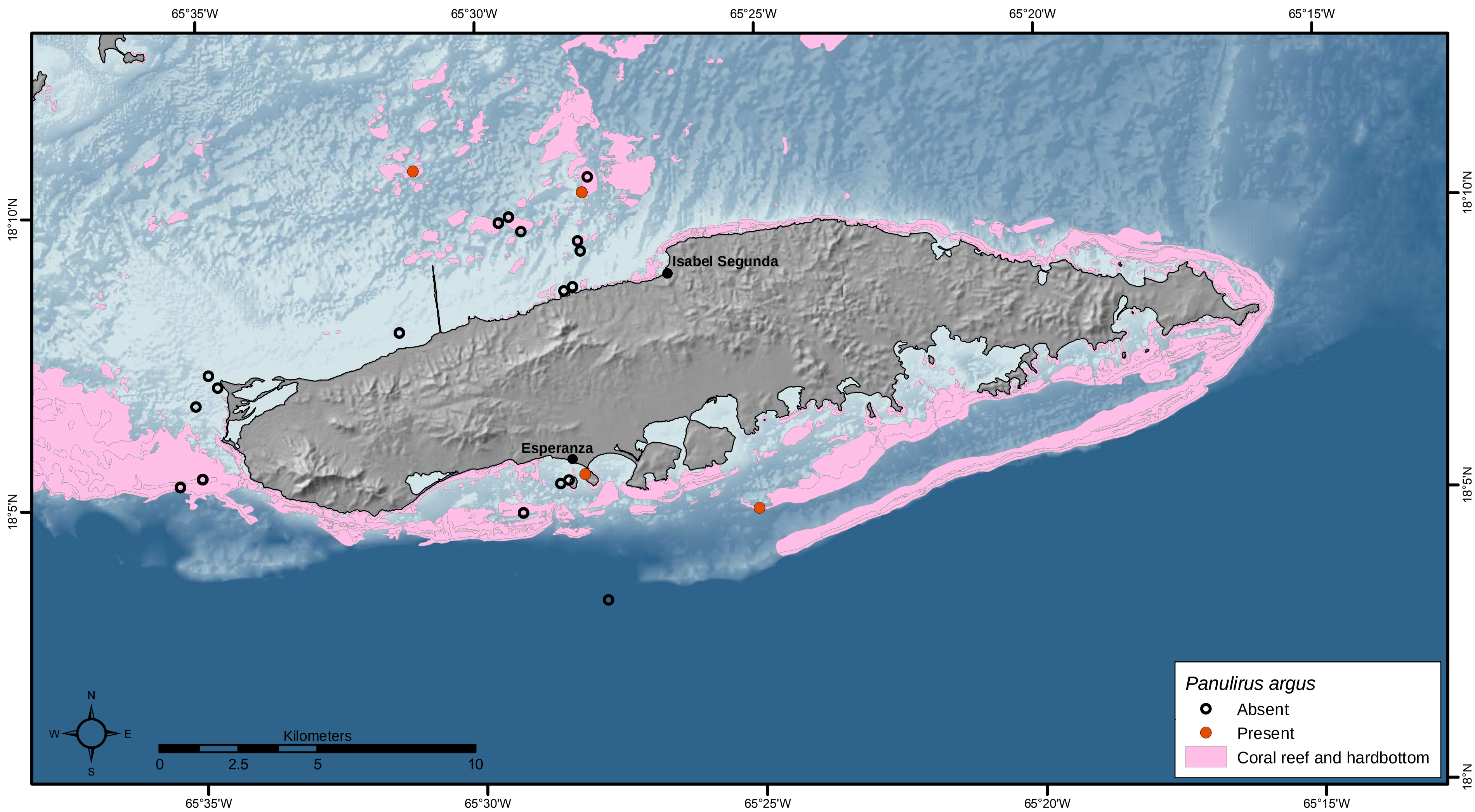


Figure 9.2. Presence of spiny lobster in recent biological assessments in Vieques (Garcia-Sais et al. 2001, 2004).

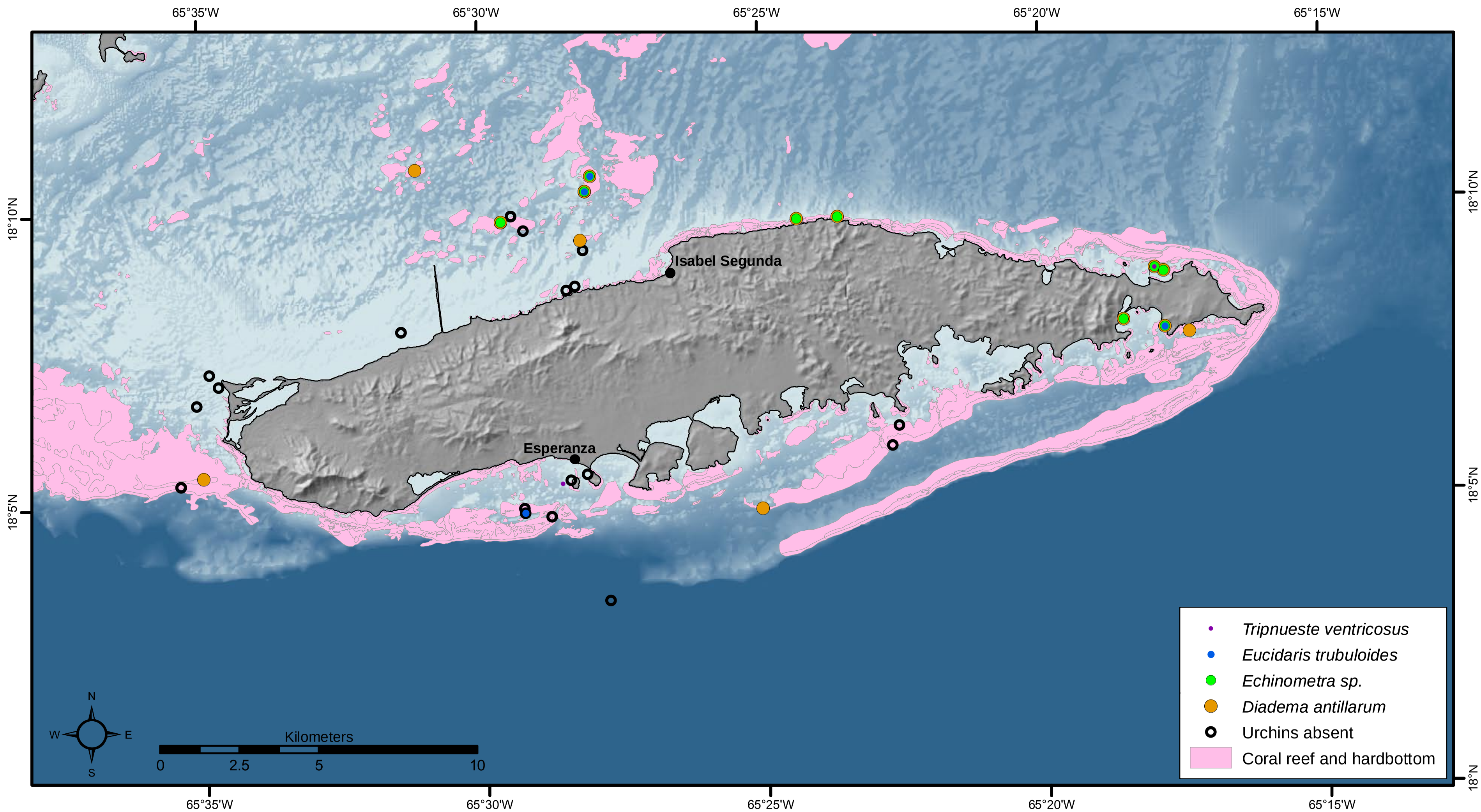


Figure 9.3. Presence of urchin species in recent biological assessments in Vieques (Garcia-Sais et al. 2001, 2004; GMI 2005).

red mangrove crab (*Goniopsis cruentata*) (Raffaele et al. 1973). Other sea star genera include *Ophioderma, Ophiocoma,* and *Astrophyton* (GMI 2003).

Although few investigations have targeted the abundance of intertidal and wetland invertebrates, the land crab, *C. guanhumi*, is an important subsistence resource on Vieques and inhabits mud and sand flats, mangroves, coastal forests and shrub areas (DOI 2007; NOAA and RIDOLFI 2006). An experimental land crab trapping program is being conducted on the eastern and western portions of the Vieques NWR to evaluate the sustainability of land crab harvesting (DOI 2007). Locations of land crab collection to study contaminants were determined based on known and potential harvesting areas and included the northwest lagoons and south shore embayments (NOAA and RIDOLFI 2006).

Little data is available on benthic infaunal communities around Vieques, with the exception of Brook (1978). Within seagrass beds, the benthic infauna is dominated by polychaetes (nearly 50% of suction dredge samples), followed by peracarideans, mollusks, and decapods (Brook 1978). Decapods were composed primarily of shrimps, crabs, and hermit crabs, and gastropods and bivalves made up the majority of the observed mollusks.

The composition and density of zooplankton around Vieques exhibit spatial and temporal variability (DON 1979). In the 1978 survey, average zooplankton densities were highest in Puerto Ferro and Puerto Mosquito, ranging from 3,676/m^3 and 2,294/m^3, respectively, in June to 3,660/m^3 and 13,151/m^3, respectively, in September. Density at the remaining stations ranged from 60 to 2,388/m^3 in June and 105 to 695/m^3 in September. Exclusive of Puerto Ferro and Puerto Mosquito, which are both mangrove lined bays (see Chapter 7: Mangroves), there were no significant differences in zooplankton density between inshore and offshore stations. Copepods formed the main component of the zooplankton community, comprising 54% and 79% of the samples in June and September, respectively. Juvenile forms of motile invertebrates included crab zoea, gastropods, decapod and nauplius larvae, and polychaetes.

Macroinvertebrates of the families Penaeidae (penaeid shrimps) and Portunidae (swimming crabs) often comprised an important part of the push net catch in the southern lagoons of Bahia Mosquito and Puerto Ferro (Burke et al. 2007). There was a high density of penaeid shrimp, which were tentatively identified as southern brown shrimp, in both lagoons (~6 ind./ 60 m^2 in Bahia Mosquito and ~3 ind. /60 m^2 in Puerto Ferro). Density of portunid crabs was less than 1 ind. / 60 m^2 in both lagoons.

The commercial fishery for queen conch and spiny lobster is artisanal in nature throughout Puerto Rico. In Vieques, the most common method for harvesting both lobster and conch is through SCUBA diving, and the primary fishing grounds are on the north side and east end of the island (Shivlani 2007). Although less common, there is some trap fishing for lobster, which primarily occurs on the south side of the island (Shivlani 2007).

Fishery management regulations for Caribbean spiny lobster are administered through the Caribbean Fishery Management Council (CFMC). The Caribbean Council's Spiny Lobster Fishery Management Plan was implemented in 1985, followed by a stock assessment in 1990 (Bohnsack et al. 1991). Restrictions include a minimum size limit, gear restrictions, and the prohibition of retaining egg-bearing female lobsters. Several assessments have been conducted since 1990 to re-evaluate the status of the fishery. A recurring problem noted in many of these stock assessments was the large percentage of undersized lobster in the Puerto Rico catch (Bohnsack et al. 1991; Matos-Caraballo 1999). In a recent

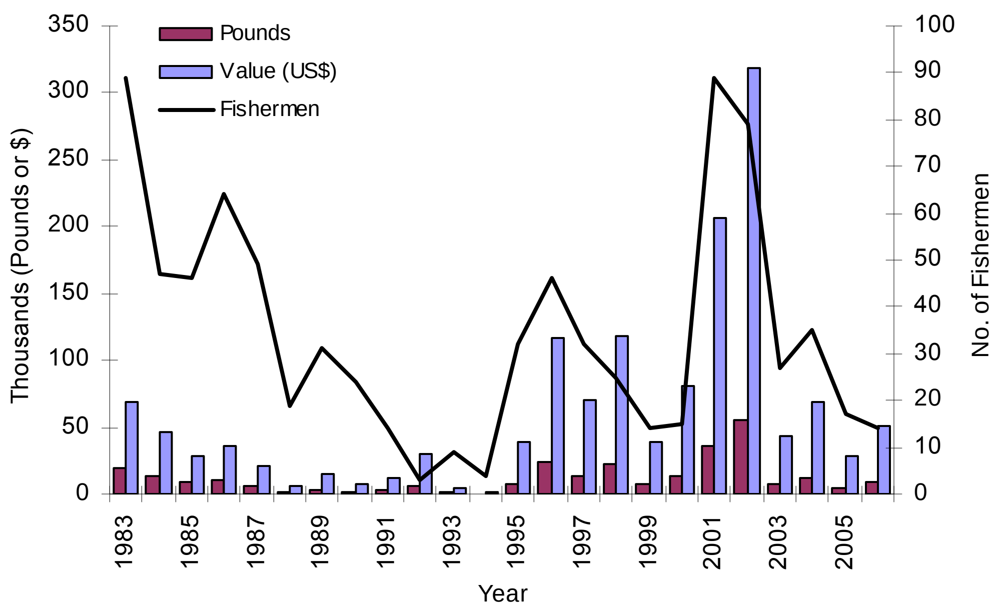


Figure 9.4. Commercial landings (lbs.), landing values (US$) and number of fishermen from the Vieques Caribbean spiny lobster fishery from 1983-2006. Data provided by NOAA-SEFSC.

assessment, Mateo (2004) determined that exploitation rates for lobster in Puerto Rico were above the optimum exploitation rate, suggesting that overfishing was occurring.

Caribbean spiny lobster landings in greater Puerto Rico have exhibited a cyclic pattern since reporting began in 1983, but have hovered around 400,000 pounds (adjusted for compliance) since the mid-1990s. The value per pound has remained consistently high and has increased from $3.50/lb in 1983 to almost $6/lb in 2005 (Accumulated Landings System Tables, NOAA-SEFSC). Approximately 15% of the Puerto Rican spiny lobster catch originates from the east coast, 45% from the south coast, and 35% from the west coast (SEDAR 2005). The commercial landings in Vieques have fluctuated widely over the time period of 1983-2006 (Figure 9.4). Landings decreased in the 1980s and stayed low in the early 1990s, particularly in 1993 and 1994. Landings subsequently increased in the following years, peaking in 2001 and 2002. In 2002, the Vieques lobster landings accounted for 18% of Puerto Rico-wide landings. The number of individuals fishing for lobster in Vieques ranged from a low of 3 in 1992 to a high of 89 in 1983 and 2001. There is a high correlation between the number of fishers and the pounds of spiny lobster landed (Spearman's R= 0.71).

Although the conch fishery was once the second most valuable fishery in the greater Caribbean, declines in the species abundance resulted in the conch being listed as commercially threatened by the Convention on the International Trade in Endangered Species (CITES) in 1985. In 1992, CITES downgraded the species' status further by listing queen conch in Appendix II, a designation that requires CITES permits be issued for all exports. In the U.S. Caribbean, *Strombus gigas* is managed by the CFMC and has been designated as both overfished and undergoing overfishing (SEDAR 2007). Regulations include size limits (both total length and lip thickness), commercial and recreational daily catch limits, and a closed season (July 1- September 30). Fishing is prohibited in EEZ waters, however the harvest in Puerto Rico is almost entirely in territory waters (Final Rule, Federal Registry). As part of the SEDAR (Southeast Data, Assessment, and Review) program developed by the NOAA Southeast Fishery Science Canter and the South Atlantic Fishery Management Council, a stock assessment workshop and report was recently developed for the queen conch fishery in Puerto Rico and the US Virgin Islands (SEDAR 2007).

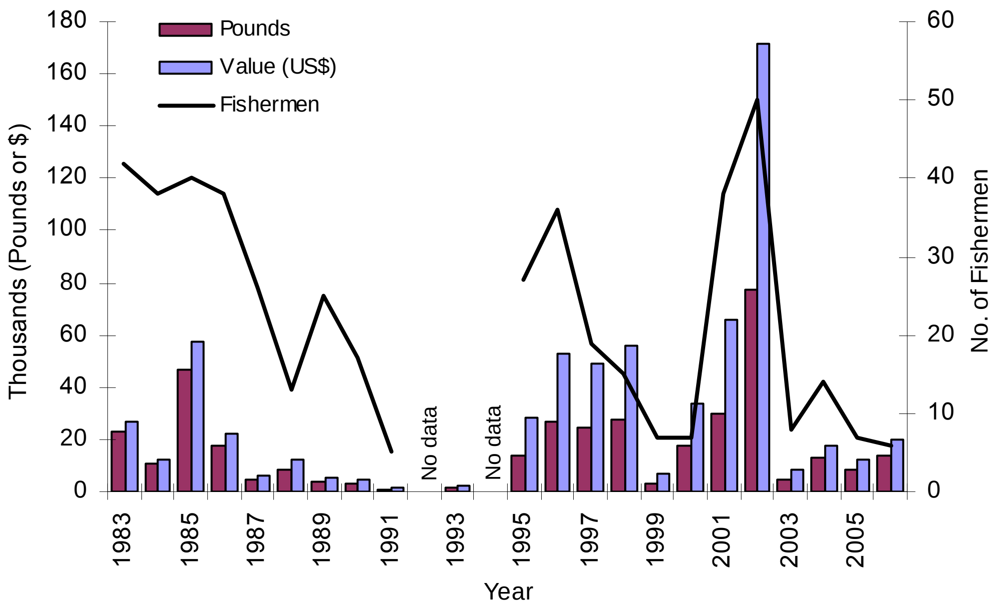


Figure 9.5. Commercial landings (lbs.), landing values (US$) and number of fishermen from the Vieques conch fishery from 1983-2006. Data provided by NOAA-SEFSC. Data were not available for years 1992 and 1994.

In Puerto Rico overall, queen conch represent approximately 7% of the combined multi-species landings. Major areas for conch fishing in Puerto Rico include the southwest coast, south coast, and east coast, including Vieques (Appeldoorn 1991). Around Vieques, the primary fishing areas for conch include the north, east, and southeast coasts. Conch landings in greater Puerto Rico declined steadily between 1984 and 1992, and then increased between 1993 and 2005. Although the Vieques landings exhibited similar trends over the time series, there was more pronounced year-to year variability (Figure 9.5). For instance, there was a downward trend in landings during the late 1980s and early 1990s, but this trend was interrupted by a large increase in 1985. Landings generally increased from 1995 to 2002, with the exception of 1999. Following a peak of nearly 90,000 pounds in 2002 (accounting for over 30% of the total Puerto Rico catch that year), landings decreased dramatically in the subsequent three years. The number of reporting fishers ranged from five in 1991 to 50 in 2002.

Vieques landings for spiny lobster and conch follow similar temporal patterns, and it is unknown whether these trends are due to population fluctuations, variations in fishing effort, or reporting discrepancies. Vieques specific reporting compliance estimates were not available at the time of this report writing but should be accounted for in the future.

