FINAL

Five-Year Review
of
Essential Fish Habitat in the U. S. Caribbean

VOLUME I: TEXT

Caribbean Fishery Management Council
268 Muñoz Rivera Avenue, Suite 1108
San Juan Puerto Rico 00918-1920

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Abbreviations and Acronyms Used in this Document

ACL	Annual Catch Limit
ABC	Acceptable Biological Catch
AMs	Accountability Measures
CFMC	Caribbean Fishery Management Council
CPUE	Catch per Unit Effort
DFW	Division of Fish and Wildlife, US Virgin Islands Department of Planning and Natural Resources
DNER	Puerto Rico Department of Natural and Environmental Resources
DPNR	US Virgin Islands Department of Planning and Natural Resources
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
FEIS	Final Environmental Impact Statement
FMC	Fishery Management Council
FMP	Fishery Management Plan
FSSI	Fish Stock Sustainability Index
FRL	Fisheries Research Lab, Puerto Rico Department of Natural and Environmental Resources
GAM	Generalized Additive Model
GIS	Geographical Information System
HAPC	Habitat Areas of Particular Concern
IUCN	International Union for the Conservation of Nature
MFMT	Overfishing Threshold
MSST	Overfished Threshold
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
MSFCMRA	Magnuson Stevens Fishery Conservation and Management Reauthorization Act
MSY	Maximum Sustainable Yield
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA Fisheries	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OY	Optimum Yield
ROV	Remotely Operated Underwater Vehicle
SEDAR	Southeast Data Assessment and Review
SEAMAP	Southeast Area Monitoring and Assessment Program
USVI	United States Virgin Islands
UVC	Underwater Visual Census
VICRNM	Virgin Islands Coral Reef National Monument

1. Introduction

The Caribbean Fishery Management Council (Council) completed in 2005 the requirements of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) to describe and identify essential fish habitat (EFH), minimize adverse effects of fishing, and identify actions to conserve and enhance EFH. The MSA requires the Secretary of Commerce to set forth a schedule for the review and update of EFH information. In addition, National Standard 2 of the MSA requires conservation and management measures contained in Fishery Management Plans (FMPs) be based on the best scientific information available. In response, the EFH regulation (50CFR 600.815(a)(10)) states that the regional Fishery Management Councils, with assistance from the National Marine Fisheries Service (NMFS) should periodically review the EFH provisions of FMPs and revise or amend those provisions as warranted.

Subpart J of 50 CFR Part 600 contains guidelines to assist Councils in developing and documenting the five -year review of EFH components in FMPs, including:

1. Descriptions and identification of EFH
2. Fishing activities that may adversely affect EFH
3. Non-Magnuson-Stevens Act fishing activities that may adversely affect EFH
4. Non-fishing activities that may adversely affect EFH
5. Cumulative impacts analysis
6. EFH conservation and enhancement recommendations
7. Prey species
8. Identification of habitat areas of particular concern (HAPC)
9. Research and information needs
10. Review and revision of EFH components of FMPs

Subpart J also states that the review of EFH information should include, but not be limited to, evaluating published scientific literature and unpublished scientific reports; soliciting information from interested parties; and searching for previously unavailable or inaccessible data. A complete review of all EFH information should be conducted as at least once every 5 years. This report documents the 5-year EFH review for the Caribbean Fishery Management Council (Council). The purpose of this review is to ensure that:

a) NMFS is in compliance with the EFH regulation and MSA to review EFH information in FMPs at least once every five years;
b) The best available scientific information is used to justify management actions, as required by National Standard 2;
c) NMFS is following the National Environmental Policy Act (NEPA) guidance regarding the periodic review and update of NEPA documents.

Based on this report, the Council and NMFS will determine the need to revise the EFH designations and descriptions. If so, the Council will accordingly initiate FMP amendments, to revise EFH components or management measures within their seven FMPs or as another generic EFH amendment for all FMPs.

1.1. Five-Year Review Approach

The CFMC contracted a consulting firm, the MRAG Americas, Inc. to undertake the 5-year EFH review of the EFH. MRAG structured the work plan according to the NMFS guidelines to achieve the purpose and meet the requirements. The guidelines recommend that the scope of the review should include the identification and description of EFH, the minimization of adverse effects of fishing; the identification of other measures to conserve EFH, and the evaluation of Habitat Areas of Particular concern (HAPC). MRAG identified climate change, lionfish invasions, lobster disease, and use of habitat models as other topics for review. The review was conducted through the evaluation of published scientific literature and unpublished scientific reports; soliciting information from interested parties, and searching for previously unavailable or inaccessible data. The final product of the review (this report) documents the results of the 2010-2011 5-year EFH review. This document includes:

1. Reviewing existing EFH descriptions and designations for shortcomings.
2. Evaluating new information available since the 2005 EFH Amendment for descriptions and designations.
3. Reviewing changes in the administrative environment.
4. Reviewing possible new methods of designating EFH.
5. Reviewing changes in the human environment.
6. Reviewing any changes and new information on fishing impacts that may adversely affect EFH.
7. Reviewing any changes and new information on non-fishing impacts that may adversely affect EFH.
8. Reviewing habitat areas of particular concern (HAPC) designations.
9. Reviewing the effects of climate change on Caribbean habitats and ecosystems.
10. Reviewing the impacts of lionfish invasions on Caribbean habitats and ecosystems.

To accomplish these tasks, MRAG Americas reviewed the 2004 EFH-FEIS for inaccuracies, gaps, or information needs; reviewed all the relevant information provided by the Council, and, in addition, performed an extensive literature search to determine if any new EFH information was available. MRAG also communicated with researchers around the Caribbean and from different NOAA Fisheries offices and centers to discover new information. MRAG explored new methods of designating EFH based mainly upon the findings of the Northwest Fishery Science Center, and conducted a literature review of the virus affecting spiny lobsters, and of the effects of climate change and lionfish invasions on Caribbean habitats and ecosystems.

Following the order of the 2004 EFH-FEIS document was not the best way to proceed for the present review, given that the new literature encompassed a broad variety of topics, some of which were related –or not- to specific sections in the original EFH. Thus, all the documents reviewed were classified into broad themes that were linked, to the extent possible, to sections in the EFH. These, added to the topics prescribed in the 5-year review guidelines, and to the new topics incorporated, formed the basis to develop a comprehensive table of contents for this document. When appropriate, cross-references of the corresponding sections in the original 2004 EFH-FEIS are provided and summarized in a matrix (Table 1). A complete list of references of all the literature reviewed is provided in Section 10.

1.2. Historical Background: Council actions to protect habitat (up to 2004)

The purpose of this section is to provide a brief historical review of the Council's actions to protect EFH before the 2004 EFH-FEIS (Essential Fish Habitat- Final Environmental Impact Statement) was issued. This historical perspective will help to understand the evolution of EFH in the U.S. Caribbean FMPs and to situate the present review in a broader context. This section corresponds to Section 2.1.5.2.2 (Caribbean Council habitat protection policies- History of Council actions to protect habitat) in the 2004 EFH-FEIS.

In 1990 the Spiny Lobster and the Reef Fish FMPs of the Caribbean Fishery Management Council were amended to include "an extensive description of habitat" of the stocks comprising the management units. These habitat sections identified habitats of particular concern (HPC), habitat threats, and habitat information needs. The priority was and has been the complete mapping of the marine habitats within the Exclusive Economic Zone (EEZ) and Territorial Seas of Puerto Rico and the USVI (see Figures 1-3). Emphasis has also been placed on the health status determination of the habitats mapped and EFH/HAPCs identified. The harvest of spiny lobster was also restricted since 1984 to non-destructive gear.

The Council developed a Coral FMP (implemented in December 1995) that protected coral reef resources by prohibiting the harvest of coral, and by prohibiting the use of chemicals, plant or plant-derived toxins or explosives to harvest reef associated species.

The first seasonal area closure to protect a spawning aggregation of the most commonly landed grouper in the US Caribbean, the red hind, *Epinephelus guttatus* was established by the Council in 1990. The area seasonally closed is known as the "Hind Bank" or grouper bank (Figures 2-6). Federal regulations in 50CFR 622.33 (a) and (b) establish seasonal and permanent area closures (Figures 2-3). Amendment 1 to the Coral FMP (1999) established the first no-take zone (Marine Conservation District or MCD) in Federal waters (Figure 4), in the EEZ southwest of St. Thomas, USVI, comprising the Hind Bank area. The area is now known as the Red Hind MCD. A permanent fishing closure and prohibition of anchoring by fishing vessels occurs at the MCD.

Other seasonal fishing closures include the mutton snapper spawning aggregation area, red hind spawning aggregation areas east of St. Croix, west of Puerto Rico at Bajo de Sico, Tourmaline Bank, and Abrir La Sierra Bank, and the entire EEZ to queen conch fishing year-round (Figure 2).