9.5 ECOLOGICAL LINKAGES

Motile invertebrates serve many functions in the Vieques marine ecosystem; they are prey for other animals, provide important ecological functions, and support valuable commercial and recreational fisheries. In turn, motile invertebrate species depend on healthy reef/hardbottom, seagrass, and mangrove for nursery habitat, food and shelter (see Chapter 5: Coral Reefs and Hardbottom, Chapter 6: Seagrass and Macroalgae, and Chapter 7: Mangroves). For instance, sea urchins are important keystone herbivores in reef communities, as *D. antillarum* and other urchin species feed on macroalgae. The increase in macroalgae on Caribbean reefs has been linked to the decline in urchin populations (Levitan 1988; Aronson and Precht 2000).

One species of commercial interest, spiny lobsters, utilizes multiple habitats and depths during their life cycle. Females migrate to the edge of reefs or coastal shelves to release larvae. The planktonic larvae spend 6-10 months in the pelagic environment before migrating to nearshore environments to settle and develop. The post-pueruli or "algal phase" lobsters inhabit clumps of red algae, mangrove roots, or seagrass beds for about 10-15 months post-settlement. Juveniles then begin to migrate from these vegetated habitats to the reef environment, where they seek out shelter in caves and crevices. Older juveniles move offshore, and reproduction generally occurs in the deeper reef environment. Lobsters feed on a variety of other invertebrates, including gastropods and crustaceans.

Queen conch are closely tied to softbottom habitats throughout much of their life cycle. Queen conch commonly occur on sandy bottoms that support the growth of seagrasses, primarily turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii*), and epiphytic algae upon which they feed (Randall 1964). Females lay demersal egg masses most commonly on patches of bare sand, but occasionally in seagrass. Conch settle in areas of soft sand and remain buried for most of the first year until they reach approximately 50-100 mm in length. Upon emergence, the juveniles migrate to nearby seagrass beds (Sandt and Stoner 1993). Larger juveniles migrate to deeper water and can be found in a variety of habitats (seagrass beds, coral rubble, algal fields, sand), but are found most often in depths less than 30 m (SEDAR 2007).

Healthy benthic habitats and prey sources are important for sustaining healthy motile invertebrate populations. Natural (e.g., hurricanes) and anthropogenic (e.g. fishing, dredging) factors can alter the population dynamics of many invertebrate species. Underwater structures can create barriers to migration; for instance, the installation of a power cable between Vieques and Culebra is thought to have disrupted seasonal migration patterns of conch in the area (CFMC 2003).

LITERATURE CITED

Appeldoorn, RS. 1991. History and recent status of the Puerto Rican conch fishery. Proceedings of the Gulf and Caribbean Fisheries Institute 40:267-282.

Aronson, RB and WF Precht. 2000. Herbivory and algal dynamics on the coral reef at Discovery Bay, Jamaica. Limnology and Oceanography 45: 251-255.

Bohnsack, J, S Meyers, R Appledoorn, J Beets, D Matos-Caraballo and Y Sadovy. 1991. Stock Assessment of Spiny Lobster, Panulirus argus, in the U.S. Caribbean. NMFS SEFSC-Miami Laboratory Contribution No. MIA-9C/91-49.

Burke, JS, WJ Kenworthy, BP Degan, G Di Carlo, JB Landry and JC Taylor. 2007. Preliminary results of a survey of coastal fishes and their habitats around the island of Vieques. Unpublished report. CCFHR, Beaufort, NC.

CFMC/CFRAMP. 1999. Report on the queen conch stock assessment and management workshop. Belize City, Belize. March 15-22, 1999. 105 pp.

CFMC 2003. Draft Environmental Impact Statement for the Generic Essential Fish Habitat Amendment to Spiny Lobster Fishery Management Plan, Queen Conch Fishery Management Plan, Reef Fish Fishery Management Plan, Coral Fishery Management Plan for the US Caribbean, Volume 1: Text. San Juan, Puerto Rico. 467 pp.

DOI (U.S. Department of the Interior). 2007. Final Comprehensive Conservation Plan/Environmental Impact Statement for Vieques National Wildlife Refuge, Vieques, Puerto Rico. Fish and Wildlife Service, Southeast Region, Atlanta, GA.

DON (Department of the Navy). 1979. Draft Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

Garcia-Sais, JR, RL Castro, JS Clavell and M Carlo. 2001. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 108 pp.

Garcia-Sais, JR, RL Castro, JS Clavell, and M Carlo. 2004. Monitoring of coral reef communities from Isla de Vieques, Puerto Rico, 2004. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 122 pp.

GMI (Geo-Marine Inc.). 2003. Navy Lands on Vieques, Integrated Natural Resources Management Plan (Final draft). Prepared for Department of the Navy, US Naval Station, Roosevelt Roads.

GMI (Geo-Marine Inc.). 2005. An assessment of the condition of coral reefs off the former Navy bombing ranges at Isla de Culebra and Isla de Vieques, Puerto Rico. Prepared for the Department of Defense, Legacy Resource Management Program, Arlington, Virginia, and US Army Corps of Engineers, Huntsville, Alabama.

Levitan, DR. 1988. Algal-urchin biomass responses following the mass mortality of the sea urchin *Diadema antillarum* Philippi at St. John, US Virgin Islands. Journal of Experimental Marine Biology and Ecology 119: 167-178.

Lessios, HA. 1988. Mass mortality of *Diadema antillarum* in the Caribbean: what have we learned? Annual Review of Ecology and Systematics 19: 371-393.

Mateo, I. 2004. Population dynamics for the spiny lobster *Panulirus argus* in Puerto Rico: a progress report. Proceedings of the Gulf and Caribbean Fisheries Institute. 55: 506-520.

Matos-Caraballo, D. 1999. Overview of the Spiny Lobster, Panulirus argus, Commercial Fishery in Puerto Rico During 1992-1998. Proceeding of the Gulf and Caribbean Fisheries Institute. 52:194-203.

Miller, RJ, AJ Adams, NB Ogden, JC Ogden and JP Ebersole. 2003. *Diadema antillarum* 17 years after mass mortality: is recovery beginning on St. Croix. Coral Reefs 22: 181-187.

NOAA (National Oceanic and Atmospheric Administration) and RIDOLPHI Inc. 2006. Final Data Report for the Vieques Island Biota Sampling Project, Vieques Island, Puerto Rico. NOAA, National Ocean Service, Office of Response and Restoration. Seattle, WA.

Raffaele, HA, MJ Velez, R Cotte, JJ Whelan, ER Keil and W Cumpiano. 1973. Rare and endangered animals of Puerto Rico. US Department of Agriculture, Soil Conservation Service, and Puerto Rico Department of Natural Resources, San Juan. 70 pp.

Randall, J. 1964. Contributions to the biology of the queen conch, *Strombus gigas*. Bulletin of Marine Science of the Gulf and Caribbean 14: 246-295.

Sandt, VJ and AW Stoner. 1993. Ontogenetic shift in habitat by early juvenile queen conch, *Strombus gigas*: patterns and potential implications. Fishery Bulletin 91: 516-525.

SEDAR (Southeast Data, Assessment and Review). 2005. Stock Assessment Report of SEDAR8: Caribbean Spiny Lobster, Assessment Report 2. Charleston, SC. 195 pp.

SEDAR (Southeast Data, Assessment and Review). 2007. SEDAR 14 Stock Assessment Report: Caribbean Queen Conch. North Charleston, SC. 171 pp.

Shivlani, M. 2007. Community studies to determine the feasibility of marine protected area (MPA) management in Vieques, Puerto Rico. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL. NOAA Coral Reef Conservation Grant NA04NMF4630335.

CHAPTER 10: SEA TURTLES

10.1 OVERVIEW

Four species of sea turtles are found within the territorial and federal waters surrounding Vieques: green (*Chelonia mydas)*, hawksbill (*Eretmoshelys imbricata*), loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*). All but loggerhead sea turtles regularly nest on the beaches of Vieques, but the island is not considered a major nesting ground. Loggerhead turtles are rarely seen.

All sea turtle species are managed by the Endangered Species Act (ESA), because of threats from natural stressors and human activities, including capture for food, habitat alteration, and incidental capture in fishing gear. Hawksbill and leatherback turtles are listed as endangered, the most critical ESA status, while green and loggerheads are listed as threatened.

Numerous studies have investigated nesting beaches and recorded sea turtle sightings at sea around Vieques. Most studies are associated with legislative mandates requiring the military to monitor species listed under the ESA, and thus have greater survey effort placed in areas used by the military (i.e., east end). Sea turtles are found in most of the nearshore waters surrounding the island, but the greatest densities are observed near Mosquito Pier, off the eastern and western shores, and close to Sun Bay (Ensendada Sombe). Similarly, nesting beaches are distributed over much of the island, but the greatest densities of turtle species and nests are found on a few beaches, particularly on the eastern end of the island.

Most individuals observed at sea are greens and hawksbills. In contrast, most sea turtle nests are made by hawksbills and leatherbacks. A baseline quantitative population estimate of each sea turtle species around Vieques is lacking. A conservation/outreach project conducted by the Puerto Rico Department of Natural and Environmental Resources (DNER) and U.S. Naval Station Roosevelt Roads provides a comprehensive sea turtle nest monitoring dataset. The project's data show many beaches are used for nesting, and that poaching and predation are a problem.

Image 10.1. Hawksbill sea turtle (*Eretmochelys imbricata*). Photo: Biogeography Branch.

10.2 SOURCES OF DATA

The objectives of early sea turtle surveys were to identify species composition, nesting beaches, habitat suitability and anthropogenic impacts around Vieques (Carr 1978; Rainey 1979; Pritchard and Stubbs 1982). An assortment of methods was used to accumulate data, including beach reconnaissance on foot, aerial surveys, boat surveys and interviews with local residents. A comprehensive description of many nesting beaches is provided by Pritchard and Stubbs (1982).

Most sea turtle surveys were supported by the U.S. Department of Navy to satisfy a legal mandate set forth by Section 7(a) of the ESA. This mandate requires that all federal agencies ensure that their activities do not jeopardize the continued existence of endangered or threatened species. Consequently, many of the data were collected in the vicinity of the Live Impact Area (LIA). More recently, Rathbun et al. (1985) and GMI (2001) used aerial surveys and equal effort around the island to provide suitable data to examine the spatial distribution of sea turtles at sea.

In 1989 the DNER and U.S. Naval Station Roosevelt Roads developed a Memorandum of Understanding to initiate the Sea Turtle Conservation Project at Vieques. The project has provided data on nesting sea turtles around the entire island of Vieques from 1991 to 2001 using beach surveys (Matos et al. 1992; Belardo et al. 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001). Annual reports from the project and studies characterizing sea turtle populations (Carr 1978; Rainey 1979; Pritchard and Stubbs 1982; Rathbun et al. 1985; GMI 2001) provide an excellent inventory of nesting beaches; however, inconsistent survey effort prohibits their use as a monitoring dataset.

10.3 METHODS

All literature was reviewed for two categories of information: nesting beach locations and sightings at sea. Spatial data were plotted in ArcGIS (ESRI, Inc.) by scanning, georeferencing and digitizing relevant elements from figures or by simply plotting locations referenced in writing.

All sighting at sea data was compiled into a single spatial framework composed of a network of grids that exhaustively covered the territorial waters (<3 nm from shore) surrounding Vieques. Grid cell size was set to 500 m X 500 m in order to balance the spatial accuracy of input data and desired output maps. The map of sightings at sea was produced to identify locations frequently used by sea turtles around the island and to assess the relationship between turtle distribution and environmental variables. Three levels of sighting frequency were mapped. Grid cells with at least one sighting from 2 or more surveys or with more than two sightings in a single survey were identified as “High Frequency”. These areas are meant to indicate preferred habitat locations. The remaining cells with sightings were recorded as “Low Frequency” and cells without sightings were identified as “No Sightings”.

The environmental variables of average depth, and seagrass cover as well as proximity to land and nesting beaches, were determined for each grid cell. Average depth was determined using bathymetry derived from sonar sources (see Chapter 4: Bathymetry), seagrass cover was estimated from seagrass areas defined in the benthic habitat maps (see Chapter 6: Seagrass and Algae), and proximity to land and nesting beaches were evaluated using cost distance surfaces produced using a straight line distance algorithm in ArcGIS.

The influence of environmental variables on sea turtle distribution was assessed using ordinal logistic regression (OLR). Individual variables were tested using an Effect Likelihood Ratio Test and any with significant ($p<0.05$) parameter estimates were listed as important. Most studies did not differentiate between species at sea and consequently species were aggregated in the analysis.

10.4 DISTRIBUTION, STATUS AND TRENDS

Four species of sea turtles are found within the territorial and federal waters surrounding Vieques: green (*Chelonia mydas*), hawksbill (*Eretmoshelys imbricata*), loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*). The four species are found throughout the Caribbean. Only the leatherback, hawksbill and green sea turtles nest regularly on the beaches of Vieques. A fifth sea turtle species, the Olive Ridley, is a rare vagrant in Puerto Rican waters (Caldwell and Erdmann, 1969). Rainey (1979) provides a description of the biology and ecology of each sea turtle species.

Notes from archival publications (in Pritchard and Stubbs 1982) and information gained from interviews (Carr 1978; Pritchard and Stubbs 1982) indicate Vieques may have once possessed a substantial population of nesting sea turtles. However, data related to abundance, species composition and nesting areas are vague. Presently, Vieques is considered to have relatively few sea turtle nests or turtles at sea compared with nearby areas such as St Croix, Culebra, Florida and the South American coast (Rainey 1979; Pritchard and Stubbs 1982). The reduction of the sea turtle populations on Vieques reflects global and regional trends (Eckert et al. 1992).

All sea turtle species found in territorial and federal waters around Vieques are listed in the ESA. Hawksbill and leatherback turtles are listed as endangered, the most critical ESA status, and green and loggerheads are listed as threatened. NOAA’s National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service share responsibility for managing sea turtles in the sea and on land, respectively.

The principle threats to sea turtles on Vieques are from human activities, including capture for food, habitat alteration, and disturbance of nesting sites or predation by introduced species (especially mongoose) (Pritchard and Stubbs 1982). Military activities may also impact sea turtles and are discussed in more detail later. Since turtles are migratory, stressors present in areas other than Vieques or that have a global distribution are problematic as well. Incidental capture in fishing gear, ocean pollution and global climate change all negatively impact sea turtle populations (Lutcavage et al. 1997).

Although sea turtles are protected in territorial and federal waters and on land, most studies on Vieques suggest that enforcement is lax and sea turtles continue to be captured and killed by humans (Carr 1978; Rainey 1979; Belardo et al. 2001). Belardo et al. (2001) has shown nest predation (likely from introduced mongoose) and poaching affected 50% of all hawksbill nests on Vieques in 2000. In the past, turtles were commonly captured at sea using gill nets and mesh tangle nets, and nests on beaches were commonly raided for eggs (Pritchard and Stubbs 1982). Interviews conducted by Carr (1978) revealed most civilians and military personnel had lim-

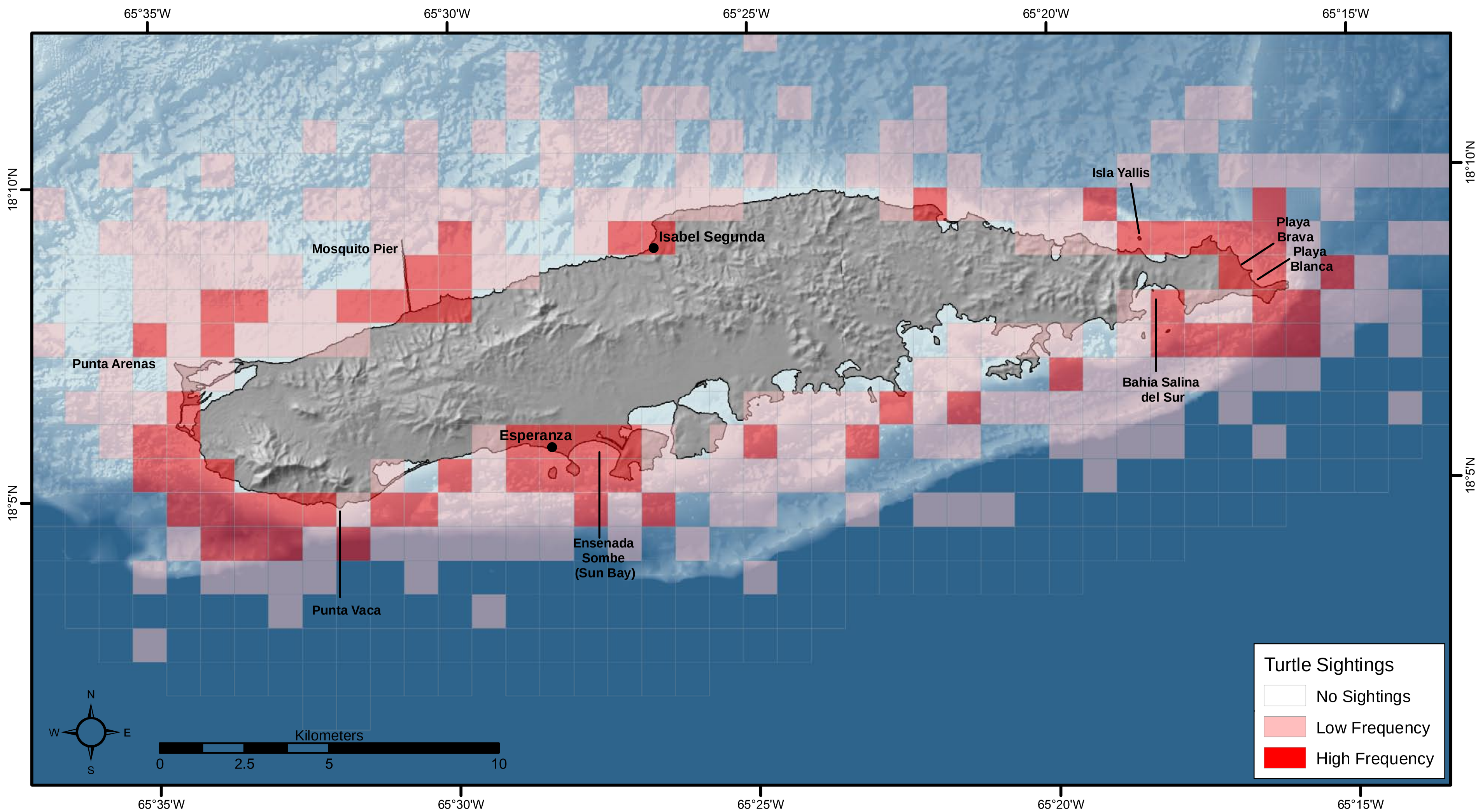


Figure 10.1. A compilation of turtle sightings at sea around the island of Vieques.

ited awareness of laws protecting turtles and for those who knew of the laws, respect for them was meager.

The Sea Turtle Conservation Project of Vieques began in 1991 (e.g., Matos et al. 1992). A major component of the project is outreach and education. It is believed that this project has reduced the threats of nest poaching and slaughter of gravid females (Belardo et al. 2001).

Table 10.1. Percent sightings of sea turtle species around Vieques. *Study included areas along the eastern shore of the main island of Puerto Rico and Culebra as well as Vieques.

Study	Green	Hawksbill	Loggerhead or Leatherback	Unidentified
Carr 1978	23%	77%	0%	0%
Rainey 1979	>50%	<50%	0%	???
Pritchard and Stubbs 1982	<50%	>50%	<1%	???
Rathbun et al. 1985	33%	5%	1%	61%
Mignucci-Giannoni et al. 2000*	38%	41%	6%	15%

Most sea turtle sightings in the waters around Vieques are made in shallow water close to shore. Figure 10.1 shows a compilation of sighting data at sea from 6 studies (Carr 1978; Rainey 1979; Pritchard and Stubbs 1982; Rathbun 1985; Mignucci-Giannoni et al. 2000; GMI 2001). Turtles have been observed in almost all nearshore waters, but sighting and abundance densities are highest in four areas: off the west coast, around Mosquito Pier, in and near Ensenada Sombe, and in the LIA from Cayo Yallis to Bahia Salina del Sur.

Generally less than half of sighting data can be used to identify species. All studies agree that the green and hawksbill turtle species are the most common, but there is some disagreement as to which predominates (see Table 10.1). The two predominant species are distantly followed by loggerhead and leatherback turtles, which together make up less than 6% of sightings at sea (Carr 1978; Rathbun et al. 1985; Mignucci-Giannoni et al. 2000; GMI 2001).

Analysis of several environmental variables suggests the spatial distribution of sea turtles at sea is more common close to shore (OLR; $p<0.0001$), and in areas with seagrass (OLR; $p<0.0001$). Variables which did not have significant model parameter estimates were percent of area covered by seagrass ($p=0.63$), depth ($p=0.22$), and distance to nesting beaches ($p=0.75$). The significant relationships between turtle distribution at sea and seagrass and distance from shore may not necessarily reflect habitat preferences, because survey effort was inconsistent among studies and within studies.

Sighting at sea data provided in most studies does not lend itself to population estimates, because survey effort is generally inconsistent (except for Rathbun 1985 and GMI 2001), many observations are for unidentified species and probabilities of detection are unknown. The acquisition of population parameter estimates for each species is critical for turtle management and should be a priority in future studies.

The relative temporal distribution of sighting at sea data reveals seasonal patterns. Rathbun et al. (1985) report average monthly sightings between August and January are approximately 40% higher than the annual average. This interval of time coincides with the time immediately following the principal nesting period.

Sea turtles spend most of their lives at sea but they return to land to nest. Turtles nest on the sandy beaches of Vieques year long, but the highest frequencies occur from the end of May to September (Pritchard and Stubbs 1982; GMI 2001). GMI (2001) found almost twice as many sea turtle tracks, which are a good indicator of nesting frequency, from May to September when compared to the annual average

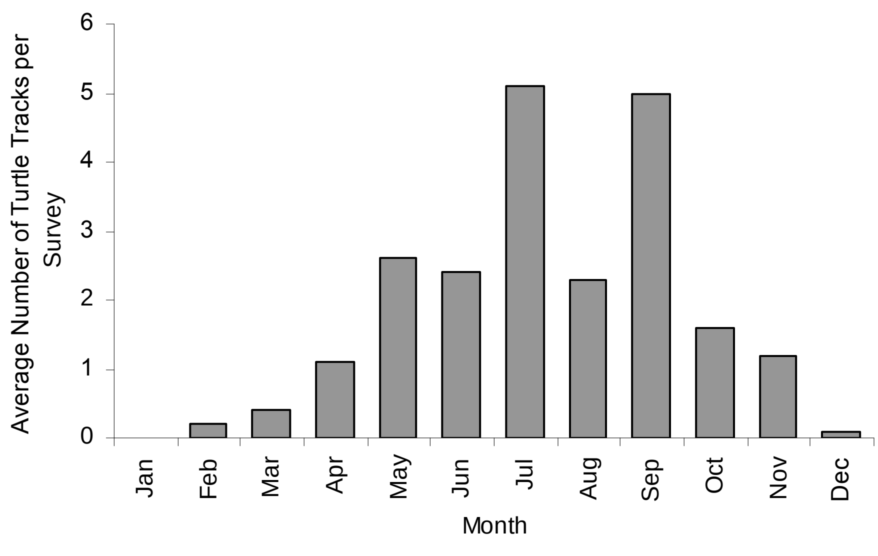


Figure 10.2. Average number of sea turtle tracks observed per survey around the island of Vieques in 2000. Data reported by GMI (2001).

(Figure 10.2). The majority of identified nests are distributed almost equally between hawksbills and leatherbacks.

Annual reports from the Sea Turtle Conservation Project and studies characterizing sea turtle populations (Carr 1978; Rainey 1979; Pritchard and Stubbs 1982; Rathbun 1985; GMI 2001; Mignucci-Giannoni et al. 2000) provide an excellent inventory of the beaches where hawksbill, leatherback and green turtles nest. To date there have not been confirmed reports of loggerhead nests. Hawksbill and leatherback nests are the most common and are found on sandy beaches distributed around the entire island (Figure 10.3). In contrast, Green nests are found almost exclusively on the eastern end of the island; the exception is Santa Maria Beach on the north shore where one nest has been documented (Belardo et al. 1995).

Descriptions of many sea turtle nesting beaches and important nesting beach characteristics are provided by Pritchard and Stubbs (1982). Several environmental factors, such as aspect, beach length and width, approach, overall slope, sand particle size and moisture content, influence beach selection by sea turtles (e.g., Mortimer 1995; Garmestani et al. 2000). The overall selectivity and relative importance of different variables are not the same among all sea turtle species. For instance, Pritchard and Stubbs (1982) reported that many beaches on Vieques can only be used by Hawksbill turtles because of rocky approaches. GMI (2001) summarizes information from previous studies and indicates the most important beaches for each species. Four beaches stand out from the rest as having nests from all three species or a large proportion of nests of a single species: Playa Barco, Playa Blanca, Playa Brava, and Yellow Beach. Yellow Beach and Playa Brava commonly have more than 50% of all leatherback and green nests found each year on the entire island, respectively. All four of these beaches occur on the eastern side of Vieques and were in the Atlantic Fleet Weapons Training Facility.

Military activities on Vieques are believed to have positive and negative impacts on sea turtles. Rainey (1979) and Pritchard and Stubbs (1982) review impacts of military activities, such as amphibious landings, lights and explosions, on turtles and conclude these impacts are minimal. They also describe the positive effect of reducing civilian access to sea turtle nesting beaches. Many early studies (e.g., Carr 1979; Pritchard and Stubbs 1982) indicated the gathering of eggs from nests or the poaching of turtles as they came on the beach to nest was having a deleterious impact on turtle numbers. Pritchard and Stubbs (1982) suggest the restriction of civilian access to turtle nesting beaches within military lands provides a beneficial de facto protected area. This benefit would have impacted beaches on the eastern end of the island the most, including the four major sea turtle nesting beaches: Playa Brava, Playa Blanca, Playa de Barco (Tortuga Beach), and Playa Matias (Yellow Beach). In addition, turtle hatchlings would likely benefit from reduced light pollution on the undeveloped parts of the island. To date there has not been a rigorous comparison of the positive and negative impacts by the military on sea turtles.

To mitigate some of the problems associated with military activities, the Sea Turtle Conservation Project relocated nests found on beaches to a turtle hatchery facility on Puerto Rico. From 1991 to 2000 over 20 thousand hatchlings were released from the facility into the sea (Belardo et al. 2001). While at the hatchery, turtles eggs were also protected from potential poaching and predation.

10.5 ECOLOGICAL LINKAGES

Sea turtle species have a worldwide distribution, are associated with several distinct habitats and migrate long distances between nesting beaches and foraging areas (e.g., Pritchard 1976; Bowen et al. 1992; Bowen 1996; Morreale et al. 1996). One study found that during 18 days a leatherback turtle traveled over 500 km, including from St. Croix to Vieques (Keinath and Musick 1993). These movements indicate sea turtles are not tied to a single location, but rather link many locations. Migration has important implications to sea turtle management, since protection in one location may be compromised by insufficient protection in another. Bowen et al. (1996) suggest sea turtle harvest on a single feeding ground can reduce nesting populations throughout the Caribbean region.

Sea turtles use different habitats at different stages of their life cycles. As a generality, after leaving the nest, hatchlings from all four species of sea turtles found on Vieques swim offshore and eventually associate with floating debris or *Sargassum* in convergence zones (Carr 1987; Witherington 2002). They remain as part of the pelagic community for several years as they feed on plankton, *Sargassum* and a variety of floating items. Once hawksbill, loggerhead and green turtles reach a certain size or age (depending on the species) they move into coastal feeding grounds; leatherback turtles disassociate with floating material, but remain associated with the pelagic community. As they age, the hawksbill, loggerhead and leatherback turtles become carnivores, but the green turtle shifts to exclusively eating plants.

Coral reefs (see Chapter 5: Coral Reefs and Hardbottom) are used extensively by hawksbill and green turtles for shelter. In addition, hawksbills have a high degree of feeding selectivity as indicated by gut content studies

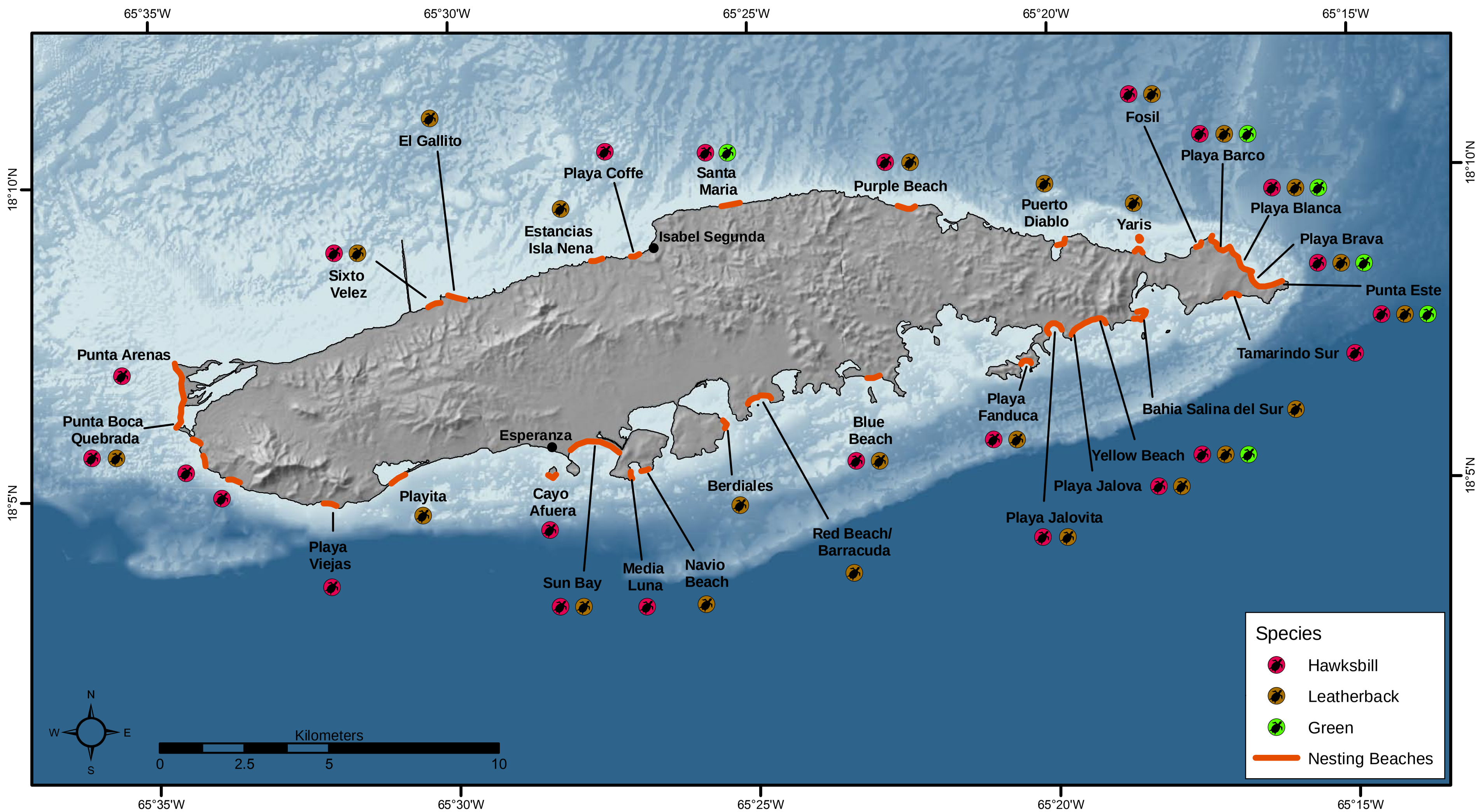


Figure 10.3. Sea turtle nesting beaches on Vieques, Puerto Rico. Data obtained from a compilation of eight studies.

(Meylan 1988; Vicente and Carballeira 1992) and their principle food items (e.g., *Nipahtes digitalis*, *Chondrilla nucula*) are frequently found among coral reef ecosystems. Some studies suggest the consumption of sponges by hawksbill turtles may influence reef succession by producing space on the reef which can be colonized by other benthic organisms like coral (USFWS and NMFS 1993).

Green turtles are frequently found among seagrass beds and macroalgae plains. Their principle food items are seagrass and algae, especially *Thalassia testudinum* (Bjorndal 1980; Mortimer 1981) which can be found in abundance around Vieques (see Chapter 6: Seagrass and Algae). Loggerheads are also associated with seagrass beds since their principle food items are mobile invertebrates, such as mollusks and crabs, and many of these depend on seagrass habitats for some part of their life cycle.

Unlike the hawksbill and green turtles, leatherbacks are principally pelagic animals. They are carnivores and feed on soft-bodied floating organisms such as jellyfish, siphonophores and salps (Eisenberg and Frazier 1983). This strategy links leatherbacks to bathymetry (see Chapter 4: Bathymetry) and motile invertebrate habitats (see Chapter 9: Motile Invertebrates).

All sea turtle species require beaches to nest and have high nesting site fidelity (Carr and Carr 1972; Bowen et al. 1992). For these reasons the long-term integrity of nesting beaches is paramount to ensure sea turtles continue to nest on Vieques. Not only should beaches be protected from coastal development and habitat alterations, but several marine habitats, organisms and physical processes that directly influence beaches should be managed carefully as well. For instance, beaches depend on coral reefs (see Chapter 5: Coral Reefs and Hardbottom) and algae (see Chapter 6: Seagrass and Algae) for sand. Further, coral reefs in conjunction with bathymetry (see Chapter 4: Bathymetry) and storms (see Chapter 2: Climate and Currents) control sand erosion and accretion by influencing hydrodynamics and sediment transport processes.

LITERATURE CITED

Belardo, E, R Matos and G Roman. 1993. 1992 Annual Report, Sea Turtle Conservation Project on Vieques Island, Final Draft. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and G Roman. 1994. 1993 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and JF Sanez. 1995. 1994 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and FJ Ortiz. 1996. 1995 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and FJ Sanez. 1997. 1996 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and FJ Ortiz. 1998. 1997 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and FJ Ortiz. 1999. 1998 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and FJ Ortiz. 2000. 1999 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Belardo, E, R Matos and FJ Ortiz. 2001. 2000 Annual Report, Sea Turtle Conservation Project on Vieques Island. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Bjorndal, KA. 1980. Nutrition and grazing behavior of the green turtle, *Chelonia mydas*. Marine Biology 56: 147-154.

Bowen, BW, AL Bass, A Garcia, CE Diez, R van Dam, A Bolten, KA Bjorndal, MM Miyamoto and RJ Ferl. 1996. The origin of hawksbill turtles in a Caribbean feeding area as indicated by genetic markers. Ecological Applications 6:566-572.

Bowen, BW, AB Meylan, JP Ross, CJ Limpus, GH Balazs and JC Avise. 1992. Global population structure and natural history of the green turtle (Chelonia mydas) in terms of matriarchal phylogeny. Evolution 46:865-881.

Caldwell, DK and DS Erdman. 1969. Pacific Ridley Sea Turtle, *Lepidochelys olivacea* in Puerto Rico. Bulletin of Southern California Academy of Sciences 68: 112.

Carr, T. 1978. A Survey of marine turtles at Vieques Island. Unpublished report to the Puerto Rico Department of Natural Resources.

Carr, A. 1987. Impact of nondegradable marine debris on the ecology and survival outlook of sea turtles. Marine Pollution Bulletin 18: 352-356.

Carr, A and MH Carr. 1972. Site fixity in the Caribbean green turtle. Ecology 53: 425-429.

Eckert, K, J Overing and B Lettsome. 1992. Sea Turtle Recovery Action Plan for the British Virgin Islands. UNEP Caribbean Environment Programme, Kingston, Jamaica. CEP Technical Report No. 15.

Eisenberg, JF and J Frazier. 1983. A leatherback turtle *Dermochelys coriacea* feeding in the wild. Journal of Herpetology 17: 81-82.

ESA (Endangered Species Act). 16 U.S.C. §§ 1531-1544, December 28, 1973, as amended 1976-1982, 1984 and 1988.

Garmestani, AS, HF Percival, KM Portier and KG Rice. 2000. Nest-site selection by the loggerhead sea turtle in Florida's Ten Thousand Islands. Journal of Herpetology 34: 504-510.

GMI (Geo-Marine, Inc.). 2001. Biological Assessment for Continuing Training Activities on the Inner Range Vieques, Puerto Rico. Report prepared for the Naval Facilities Engineering Command. 415 pp.

Keinath, JA and JA Musick. 1993. Movements and diving behavior of a leatherback turtle. Copeia 1993(4): 1010-1017.

Lutcavage, ME, P Plotkin, B Witherington and PL Lutz. 1997. Human impacts on sea turtle survival. pp. 387-409. In: Lutz, PL and JA Musick, eds. The biology of sea turtles. CRC Press, Boca Raton, FL.

Matos, R, E Belardo and G Roman. 1992. 1991 Annual Report, Vieques Island Sea Turtle Conservation Project with Management Recommendations. Department of Natural and Environmental Resources, San Juan, Puerto Rico. Report to U.S. Naval Station Roosevelt Roads.

Meylan, AB. 1988. Spongivory in hawksbill turtles: a diet of glass. Science 239: 393-395.

Mignucci-Giannoni, AA, MC Cardona-Maldonado, MC Ortíz-Rivera, MA Rodríguez-López and GM Toyos-González. 2000. Censos poblacionales de mamíferos y tortugas marinas en aguas adyacentes a la Isla de Vieques, Puerto Rico [Spanish]. Laboratory of Marine Mammals of the Caribbean, Department of Sciences and Technology and School of Environmental Matters, Metropolitan University, San Juan, Puerto Rico. 40 pp.

Morreale, SJ, EA Standora, JR Spotila and FV Paladino. 1996. Migration corridor for sea turtles. Nature 384: 319-320.

Mortimer, JA. 1981. The feeding ecology of the west Caribbean green turtle (*Chelonia mydas*) in Nicaragua. Biotropica 13: 49-58.

Mortimer, JA. 1995. Factors influencing beach selection by nesting sea turtles. pp. 45–51, *In* K.A. Bjorndal (Ed.). Biology and Conservation of Sea Turtles. Smithsonian Institution Press, Washington, DC. 615 pp.

Pritchard, P. 1976. Post-nesting movements of marine turtles (Cheloniidae and Dermochelyidae) tagged in the Guianas. Copeia 1976:749-754.

Pritchard, P and T Stubbs. 1982. An evaluation of sea turtle populations and survival status on Vieques Island. Field Report, Dept. Navy (Naval Oceans Systems Center, San Diego); contract N66001-80-C-0560.