In 1993, Amendment 2 to the Reef Fish FMP restricted the collection of marine aquarium fishes to hand- held dip nets and slurp guns; closed, to all fishing, two additional red hind spawning aggregation areas (Tourmaline Bank, west of Mayaguez, Puerto Rico and Lank Bank in the EEZ east of St. Croix, USVI), from December through February every year; and closed a spawning aggregation area, to all fishing, for mutton snapper (*Lutjanus analis*) from March through June each year in St. Croix, USVI (Figures 2-3). In 1996, a regulatory amendment to the Reef Fish FMP was implemented, which adjusted the boundary of the existing red hind spawning aggregation seasonal area closure in the EEZ off western Puerto Rico and added two red hind spawning aggregation seasonal area closures. Amendments to the Reef Fish FMP also included trap/pot mesh size restrictions, requirement of degradable panels, and degradable fastening material for the trap/pot doors.

The 1998 EFH Generic Amendment to the FMPs of the US Caribbean addressed the requirements of the MSFMCA regarding EFH. The following is a summary of the Generic Amendment:

1. EFH was identified as everywhere that the 17 selected managed species (Nassau grouper, red hind, coney, yellowtail snapper, mutton snapper, schoolmaster, grey snapper, silk snapper, butterfly fish, squirrel fish, white grunt, queen triggerfish, sand tilefish, red tail parrotfish, trunkfish, spiny lobster, and queen conch) and the coral complex commonly occur. Therefore, EFH includes virtually all marine waters and substrates (mud, shell, rock, coral reefs, and associated biological communities) from the shoreline to the seaward limit of the EEZ.
2. Threats to EFH from fishing and non-fishing activities were identified.
3. Options to conserve and enhance EFH were provided and research needs identified.
4. No fishing-related management measures to minimize impacts, and, therefore, no regulations were proposed at that time.

In compliance with the NEPA of 1969, the CFMC prepared a final environmental impact statement (FEIS), published on April 23, 2004 (69 FR 22025) to evaluate alternatives for bringing the EFH Amendment into compliance with the EFH mandates of the Magnuson-Stevens Act. For each of the four Caribbean FMPs, the FEIS analyzes a range of potential alternatives to: (1) describe and identify EFH for the fishery; (2) identify other actions to encourage the conservation and enhancement of such EFH; and (3) identify measures to minimize, to the extent practicable, the adverse effects of fishing on EFH. The FEIS contains the methods and data used in the analyses, background information on the physical, biological, human, and administrative environments, and a description of the fishing and non-fishing threats to EFH (ROD, 69FR 29693).

1.3. Changes in the Administrative Environment: Council actions (after 2004)

This section summarizes the main actions undertaken by the Council since the 2004 EFH-FEIS to issue regulatory amendments to Caribbean FMPs, to assemble comprehensive data bases and to standardize procedures for analyses of the information necessary to support those amendments. Some of these actions may or may not have direct implications for EFH, but they represent the context within which the current review is occurring at the Council. This section updates the information in Sections 3.4 (Affected Environment-Administrative Environment), 4.2 (Environmental Consequences-Effects of missing information), 4.3 (Consequences of EFH Alternatives to the Administrative Environment), 4.4 (Consequences of alternatives for identifying HAPCs for the Administrative Environment), and 4.5 (Consequences for the Administrative Environment of alternatives for preventing the adverse effects of fishing on EFH) of the 2004 EFH-FEIS.

1.3.1. Comprehensive Sustainable Fisheries Amendment (SFA) to the Fishery Management Plans (FMPs) of the U.S. Caribbean:

Effective on November 28, 2005, NMFS issued a final rule (70 FR 62073) to implement a comprehensive amendment to the four fishery management plans (FMPs) of the Caribbean

Fishery Management Council. Known as the Comprehensive SFA Amendment, the final rule implements the following amendments:

- Amendment 2 to the FMP for the Spiny Lobster Fishery of Puerto Rico and the USVI.
- Amendment 1 to FMP for the Queen Conch Resources of Puerto Rico and the USVI.
- Amendment 3 to the FMP for the Reef Fish Fishery of Puerto Rico and the USVI.
- Amendment 2 to the FMP for the Corals and Reef Associated Invertebrates of Puerto Rico and the USVI Including Supplemental Environmental Impact Statement, Regulatory Impact Review, and Regulatory Flexibility Act Analysis3

The Comprehensive SFA Amendment is designed to ensure the FMPs are fully compliant with the 1996 Sustainable Fisheries Act (SFA) provisions of the Magnuson-Stevens Act. This amendment redefines the fishery management units for the FMPs; establishes seasonal closures; imposes gear restrictions and requirements; revises requirements for marking pots and traps; and prohibits the filleting of fish at sea. It establishes biological reference points and stock status criteria; establishes rebuilding schedules and strategies to end overfishing and rebuild overfished stocks; provides for standardized collection of bycatch data; minimizes bycatch and bycatch mortality to the extent practicable; designates EFH and HAPCs; and minimizes adverse impacts on such habitat to the extent practicable. The intended effect of this Comprehensive SFA Amendment is to achieve optimum yield in the fisheries and provide social and economic benefits associated with maintaining healthy stocks (FR 2005).

1.3.2. 2010 ACL Amendment

The 2010 Annual Catch Limit Amendment 2 to the Queen Conch FMP and Amendment 5 to the Reef Fish FMP were designed to bring those fisheries into compliance with the 2007 revisions to the MSFCMA. This amendment focuses on those species previously defined as undergoing overfishing (CFMC and NOAA 2010). Included in the provisions are to:

- Amend the composition of the fishery management units for snapper and grouper.
- Transition management from the 2005 Comprehensive Sustainable Act to the mandated provisions of the MSA.
- Allocate harvest among island groups (Puerto Rico, St. Thomas/St. John, and St. Croix).
- Prohibit harvest of three species of parrotfish (midnight, blue, rainbow).
- Establish recreational fishing bag limits for snapper, grouper, and parrotfish.
- Define and implement accountability measures.

There are no new provisions for EFH in the ACL Alternatives, but the Council and NMFS determined that there are no adverse effects to EFH in this amendment (NMFS and CFMC 2010). NOAA is currently seeking public comment on the revised 2010 Caribbean ACL, so the amendment should be implemented by the beginning of 2012.

1.3.3. 2011 Comprehensive Annual Catch Limit (ACL) Amendment for the US Caribbean

As a second phase in the ACL Amendment process, in 2011 the CFMC issued the Comprehensive Annual Catch Limit (ACL) Amendment for the U.S. Caribbean: Amendment 6 to the Reef Fish Fishery Management Plan of Puerto Rico and the U.S. Virgin Islands;

Amendment 5 to the Fishery Management Plan for the Spiny Lobster Fishery of Puerto Rico and the U.S. Virgin Islands; Amendment 3 to the Fishery Management Plan for the Queen Conch Resources of Puerto Rico and the U.S. Virgin Islands, Amendment 3 to the Fishery Management Plan for Corals and Reef Associated Plants and Invertebrates of Puerto Rico and the U.S. Virgin Islands (NOAA and CFMC 2011).

The 2011 ACL Amendment to these FMPs is designed to bring those fisheries into compliance with the 2007 revisions to the MSA. As the 2010 Amendment, these alternatives will also consider measures to revise management reference points, implement annual catch limits (ACLs) and accountability measures (AMs) to prevent overfishing in both the commercial and recreational sectors, revise management of aquarium trade species and conch resources, establish recreational fishing bag limits, establish exclusive economic zone sub-boundaries for purposes of applying AMs, adjust management measures as needed to constrain harvest to specified ACLs, and minimize to the extent practicable negative socioeconomic impacts. The amendment, however, focuses on those species with overfishing determination unknown (NOAA and CFMC 2011).

1.3.4. Bajo de Sico Closure Extension

On November 2, 2010, NMFS issued a final rule (75 FR 67247) that implements a regulatory amendment to the Fishery Management Plan for the Reef Fish Fishery of Puerto Rico and the U.S. Virgin Islands (FMP) prepared by the Caribbean Fishery Management Council (Council). This rule modifies the Bajo de Sico seasonal closure from a 3-month closure to a 6-month closure (October 1 through March 31, each year) and prohibits fishing for and possession of Caribbean reef fish in or from the exclusive economic zone (EEZ) portion of Bajo de Sico during the closure (see Figure 5). The final rule also prohibits anchoring in the EEZ portion of Bajo de Sico year-round. In addition to the measures contained in the regulatory amendment, this final rule also adds spear guns to the list of allowable gears in the commercial sector of the Caribbean reef fish fishery and revises the title of the FMP in the list of authorized fisheries and gear. The intended effect of this rule is to provide further protection for red hind spawning aggregations and large snappers and groupers from directed fishing mortality to achieve a more natural sex ratio, age, and size structure, and better protect the essential fish habitat (EFH) where these species reside, while minimizing adverse social and economic effects.