Rainey, WE. 1979. Status of Sea Turtles at Vieques Island. Unpublished Report to the Navy. 64 pp.

Rathbun, GB, T Carr, N Carr and CA Woods. 1985. The distribution of manatees and sea turtles in Puerto Rico, with emphasis on Roosevelt Roads Naval Station. NTIS Publication PB86-1518347AS.

USFWS (US Fish and Wildlife Service) and NMFS (National Marine Fisheries Service). 1993. Recovery Plan for hawksbill turtles in the US Caribbean Sea, Atlantic Ocean, and Gulf of Mexico. National Marine Fisheries Service, St. Petersburg, Florida.

Vicente, VP, and NM Carballeira. 1992. Studies on the feeding ecology of the hawksbill turtle, *Eretmochelys imbricata*, in Puerto Rico. Proceed. 11th Annual Workshop on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-302. pp. 117-120.

Witherington, BE. 2002. Ecology of neonate loggerhead turtles inhabiting lines of downwelling near a Gulf Stream front. Marine Biology 140: 843-853.

CHAPTER 11: MARINE MAMMALS

11.1 OVERVIEW

Image 11.1. Manatee cow and calf offshore of Vieques. Photo: CCFHR.

Eight species of marine mammals have been identified around Vieques. Another 20 species are considered likely to be found around the island due to sightings in the region. All but one of the marine mammal species are cetaceans which include members in the Delphnidae (dolphins), Physeteridae (sperm whales), Ziphidae (beaked whales) and Balaenopteridae (rorquals) families. The remaining species is the West Indian manatee (Family: Trichechidae).

Six species are listed as endangered by the Endangered Species Act (ESA, 16 U.S.C. 1531 et seq.) and analogous territorial Acts (Puerto Rico's Commonwealth Wildlife Act, the Commonwealth of Puerto Rico Vulnerable and Endangered Species Management Regulation). The protection afforded to these species is the rationale behind the vast majority of marine mammal surveys in the area, especially those conducted by the military.

Few data exist on the abundance or distribution of cetaceans around Vieques. Most data has been interpolated from regional-scale surveys of the Puerto Rican Bank region (i.e. insular shelf of Puerto Rico, Vieques, Culebra and U.S. Virgin Islands). Of the few marine mammal sightings available, several included cow-calf pairs and juveniles. This has led to the suggestion that the waters around Vieques may be an important nursing ground for several marine mammal species. There is a clear need for more studies to assess which cetaceans can be found around Vieques, the area's ecological role and potential impacts from human use.

Several surveys have investigated the West Indian manatee population around Vieques. These surveys have provided information on the spatial distribution and environmental factors which affect manatees. The greatest densities of manatees occur in the area northwest of Vieques in the lee of Mosquito pier and along the south coast near protected bays. Accurate estimates of abundance are lacking and this prohibits population monitoring.

11.2 SOURCES OF DATA

There have been numerous surveys of marine mammals in the Puerto Rican Bank region, which includes Vieques along with other islands of Puerto Rico, the U.S. Virgin Islands and British Virgin Islands. Finer-scale surveys around Vieques are lacking for cetaceans, but several exist for the West Indian manatee.

Erdman (1970), Erdman et al. (1973), Mignucci-Giannoni (1996), Mignucci-Giannoni et al. (1998), Roden and Mullin (2000), Swartz and Burks (2000) and Swartz et al. (2002, 2006) have reported number of sightings, acoustic reports and taxonomic composition of cetaceans for the Puerto Rican Bank region. Mignucci-Giannoni et al. (1999) supplements this data with a compilation of cetacean strandings in the region. Most of these data from the Puerto Rican Bank region, except by Erdman et al. (1973), Swartz and Burks (2000) and Swartz et al. (2002), provide insufficient spatial information to identify records collected around Vieques. Mignucci-Giannoni et al. (2000) and GMI (2001) provide surveys with greater sampling effort around Vieques and are the sources of most cetacean information in this chapter.

Mignucci-Giannoni et al. (2000) gathered data from east of Puerto Rico, Culebra and Vieques. The study included 144 sightings from aerial and shipboard surveys from 1999 to 2000. GMI (2001) gathered data from aerial surveys and from observations taken from an observation platform (OP-1) on land from 1990-2000. Although a significant amount of data exists from opportunistic sightings from OP-1, these cannot be used for spatial analyses, because the data have an inherent spatial bias towards areas close to OP-1 and in the LIA and do not possess taxonomic information. In contrast, aerial surveys were completed over the waters surrounding all of Vieques from January 2000 to February 2001 and are presented in two parts, Jan 2000-Dec 2000 and Sept 2000-Feb 2001, for unknown reasons.

Numerous assessments of the manatee population around Vieques have occurred since the late 1970's (Magor 1979; Powell et al. 1981; Rathbun et al. 1985; Freeman and Quintero 1990; Mignucci-Giannoni et al. 2000; GMI 2001). A major impetus for most of these assessments comes from a cooperative agreement between the US Fish and Wildlife Service and the Navy to satisfy the requirements of the ESA and MMPA. Assessments typically use aerial surveys (fixed-wing airplanes and helicopters) to obtain data on number, and life-stage (e.g. calf, mature) of manatees. Many of these sources indicate the habitat in which manatees were sighted and their behavior. A radio-tracking study, the Sirenia project (Reid 1993), provided insight into manatee distribution and movement not offered by sighting data.

11.3 METHODS

A compilation of sighting, stranding and acoustic data from all sources was used to produce an inventory of marine mammal species with confirmed or possible occurrence around the island of Vieques. Three distinct probabilities of occurrence were assigned according to where data was gathered: known, likely, or possible. Species with known occurrence have confirmed sighting or acoustic data collected around Vieques. Species with likely occurrence have been observed in the Puerto Rican Bank region, but were not explicitly found around Vieques. Species with possible occurrence have been observed in the Caribbean, but not explicitly within the Puerto Rican Bank region.

Due to differences in survey effort among cetacean and manatee studies these groups were examined separately. All cetacean data were compiled into a single spatial framework composed of a network of grids which exhaustively covered the territorial waters surrounding Vieques. Grid cell size was set to 500 m X 500 m in order to balance the spatial accuracy of input data and desired resolution of output maps. The paucity of data prohibited any modeling, such as an assessment of habitat affinities.

A similar map of manatee distribution around Vieques was produced from all manatee sighting data. This map was produced to identify important areas used by manatees and to assess the relationship between manatee distribution and environmental variables, such as depth, and proximity to land. The same spatial framework used to map cetacean data was used. Two levels of sighting frequency were mapped. Grid cells with at least one sighting from 2 or more surveys were identified as “High Frequency” and are meant to indicate preferred locations for feeding, nursing and resting. The remaining cells with sightings were listed as “Low Frequency” and cells without sightings were listed as “No Sightings”. The average depth, seagrass cover and proximity to land and freshwater sources were determined for each grid cell. Average depth was determined using bathymetry derived from NOAA hydrographic data (see Chapter 4: Bathymetry), seagrass cover was estimated from seagrass areas defined in the NOAA benthic habitat map (see Chapter 6: Seagrass and Algae), and proximity to land and freshwater were evaluated using cost distance surfaces produced in ArcGIS. The nearest perennial freshwater sources were the Cape Hart Sewage Treatment plant, and the Humacao, Guayanes and Urbano rivers, located on the southeast coast of Puerto Rico. The influence of individual variables on manatee distribution was assessed using an Effect Likelihood Ratio Test.

11.4 DISTRIBUTION, STATUS AND TRENDS

Eight species of marine mammals have been identified around the island of Vieques. Another 20 species are considered likely to be found around the island due to sightings in the region. Table 11.1 provides a species inventory and indicates each species' probability of occurrence. Many species on the list have not been observed in the territorial waters of Vieques, but are included because they have been seen in the Puerto Rican Bank region or in the Caribbean. Most marine mammal species have low probabilities of detection and are highly mobile, thus if they have been observed in the region their range may include the waters around Vieques.

Twenty-seven of the twenty-eight marine mammal species in the Puerto Rican Bank region are cetaceans. Cetacean species include members in the Delphnidae (dolphins), Physeteridae (sperm whales), Ziphidae (beaked whales) and Balaenopteridae (rorquals) families. The remaining marine mammal species is the West Indian manatee (Family: Trichechidae). A few strandings of the Hooded seal (Family: Phocidae) have also been reported in the region (Mignucci-Giannoni and Odell 2001), but this species' typical distribution ranges from Svalbard to the Gulf of St. Lawrence in the Arctic and does not normally occur in the Caribbean.

A compilation of cetacean sightings near Vieques is presented in Figure 11.1 (Erdman et al. 1973; Mignucci-Giannoni et al. 2000; GMI 2001). This compilation is by no means an exhaustive map of cetacean distribution, because few surveys exist, survey effort is biased towards the east end of the island (i.e. data from OP-1) and cetaceans have a low probability of detection.

Table 11.1. Inventory of marine mammals that occur or possibly occur around the island of Vieques. An occurrence likelihood that is dependent on sighting locations is given (Known = Vieques, Likely = Puerto Rican Bank Region, Possible = Caribbean). Listed conservation status according to IUCN. References: 1 – Harmer 1923, 2 – Erdman 1970, 3 – Mignucci-Giannoni 1998, 4 – Mignucci-Giannoni 1999, 5 – Swartz and Burks 2000, 6 – Roden and Mullin 2000, 7- Mignucci-Giannoni et al. 2000, 8- GMI 2001, 9 – Swartz et al. 2002, 10 – Swartz et al. 2006, 11-e.g., Magor 1979, Powell et al. 1981, Rathbun et al. 1985.

Species	Common Name	Occurrence Likelihood	Status	Reference(s)
Order Cetacea				
Family: Balaenopteridae				
Megaptera novaeangliae	Humpback whale	Known	Endangered	2,3,4,6,7
Balaenoptera edeni	Bryde's whale	Likely		4
Balaenoptera acutorostrata	Minke whale	Likely		2,3,6
Balaenoptera borealis	Sei whale	Possibly	Endangered	
Balaenoptera musculus	Blue whale	Possibly	Endangered	1
Balaenoptera physalus	Fin whale	Possibly	Endangered	3
Family: Delphinidae				
Stenella frontalis	Atlantic spotted dolphin	Known		3,4,6,7,9,10
Steno bredanencis	Rough-toothed dolphin	Known		3,4,8
Grampus griseus	Risso's dolphin	Known		2,3,4,8
Tursiops truncatus	Bottlenose dolphin	Known		2,3,4,6,7,10
Globichephala macrorhyncus	Short fin pilot whale	Known		2,3,4,6,7,9,10
Peponocephala electra	Melon-headed whale	Likely		4
Pseudorca crassidens	False killer whale	Likely		3,4,9,10
Stenella attenuata	Pantropical spotted dolphin	Likely		6,10
Stenella coeruloealba	Striped dolphin	Likely		3,4,6
Stenella longirostris	Spinner dolphin	Likely		3,4,9,10
Feresa attenuata	Pygmy killer whale	Likely		4
Delphinus delphis	Short-beaked common dolphin	Likely		2
Lagenodephis hosie	Fraser's dolphin	Likely		
Orcinus orca	Killer whale	Possibly		3
Family: Physeteridae				
Physeter macrocephalus	Sperm whale	Known	Endangered	2,3,5,6,9,10
Kogia breviceps	Pygmy sperm whale	Likely		3,4
Kogia simus	Dwarf sperm whale	Likely		4
Family: Ziphiidae				
Ziphius cavirostris	Cuvier's beaked whale	Known		2,3,4,8,9,10
Mesoplodon densirostris	Blainsville's beaked whale	Likely		4
Mesoplodon eusopaeus	Gervais' beaked whale	Likely		4
Order Sirenia				
Family: Trichechidae				
Trichechus manatus	West Indian manatee	Known	Endangered	2,11

Most sighting data are for unidentified species. Of those sightings that could be identified to the species level, species included the bottlenose dolphin (n=5), and humpback (n=2), sperm (n=2) and short-fin pilot (n=1) whales (Erdman et al. 1973; Mignucci-Giannoni et al. 2000; GMI 2001). Cuvier's beaked whale and Risso's dolphin have not been sighted at sea, but have been stranded on Vieques' beaches (GMI 2001). Those species identified around Vieques conform to the community composition identified for the Puerto Rican Bank region, which includes all U.S. territorial waters around Puerto Rico and the Virgin Islands (Erdman et al.1973; Mignucci-Giannoni et al. 1999; Swartz et al. 2002).

Several studies (Mignucci-Giannoni et al. 2000; Roden and Mullin 2000; GMI 2001) have reported cow-calf pairs and juveniles of humpback and sperm whales and Atlantic spotted dolphins in the vicinity of Vieques. It is documented that the Caribbean region is a winter calving ground for several species of whales (e.g., NMFS

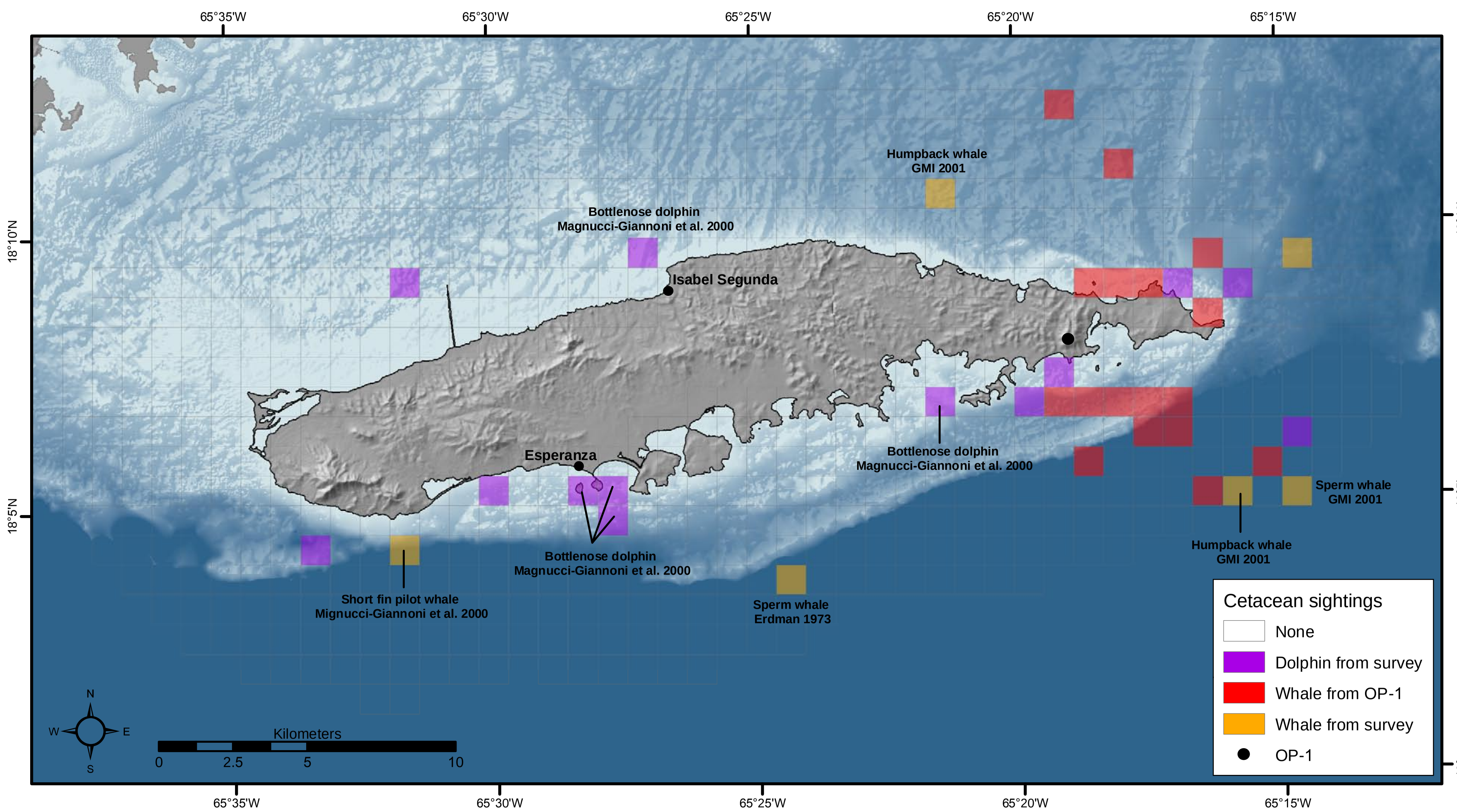


Figure 11.1. Cetacean sightings near Vieques from Erdman et al. (1973), Mignucci-Giannoni et al. (2000) and GMI (2001). Most data come from opportunistic sightings from OP-1 (GMI 2001). Whenever possible taxonomic information is provided. OP-1=Observation Post-1.

1991). Mignucci-Giannoni (2000) has suggested the waters to the south of Vieques may be important nursing grounds for these species.

A total of 22 sightings were made from OP-1 between February 1990 and October 2000. Most sightings were made offshore of the LIA (86%), within 2 km from shore (90%) and in depths less than 30 m (77%). All but one sighting was made during the months of February, March or April, which conforms with the peak sightings period of the Humpback whale. There does not appear to be a change in spatial pattern with time.

The majority of dolphin sightings (Family: Delphinidae) near Vieques are unidentified, but there are records for the rough-toothed dolphin and bottlenose dolphin. In addition, a spotted dolphin was observed by Erdman et al. (1973) 13 km off the southeast of Vieques. The most commonly sighted dolphin species in the Puerto Rican Bank Region are the bottlenose dolphin, Short-fin pilot whale, Pantropical spotted dolphin, Atlantic spotted dolphin and spinner dolphin (Erdman et al. 1973; Mignucci-Giannoni 1998; Mignucci-Giannoni et al. 2000; Roden and Mullin 2000; Swartz et al. 2002).

Aerial surveys by Mignucci-Giannoni et al. (2000) and GMI (2001) around Vieques indicate dolphins are generally observed closer to land, more uniformly around the island and in larger groups (>3) than whales (Figure 11.1). Dolphin sightings were also distributed throughout the year, suggesting a more uniform seasonal distribution than whales.

The seasonal abundance and distribution for most cetacean species in the northeastern Caribbean are poorly known (Mignucci-Giannoni 1998; Mignucci-Giannoni et al. 1999; Roden and Mullin 2000). Some cetaceans, such as the humpback whale use the northeastern Caribbean region, including the Puerto Rican Bank region, for breeding and calving during winter months (NMFS 1991). These species migrate from summer, high-latitude feeding grounds, such as the east coast of the continental U.S., to the tropics in the winter to take advantage of warmer water temperatures (Matilla and Clapham 1989). Most observations of migrating species in the Caribbean are between the months of November and April (Erdman et al. 1973; NMFS 1991). Mignucci-Giannoni (1998) indicates most species, even those considered summer species such as the Bottlenose dolphin, show seasonality. In contrast to Erdman et al. (1973) who showed dolphin sightings increased in summer months, Mignucci-Giannoni (1998) reports most species, including dolphins, were sighted in the winter and early spring.

The population of West Indian manatees found around Vieques belong to the Antillean manatee (*T. manatus*) subpopulation (Garcia-Rodriguez et al. 1989). The subpopulation is found throughout the Caribbean and central and South America (Domning and Hayek 1986; Garcia-Rodriguez et al. 1989), but the only portion of the subpopulation under U.S. jurisdiction is found around Vieques and Puerto Rico. Information on the long-term temporal patterns of manatee abundance is lacking and there currently is no accurate estimate of abundance around Vieques. However, historical accounts indicate manatees were once more common (Powell et al. 1981; Thornback and Jenkins 1982; Lefebvre et al. 1989). Powell et al. (1981) report several sources that document manatees around Puerto Rico since the arrival of Spanish explorers and implies a much higher population of manatees than currently exist. The first documented survey of manatees around Vieques was conducted by Magor in 1979. In this study, Magor interviewed residents who provided some historical anecdotal distribution data and indicate that manatees have been around Vieques since at least 30 years prior to the survey – 1949. The subpopulation has been affected in recent decades by habitat degradation, red tide outbreaks, collisions with boats, hunting and incidental catch (O'Shea et al. 1985, 1991, 1995; Mignucci-Giannoni 1990). It is now considered endangered by both federal and territorial conservation acts, including the ESA.

The West Indian manatee is an obligate herbivore and is the only marine mammal species that grazes on seagrass. It is also large (1-2 m) and slow, seeks out sheltered bays away from human disturbance, and requires freshwaters sources (e.g., Magor 1979, Rathbun et al. 1985). For these reasons the distribution of manatee sightings around Vieques is not uniform. Most manatees are sighted off the northwest shore, from Mosquito Pier to Boca Quebrada, and on the south coast near protected bays (e.g., Magor 1979; Powell et al. 1981; Freeman and Quintero 1990, Reid 1993). Manatees have rarely been observed off the north central, northeast or eastern coasts. The greatest density of manatees occurs in the area northwest of Vieques in the lee of Mosquito pier (Rathbun et al. 1985; Freeman and Quintero 1990; GMI 2001).

Freshwater runoff on Vieques is rare. The island receives approximately 100 cm of rain annually and much of this is lost by evaporation and evapotranspiration (see Chapter 2: Climate and Currents). However, Vieques residents have frequently observed manatees near the mouths of the two streams with the highest discharge rates, especially in the rainy seasons (Magor 1979). These streams discharge east of the Laguna Kiani on the northwest coast and on the southwest coast. Manatees also traverse the passage between Puerto Rico and Vieques to obtain freshwater from perennial sources, such as sewage outflows and rivers (Magor 1979; Powell et al. 1981; Freeman and Quintero 1990; Reid 1993, 1995). The Cape Hart Sewage Treatment plant is considered an important source of freshwater for manatees that are typically found around Vieques (Reid 1993).

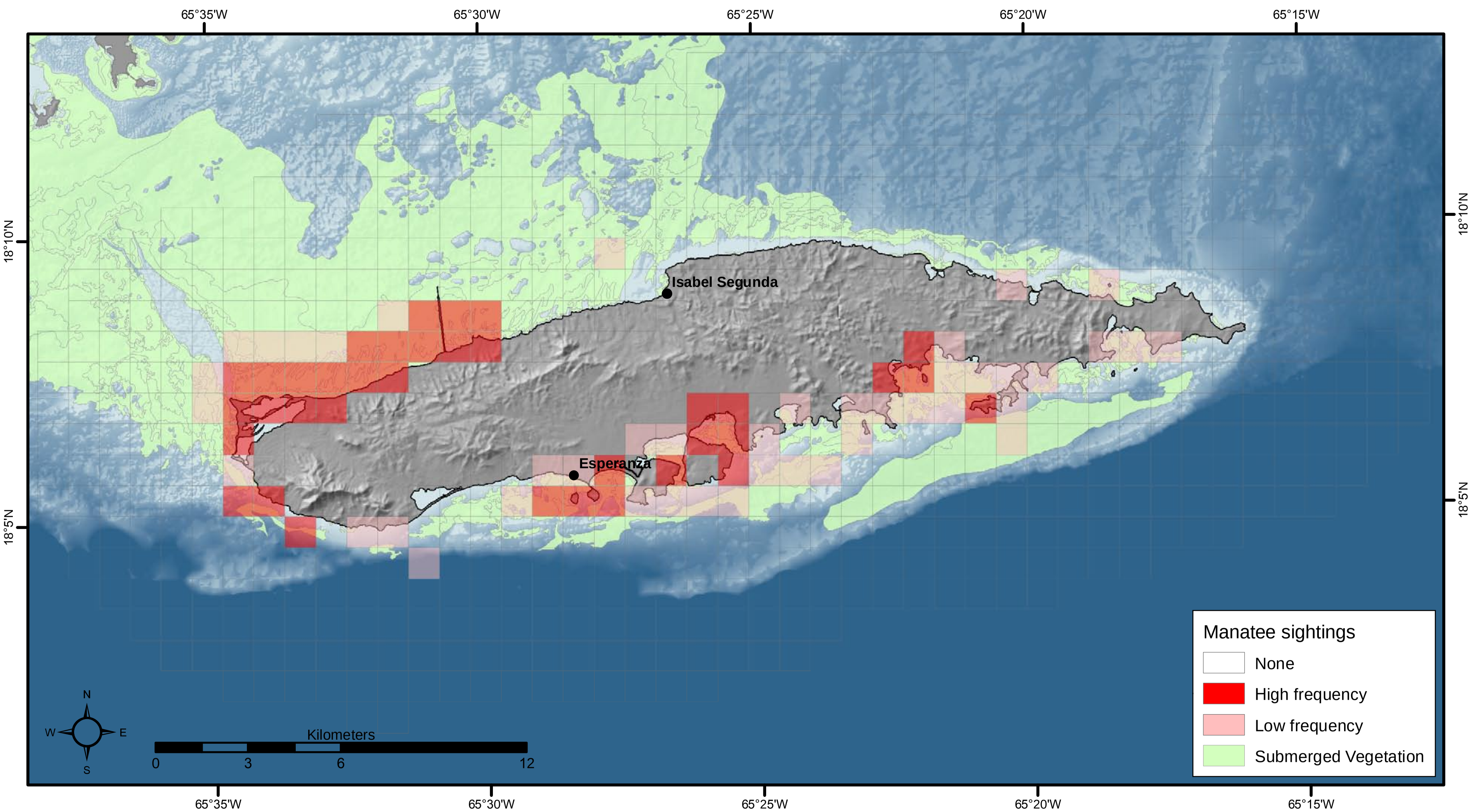


Figure 11.2. Manatee sightings around Vieques from several sources.

From 1992 to 1996 a radio tracking project (Reid 1993, 1994, 1995, 1996) supplemented sighting data from aerial surveys. The project tracked seven manatees captured near the Cape Hart Sewage Treatment plant and revealed some new findings, including the preference for shallow seagrass beds (1.5 and 3 m deep), *Halodule wrightii* over other species of seagrasses as food, and significant usage of the southern shore of Vieques for feeding and mating (Reid 1993, 1994, 1995, 1996). The project also confirmed manatee movement between Puerto Rico and Vieques.

A compilation of data from all aerial surveys and the radio tracking project was used to comprehensively examine the spatial distribution of manatees around Vieques (Figure 11.2). The principle locations of manatee sightings were to the northwest, west and south of Vieques. The majority of sightings on the south shore were in or near protected bays, including Bahia Mosquito, Puerto Ferro and Ensenada Honda.

Ordinal logistic regression indicated manatee sightings could be modeled using seagrass cover and proximity to protected bays, land and freshwater sources (OLR, pval<0.0001). In contrast to other studies (e.g., Rathbun et al. 1985, Diaz 1992), depth was not found to be a significant variable affecting manatee distribution. One reason for this difference may be that the larger spatial scale of the data used in the model (500 m by 500 m) blurred significant bathymetric relationships with manatees. The principle variable associated with manatee sightings was proximity to protected bays (χ^2=45.81); the remaining variables all had similar associations with sightings (proximity to water sources χ^2=17.74, seagrass χ^2=17.57, and proximity to land χ^2= 19.69).

One variable not included in this model, but likely has an impact on manatee distribution, is human disturbance. Unfortunately, there was no dataset available to indicate locations of human disturbance. It should be expected that high amounts of human disturbance will decrease the abundance of manatees in an area.

Worthy (1999) summarized the findings by Magor (1979), Powell et al. (1981), Rathbun et al. (1985) and Freeman and Quintero (1990) and found that manatee distribution and abundance had not changed significantly from 1978 to 1990; however Worthy's study did not include data from (GMI 2001, 2003) or Reid (1993, 1994, 1995, 1996) who showed a much greater use of the southern shore than previously thought. Whether the difference found is a result of changes in sampling effort (the Navy did not allow as many surveys on the eastern portion of the island as they did on the western portion) or an actual change in the distribution of manatees over time is unknown. Data examined by Worthy is provided in Table 11.2. In addition, data available from GMI (2001, 2003) have been appended.

Worthy (1999) did not discuss differences in percent of manatee calves seen among surveys. In 1978, Magor (1979) observed that 25% of all sighted manatees were calves. Surveys conducted after 1978 found between 3.2% and 0.6% of manatees were calves (Table 11.2). This inconsistency may be due to unequal survey effort. Rathbun et al. (1985) showed a greater percentage of calves on the western side of the island, especially the northwest of Vieques. Due to military restrictions most of Magor's survey was conducted on the western side of the island. The presence of calves has led to the suggestion that the waters around Vieques may be an important nursery ground for manatees (Mignucci-Giannoni et al. 2000).

Table 11.2. A summary of manatee statistics from surveys conducted around Vieques. * Data provided in table corresponds to range of values of segments in Rathbun et al. (1985).

Survey Year(s)	Reference	Sightings	Surveys	Sightings/ Survey	Sightings / flight hour	% Calves
1978	Magor 1979	40	28	1.4	0.62	25
1976-1979	Powell et al. 1981	17	10	1.7	Not Available	Not Available
1984-1985	Rathbun et al. 1985	161-0*	49-18*	3.2-0*	Not Available	7.6
1989-1988	Freeman and Quintero 1990	7	8	0.9	Not Available	0
2000-2001	GMI 2001	33	51	0.6	0.46	3
2000-2001	GMI 2003	114	71	1.6	Not Available	4

12.5 ECOLOGICAL LINKAGES

Cetaceans and West Indian manatees found near Vieques are not permanent residents of that island alone and thus have population linkages to other areas. Many cetaceans, such as the Humpback whale, migrate from feeding areas in the Atlantic (NMFS 1991) and the West Indian manatee is known to travel between Vieques and the Cape Hart Sewage Treatment plant on Puerto Rico (e.g., Reid 1993). Consequently, impacts to marine mammal populations near Vieques will affect connected areas and vice versa.

Cetaceans are clearly associated with bathymetry. Several dolphin and whale species, such as the Humpback whale (Mignucci-Giannoni 1998), are associated with shallow areas on the insular shelf; other species, such as the Sperm Whale (e.g., Rice 1989, Watson 1981), are associated with the shelf edge and open ocean. A zoogeographical analysis of cetaceans off Puerto Rico, including Vieques, and the U.S. Virgin Islands by Mignucci-Giannoni (1998) showed correlations between species spatial distributions and bathymetric complexity.

Since the West Indian manatee is an obligate herbivore it is tightly linked to seagrass habitats. Several studies have shown the influence of seagrass composition and distribution on manatee distribution and vice versa (e.g., Magor 1979; Powell et al. 1981; Freeman and Quintero 1990; Reid 1993).

It has also been shown that manatees can influence seagrasses. Diaz (1992) found that feeding scars produced by manatees as they feed could affect seagrass succession, algae composition, especially *Halimeda incrassata*, and seagrass productivity levels. Due to their dependence on seagrass beds, manatees are indirectly affected by factors that influence seagrass distribution, including changes to water temperature, turbidity and hydrodynamics (see Chapter 6: Seagrass and Algae).

LITERATURE CITED

Diaz, CA. 1992. Status, distribution and population assessment of the Antillean Manatee at Roosevelt Road and Vieques Island Naval Stations. Final Report to the Navy.

Domning, DP and LC Hayek. 1986. Interspecific and intraspecific morphological variation in manatees (Sirenia:TRichechus). Marine Mammal Science 2: 87-144.

Erdman, DS. 1970. Marine mammals from Puerto Rico to Antigua. Journal of Mammology 51(3): 636-639.

Erdman, DS, J Harms and MM Flores. 1973. Cetacean records from the northeastern Caribbean region. Cetology 17:1-14.

Freeman, J and H Quintero. 1990. The Distribution and Status of the West Indian Manatee (Trichechus manatus) in Roosevelt Roads Naval Station and Vieques, Puerto Rico. U.S. Fish and Wildlife Service, Atlanta, GA.

Garcia-Rodriguez, AI, BW Bowen, D Domning, AA Mignucci-Giannoni, M Marmontel, RA Montoya-Ospina, B Morales-Vela, M Rudin, RK Bonde and PM McGuire. 1998. Phylogeography of the West Indian Manatee (*Trichechus manatus*): How many populations and how many taxa? Molecular Ecology 7: 1137-1149.

GMI (Geo-Marine, Inc.). 2001. Biological Assessment for Continuing Training Activities on the Inner Range Vieques, Puerto Rico. Report prepared for the Naval Facilities Engineering Command. 415 pp.

GMI (Geo-Marine, Inc.). 2003. Navy Lands on Vieques: Integrated Natural Resources Management Plan. Report prepared for the Naval Facilities Engineering Command. 285 pp.

Harmer, SF. 1923. Cervical vertebrae of a gigantic blue whale from Panama. Proceedings of the Zoological Society of London 1923: 1085-1089.

Lefebvre, LW, TJ O'Shea, GB Rathbun and RC Best. 1989. Distribution, status, and biogeography of the West Indian manatee. pp. 567-610. In: Woods, CA, ed. Biogeography of the West Indies. Sandhill Crane Press, Gainesville, FL.

Magor, DM. 1979. Survey of the Caribbean Manatee, *Trichechus manatus*, L. on Vieques Island, Puerto Rico. Unpublished report to the U.S. Navy. 58 pp.

Mattila, DK and PJ Clapham. 1989. Humpback whales and other cetaceans on Virgin Bank and in the northern Leeward Islands, 1985 and 1986. Canadian Journal of Zoology 67: 2201-2211.

Mignucci-Giannoni, AA. 1990. Manatee mortality in Puerto Rico: urgent need for assessment and preventative action. Whale Watcher 24: 10-12.

Mignucci-Giannoni, AA. 1996. Marine mammal strandings in Puerto Rico and the United States and British Virgin Islands. PhD thesis. Department of Marine Sciences, University of Puerto Rico, Mayaguez, Puerto Rico.

Mignucci-Giannoni, AA and CA Beck. 1998. The Diet of the Manatee (*Trichechus manatus*) in Puerto Rico. Marine Mammal Science 14:394-397.

Mignucci-Giannoni, AA, B Pinto-Rodríguez, RA Montoya-Ospina, NM Jiménez-Marrero, MA Rodríguez-López, EH Williams, DK Odell. 1999. Cetacean strandings in Puerto Rico and the Virgin Islands. Journal of Cetacean Research and Management 1(2): 191-198.

Mignucci-Giannoni, AA, MC Cardona-Maldonado, MC Ortíz-Rivera, MA Rodríguez-López, and GM Toyos-González. 2000. Censos poblacionales de mamíferos y tortugas marinas en aguas adyacentes a la Isla de Vieques, Puerto Rico [Spanish]. Laboratory of Marine Mammals of the Caribbean, Department of Sciences and Technology and School of Environmental Matters, Metropolitan University, San Juan, Puerto Rico. pp. 28-36.

Mignucci-Giannoni, AA and DK Odell. 2001. Tropical and subtropical records of hooded seals (*Cystophora cristata*) dispel the myth of extant Caribbean monk seals. Bulletin of Marine Science 68(01) 47-58.

NMFS (National Marine Fisheries Service) 1991. Recovery plan for the Humpback whale (*Megaptera navae-angliae*). Prepared by the Humpback Whale Recovery Team for the National Marine Fisheries Service, Silver Spring, Maryland.105 pp.

O'Shea, TJ, CA Beck, RK Bonde, HI Kocjman and DK Odell. 1985. An analysis of manatee mortality patterns in Florida, 1976-1981. Journal of Wildlife Management 49: 1-11.

O'Shea, TJ, GB Rathbun, RK Bonde, HI Kocjman and DK Odell. 1991. An epizootic of Florida manatees associated with dinoflagellate bloom. Marine Mammal Science 7: 163-179.

O'Shea, TJ, BB Ackerman and HF Percival. 1995. Introduction In: Population Biology of the Florida Manatee (eds. O'Shea, TJ, BB Ackerman and HF Percival), pp1-5. National Biological Service Information and Technical Report 1, U.S. Department of the Interior, Washington D.C.

Powell, JA, DW Belitsky and GB Rathbun. 1981. Status of the West Indian Manatee (Trichechus manatus) in Puerto Rico. Journal of Mammalogy 62:642-646.

Rathbun, GB, T Carr, N Carr and CA Woods. 1985. The Distribution of Manatees and Sea Turtles in Puerto Rico, with Emphasis on Roosevelt Roads Naval Station. National Technical Information Service, Springfield VA. 83 pp.

Reid, JP. 1993. 1993 Annual Report on the Radiotelemetry of Manatees in Puerto Rico. Unpublished report to the U.S. Navy. 24 pp.

Reid, JP. 1994. 1994 Annual Report to the U.S. Navy on the Radio-Tracking Of Manatees at Roosevelt Roads, Naval Station, Puerto Rico. Unpublished report to the U.S. Navy. 5 pp.

Reid, JP. 1995. 1995 Annual Report to the U.S. Navy on the Radio-Tracking Of Manatees at Roosevelt Roads, Naval Station, Puerto Rico. Unpublished report to the U.S. Navy. 7 pp.

Reid, JP. 1996. 1996 Annual Report to the U.S. Navy and Naval Station Roosevelt Roads on Manatee Studies in Eastern Puerto Rico. Unpublished report to the U.S. Navy. 7 pp.

Rice, DW. 1989. Sperm whale *Physeter macrocephalus* Linnaeus, 1758. pp.177-233. In: S Ridgway and R Harrison (eds.) Handbook of marine mammals, Vol 4. River dolphins and Larger toothed whales. Academic Press, San Diego.

Roden, CL and KD Mullin. 2000. Sighting of cetaceans in the northern Caribbean Sea and adjacent waters, Winter 1995. Caribbean Journal of Science 36(3-4): 280-288.

Swartz, SL and C Burks. 2000. Cruise results: Windwards Humpback whale (*Megaptera novaeagliae*) survey. NOAA Technical Memorandum NMFS-SEFSC 438. 30 pp.

Swartz, SL, A. Martinez, and J Stamates, C Burks and AA Mignucci-Giannoni. 2002. Acoustic and visual surveys of cetaceans in the waters of Puerto Rico and the Virgin Islands: February – March 2001. NOAA Technical Memorandum NMFS-SEFSC- 463. 62 pp.

Swartz, SL, T Cole, MA McDonald, JA Hildebrand, EM Oleson, A Martinez, PJ Clapham, J Barlow and ML Jones. 2006. Acoustic and visual survey of humpback whale (Megaptera novaeangliae) distribution in the eastern and southeastern Caribbean Sea. Caribbean Journal of Science 39:195-208.