1.3.5. Data

1.3.5.1. U.S. Caribbean Data Workshop

The Southeast Data Assessment and Review panel (SEDAR) convened a procedural “Caribbean Fisheries Data Evaluation” in January, 2009 in San Juan, Puerto Rico, (SEDAR Procedures Workshop 3) to evaluate Caribbean data sources and data needs in the U.S. Caribbean, including the Puerto Rico and Virgin Island platforms. The Council-Federal cooperative SEDAR process provides stock assessments for fisheries resources of the NMFS Southeast Region. Regional assessment priorities are typically based upon management needs or perceptions of management or population problems. Data availability is seldom explicitly considered when setting such priorities. As a result, despite several attempts (i.e., SEDAR assessments of Caribbean deepwater snapper-grouper, Caribbean spiny lobster, queen conch, yellowtail snapper, Nassau grouper, yellowfin grouper, mutton snapper), no acceptable quantitative assessments have been developed for Caribbean stocks because data to support traditional stock assessment methods do not exist for the species considered so far. Several SEDAR peer review panels (SEDAR Nos. 4, 8, and 14, see http://www.sefsc.noaa.gov/sedar/) suggested reviewing basic data availability and evaluating alternative assessment methods before again assigning scarce resources to produce more traditional assessments that are unlikely to provide informative results. Identifying and evaluating available data sources across all managed species is a strong first step that is consistent with peer review and assessment report recommendations. Further, alternative methods need to be developed that will allow assessing Caribbean fisheries resources in a manner that is consistent with the information content of the available data sources that will therefore withstand independent peer review (SEFSC 2009).

Participants included representatives from Federal agencies, territorial governments, nongovernmental organizations, Council technical and constituent advisors, and university researchers. Prior to the workshop Federal and territorial agency representatives summarized and cataloged basic data sources and explored alternative assessment methods. During the workshop, participants reviewed these initial efforts and discussed each data source and potential method in detail. The terms of reference for the workshop were (SEFSC 2009):

1) Review available data and develop recommendations regarding their accuracy and reliability for use in assessing U.S. Caribbean fish stocks. Provide complete tables documenting the quantity and quality of data by stock and area.
2) Review the basis for existing stock complexes and evaluate whether adjustments to these complexes are suggested based on available data.
3) Recommend species or stock complexes for which informative SEDAR benchmark assessments may be feasible.
4) Review alternative methods for estimating mortality rates and abundance trends that might be useful for those species or stock complexes for which data are deemed sufficient.
5) Review the research and monitoring recommendations from the previous assessments in the U.S. Caribbean. Note any which have been completed, make any necessary additions or clarifications, and prioritize data and research needed to successfully complete benchmark stock assessments.
6) Provide guidance on developing ACLs given data accuracy and reliability recommendations and comment on issues that should be considered by the Council and its committee's when making ACL determinations.

The workshop covered the following aspects (SEFSC 2009):

- MSRA requirements for fishing level recommendations and the information provided by stock assessments to support those recommendations (SEFSC)
- An overview of the fisheries of Puerto Rico and the USVI (fishermen)
- Information on data availability and collection programs: commercial, recreational statistics, SEAMAP data (territorial agency representatives)
- Other sources of fishery-independent data (SEFSC)
- Catch records and adjustment factors (SEFSC)
- CPUE analyses and problems with multi-species fisheries (SEFSC)

- Length based and other assessment methods, with application to several Puerto Rico stocks (SEFSC).
- Approaches to evaluating management complexes (SERO)
- Other assessment methods, Parfish (CIE)
- Overview of the recent National SSC meeting, with emphasis on ACL recommendations (NOAA-SSC).

1.3.5.2. Data Improvement Project

NMFS and the CFMC contracted with MRAG Americas, Inc. in September 2009 to conduct a comprehensive review of the current commercial data collection system in the US Caribbean and make recommendations as to required changes which if implemented would result in statistically sound data being collected. This information is required in order to carry out credible stock assessment analyses. The information collected was provided to NMFS stock analysts and managers from the USVI, DPNR (DFW) and Puerto Rico, DNER for use in ongoing stock assessment evaluations. Specifically, the products from this project are also available for use in resource evaluations relating to determination of Annual Catch Limits (ACLs) for the US Caribbean fisheries, which are congressionally mandated by 2010 and 2011. In addition, this project identified and prioritized needed adjustments to the current data collection system to develop adequate accountability measures (AM's) for effective management.

1.4. Current EFH Designations

This section briefly reviews the events that led to the development of EFH provisions in Caribbean FMPs, defines EFH and reviews the original EFH designations according to preferred Alternative 2 in the 2004 EFH-FEIS. This section corresponds to Section 2.3 (FMP Alternatives for EFH) in the 2004 document, and to Section 6.7.1 in the 2005 Comprehensive Amendment.

In 1998, the Caribbean Fishery Management Council developed a Generic Essential Fish Habitat Amendment to the Fishery Management Plans (FMPs) of the U.S. Caribbean, including a Draft Environmental Assessment. NOAA Fisheries approved the Generic EFH Amendment for the selected species list in the amendment. In 1999, a lawsuit brought forth by a coalition of environmental groups (AOC *et al.* v. Daley *et al.*) determined that the Environmental Assessment for the Generic Amendment was in accordance with the MSFCMA, but deficient with regard to the National Environmental Policy Act (NEPA) requirements and had not appropriately identified alternatives for EFH. In 2001 NOAA Fisheries committed to preparing an Environmental Impact Statement (EIS) for EFH, with more thorough NEPA analysis that might lead to fishery management plan amendments.

In 2004, the Council completed a Final Environmental Impact Statement for the Generic Essential Fish Habitat Amendment (EFH-FEIS, CFMC, 2004) addressing all required EFH components. As a result of the 2004 EFH-FEIS, the Council produced the 2005 Comprehensive SFA Amendment to the Fishery Management Plans (FMPs) of the U.S. Caribbean to address required provisions of the MSFCMA (CFMC and NMFS 2005, FR 2005).

The 2005 Comprehensive SFA Amendment described and identified EFH according to the preferred Alternative 2, as the functional relationships between life history stages of federally-managed species and Caribbean marine and estuarine habitats. This alternative specifies functional relationships for life stages and habitat types that might be regarded as meriting special attention for their importance to managed species. The MSFCMA defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." These are the functions that marine and estuarine habitats support. Under this alternative, the distribution of species and life stages is inferred from information on these functional relationships. In particular, EFH is defined as (CFMC and NMFS 2005):

1. **Spiny Lobster FMP**: EFH in the US Caribbean consists of all waters from mean high water to the outer boundary of the EEZ- habitats used by phyllosoma larvae - (Figure 2.2; EFH-FEIS) and seagrass, benthic algae, mangrove, coral, and live/hard bottom substrates from mean high water to 100 fathoms depth -used by other life stages- (Figure 2.38; EFH-FEIS), shown in the aggregate as Figure 2.39 (2004 EFH-FEIS).
2. **Queen Conch FMP**: EFH in the US Caribbean consists of all waters from mean high water to the outer boundary of the EEZ – habitats used by eggs and larvae – (Figure 2.2; EFH-FEIS) and seagrass, benthic algae, coral, live/hard bottom and sand/shell substrates from mean high water to 100 fathoms depth –used by other life stages – (Figure 2.40; EFH-FEIS), shown in the aggregate as Figure 2.39 (2004 EFH-FEIS).
3. **Reef Fish FMP**: EFH in the US Caribbean consists of all waters from mean high water to the outer boundary of the EEZ – habitats used by eggs and larvae – (Figure 2.2; EFH-FEIS) and all substrates from mean high water to 100 fathoms depth – used by other life stages – (Figure 2.41; EFH-FEIS), shown in the aggregate as Figure 2.39 (2004 EFH-FEIS).
4. **Coral FMP**: EFH in the US Caribbean consists of all waters from mean low water to the outer boundary of the EEZ – habitats used by larvae – (Figure 2.2; EFH-FEIS) and coral and hard bottom substrates from mean low water to 100 fathoms depth – used by other life stages – (Figure 2.42; EFH-FEIS), shown in the aggregate as Figure 2.39 (2004 EFH-FEIS).

The aggregate EFH map for each FMP can be obtained with the NMFS-EFH Mapper online tool (described in Section 4.1.4, see http://www.habitat.noaa.gov/protection/efh/habitatmapper.html). Each species' EFH designation can be displayed by life history stage (Post-Egg/Larval, Larval, and All). An example of the spiny lobster EFH designation using EFH Mapper is provided in Figure 8.