Thornback, J and M Jenkins. 1982. Caribbean manatee In Red Data Book, Vol I, pp.429-438. Mammalia, International Union for Conservation of Nature and Natural Resources, Morge, Switzerland.

Watson, L. 1981. Sea guide to whales of the world. E.P. Dutton, New York 302 pp.

Worthy, GAJ. 1999. Ecology and distribution of the West Indian manatee in the waters around Puerto Rico, with emphasis on Vieques Island. Report prepared for Commander, Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia under Contract Number N62470-91-D-1160.

CHAPTER 12: SEABIRDS

12.1 OVERVIEW

At least 16 species of seabirds are known to occur on Vieques. Some species breed on Vieques, while others are non-breeding residents, winter migrants and accidental strays. Much of the information about seabirds of Vieques is concentrated on two species: the Caribbean Brown Pelican (*Pelicanus occidentalis occidentalis*) and the Roseate Tern (*Sterna dougallii*). Both are currently protected under the Endangered Species Act (ESA) and an analogous commonwealth statute.

Image 12.1. Brown booby (*Sula leucogaster*) offshore of Vieques. Photo: D. Gemmill.

Several major seabird nesting, roosting and feeding sites have been identified by various ornithological surveys. The majority are found close to shore among fringing mangroves, isolated islets, inaccessible limestone cliffs and shoreline lagoons. There is also a concentration of these sites on the southern coast relative to the rest of the island.

Cayo Conejo is an important nesting site for several species of birds, including the Caribbean Brown Pelican and Roseate Tern. This nesting site comprises the majority of the nesting pelican population in Puerto Rico and a significant proportion of the nesting population in the Caribbean. Other significant nesting sites include Punta Este, Ensenada Sombe and Punta Ferro. A major roosting site for Magnificent Frigatebirds is on Isla Chiva.

Few data exist on the population changes among years or current status of seabirds on Vieques. More attention has been paid to land birds and neo-tropical migrants, which were not included in this report. Of the few studies that exist, one found that between the 1980's and 1990's pelican counts dropped by more than 70%. The reasons for the decline could not be discerned.

12.2 SOURCES OF DATA

Sorrie (1975) and later DON (1986), GMI (2001, 2003) and Wiley (2000) provide lists of ornithological surveys conducted on Vieques. These surveys provide an inventory of seabird species found on Vieques and the surrounding islets.

The earliest reports on seabirds (i.e., Wetmore 1916; Sorrie 1975, 1978) focused on preparing an inventory of species and their habitats. Following the 1970 listing of the Caribbean Brown Pelican by the ESA, several studies assessed the status and influence of military activities on the Brown Pelican population in Vieques (DON 1979; Schreiber et al. 1981; Collazo and Klaas 1985; DON 1986; USFWS 1986; Collazo et al. 1998; GMI 2000). Although the Roseate Tern was first recorded to nest at Vieques in 1978 (Sorrie 1978) and was listed in the ESA as threatened in 1987, it has not elicited the same amount of attention.

Several data gaps exist in the available sources of data. Most notably, there is a paucity of data on population estimates for seabird species. More data exists for the Brown Pelican than any other species, but even this is discontinuous over time and there are no published reports of population estimates since 1995. Population estimates are critical for effective seabird management. A more up to date report on the status and abundance of seabirds is being written and is expected to be published in 2009 (Gemmill pers. comm.). Another significant gap is the lack of data coming from offshore. Many seabird species spend a considerable amount of time at sea, but most data comes from within 1 km of shore.

12.3 METHODS

All data sources were compiled to create an inventory of seabird species and plot all known nesting, roosting and feeding sites in ArcGIS. Most of the information on the spatial distribution of seabirds comes from descriptive surveys (Sorrie 1975, 1978; Collazo and Klaas 1985; DON 1986; Collazo et al. 1998) and used place names to identify sighting locations. In these cases, the locations were positioned as well as possible, generally in the center of a described geographic feature. Unfortunately, these descriptions did not allow area estimates.

In some reports, the authors mentioned *potential* nesting, roosting and feeding sites. These sites were communicated either through verbal reports by locals or by observation of behaviors associated with nesting. Potential sites were also mapped, and are described as such.

12.4 DISTRIBUTION, STATUS AND TRENDS

Seabirds are differentiated from other groups of birds, such as landbirds and shorebirds, by their regular use of the open sea for feeding; however they are bound to land for reproduction and roosting. While on land, most seabirds are typically found in habitats close to shore and where human disturbance is minimal. On Vieques most seabird sightings are among or near fringing mangroves, small isolated islets and shoreline lagoons.

At least 16 species of seabirds have been observed on the Island of Vieques and adjacent islets (Sorrie 1978; DON 1986; GMI 2001; Gemmill pers.comm.). GMI (2003, 2006) included the Arctic Tern (*Sterna paradisaea*) and Common Tern (*Sterna hirundo*); however these species have not been sighted by others and they did not provide a sighting location. Some reports include the American Oystercatcher as a seabird (e.g. GMI 2001), but it is considered a shorebird in this report, because it does not feed at sea. Table 12.1 provides the species inventory from all known surveys in Vieques, with the exception of the Arctic Tern, Common Tern and American Oystercatcher.

Notable exclusions to the species list include the Audobon Shearwater (*Puffinus lherminieri*), Red Footed Booby (*Sula sula*), Masked Booby (*Sula dactylatra*), Cayenne Tern (*Sterna sandvicensis eurygnathatha* or *Sterna eurygnathatha*), and Brown Noddy (*Anous stolidus*) that have been sighted on the surrounding islands of the Puerto Rican Bank or nest on the nearby island of Culebra (Furniss 1983), but have not been documented in Vieques.

Table 12.1. Inventory of seabirds on Vieques (Sorrie 1978; DON 1986; GMI 2001, 2003). Likely use of the island for each species are also provided.

Species Name	Common Name	Island Use
Order Charadriiformes		
Family Laridae		
Hydroprogne caspia	Caspian Tern	Rare Visitor
Larus argentatus	Herring Gull	Rare Visitor
Larus atricilla	Laughing Gull	Roosts
Sterna anaethetus	Bridled Tern	Temporary Resident
Sterna dougallii	Roseate Tern	Breeds
Sterna fuscata	Sooty Tern	Temporary Resident
Sterna nilotica	Gull-billed Tern	Rare Visitor
Sterna sandvicensis	Sandwich Tern	Temporary Resident
Sternula antillarum	Least Tern	Breeds
Thalasseus maximus	Royal Tern	Temporary Resident
Order Pelicanformes		
Family Fregatidae		
Fregata magnificens	Magnificent Frigatebird	Roosts
Family Pelicanidae		
Pelecanus erythrorhynchos	American white Pelican	Rare visitor
Pelecanus occidentalis occidentalis	Caribbean Brown Pelican	Breeds
Family Phaethontidae		
Phaethon aethereus	Red-billed Tropicbird	May Breed
Phaethon lepturus	White-tailed Tropicbird	Breeds
Family Sulidae		
Sula leucogaster	Brown Booby	Roosts

Many seabirds are transients although some are permanent residents. Some transients are seasonal migrants that overwinter in Vieques from areas to the north, while others are taking advantage of Vieques' strategic position between the main island of Puerto Rico and the Virgin Islands as a resting spot. Several studies have documented the transient nature of seabird populations on the island and the interconnectivity among islands of the Puerto Rican Bank (USFWS 1986; USFWS 1993).

The spatial distribution of identified nesting, roosting, and feeding sites (Figure 12.1) and use by species (Figure 12.2) are not random or homogenous. Most sites, especially nesting sites are located along the south shore of the island. Nesting sites are critical for maintaining seabird populations and are rare. Five known nesting sites and four additional potential nesting sites are distributed around the island. The locations of nesting sites are generally among isolated islets or inaccessible limestone cliffs along the southern shore. Detailed descriptions of nesting

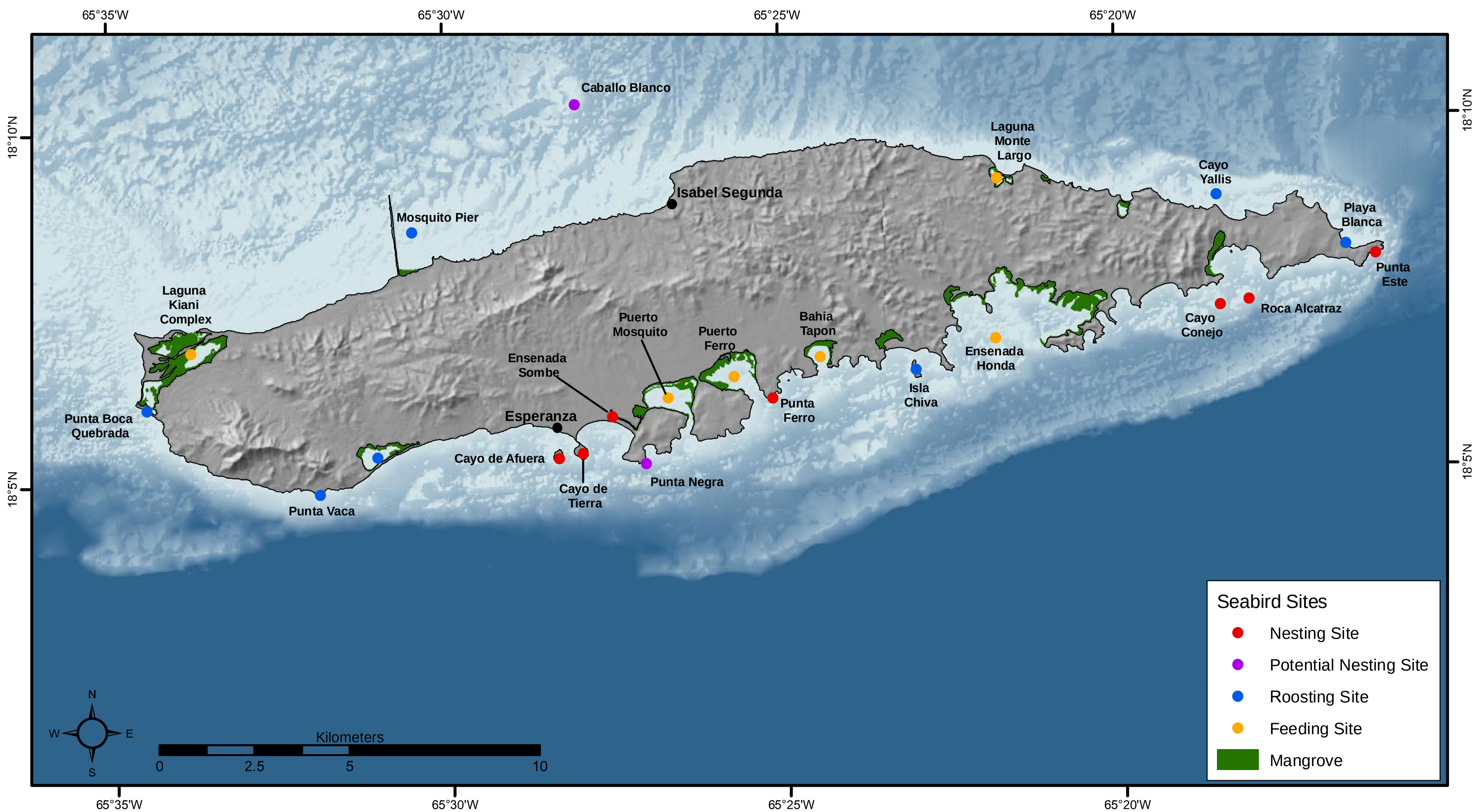


Figure 12.1. Location of seabird nesting, roosting and feeding sites on Vieques. Potential nesting sites were documented through verbal reports by locals or by observation of behaviors associated with nesting.

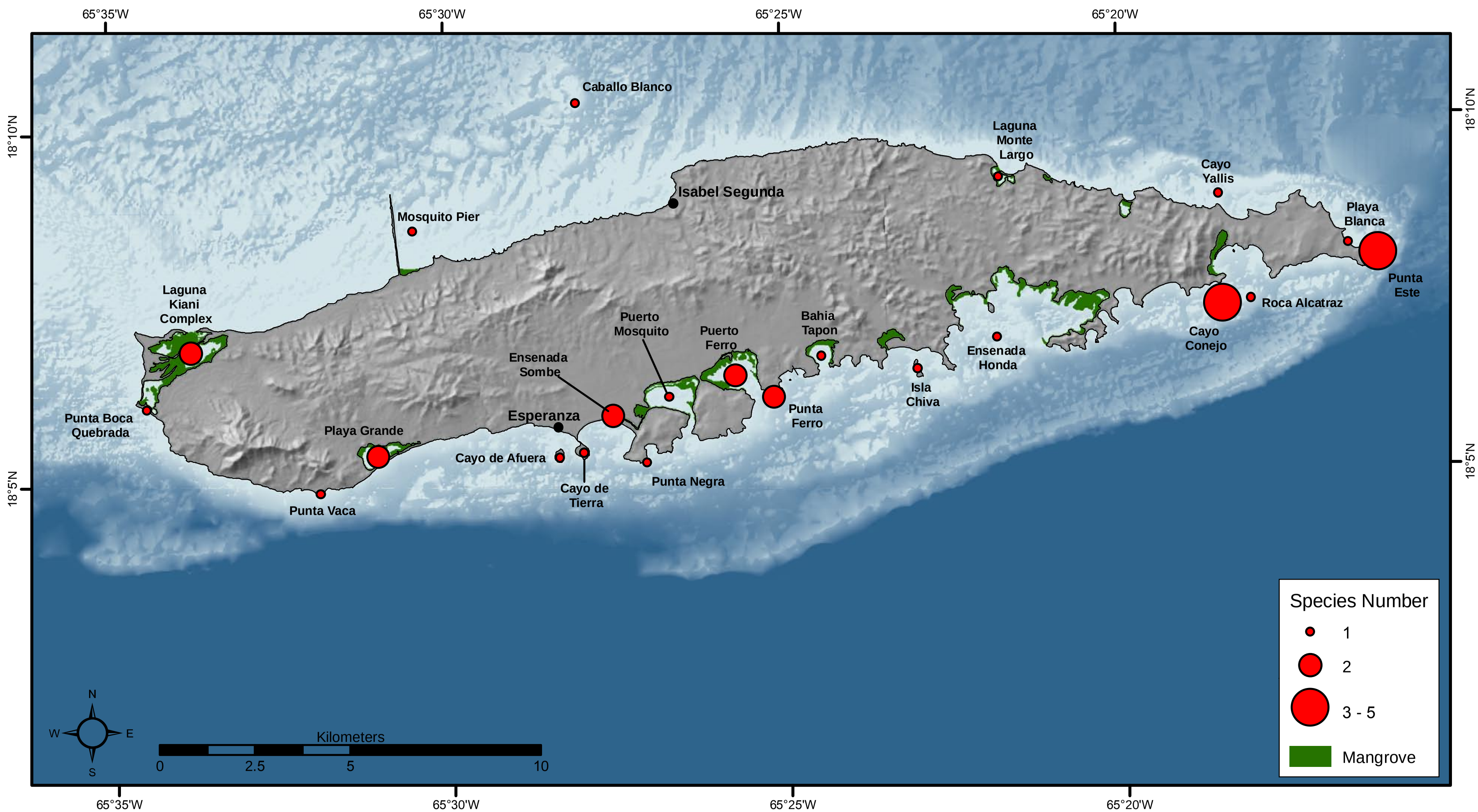


Figure 12.2. Species diversity among nesting, roosting and feeding sites on Vieques.

sites are provided by Sorrie (1974, 1978). In addition to being located where human disturbance is minimal, Raffaele (1972) mentioned that potential access by mongooses and rats may be an additional factor affecting ground-nesting birds.

Cayo Conejo, a small cay south of Bahia Salina del Sur, is likely the most important nesting site on Vieques. Five species of seabirds are known to nest on the cay, including the endangered Brown Pelican and threatened Roseate Tern (Sorrie 1978); other species include the Brown Booby (DON 1986), White-tailed Tropicbird (Sorrie 1978) and American Oystercatcher (DON 1979; Figure 12.2). Laughing Gulls have also been observed roosting there (Sorrie 1978).

In the 1970s and 1980s Cayo Conejo was a major nesting site for the endangered Caribbean Brown Pelican population. Schreiber reported (1978) as many as 100 breeding pairs at the nest site. This number comprised the majority of the Brown Pelican nesting population in Puerto Rico, and an estimated 7% of all nesting Brown Pelicans in the West Indies (Schreiber 1999). More recent data suggest the nesting population has declined considerably. Four recent surveys of Cayo Conejo in 2007 and 2008 found only 8 nests and a maximum of 20 adults (Gemmill pers. comm.). Only two other Brown pelican nesting sites, Montalva Bay and Anasco Bay, are known to exist in Puerto Rico and they are over 100 km to the west. In the past, two other pelican nesting sites are thought to have existed on Vieques (Roca Alcatraz and Caballo Blanco; Schreiber 1978; Wetmore 1916), but they have since been abandoned. Schreiber (1999) suggested the principle reason for Brown pelican success on Cayo Conejo was restricted human access. From the 1950's to 2003 the cay was within the AFTWTF and access was restricted. The recent decline could be due to natural breeding fluctuations or increased human disturbance.

On the far eastern tip of Vieques, White-tailed Tropicbirds (DON 1986) and Roseate Terns (GMI 2001) have been observed nesting among the inaccessible limestone cliffs of Punta Este. White-tailed Tropicbirds have also been found nesting at Punta Ferro and Least Terns at Ensenada Sombe (Sorrie 1978). Potential nesting sites for Bridled Terns and Red-billed Tropicbirds are located at Punta Negra (Sorrie 1978) and at Cayo de Afuera (Sorrie 1975), respectively.

In addition to using Vieques for nesting, many of the isolated mangrove lagoons, beaches, offshore cays, and rocky coastlines are used for roosting. These sites are critical to seabirds, because they need safe areas to preen, rest, and sleep (Schreiber and Chovan 1986; Schreiber 1999). In general, roosting has been observed where human disturbance is low. Sorrie (1978), GMI (2001) , Collaza (1985) and Gemmill (pers. comm.) have identified numerous roosting sites distributed over the island and the species found at each (Figures 12.1, 12.2). Traditional roosting sites for Brown Pelicans include rocky outcrops near Punta Vaca and Punta Boca Quebrada and the pilings at Mosquito Pier. Several additional major roosting sites such as Cayo Yallis, Cayo Conejo, and Punta Este are utilized by multiple species. A major frigatebird roosting site has been found on Isla Chiva.

USFWS (1986) and GMI (2000) provide vital information on where the Brown Pelican feeds around Vieques and what habitat characteristics are important. Generally pelicans are observed feeding near fringing mangroves in bays and lagoons, including the Laguna Kiani complex and Laguna Monte Largo (USFWS 1986; GMI 2000) or around Mosquito Pier. Other areas used by pelicans include Puerto Mosquito, Puerto Ferro, Bahia Tapon and Ensenada Honda. Large aggregations of pelicans are observed around the western and northwestern portions of the island.

Population assessments of the Brown Pelican in Puerto Rico (including Vieques) and for only Vieques were prepared by Collazo et al. (1998) and Schreiber (1999), respectively. Collazo et al. (1998) found significant declines from 1980-1982 to 1993-1995 in mean winter counts and lower mean young per nest. They did not provide a reason for these changes, but indicated pesticides or habitat loss were not likely causes. Schreiber (1999) could not find evidence that showed the military presence on Vieques harmed brown pelicans and noted that the restriction of civilian access to Cayo Conejo was likely the only reason birds, including the Brown Pelican, still bred on the island. As mentioned earlier more recent data suggests the Brown Pelican may use Cayo Conejo less.

Few population assessments on other species, including the Roseate Tern, exist. For instance, despite its listing in the ESA, only two surveys have observed the Roseate Tern on Vieques (Sorrie 1978; GMI 2003). This lack of information is in part due to the lack of surveys, but also some species' rarity. In addition, surveys have predominantly focused on individuals over land and many seabird species spend significant amounts of time at sea.

Many species of seabirds found in the Caribbean are endemic and most are represented by only several thousand nesting pairs. Consequently, the loss of any individuals or habitat is significant. Most seabirds are long-lived, have deferred maturity and low reproductive rates. The combined result is that seabirds are slow to recover from disturbance. Several species found on Vieques are considered endangered, threatened or vulnerable at federal and territorial levels. Coastal development, the introduction of predators, disease, predation by man, and human disturbance of nesting sites are the principle stressors (Halewyn and Norton 1984; Schreiber and Lee 2000).

All 16 species are listed under the US Migratory Bird Treaty Act. This act was implemented to terminate population declines due to extensive commercial trade of birds and their feathers, and grants full protection to birds on the list. In addition, to increase regional conservation awareness and inform management decisions several species watchlists have been produced (see Table 12.2). In 1973, the USDA in partnership with Puerto Rico's Department of Natural and Environmental Resources created a watchlist of rare and endangered species in Puerto Rico (USDA 1973). The watchlist included 5 endangered species. Decades later, Schreiber (2000) prepared an action plan for conservation of West Indian seabirds and listed seven species. Most recently, the USFWS (2002) listed 6 species as species of conservation concern. Although these lists are not associated with any legal statutes they provide the most up-to-date assessment of species status in the region.

Table 12.2. Conservation status in Endangered Species Act and territorial Regulation 6766, and summary of watchlist for species of concern. Number of nesting pairs given for Schreiber and Lee (2000).

Species	USDA/DNER 1973	Schreiber and Lee 2000	USFWS 2002	ESA	Regulation 6766	Number of Pairs
Brown Pelican	Undetermined	Endangered		Endangered	Endangered	1500±
Royal Tern	Endangered	Endangered				450-800
Roseate Tern	Endangered			Threatened	Vulnerable	
White-tailed Tropicbird		Vulernable	Conservation Concern			2500-3500
Red-billed Tropicbird	Endangered	Vulnerable	Conservation Concern			1800-2500
Sandwich Tern	Endangered	Vulnerable				2100-3000
Least Tern	Endangered	Vulnerable	Conservation Concern		Data Deficiency	1500-3000
Brown Booby			Conservation Concern			
Magnificent Frigatebird		Near Threatened	Conservation Concern			4300-5300

The Brown Pelican and Roseate Tern were listed in the ESA in 1970 and 1987, respectively. The Brown Pelican was listed as endangered due to severe population losses in the continental U.S. from pollutants (Collazo and Klaas 1985). The Roseate Tern was listed as threatened due to exploitation for the millinery (hat) trade and habitat competition with seagulls. Although knowledge of their distribution in Puerto Rico existed at these times, the impetus for their listings was associated with declines in continental populations.

Listing in the ESA offers significant protections to species, however protection is afforded only in areas within federal jurisdiction. Only parts of Vieques fall within U.S. jurisdiction; the remainder is governed by commonwealth laws. In 1978 the governor of Puerto Rico sued DON for violating a number of laws including the ESA (Barcelo vs. Brown, 478 F. Supp. 646 [13 ERC 2105], DPR 1979). Since the lawsuit, DON focused ecological investigations on species listed in the ESA.

In 2004, using information from the territorial and federal reports listed above, the Department of Natural and Environmental Resources listed the Brown Pelican as endangered, the Roseate Tern as vulnerable, and the Least Tern as data deficient (DNER 2004) in Regulation 6766. This regulation is the commonwealth's equivalent of the ESA and offers these species considerable protection.

12.5 ECOLOGICAL LINKAGES

Seabirds are intimately connected to the sea from which they usually obtain food, and the land on which they nest and roost. Several ecological characteristics, including flora and geology, are important at nesting, roosting and feeding sites. Sorrie (1974, 1978) and USFWS (1986) describe the ecological characteristics of these important sites. As with most other information, much of the data is for Caribbean Brown Pelicans.

Nests have been found among the limestone cliffs and at Cayo Conejo, both of which are difficult for humans to access (Sorrie 1975, 1978; USFWS 1986). Similar islets with more frequent human disturbance do not possess nests. These findings suggest that ecological characteristics (e.g., steep slopes, barrier reef) that restrict human access are critical to nesting seabirds. Sorrie (1978) suggests many of the seabirds observed on Vieques are there because of the military's restrictions that have minimized human disturbance, especially among nesting sites.

Image 12.2. Royal tern (*Thalasseus maximus*) offshore of Vieques. Photo: D. Gemmill.

GMI (2000) examined the impact of military activity on Brown Pelican behavior on Cayo Conejo. Their findings suggest adults may be habituated to noise levels associated with military activities, however they saw young pelicans exhibit a startle response during the initial stages of a bombardment exercise.

Brown Pelicans generally place nests above the ground and consequently require vegetation at nesting sites. This strategy decreases the risk of predation and flooding. At Cayo Conejo nests are placed in *Coccoloba uvifera* (sea grape), *Capparis flexuosa* (falseteeth), and *Pithecellobium unguis-cati* (cat's claw) (Collazo et al. 1998). These plant species are commonly used at other nesting sites in Puerto Rico and the Virgin Islands (USFWS 1986).

On Vieques, pelican roosting sites are generally found in or on fringe mangrove forests, especially red mangrove (*Rhizophora mangle*) that border protected bays and coves and overwash stands on islets (USFWS 1986; see Chapter 7: Mangroves). USFWS (1986) describes alternative locations where pelicans are known to roost and loaf in the rest of Puerto Rico and Virgin Islands. Roosting locations are generally remote to ensure human interference is kept at a minimum. Sorrie (1978) suggests that roosting islets with ecological traits similar to Cayo Conejo, such as Cayo Chiva, could serve as potential nesting sites if human access were completely restricted.

Large aggregations of Brown Pelicans have been sighted feeding along the western and northwestern portions of the island (Schreiber et al. 1981). Feeding has also been consistently seen in several bays along the southern coast (DON 1979; DON 1986). These areas share several traits in common: they are close to roosting sites, they are near large areas of mangroves and they are sheltered. Along with an abundant supply of food, it is expected that these ecological traits are all important for Brown Pelican feeding sites.

LITERATURE CITED

Collazo, JA and EE Klass. 1985. Status and Ecology of the Brown Pelican in the Greater Puerto Rican Bank Region. Iowa Cooperative Fish and Wildlife Research Unit, Iowa State University. 200 pp.

Collazo, JA, T Agardy, EE Klaas, JE Saliva and J Pierce. 1998. Interdecadal comparison of Population Parameters of Brown Pelicans in Puerto Rico and the U.S. Virgin Islands. Colonial Waterbirds 21(1): 61-65.

DNER (Department of Natural and Environmental Resources). 2004. Reglamento para regir las especies vulnerables y en peligro de extinción en el Estado Libre Asociado de Puerto Rico. Departamento de Estado Número Reglamento 6766. ELA, DRNA, San Juan, PR 60 pp.

DON (U.S.Department of the Navy). 1979. Draft Environmental Impact Statement for the Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

DON (U.S. Department of the Navy). 1986. Environmental Assessment of Continued Use of the Atlantic Fleet Weapons Training Facility Inner Range, Vieques, Puerto Rico. Prepared by Ecology and Environment, Inc.

Furniss, S. 1983. Status of the seabirds of the Culebra archipelago, Puerto Rico. Colonial Waterbirds 6: 121-125.

GMI (Geo-Marine, Inc.). 2000. Caribbean Brown Pelican behavioral responses to joint force exercise on Vieques Island Puerto Rico. Report prepared for the Naval Facilities Engineering Command and U.S. Naval Station Roosevelt Roads. 16 pp.

GMI (Geo-Marine, Inc.). 2001. Biological assessment for continuing training activities on the Inner Range, Vieques, Puerto Rico. Report prepared for the Naval Facilities Engineering Command. 415 pp.

GMI (Geo-Marine, Inc.). 2003. Navy Lands on Vieques: Integrated Natural Resources Management Plan. Report prepared for the Naval Facilities Engineering Command. 285 pp.

GMI (Geo-Marine, Inc.). 2006. Final biological assessment for the former Live Impact Area within the former Vieques Naval Training Range. Prepared for CH2MHill and the Naval Facilities Engineering Command. 157 pp.

Raffaele, HA. 1972. Section 10: Fauna. In: Vieques 1972 Survey of the Natural Resources. Environmental Quality Board, Commonwealth of Puerto Rico, Office of the Governor.

Schreiber, EA. 1999. Brown Pelicans on Vieques, Puerto Rico: Assessment of Status and Summary Report of Literature. Report prepared for the Naval Facilities Engineering Command.

Schreiber, EA. 2000. Action plan for conservation of West Indian seabirds. pp. 182–191 in Schreiber, EA and DS Lee (Eds.), Status and conservation of West Indian seabirds. Society of Caribbean Ornithology, Special Publication No. 1. Ruston, Louisiana.

Schreiber, EA and DS Lee. 2000. West Indian seabirds: a disappearing natural resource. Pp. 1-10 in Schreiber, EA, and DS Lee (Eds.), Status and Conservation of West Indian Seabirds. Society of Caribbean Ornithology, Special Publication No. 1. Ruston, Louisiana.

Schreiber, RW. 1978. The Brown Pelican in Isla Vieques, Puerto Rico: a preliminary analysis of its population status. Report submitted to the Deptartment of the Navy.

Schreiber, RW, DW Belitsky and BA Sorrie. 1981. Notes on Brown Pelicans in Puerto Rico. Wilson Bulletin 93(3): 397-400.

Schreiber, RW and JL Chovan. 1986. Roosting by pelagic seabirds: energetic, populational and social considerations. The Condor 88(4) 487-492.

Sorrie, B. 1975. Observations on the Birds of Vieques Island, Puerto Rico. Caribbean Journal of Science 15(1-2): 89-103.

Sorrie, B. 1978. Draft report on the birds of Vieques Island, Puerto Rico – 1978. Unpublished Report to the Navy. 31+ pp.

USDA (United States Department of Agriculture). 1973. Rare and endangered animals of Puerto Rico: A committee report. USDA Soil Conservation Service in cooperation with the Department of Natural Resources of the Commonwealth of Puerto Rico.

USFWS (United States Fish and Wildlife Service). 1993. Caribbean Roseate Tern Recovery Plan. Prepared by J. Saliva for the U.S. Fish and Wildlife Service, Atlanta, Georgia, 40 pp.

USFWS (United States Fish and Wildlife Service). 1986. Caribbean Brown Pelican Recovery Plan. Prepared by J.A. Collazo and E.E. Klass for the U.S. Fish and Wildlife Service, Atlanta, Georgia, 40 pp.

Van Halewyn, R and RL Norton. 1984. The status and conservation of seabirds in the Caribbean. pp. 169-222. In: JP Croxall, H Evans and RW Schreiber, Eds., Status and Conservation of the World's Seabirds International Council for Bird Preservation Technical Publication 2.

Wetmore, A. 1916. The birds of Vieques Island, Puerto Rico. Auk 33: 403-419.

Wiley, JW. 2000. A bibliography of seabirds in the West Indies. In Status and Conservation of West Indian Seabirds. Eds. E.A. Schreiber and D.S. Lee. Society of Caribbean Ornithology, Special Publication Number 1, Ruston, LA.

CHAPTER 13: DATA GAPS AND RECOMMENDATIONS FOR MONITORING

This ecological characterization report is a compilation and integration of known data and information on the marine resources of Vieques. A concerted effort was made to locate all relevant and recent information for each topic; however, in many instances a limited number of studies have been conducted. Further, data have often been collected in particular areas to address certain objectives and as such, may not be representative of the island as a whole. For example, much of the data on habitats and associated biological communities have been collected in the former Navy areas on the east end of the island by the military or its contractors. The purpose of this section is to highlight data gaps and future research needs that would provide managers with more complete information with which to manage natural resources.

Much of the information on the physical environment of Vieques is dated or inferred from nearby islands. For instance, the collection of climatological data has historically been inconsistent on Vieques, and currently, there is no NOAA weather station located on the island. The recent addition of a Remote Automated Weather Station (RAWS) owned by the Fish and Wildlife Service, will help to fill in this gap. However, due to the spatial diferences in rainfall and temperature across the island (i.e., east vs. west, inland vs. coastal), additional weather stations are recommended. In addition, the closest maritime data buoys, which measure oceanographic parameters, are located in the USVI and offshore of the main island of Puerto Rico. Although regional current patterns have been modeled, data on small scale patterns around Vieques is not available. This information would benefit multiple research areas (e.g., larval transport) and would enhance predictions of the behavior of land-based sediment and pollutant runoff.

Available depth soundings data were sufficient to generate a nearshore, island-wide bathymetry map, but due to the age of the data, coarse spacing of the depth soundings, and gaps in the spatial extent of data collection, it is likely that some features (e.g., small patch reefs), were not captured. The map would benefit from new, fine-scale bathymetric data that would enable the bathymetry to be mapped at a higher resolution. This could be accomplished in shallow areas by additional LIDAR data, and in deeper areas by additional remote sensing technologies (e.g., multibeam sonar).

Benthic habitat maps are necessary to describe and monitor changes in the distribution of marine habitats, and are the foundation for designing and stratifying field surveys. The most recent habitat map around Vieques, based on 1999 aerial photography, will be updated in Part II of this report in order to fill in existing gaps in the map and analyze any recent changes in habitat distribution. Other anticipated improvements include a smaller minimum mapping unit and a more detailed classification scheme. Aerial imagery should periodically be collected to re-evaluate changes in the distribution and condition of habitats. In addition, a characterization of deep reef habitats around Vieques, which have received little attention to date, is needed.

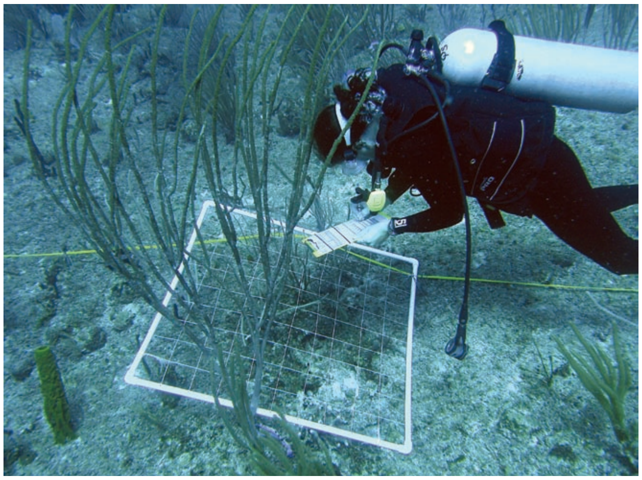


Image 13.1. Diver collecting benthic habitat data. Photo: Biogeography Branch.

Island-wide field assessments of coral reef/hardbottom, seagrass, and mangrove habitats and their associated biological communities are rare, as most historical studies have focused on either military areas or non-restricted locations offshore of the municipality. Data on mangrove communities, including mangrove species zonation and associated fauna, is particularly lacking for most areas. A number of fish species, lobster, and conch are commercially exploited, but insufficient data exists on the population levels and size distribution of these species and the amount of fishing effort taking place. Large fish aggregations are common along the insular shelves of nearby islands, but few data exist for Vieques. Although landings data are available for the reef fish, conch and lobster fisheries, information on reporting compliance is deficient. In addition, there is no information on the size distribution of the landings, and the species composition of reef fish landings is unknown. These data are crucial in order to manage and conserve ecologically and commercially sustainable populations.

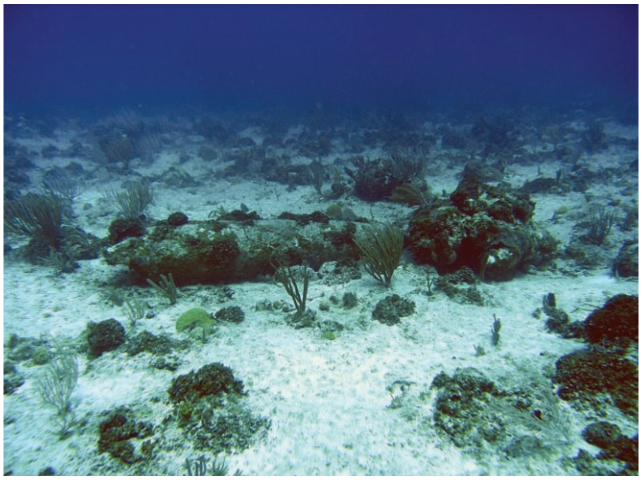


Image 13.2. Unexploded ordnance offshore of Vieques. Photo: Biogeography Branch.

The recent establishment of permanent monitoring sites on reefs on the east end and west end areas provide a foundation for which to assess changes in the coral and fish communities at these locations. An island wide, stratified random survey would compliment the data from the permanent sites. Results from a 2007 survey of reef/hardbottom fish and habitats will be presented in Part II of this assessment and will serve as a baseline. This fishery-independent data provides managers with population estimates and size-spectra information of fished species. Regular monitoring using a consistent sampling design and survey methods is necessary to assess temporal trends in fish community and fishery metrics. A similar effort should be made to include soft-bottom, deep reef and mangrove habitats in a long-term fish monitoring program.

In general, there is a lack of quantitative spatial data on seabirds, marine mammals, and turtles that can be used for population estimation. Consistent, spatially comprehensive monitoring is necessary to assess the abundance of all three groups. Also, little is known of their connectivity to other areas. This information is critical to managers. To date, most seabird survey efforts have been devoted to the Caribbean Brown Pelican, due to its designation by the Endangered Species Act. Known nesting, roosting, and feeding sites should continue to be monitored, and efforts should be expanded to include additional bird species, including the endangered Roseate Tern. Monitoring data for migrant bird species is also deficient. Fine-scale data on cetacean distribution and abundance in the local waters around Vieques is needed, and continued manatee tracking and monitoring is warranted. Programs such as the Sea Turtle Conservation Project of Vieques should continue with consistent survey efforts.