1.5. Current HAPC Designations

The EFH guidelines provide for the designation of subsets of EFH as habitat areas of particular concern (HAPC) in order to focus conservation priorities on specific habitat areas that play a particularly important role in the life cycles of federally managed fish species. The alternatives presented for HAPCs in the 2004 EFH-FEIS were not mutually exclusive, and were presented to the Council to choose from to amend FMPs. In the 2005 Comprehensive SFA Amendment, Alternative 3 (Preferred) was selected to designate HAPCs in the Reef Fish and Coral FMPs based on confirmed spawning locations and on areas or sites identified as having particular ecological importance to managed species. This section updates the information in section 2.4 with the selected alternative presented in section 6.7.1.3 of the 2005 Comprehensive Amendment. The following areas were designated as HAPCs for the various FMPs (CFMC and NMFS 2005):

Alternative 3a. Designate HAPCs in the Reef Fish FMP at the following areas based on the occurrence of confirmed spawning locations

I. Puerto Rico

A. Tourmaline Bank/Buoy 8 (Figure 2.26; EFH-FEIS) (50 CFR 622.33(a));
B. Abrir La Sierra Bank/Buoy 6 (Figure 2.26; EFH-FEIS) (50 CFR622.33(a));
C. Bajo de Sico (Figure 2.26; EFH-FEIS) (50 CFR 622.33(a)); and
D. Vieques, El Seco (Figure 2.27; EFH-FEIS).

II. St. Croix

A. Mutton snapper spawning aggregation area (Figure 2.26; EFH-FEIS) (50 CFR 622.33(a));
B. East of St. Croix (Lang Bank) (Figure 2.26; EFH-FEIS) (50 CFR 622.33(a)).

III. St. Thomas

A. Hind Bank MCD (Figure 2.26; EFH-FEIS) (50 CFR 622.33(b)); and
B. Grammanik Bank (Figure 2.26; EFH-FEIS).

Alternative 3b. Designate HAPC for the Reef Fish FMP as those EFH habitat areas or sites identified as having particular ecological importance to Caribbean reef fish species.

I. Puerto Rico

A. Hacienda la Esperanza, Manatí (Figure 2.31; EFH-FEIS);
B. Bajuras and Tiburones, Isabela (Figure 2.31; EFH-FEIS);
C. Cabezas de San Juan, Fajardo (Figure 2.31; EFH-FEIS);
D. JOBANNERR, Jobos Bay (Figure 2.31; EFH-FEIS);
E. Bioluminescent Bays, Vieques (Figure 2.31; EFH-FEIS);
F. Boquerón State Forest (Figure 2.32; EFH-FEIS);
G. Pantano Cibuco, Vega Baja (Figure 2.31; EFH-FEIS);
H. Piñones State Forest (Figure 2.31; EFH-FEIS);
I. Río Espiritu Santo, Río Grande (Figure 2.31; EFH-FEIS);
J. Seagrass beds of Culebra Island (nine sites designated as Resource Category 1 and two additional sites) (Figure 2.31; EFH-FEIS); and
K. Northwest Vieques seagrass west of Mosquito Pier, Vieques (Figure 2.33; EFH-FEIS).

II. St. Thomas

A. Southeastern St. Thomas, including Cas Cay, the Mangrove Lagoon and St. James Marine Reserves and Wildlife Sanctuaries (Figure 2.34; EFH-FEIS); and
B. Saba Island/Perseverance Bay, including Flat Key and Black Point Reef (Figure 2.34; EFH-FEIS).

III. St. Croix

A. Salt River Bay National Historical Park and Ecological Preserve and Marine Reserve and Wildlife Sanctuary (Figure 2.36; EFH-FEIS);
B. Altona Lagoon (Figure 2.36; EFH-FEIS);
C. Great Pond (Figure 2.36; EFH-FEIS);
D. South Shore Industrial Area (Figure 2.36; EFH-FEIS); and
E. Sandy Point National Wildlife Refuge (Figure 2.36; EFH-FEIS)

Alternative 3c. Designate HAPC for the Coral FMP as those EFH habitat areas or sites identified as having particular ecological importance to Caribbean coral species.

I. Puerto Rico

A. Luis Peña Channel, Culebra (Figure 2.31; EFH-FEIS);
B. Mona/Monito (Figure 2.31; EFH-FEIS);
C. La Parguera, Lajas (Figure 2.32; EFH-FEIS);
D. Caja de Muertos, Ponce (Figure 2.32; EFH-FEIS);
E. Tourmaline Reef (Figure 2.32; EFH-FEIS);
F. Guánica State Forest (Figure 2.32; EFH-FEIS);
G. Punta Petrona, Santa Isabel (Figure 2.31; EFH-FEIS);
H. Ceiba State Forest (Figure 2.31; EFH-FEIS);
I. La Cordillera, Fajardo (Figure 2.31; EFH-FEIS);
J. Guayama Reefs (Figure 2.31; EFH-FEIS);
K. Steps and Tres Palmas, Rincon (Figure 2.31; EFH-FEIS);
L. Los Corchos Reef, Culebra (Figure 2.31; EFH-FEIS); and
M. Desecheo Reefs, Desecheo (Figure 2.31; EFH-FEIS)

II. St. Croix

A. St. Croix Coral Reef Area of Particular Concern, including the East End Marine Park (Figure 2.36; EFH-FEIS);
B. Buck Island Reef National Monument (Figure 2.36; EFH-FEIS);
C. South Shore Industrial Area Patch Reef and Deep Reef System (Figure 2.36; EFH-FEIS);
D. Frederiksted Reef System (Figure 2.36; EFH-FEIS);
E. Cane Bay (Figure 2.36; EFH-FEIS); and
F. Green Cay Wildlife Refuge (Figure 2.36; EFH-FEIS).

As noted in the 2005 Comprehensive Amendment (CFMC and NMFS 2005), identified sites in Alternative 3a, with the exception of Vieques – El Seco, have been documented in other Council actions to be sites of particular importance to specific reef fish species (e.g., red hind at Tourmaline Bank). Identification of these areas as HAPCs is consistent with other Council actions to afford them either seasonal or annual protection. Identifying these sites as HAPCs will not result in any direct effects to the environment. Vieques – El Seco is in state waters, and is therefore out of the Council's jurisdiction. Likewise, the sites identified in Alternatives 3b and 3c are in state waters. Therefore, the Council and NMFS cannot take direct action to manage fisheries in these areas. Portions of La Parguera, Tourmaline Reef, and Caja de Muertos extend partially into the EEZ, and the Council and NMFS could implement management actions to protect and conserve EFH in the portion that resides in federal waters. Additional discussion on the indirect effects on the environment and their significance related to these alternatives are detailed in Section 4.4 of the 2004 EFH-FEIS.

Note: All the maps (figures) in the 2004 EFH-FEIS listed above can be reproduced with the NMFS-EFH Mapper and/or the NOAA-MPA Viewer online tools described in Sections 4.1.4 and 4.1.5, respectively. A map showing all the HAPCs in the US Caribbean, created with EFH Mapper is illustrated in Figure 9. Other examples of maps produced with these tools are provided in Figure 10 (La Parguera, PR) and Figure 11 (Cas Cay and Mangrove Lagoon, Southeast St. Thomas; and Salt River Bay, St. Croix).

1.6. Marine Protected Areas in the U.S. Caribbean

As noted from the EFH and HAPC designations in Sections 1.3 and 1.4 above, Marine Protected Areas are an essential tool for the conservation and management of marine habitats, including Essential Fish Habitats in the U.S. Caribbean. This section provides further details of all the MPAs that have been designated at the Federal and Territorial levels in Puerto Rico and the U.S. Virgin Islands, and complements sections 1.3 to 1.5 of this report. In addition, it serves to update section 3.4.6 (Administrative Environment-Non-fishery management laws and regulation) of the 2004 EFH-FEIS. All the managed areas in the U.S. Caribbean within territorial and federal jurisdictions are illustrated in Figures 6-7, 9, and 12-14. Information for each MPA, including the government level, management authority, year of establishment, objectives, and level of protection is summarized in Table 2 (Puerto Rico) and Table 3 (U.S. Virgin Islands).

1.7. EFH Areas Protected from Fishing Impacts in the U.S. Caribbean

A data sheet issued by the NOAA Habitat Program (NOAA 2010) summarizes the steps taken by the CFMC to protect EFH in support of healthy ecosystems and sustainable fisheries in the U.S. Caribbean. These include EFH areas protected from fishing (Figure 12); gear restrictions in the EEZ, and additional restrictions in Abrir La Sierra Bank, Bajo de Sico closed area, Grammanik Bank closed area, Lang Bank red hind spawning aggregation area, Mutton snapper spawning aggregation area, and Tourmaline Bank (Table 4), as well as a no-take MCD (Hind Bank St. Thomas). This section complements sections 1.4 to 1.6 of this report and updates the information in sections 2.3, 2.4, and 2.5 in the 2004 EFH-FEIS.

1.8. Current Measures to Minimize Fishing Impacts to EFH

The Caribbean Council has addressed threats to habitat from fishing activities and has included management measures to minimize these adverse threats in the fishery management plans since 1980’s. The 1998 EFH Generic Amendment identified EFH and adverse impacts from fishing and non- fishing activities. The 2004 EFH-FEIS evaluated the relative risk of impacts to EFH resulting from fishing activities and provided the basis for developing alternatives to prevent, mitigate, or minimize adverse effects of fishing on EFH. A fishing gear sensitivity index (fishing impact index) and fishing effort were used to analyze the relative risk of impacts to EFH resulting from various fishing activities.

The 2005 Comprehensive SFA Amendment proposed Alternative 2 (Preferred) to prevent, mitigate, or minimize the adverse effects of fishing on EFH in the US Caribbean EEZ: establish modifications to anchoring techniques; establish modifications to construction specifications for pots/traps; and close areas to certain recreational and commercial fishing gears (i.e., pots/traps, gill/trammel nets, and bottom longlines). The information reproduced in this section from the 2005 Comprehensive SFA Amendment (Section 6.7.1. Describe and identify EFH) serves to update section 2.5 in the 2004 EFH-FEIS.

The measures include the following:

1) Prohibit the use of gill and trammel nets to fish for Caribbean reef fish or Caribbean spiny lobster in the EEZ, with the exception of those nets used for catching ballyhoo, gar (houndfish), and flying fish.
2) Require gill nets used to fish for bait fish in the EEZ to be tended at all times.
3) Require at least one buoy that floats on the surface for all traps/pots fished individually for all fishing vessels that fish for or possess Caribbean spiny lobster or Caribbean reef fish species in or from the EEZ;
4) Require at least one buoy at each end of trap lines linking traps/pots for all fishing vessels that fish for of possess Caribbean spiny lobster or Caribbean reef fish species in or from the EEZ;
5) Prohibit use of pots/traps, gill/trammel nets, and bottom longlines on coral or hard bottom year-round in the existing seasonally closed areas (PR and USVI) and Grammanik Bank in the EEZ; and
6) Require an anchor retrieval system for all vessels that fish for or possess Caribbean reef fish species in or from the EEZ.

Details of measures to protect EFH from fishing impacts in the U.S. Caribbean (gear restrictions in the EEZ and additional restrictions in specific areas) are provided in Table 4.

2. Review Existing EFH Descriptions and Designations

One of the requirements for this document is to review the 2005 EFH Amendment for inaccuracies in existing EFH descriptions or identifications. MRAG Americas consulted the NOAA Habitat Conservation Division of the Southeast Regional Office, the Habitat Conservation Division of the U.S. Caribbean Field Office, and the CFMC to identify shortcomings or inaccuracies in previous EFH descriptions. No shortcomings could be identified at the time of this review, thus there are no issues to address under this requirement. This section involved the review of sections 2.3 and 2.4 in the 2004 EFH-FEIS and 6.7 (Achieving the MSSFCMA EFH Mandates) in the 2005 SFA Amendment.

3. Review Changes in the Biological Environment

In this section, all new official documents and scientific literature were evaluated to determine whether new information was available for the species within the four FMPs of the U.S. Caribbean. A literature survey of Caribbean Fishery Management Council’s reports, rules and regulations, and amendments, as well as a literature survey of published and unpublished scientific literature was conducted. The literature survey resulted in approximately 200 publications concerning EFH and managed species distributions in the U.S. Caribbean.

First, the 2005 Comprehensive SFA Amendment, Amendment 2 to the Queen Conch FMP, and Amendment 5 to the Reef Fish FMP (NOAA and CFMC 2010) were reviewed to identify changes in the Fishery Management Units. Second, the Southeast Data, Assessment, and Review workshop reports (SEDAR) produced since 2005 for US Caribbean managed species were examined to identify possible changes in stock status resulting from stock assessments. Finally, a summary of the main findings is presented for each FMP below. This section serves to update Section 3.2 (Affected Biological Environment) and Section 4.2 (Environmental Consequences- Effects of missing information in assessing environmental consequences) of the 2004 EFH-FEIS.

3.1. Species Added or Eliminated from Fishery Management Units

In 2005, NMFS issued a final rule to implement the Comprehensive SFA Amendment to the Fishery Management Plans of the Caribbean (see Section 1.3.1). This rule moved a number of species in the FMPs to a data collection only category, meaning fishery management restrictions no longer applied to these species (FR 2005, CFMC and NMFS 2005).

Among other requirements and regulations to gear and fishing areas and practices, the 2005 Comprehensive SFA Amendment also redefined the fishery management units (FMUs) for the FMPs, designated EFH and HAPC areas and minimized adverse impacts on these habitats to the extent practicable (FR 2005).

The MSRA of 2006 (The Act) established new requirements to end and prevent overfishing through the use of annual catch limits (ACLs) and accountability measures (AMs). Since then, Federal fishery management plans should have established mechanisms for ACLs and AMs by 2010 for fisheries subject to overfishing and by 2011 for all others. The Act also specified additional requirements for the role of scientific advice in this process, specifically through the Fishery Management Councils’ Scientific and Statistical Committees.

ACL guidelines derived from The Act (NMFS 2009) define Annual Catch Limits (ACLs) as the level of annual catch of a stock or stock complex that if met or exceeded triggers accountability measures, such as a seasonal closure or a quota closure, which is referred to as an accountability measure (AM). The Act requires ACLs be set at levels that prevent overfishing from occurring. AMs are defined management controls to prevent ACLs from being exceeded, and to correct overages of ACLs if they occur.

ACL guidelines further state that there can only be two species categories: those that are managed and for which ACLs must be set, and those that are Ecosystem Component species and for which ACLs do not have to be set. The Ecosystem Component criteria includes species that are federally managed but are non-target species, not subject to overfishing or overfished nor likely to become so; and are generally not retained for sale or personal use. Other exceptions to the ACL requirement are species that have a life cycle of one year or less and stocks subject to management under an international fishery agreement (B. Arnold, pers. comm., NMFS 2009).

The National Standard 1 guidelines establish that, as a default, all stocks currently in an FMP are considered to be "in the fishery" unless a stock has been specifically identified through an FMP or FMP amendment as an “Ecosystem Component species.”

Based on The Reauthorization Act of 2006, in 2010 the CFMC issued the Draft Amendment 2 to the FMP for the Queen Conch Fishery and Amendment 5 for the Reef Fish FMP (NOAA and CFMC 2010). The 2010 ACL Amendment includes six actions to achieve the Annual Catch Limit (ACL) and Accountability Measure (AM) objectives for species or species groups classified as overfished or undergoing overfishing. Action 1 amends the stock complexes in the reef fish fishery management unit. Two sub-actions are included in Action 1, the first amends the U.S. Caribbean grouper complex, and the second amends the snapper complex.

This section notes changes to the Fishery Management Units (FMUs) according to the 2005 Comprehensive SFA Amendment, to the draft 2010 ACL Amendment I (NOAA and CFMC 2010) and to the draft 2011 Comprehensive ACL Amendment (NOAA and CFMC 2011). This information modifies section 3.2.11 (Fishery resources under FMPs/ Species FMUs) in the 2004 EFH-FEIS and the corresponding tables in that document (Tables 2.1, 2.2, 2.3, 2.4). Proposed amendments to FMUs are summarized in Table 9.

1. **Spiny Lobster FMP.** No changes were made to the spiny lobster FMU. Three species of spiny lobsters are included in the plan (Caribbean spiny lobster, *Panulirus argus*; Spotted spiny lobster, *P. guttatus*; Smoothtail spiny lobster, *Panulirus laevicauda*), and no species were added or removed (Table 5).

2. **Queen Conch FMP**. There are currently nine species managed within the Queen Conch FMP (Table 6) One species, Queen conch (*Strombus gigas*), is included in the fishery management plan (FMP) while eight additional species are included for data collection purposes only. Four species were removed from the FMP, including *Cassis flammea*, *C. tuberosa*, *Cittarium pica*, and *Vasum muricatum*.

   Action 4 in the 2011 Comprehensive ACL Amendment proposes to redefine the management of conch species FMU within the Queen Conch FMP. Four alternatives are presented:

   Alternative 1: No action. Do not re-evaluate and revise the conch species FMU.
   Alternative 2: Remove all conch species, except for the queen conch (*Strombus gigas*), from the Queen Conch FMP.
   Alternative 3: Delegate management authority, for all conch species except queen conch, listed in the Queen Conch FMP, to the jurisdiction of the appropriate commonwealth or territory as defined by Action 5.
   Alternative 4: Retain all conch species under the Queen Conch FMP and define management reference points or proxies based on the ACL established for queen conch in the 2010 ACL Amendment.