Anthropogenic practices on land can influence marine resources through runoff of sediments, nutrients, and pollutants. The impact of military or civilian activities on marine habitats, flora and fauna has usually been described in qualitative terms or has been tenuous. A detailed land cover map for Vieques is available and should be updated periodically to reflect any changes in land use and vegetative cover as a result in increased development, clearing for munitions clean-up, etc.. A characterization of contaminants in sediments and corals and nutrients in coastal waters, which have historically not been quantified, has recently been conducted by NOAA's Center for Coastal Monitoring and Assessment and will be presented in Part II of the ecological assessment. With the exception of several reef locations on the east end, sedimentation rates have not been studied. The sedimentation rates and composition of delivery at stream outflow points and nearshore turbidity have not been quantified. Further, it is likely that storm events such as tropical cyclones result in higher than average outputs, but the magnitude of which this increases land-based inputs has not been determined.

As Vieques changes and grows, the need to fill in the data collection gaps and establish a baseline becomes even more important in order to effectively manage and conserve marine resources. To date, most biological data has been collected by the military or military contractors, and the departure of the Navy will leave a large void in data collection. This additional challenge will require a coordinated effort by local, commonwealth, and federal institutions to design and implement a comprehensive monitoring program. Local outreach activities, such as those conducted by the Vieques Conservation and Historical Trust and the Sea Turtle Conservation Project, should continue and be expanded in order to educate residents and visitors about the marine resources of the island.

APPENDIX A

Appendix A. A list of the fish species observed around Vieques. References refer to 1-DON (1979), 2-DON (1986), 3-GMI (2003), 4-Garcia-Sais et al. (2004), 5-Garcia-Sais et al. (2001), 6-Burke et al. (2007).

Species	Common Name	References
Abudefduf saxatilis	Seargent Major	1,2,3,4,5,6
Abudefduf taurus	Night Sergeant	1,2,4
Acanthocybium	Wahoo	2
Acanthostracion quadricornis	Scrawled Cowfish	2,3,4,5
Acanthurus bahianus	Ocean Surgeon	1,2,3,4,5,6
Acanthurus chirurgus	Doctorfish	1,2,3,4,5,6
Acanthurus coeruleus	Blue Tang	1,2,3,4,5,6
Aetobatus narinari	Spotted Eagle Ray	2,3
Alectis ciliaris	African pompano	6
Aluterus schoepfi	Orange Filefish	2,3
Aluterus scriptus	Scrawled filefish	6
Amblycirrhitus pinos	Redspotted Hawkfish	3,6
Anisotremus surinamensis	Black Margate	2,4,6
Anisotremus virginicus	Porkfish	2,3,4,5,6
Apogon binotus	Barred Cardinalfish	3
Apogon maculatus	Flamefish	1
Apogon townsendi	Belted Cardinalfish	1
Atherinidea, Clupidae & Engraulidadae	silversides, herrings, anchovies	2,6
Aulostomus maculatus	Trumpetfish	1,2,3,4,5,6
Balistes capriscus	Gray triggerfish	6
Balistes vetula	Queen Triggerfish	1,2,3,4,5,6
Bodianus pulchellus	Spotfin Hogfish	3
Bodianus rufus	Spanish Hogfish	1,2,3,4,5,6
Bothus lunatus	Peacock Flounder	1,2,3,5
Calamus bajonado	Folthead Porgy	1,2,3,5
Calamus calamus	Saucereye Porgy	3,6
Calamus penna	Sheepshead Porgy	3
Calamus pennatula	Pluma	4,5,6
Calamus sp.	Porgy	3,6
Cantherhines macrocerus	Whitespotted filefish	5
Cantherhines pullus	Tail-light Filefish	1,2,3,4,5
Canthigaster rostrata	Caribbean Puffer	1,2,3,4,5,6
Caranx bartholomaei	Yellow Jack	6
Caranx crysos	Blue Runner	1,2,3,4,5,6
Caranx lugubris	Black Jack	4
Caranx ruber	Bar Jack	1,2,3,4
Carcharhinus limbatus	Blacktip Shark	2
Carcharhinus perezi	Reef Shark	3,4
Centropomus undecimalis	Snook	2
Cephalopholis cruentatus	Graysby	1,2,3,4,6
Cephalopholis fulva	Coney	1,2,3,4,5,6
Chaetodipterus faber	Spadefish	4,6
Chaetodon aculeatus	Longsnout butterflyfish	5
Chaetodon capistratus	Foureye Butterflyfish	1,2,3,4,5,6
Chaetodon ocellatus	Spotfin Butterflyfish	3,4,5,6
Chaetodon sedentarius	Reef Butterflyfish	3,6
Chaetodon striatus	Banded Butterflyfish	1,2,3,4,5,6
Chromis cyanea	Blue Chromis	1,2,3,4,5,6
Chromis multilineata	Brown Chromis	1,2,3,4,5,6
Chromis scotti	Purple reeffish	6
Clepticus parrae	Creole Wrasse	2,3,4,5,6
Coryphaena hippuru	Dolphin-fish	2
Coryphopterus dicrus	Colon Goby	3
Coryphopterus glaucofraenum	Bridled Goby	1,2,3,4,6
Coryphopterus lipernes	Peppermint Goby	4,5
Coryphopterus personatus/hyalinus	Masked Goby	1,3,4,5,6
Coryphopterus sp.	Unknown Goby	4,5
Cryptotomus roseus	Bluelip parrotfish	6
Dactylopterus volitans	Flying gournard	2
Dasyatis americana	Southern Stingray	2,3,4,5,6
Dasyatis sp.	Stingray	3
Decapterus macarellus	Mackerel scad	5
Decapterus sp.	Scad	3,6
Diodon histrix	Porcupinefsh	1,2,3,4
Diodon holocanthus	Ballon Fish	2
Diplectrum formosum	Sand perch	6
Doratonotus megalepis	Dwarf wrasse	6
Echeneis naucrates	Sharksucker	3,4
Echidna catenata	Chain Moray	3
Elagatis bipinnulatus	Rainbow Runner	1,2,3,4
Epinephelus adscencionis	Rock Hind	1,2,3,4,6
Epinephelus guttatus	Red Hind	1,2,3,4,5,6
Epinephelus morio	Red Grouper	1
Epinephelus striatus	Nassau Grouper	1,2,3,4,5
Equetus acuminatus	High Hat	1,2,3,5
Equetus lanceolatus	Jackknife Fish	2,3,6
Equetus punctatus	Spotted Drum	2,5
Eucinostomus melanopterus	Flagfin mojarra	6
Fistularia tabacaria	Bluespotted Cornetfish	2,5
Gerres cinereus	Yellowfin Mojarra	1,2,3,4,5,6
Ginglymostoma cirratum	Nurse Shark	1,2,3,4,5,6
Gnatholepis thompsoni	Goldspot Goby	1,3,4
Gobiosoma evelynae	Sharknose Goby	2,4,5
Gobiosoma genie	Cleaning Goby	1,2,3
Gobiosoma oceanops	Neon goby	2,6
Gramma loreto	Royal Gramma	1,2,3,4,5,6
Gymnothorax funebris	Green Moray	2,3,5
Gymnothorax miliaris	Goldentail Moray	2,4
Gymnothorax moringa	Spotted Moray	1,2,3,4
Haemulon album	White Margate	1,2,3,4
Haemulon aurolineatum	Tomtate	1,2,3,4,5,6
Haemulon carbonarium	Caesar Grunt	2,3,4,5
Haemulon chrysargyreum	Smallmouth Grunt	1,2,3,4,5,6
Haemulon flavolineatum	French Grunt	1,2,3,4,5,6
Haemulon macrostomum	Spanish Grunt	1,2,3,4,5
Haemulon melanarum	Cottonwick	1,2
Haemulon plumieri	White Grunt	1,2,3,4,5,6
Haemulon sciurus	Bluestripped Grunt	1,2,3,4,5,6
Haemulon sp.	Grunts	3,4
Haemuon striatum	Striped Grunt	3,6
Halichoeres bivittatus	Slippery Dick	1,2,3,4,5,6
Halichoeres caudalis	Painted Wrasse	1,2
Halichoeres cyanocephalus	Yellowcheek wrasse	6
Halichoeres garnoti	Yellowhead Wrasse	1,2,3,4,5,6
Halichoeres maculipinna	Clown Wrasse	1,2,3,4,5,6
Halichoeres pictus	Rainbow Wrasse	3,5,6
Halichoeres poeyi	Blackear Wrasse	1,2,3,6
Halichoeres radiatus	Pudding Wife	1,2,3,4,5,6
Halichoeres sp.	Unknown Wrasse	5,6
Hemiemblemaria simulus	Wrasse blenny	6
Hemiramphus brasiliensis	Ballyhoo	2
Hetetoconger halis	Brown garden eel	6
Holacanthus ciliaris	Queen Angelfish	1,2,3,4,5,6
Holacanthus tricolor	Rock Beauty	1,2,3,4,5,6
Holocentrus adscensionis	Squirrelfish	1,2,3,4,5,6
Holocentrus rufus	Longspine Squirrelfish	1,2,3,4,5,6
Hypleurochilus bermudensis	Barred Blenny	3
Hypoplectrus aberrans	Yellowbellied Hamlet	2
Hypoplectrus chlorurus	Yellowtail Hamlet	3,4,5,6
Hypoplectrus guttavarius	Shy Hamlet	4
Hypoplectrus indigo	Indigo Hamlet	1
Hypoplectrus nigricans	Black Hamlet	1,2,3,4,6
Hypoplectrus puella	Barred Hamlet	1,2,3,4,5,6
Hypoplectrus sp.	Hamlet	3,4,5,6
Hypoplectrus unicolor	Butter Hamlet	1,2,3,4,5,6
Inermia vittata	Boga	4
Kyphosus sectatrix/incisor	Bermuda/Yellow Chub	1,2,3,5
Lachnolaimus maximus	Hogfish	1,2,3,4,5,6
Lactophrys bicaudalis	Spotted Trunkfish	2,3,4,5
Lactophrys polygonia	Honeycomb Cowfish	3,6
Lactophrys quadricornis	Scrawled trunkfish	2
Lactophrys trigonus	Trunkfish	2,5
Lactophrys triqueter	Smooth Trunkfish	1,2,3,4,5,6
Liopropoma rubre	Peppermint Bass	3
Lutjanus analis	Mutton Snapper	1,3,4,5,6
Lutjanus apodus	Schoolmaster	1,2,3,4,5,6
Lutjanus cyanopterus	Cubera snapper	6
Lutjanus griseus	Gray Snapper	2,3,4,5,6

Species	Common Name	References
Lutjanus mahogani	Mahogany Snapper	1,2,3,4,5,6
Lutjanus synagris	Lane Snapper	2,3,4,5,6
Lutjanus vivanus	Silk Snapper	2
Makaira sp.	Marlin	2
Malacanthus plumieri	Sand Tilefish	1,2,3,4,6
Malacoctenus boehlkei	Diamond Blenny	3
Malacoctenus macropus	Saddeled Blenny	3,6
Malacoctenus triangulatus	Saddled Blenny	3,4,5
Manta birostris	Manta	3
Melichthys niger	Black Durgon	1,2,3,4,5,6
Microspathodon chrysurus	Yellowtail Damselfish	1,2,3,4,5,6
Monacanthus tuckeri	Slender Filefish	3,5
Mugilidae	Mullet	2
Mulloidichthys martinicus	Yellowtail Goatfish	1,2,3,4,5,6
Mycteroperca bonaci	Black Grouper	2,3
Mycteroperca tigris	Tiger Grouper	2,4,6
Mycteroperca venenosa	Yellowfin Grouper	2
Myrichthys ocellatus	Goldspotted Eel	3
Myripristis jacobus	Blackbar Soldierfish	1,2,3,4,5,6
Neoniphon marianus	Longjaw Squirrelfish	1,2,4,5
Nes longus	Orangespotted goby	6
Ocyurus chrysurus	Yellowtail Snapper	1,2,3,4,5,6
Odontosscion dentex	Reef Croacker	3,6
Ophioblennius atlanticus	Redlip Blenny	1,2,3,4,5
Opistognathus aurifrons	Yellohead Jawfish	3,6
Opistognathus macrognathus	Banded Jawfish	3
Pempheris schomburgki	Glass Sweeper	1,2
Pomacanthus arcuatus	Gray Angelfish	1,2,3,4,5,6
Pomacanthus paru	French Agelfish	1,2,3,4,5,6
Priacanthus arenatus	Bigeye	1,2,5
Priacanthus cruentatus	Glasseye Snapper	1,2,3,4,5,6
Priolepis hipoliti	Rusty Goby	3
Pseudupeneus maculatus	Spotted Goatfish	1,2,3,4,5,6
Remora remora	Remora	2,3
Rypticus saponaceus	Greater Soapfish	2
Sargocentron coruscus	Reef Squirrelfish	1,2,3
Sargocentron vexilliarum	Dusky Squirrelfish	1
Scarus coelestinus	Midnight Parrotfish	1,2,4
Scarus coeruleus	Blue Parrotfish	1,3,5
Scarus guacamaia	Rainbow Parrotfish	1,2,3
Scarus iserti	Stripped Parrotfish	1,2,3,4,5,6
Scarus taeniopterus	Princess Parrotfish	1,2,3,4,5,6
Scarus vetula	Queen Parrotfish	1,2,4,5,6
Scomberomoru cavalla	King Mackerel	2,5
Scomberomoru regalis	Cero Mackerel	1,2,3,4,5,6
Scombridae	Mackerel	2
Seriola dumerili	Greater Amberjack	1,5
Serranus baldwini	Lantern Bass	3,6
Serranus tabacarius	Tobacco Fish	3,4,6
Serranus tigrinus	Harlequin Bass	1,2,3,4,5,6
Serranus tortugaram	Chalf Bass	3,6
Sparisoma atomarium	Greenblotch Parrotfish	3,6
Sparisoma aurofrenatum	Redband Parrotifish	1,2,3,4,5,6
Sparisoma chrysopterum	Redtail Parrotfish	1,2,3,4,5,6
Sparisoma radians	Bucktooth Parrotfish	1,2,3,4,5,6
Sparisoma rubripinne	Yelowtail Parrotfish	1,2,3,4,5,6
Sparisoma sp.	Unknown Parrotfish	3,5,6
Sparisoma viride	Stoplight Parrotfish	1,2,3,4,5,6
Sphoeroides nephelus	Southern Puffer	2
Sphoeroides splengleri	Bandtail Puffer	2,3
Sphyraena barracuda	Great Barracuda	1,2,3,4,5,6
Sphyraena gauchancho	Guanguanche	6
Sphyyrna mokarran	Great hammerhead	6
Stegastes adustus	Dusky Damselfish	1,2,3,4,5,6
Stegastes diencaeus	Longfin Damselfish	1,2,3,6
Stegastes leucostictus	Beaugregory	1,2,3,4,5,6
Stegastes partitus	Bicolor Damselfish	1,2,3,4,5,6
Stegastes planifons	Yellow-eye Damselfish	1,2,3,4,5,6
Stegastes sp.	Damselfish	3,6
Stegastes variabilis	Cocoa Damselfish	1,2,3,4,5,6
Stephanolepis setifer	Pygmy Filefish	2
Syacium gunteri	Dusky flounder	6
Synodus intermedius	Sand Diver	1,2,3,4,5,6
Synodus sp.	Unknown Lizardfish	3,5
Thalassoma bifasciatum	Bluehead Wrasse	1,2,3,4,5,6
Thunnus sp.	Tuna	2
Xanthychihys ringens	Sargassum Triggerfish	4,5
Xyrichthys matinicensis	Rosy razorfish	6
Xyrichthys novacula	Pearly Razorfish	1,6
Xyrichthys splendens	Green Razorfish	2,3,6

ACKNOWLEDGEMENTS

Numerous individuals generously shared time, information, data, and provided many helpful suggestions during preparation of this report. In particular, we wish to thank those who provided comments during review. Many thanks to the following:

Richard Appeldoorn (UPR Mayagüez, Magueyes Island Marine Laboratories)
Roy Armstrong (UPR Mayagüez, Magueyes Island Marine Laboratories)
Tim Battista (NOAA/NOS/NCCOS/CCMA, Silver Spring, MD)
Edgardo Belardo (PRNDER, Vieques, PR)
Joshua Bennett (NOAA/NMFS/SEFSC/SFD, Miami, FL)
John Burke (NOAA/NOS/NCCOS/CCFHR, Beaufort, NC)
Chris Caldow (NOAA/NOS/NCCOS/CCMA, Silver Spring, MD)
Jorge Capella (Oceanographer, UPR Mayagüez)
John Christensen (NOAA/NOS/NCCOS/CCMA, Silver Spring, MD)
Matt Connolly (USFWS, Vieques National Wildlife Refuge, Vieques, PR)
Ken Deslarzes (Geo-Marine, Inc., Plano, TX)
Ernesto Diaz (PRDNER, Marine Resources Division, Rio Piedras, PR)
Oscar Diaz (USFWS, Cabo Rojo and Laguna Cartagena National Wildlife Refuges, Boqueron, PR)
Graciela Garcia-Moliner (Caribbean Fisheries Managment Council, San Juan, PR)
Jorge “Reni” Garcia-Sais (UPR Mayagüez, Magueyes Island Marine Laboratories)
Daphne Gemmill (Wildlife Consultant, Going Birding, Inc.)
David Gilliam (NCRI, Dania Beach, FL)
George Graettinger (NOAA/NOS/ORR, Seattle, WA)
Dave Green (PIKA, Stafford, TX)
Andrew Gude (USFWS, National Wildlife Refuge System, Arlington, VA)
Edwin Hernandez (UPR Rio Piedras, San Juan, PR)
William Hernandez (USFWS, Boqueron, PR)
David Holst (NOAA/NOS/ORR, Silver Spring, MD)
David James (DON, Naval Facilities Engineering Command, Norfolk, VA)
Jud Kenworthy (NOAA/NOS/NCCOS/CCFHR, Beaufort, NC)
Craig Lileystrom (PRDNER, Marine Resources Division, Rio Piedras, PR)
Felix Lopez (USFWS, Boqueron, PR)
Mark Martin (Puerto Rico Conservation and Historical Trust, Vieques, PR)
Andrew Mason (NOAA/NOS/NCCOS/CCMA, Silver Spring, MD)
Antonio Mignucci-Giannoni (Antonio Mignucci Investigación Ambiental, Inc., San Juan, PR)
Johnny Noles (DON, Naval Facilities Engineering Command, Norfolk, VA)
Tony Pait (NOAA/NOS/NCCOS/CCMA, Silver Spring, MD)
Varis Ransibrahmankul (NOAA/NOS/NCCOS/CCMA, Silver Spring, MD)
Jim Reid (USGS, Gainesville, FL)
Danny Rodriguez (EPA, Vieques, PR)
Jason Rolfe (NOAA/NOS/ORR, Silver Spring, MD)
Jorge Saliva (USFWS, Boqueron, PR)
Minoj Shivlani (University of Miami RSMAS, Miami, FL)
Diane Wehner (NOAA/NOS/ORR, Highlands, NJ)
Dave Whitall (NOAA/NOS/NCCOS/CCMA, Silver Spring, MD)

Special thanks to Martha Prada for the Spanish translation of the executive summary.

United States Department of Commerce

Carlos M. Gutierrez
Secretary

National Oceanic and Atmospheric Administration

Vice Admiral Conrad C. Lautenbacher, Jr. USN (Ret.)
Under Secretary of Commerce for Oceans and Atmopsheres

National Ocean Service

John H. Dunnigan
Assistant Administrator

An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico
Part I: Historical Data Synthesis - NOAA Technical Memorandum NOS NCCOS 86