3. **Reef Fish FMP.** There are 80 species or species groups included in the FMP while an additional 57 aquarium trade species are included for data collection purposes only

(Table 7). Two species have been removed from the FMP: cardinal soldierfish (*Plectrypops retrospinis*) and trumpetfish (*Aulostomus maculates*).

In the 2010 ACL Amendment, Action 1 proposes amending the Grouper and Snapper stock complexes in the Reef Fish FMUs. The preferred alternative in Action 1(a) proposes several changes to the grouper Fishery Management Units for the U.S. Caribbean, including the removal of creole-fish (*Paranthias furcifer*) from Unit 3, addition of black grouper (*Mycteroperca bonaci*) to Unit 4, and movement of yellowedge grouper (*Epinephelus flavolimbatus*) and misty grouper (*E. mystacinus*) into a Unit of their own (Table 9).

The preferred alternative in Action 1(b) proposes to modify the snapper FMUs by adding cardinal snapper (*Pristipomoides macrophthalmus*) to Snapper Unit 2 and moving wenchman (*Pristipomoides aquilonaris*) into Snapper Unit 1 (Table 9).

Action 4 proposes management measures with specific emphasis on harvest prohibitions for three parrotfish species (Midnight, Blue, and Rainbow) that serve an essential ecological function (Table 9). This action addresses concerns related to the potential overharvest of these species due to their combination of large body size, a high susceptibility to spear gear and fish traps, resultant relatively low resilience, and lack of abundance compared with most parrotfish occupying U.S. Caribbean waters (NOAA and CFMC 2010).

4. **Coral FMP**. There are 99 species or species groups included in the FMP while an additional 62 aquarium trade species are included for data collection purposes only (Table 8). One species, *Carijoa riisei*, was added to the FMP. Six species or species groups have been removed from the FMP: *Charonia tritonis*, *Halimeda spp*., *Penicillus spp*., *Caulerpa spp*., *Ventricaria ventricosa*, and *Udotea spp*.

5. **Coral and Reef Fish FMPs**. In the 2011 Comprehensive ACL Amendment, Action 3 presents alternatives to redefine the management of aquarium trade species within the Reef Fish and the Coral and Reef Associated Plants and Invertebrates FMP (Coral FMP). Alternative 2 proposes the consolidation of all the managed aquarium trade species into a single FMP, providing 4 Alternatives with several sub-alternatives: (1) No action, retain fish and coral aquarium trade species as defined in the SFA Amendment; (2) Consolidate all aquarium trade species in the Coral and Reef Fish FMPs into a single FMP; (3) Remove all aquarium trade species from both FMPs, with the result that they will no longer be subject to federal management; (4) Manage only those aquarium trade species listed in either the Coral or the Reef Fish FMP, for which landings data are available during the year sequence chosen in Action 1(a). Remove remaining aquarium trade species from the FMPs; (5) Delegate management authority for all aquarium trade species listed in either the Coral the Reef Fish FMP to the jurisdiction of the appropriate commonwealth or territory (see Table 4.3.1 in 2011 ACL Amendment, NOAA and CFMC 2011).

3.2. Changes to the Status of Managed Species and Regulatory Amendments

The status of only a few Caribbean species has been formally assessed by the SEDAR process (SEFSC 2005, 2007a, 2007b, 2007c) and in most cases, data were insufficient to determine if the species was overfished or undergoing overfishing (Table 10). This information complements section 3.2.11 (Fishery resources under FMPs) in the 2004 EFH-FEIS.

3.2.1. Spiny Lobster

Caribbean spiny lobster stock status was most recently reviewed by a series of SEDAR workshops conducted by the Southeast Fisheries Science Center (SEFSC-NMFS) in 2005. During the workshops, Caribbean lobster data from Puerto Rico and the U.S. Virgin Islands were assembled for the first time, and attempts were made to fit different assessment models: a non-equilibrium production model (ASPIC), an age-structured production model and a Bayesian catch free model (based on life history characteristics). Several trials were performed with each model using different assumptions, subsets or combinations of data (e.g., Puerto Rico, USVI, Puerto Rico and St Croix, St. Thomas and St John, etc.). Results, however, were mostly inconclusive due to the large variability encountered in the data and to the lack of contrast or clear trends in the estimated indices of abundance. The panel recommended that the US Caribbean spiny lobster stock status be considered “unknown” with respect to both overfishing and overfished status (SEFSC 2005).

In regard to management of the Caribbean Spiny Lobster fishery, the 2011 Comprehensive ACL Amendment (NOAA and CFMC 2011) provides five alternatives to set management reference points. Alternative 1 proposes no action, or retaining the year sequence for Spiny Lobster FMP landings as defined in the 2005 Comprehensive SFA Amendment. The other four alternatives propose that management reference points or proxies for the Spiny Lobster FMP be based on different sequences of reliable landings data for each island group (Puerto Rico, St. Croix, and St. Thomas/St. John). Unfortunately, the U.S. Caribbean is considered data poor with regard to fisheries landings information, severely compromising the Council’s ability to establish quantitative benchmarks for reference points. Thus, none of the reference points or proxies considered in the 2011 ACL represents empirical estimates derived from a comprehensive stock assessment; rather, all were calculated based on landings data averaged over alternative time series. The 2011 ACL Amendment provides current reference points or proxies as well as alternative MSY proxies, OFL, ABC, ACL and OY definitions, considered by the Council to better comply with new mandates of the MSA (NOAA and CFMC 2011). These new estimates should be used to update the information provided in Section 3.2.11.2 (Spiny Lobster FMU) of the 2004 EFH-FEIS.

3.2.2. Queen Conch

The stock status of queen conch in the U.S. Caribbean, most recently reviewed by SEDAR (SEFSC 2007), was determined as overfished with overfishing continuing to occur. This report noted the preferred habitat for queen conch was seagrass meadows, coral rubble, algal plains and sandy substrates. It is also noted that the Queen Conch Fishery Management Plan (FMP) uses queen conch (*Strombus gigas*) as the indicator species for a group of gastropods that were also managed under the FMP including smaller conchs (Milk Conch, *S. costatus;* West

Indian Fighting Conch, *S. pugilis;* Roostertail Conch, *S. gallus;* Hawkwing conch, *S. raninus*) and True Tulip (*Fasciolaria tulipa*)*,* Atlantic Triton's Trumpet (*Charonia variegate*), Cameo Helmet (*Cassis madagascarensis*), and Green Start Shell (*Astrea tuber*).

In 2007, the CFMC decided to develop a manual that would facilitate the quantitative research work necessary for Caribbean countries to comply with the CITES requirements concerning the international trade of queen conch, which resulted in the "Queen Conch (*Strombus gigas*) Stock Assessment Manual" (Ehrhardt and Valle-Esquivel 2008).

Ehrhardt and Valle-Esquivel (2008) described stock assessment models appropriate for the species, the fisheries, and the kind of data available in the Caribbean islands and countries, including the U.S. Caribbean. They presented the models in a constructive approach with the understanding that three fundamental variables in *S. gigas* assessments and management are necessary to comply with CITES Appendix II: population densities and abundance should be sufficient to sustain the reproductive capacity of the stocks; and fishing mortality should be regulated by management control of fishing capacity. The authors incorporated critically important population dynamics features of the species in the stock assessment models that they presented. These models aimed at providing robust answers to the many issues of *S. gigas* stock assessments. The authors recommended that these methods be used for future assessments of queen conch in the Caribbean.

The 2010 ACL Amendment reports that queen conch is currently classified as overfished and subject to overfishing in NMFS' report to Congress on the status of U.S. marine fisheries and that the species is currently entering the sixth year of a rebuilding plan designed to rebuild the stock by 2019. Action 2 in this Amendment proposes to redefine management reference points or proxies for the queen conch complex. The no action alternative proposes to retain the current reference points or proxies. Alternative 2 (preferred) proposes to redefine management reference points or proxies for queen conch based on the longest time series of pre-Comprehensive SFA Amendment catch data that is considered to be consistently reliable across all islands (1999-2005). Alternatives 3 and 4 propose the use of different sequences of reliable landings data. The primary difference between the action alternatives is the time series of catch data on which they are based. The 2010 ACL Amendment provides current reference points as well as alternative MSY proxies, OFL, ABC, ACL and OY definitions, considered by the Council to better comply with new mandates of the MSA (NOAA and CFMC 2011). These new estimates should be used to update the information provided in Section 3.2.11.3 (Queen Conch FMU) of the 2004 EFH-FEIS.

Action 4 in the 2011 Comprehensive ACL Amendment proposes to redefine the management of conch species FMU within the Queen Conch FMP. Four alternatives are presented:

Alternative 1: No action. Do not re-evaluate and revise the conch species FMU.

Alternative 2: Remove all conch species, except for the queen conch (*Strombus gigas*), from the Queen Conch FMP.

Alternative 3: Delegate management authority, for all conch species except queen conch, listed in the Queen Conch FMP, to the jurisdiction of the appropriate commonwealth or territory as defined by Action 5.

Alternative 4: Retain all conch species under the Queen Conch FMP and define management reference points or proxies based on the ACL established for queen conch in the 2010 ACL Amendment.

3.2.3. Reef Fish and Coral

There have been several SEDAR assessments of Caribbean reef fish, including the deepwater snapper- grouper complex (SEDAR 4), yellowtail snapper (SEDAR 8A), yellowfin grouper, mutton snapper (SEDAR 14), and queen snapper, silk snapper, redtail parrotfish (SEDAR 26, in progress) (see http://www.sefsc.noaa.gov/sedar/). Despite the intensive efforts to use the best available information and the most appropriate modeling techniques, no acceptable quantitative assessments had been developed for Caribbean stocks until 2007 because data to support traditional stock assessment methods did not exist for the species considered until then. Complete results from SEDAR 26 are not yet available, as the final Review workshop will be conducted in October 2011. In general, for all the species analyzed up to 2007 (including reef fishes, spiny lobster, and queen conch), stock status is uncertain or unknown (Table 10). Nevertheless, reference points and management benchmarks for species undergoing overfishing and not determined to be undergoing overfishing have been addressed through the 2010 and 2011 ACL Amendments (NOAA and CFMC 2010, 2011).

Information is not available regarding natural abundance, sustainable harvest levels, or current harvest of other reef-associated invertebrates included in the Coral FMP management unit. No formal assessments of the status of coral species have been made, except for multiple scientific surveys that describe distribution and relative abundance of coral species in the U.S. Caribbean, described in section 3.3.4. There is no change in status in relation to the 2004 EFH-FEIS. However, Action 3(B) in the 2011 Comprehensive ACL Amendment proposes to establish an MSY proxy for the aquarium trade species FMU (including reef fish and corals) still under federal management after the management aquarium species FMU has been redefined (under Action 3A) (NOAA and CFMC 2011).

3.3. New Information about Species or Life Stage Distribution, Abundance, Density, Productivity, or Habitat Associations

In this section, new literature was evaluated to determine whether new information was available for species within the different FMPs to update section 3.2.11 (Fishery resources under FMPs) in the 2004 EFH-FEIS. A literature survey of the published and unpublished scientific literature was performed. The literature survey resulted in approximately 200 publications concerning EFH and managed species distributions within the U.S. Caribbean.

The new data and maps produced serve to update and/or complement many of the figures provided in the 2004 EFH-FEIS: the habitat distribution mosaic maps (Figures 2.5 to 2.15), the known and potential habitat maps (Figures 2.16 to 2.22), the EFH designation maps for each FMP (Figures 2.38 to 2.46), and the managed areas around Puerto Rico and the U.S. Virgin Islands (Figures 2.31 to 2.36).

A summary of the literature reviewed for each FMP (Spiny Lobster, Queen Conch, Reef Fish, Coral) is presented in the sections that follow, with cross-references to corresponding sections in the 2004 EFH-FEIS (Table 1).

3.3.1. Spiny Lobster

Spiny lobster EFH in the US Caribbean was identified in the 2004 EFH-FEIS and subsequently, in the 2005 Comprehensive SFA Amendment as “all waters from mean high water to the outer boundary of the EEZ - habitats used by phyllosoma larvae - and seagrass, benthic algae, mangrove, coral, and live/hard bottom substrates from mean high water to 100 fathoms depth - used by other life stages”.

The 2004 EFH-FEIS described the habitat use by species in the Spiny Lobster FMU, indicating that during its six life history stages, the spiny lobster uses three distinct habitats: open ocean, the shallow vegetated coastal zone, and coral reefs. The spiny lobster larvae spend months in the pelagic plankton, and may travel large distances. Postlarvae migrate to nearshore areas and settle to the bottom. Postlarvae molt to juveniles that live in algal beds or among mangrove roots, and subsequently move to crevices in shallow areas. Sub adults and adults live on reefs.

The new literature since the 2004 EFH-FEIS describing EFH for the species in the Spiny Lobster FMU is reviewed below, for different life-history stages and different areas in the U.S. Caribbean. The new information and/or distribution maps resulting from these studies serve to update or complement the spiny lobster EFH designation (Figures 2.38 and 2.44 in the 2004 EFH-FEIS) and distribution maps in the Appendices of that document.

Butler IV et al. (2011) examined the effects of the behavior of spiny lobster larvae on their long-distance dispersal. The authors conducted laboratory tests of ontogenetic change in larval phototaxis and examined size-specific patterns of larval distribution in the plankton to characterize ontogenetic vertical migration (OVM) in the Caribbean spiny lobster during its long, six-month pelagic larval durations (PLD). They also used a coupled biophysical model to explore the consequences of OVM and hydrodynamics on larval *P. argus* dispersal in the Caribbean Sea. Results from this study showed that larvae reared in the laboratory were positively phototatic for the first 2 months and then avoided light, similar to field observations of the planktonic distribution of same-sized larvae. Simulations of larval dispersal from 13 spawning sites in the Caribbean Sea predicted that twice as many larvae would recruit to nurseries if they displayed OVM compared with passive dispersers. Larvae with OVM typically settled <400 km from where they were spawned, while passive dispersers often settled >1000 km away. Hydrodynamics created subregional differences in the potential for self-recruitment. Findings from this research have important implications for the understanding of *P. argus* dispersal mechanisms: (1) larval behavior constrains the dispersal of even long-lived larvae, particularly in retentive oceanographic environments, and (2) larval sources of *P. argus* in the Caribbean Sea cannot be estimated from passive transport and surface circulation (Butler IV et al. 2011).

In an evaluation of the size distribution of spiny lobsters inside and outside marine reserves, Cox and Hunt (2005) found that there are significantly more legal-sized spiny lobsters inside the Buck Island Reef National Monument reserve that in the surrounding fishery. Additionally, once boundary markers were put in place to identify the reserve, there was a significant increase in legal-sized abundance than 3 years prior to the boundary markers.

During 2003-2004, Davis and colleagues (Davis et al. 2006) conducted a research project in Puerto Rico to advance the culture of spiny lobster through novel pueruli collection methods. Recruitment of 1000's of spiny lobster pueruli to submerged fish sea cages in Puerto Rico was first observed by Snapperfarm, Inc. in spring of 2003. Studies were conducted from July 2003 to January 2004 to determine the feasibility of collecting spiny lobsters from sea cages for growout. Results showed that year-round collection of pueruli from submerged sea cages is feasible, with the highest collection occurring in the spring and near the new moon phase. Newly settled pueruli and pigmented post larvae were observed during each month of the study. Over 400 juvenile lobsters were collected from the submerged sea cages; 40 were placed in a growout study and the rest were relocated to a nearby marine reserve. The findings from this study indicate that collection of lobster pueruli and juveniles from sea cages for growout is technically feasible and has potential to be developed into a commercial venture.

As part of the Caribbean SEAMAP program, Gordon and Vasques (2004) analyzed spatial and temporal variations in *P. argus* pueruli settlement and relative abundance within marine reserve habitats located on the east end of St. Thomas, USVI by comparing trends in relative abundance and settlement between 1992-93, 1997-98, and 2002-03. This study also evaluated the use of artificial habitat enhancement structures on juvenile lobster occupancy and abundance. This study found that the overall abundance of pueruli at most sites was consistently low and pueruli settlement has steadily declined from 1992-1993 through 2002-2003. Peaks in pueruli settlement were observed to occur primarily in the spring and early summer, however further work is required to investigate the role habitat has on newly recruited juvenile lobsters, particularly exploring mangrove and coral reef habitats. Gordon and Vasques (2004) note that pueruli supply is not likely to be related to adult mortality or catch in the U.S. Virgin Islands due to the long duration of lobster larval cycles and recommended a coordinated regional sampling program be initiated to detect correlations among lobster pueruli distribution and large scale settlement and recruitment variations. Further, this study emphasizes the importance of studying the relationships between lobster settlement and recruitment to better understand and manage adult lobster stocks across the region. Gordon and Vasques (2004) postulate that as more Caribbean islands participate in data collection, a better understanding of local and regional spiny lobster dynamics should develop, which could provide the basis for implementing some form of regional lobster fishery management program.

Jiménez (2004) and Jiménez and Figuerola (2004) conducted surveys in southwest Puerto Rico as part of the SEAMAP juvenile lobster settlement assessment project. The two sites sampled included shallow water sea grass bed habitats associated with El Ron reef (depth contour 2-3 m); and hard bottom habitats with some hard corals and gorgonians (depth averaging 10 m) close to Tourmaline reef. In seagrass habitats, the authors observed a decrease in the number of recruits between January and February, noting that high swells are characteristic of these months because of the cold fronts. These weather systems stir the seafloor considerably, which may account for a reduction of recruits in artificial shelters. No juvenile recruits were found on hard bottom habitats. Strong currents and perhaps fishing activities destroyed the square formation of several shelters. The authors concluded habitat type may influence the lack of recruitment is this area, besides the strong currents that might prevent the settlement of pueruli.

Rosario and Figuerola (2004) also conducted surveys off the west coast of Puerto Rico to provide larval recruitment information for the spiny lobster fishery. A total of 188 post larvae (stages 1 to 3) and 43 juveniles (stage 4) were collected with ~48% of pueruli recorded from collectors less than 500 m from the shore in Bramadero Bay. Approximately 55% of pueruli were collected from August to October. The authors reported that the most productive pueruli collectors were set in areas with a combination of bottom types incorporating mud sediment, hard ground and *Thalassia testudinum* seagrass (also known as turtle grass) and collectors set near rocky shores.

Pittman et al. (2008) only recorded a total of 24 spiny lobsters (*Panulirus argus*) over hardbottom areas in a survey of Buck Island Reef from 2003 to 2006. There were no lobsters observed in 2004. Fifteen spiny lobsters were observed inside BIRNM and nine outside. The highest densities at individual sites were observed in patch reef and colonized pavement habitat types dominated by branching corals (three and nine lobsters respectively). Five lobsters were observed over scattered coral/rock in sand habitat type. No lobsters were observed on softbottom sites. However, the abundance of lobsters detected using existing techniques is very likely to be an underestimate of abundance.

Pittman et al. (2010) reported on analyses of data collected from 2001 to 2007 in the Reserva Natural La Parguera in southwest Puerto Rico as part of the Caribbean Coral Reef Ecosystem Monitoring project (CREM) of NOAA's Coral Reef Conservation Program (CRCP). Juvenile and adult Caribbean spiny lobster (*Panulirus argus*) were observed at 14 of 469 (approximately 3.0%) sites from 2005-2007 during UVC surveys, on three substrate types (soft, hard and mangrove) in 2005, on hard and mangrove sites in 2006, and only on hardbottom habitats in 2007. It is important to note however, that the stratified random sampling design utilized by this study provided limited opportunities to conduct spiny lobster surveys and determine their broad-scale distribution in La Parguera. The authors noted that a dedicated lobster-monitoring program will be needed to document long-term changes in lobster populations in La Parguera.

3.3.2. Queen Conch

In the EFH-FEIS (2004) and subsequently in the 2005 Comprehensive SFA Amendment EFH for the Queen Conch FMP in the U.S. Caribbean was defined as all waters from mean high water to the outer boundary of the EEZ – habitats used by eggs and larvae – and seagrass, benthic algae, coral, live/hard bottom and sand/shell substrates from mean high water to 100 fathoms depth – used by other life stages –.

There were few studies conducted since the 2004 EFH-FEIS that described EFH for the species in the Queen Conch FMU. The new information and/or distribution maps resulting from these studies serve to update or complement the queen conch EFH designation (Figures 2.40 and 2.45 in the 2004 EFH-FEIS) and distribution maps in the Appendices of that document.

Results of the main reports reviewed are outlined below.

The Caribbean Coral Reef Ecosystem Monitoring (CREM) project started recording data on queen conch (*Strombus gigas)* distribution, density and maturity within the Reserva Natural La

Parguera in southwest Puerto Rico in 2004. Analysis of survey results from 2004-2007 in Pittman et al. (2010) reported *S. gigas* density of 7 animals per hectare with 76% of the 45 individuals observed to be undersize and immature. Pittman et al. (2010) concluded that it is very likely that densities of queen conch in La Parguera now are too low for successful reproduction and recruitment, which may be preventing queen conch abundance and occurrence from increasing. It may be noted however that Diaz (2007) reported that west coast Puerto Rican fishers insist that at La Parguera, most conch occur off-shore toward the shelf edge in deeper waters at 30 m rather than at shallower depths where visual surveys for conch were conducted (Figure 19). Further surveys may therefore be required to verify the occurrence and abundance of *S. gigas* in deeper waters toward the shelf edge.

Ehrhardt and Valle-Esquivel (2008) developed a "Queen Conch, *Strombus gigas*, Stock Assessment Manual" for the CFMC, with the aim of providing a robust framework to assess the status of exploitation of queen conch stocks in the Caribbean region. This manual explains the quantitative research methods necessary to comply with the CITES requirements concerning the international trade of this protected large marine gastropod.

During the characterization of the mesophotic reefs (30–50 m) in Abrir La Sierra (ALS), Puerto Rico, Garcia-Sais et al. (2010) reported a wide distribution of *S. gigas* in all habitats, with particularly high densities of adults in the rhodolith reef areas. This preferred habitat has extensive macroalgal availability and functions as an essential (foraging) habitat for this invertebrate at ALS. High abundance of queen conch was also noted at the top of the insular slope (30–33 m) and at the rhodolith and sand habitat within the deep terrace. Queen conch and red hind were observed to be the most prominent species of commercial value within mesophotic habitats (30–50 m) at ALS. This study provides new information for the description of habitat utilization by adult queen conch.

Gordon and Tobias (2010) reported on the spatial and temporal variation in stock abundance of queen conch in the U.S. Virgin Islands. Between 2008 and 2010, the authors conducted conch density surveys in St. Thomas, St. John and St. Croix using underwater scooter transects. They estimate juvenile and adult density (in conch per hectare) in different locations. Overall conch densities were 74 conch/ha (St John), 58 conch/ha (St. Thomas) and 63 conch/ha (St. Croix). Estimates of conch density by habitat type showed that both juveniles and adults prefer seagrass habitats, followed by algal plains. Almost 60% of the individuals observed were juveniles. Most juveniles were found in the 0-6m depth range, while most adults were found in the 25-30m depth range. Overall conch densities were higher than in previous years (1990, 1996, 2001); however, adult densities were less than 50 conch/ha.

Marshak et al. (2006) carried out fisheries-independent underwater surveys of queen conch along the west coast of Puerto Rico in 2001-2002 and plotted the spatial distribution in GIS. Densities per depth, age class and habitat were calculated. No significant correlation was found between size and depth; conch in shallow areas were overwhelmingly found in seagrass beds, while conch in deeper waters were most frequently observed in sand habitats. The highest densities of juveniles (26.1-27.4 conch/ha) and adults (9.7-10.1 conch/ha) were found within shallow seagrass beds, while densities of older conch (0.82-0.88 conch/ha) were highest within *Syringodium* habitats. Juveniles were the most frequently encountered conch stage. Spatial analysis in GIS identified large-scale, high-density areas encompassing several habitats and depths. It revealed specific geographic areas along the western insular shelf where conch were aggregated in comparatively high densities. The data also indicated low densities of conch in all areas covered, which suggests that the fishery has not recovered.

Paris et al. (2008) conducted a study on the connectivity of queen conch populations in Mexico that addresses important questions on the drift and survival of veliger larvae across the Caribbean. Conventional expectations presume that *S. gigas* populations are largely connected, but results from this study conducted in the Yucatan Peninsula suggested otherwise. Spatial patterns of observed and simulated larval stages during the reproductive season revealed segregation of the Mexican populations, with high levels of larval retention in the Campeche Bank, contrasted to variable larval transport along the Mexican Caribbean coast into the Yucatan Current, and eventually into the Loop Current. Consequently, the probability that *S. gigas* larvae originating from the Mexican Caribbean settle to Alacranes Reef, the Florida Keys, the NW Bahamas or Cuba is extremely low. The authors concluded that this limited long-distance dispersal may not be sufficient to replenish the downstream populations. This study constitutes a first step in understanding queen conch metapopulation structure in the Caribbean, and calls for more local management actions for the recovery of depleted stocks (Paris et al. 2008).

In a characterization of the benthic habitats of Buck Island National Monument (St. Croix, USVI), Pittman et al. (2008) found that the coral reef ecosystems of the study region, particularly the large expanse of seagrasses between Buck Island and St. Croix support regionally important populations of adult and juvenile queen conch.

In a study of the coral reef ecosystems of La Parguera, PR conducted by Pittman et al. (2010), they collected information of queen conch abundance. Their results suggested that regulations have not been effective in protecting queen conch assemblages because densities and occurrence of queen conch were relatively low. This study surveyed 6.18 ha and observed queen conch at only 6% of the 618 surveys in the region between August 2004 and August 2007. Average queen conch density was 0.073 individuals per 100 m^2, with highest density being two adult mature individuals per 100 m^2. Additionally, the maximum number of conch observed during a sampling mission was 12 individuals in August 2006. Not only was observed conch abundance very low in La Parguera, but 76% of conch encountered were immature (i.e., their shells had not yet developed a lip) and were below the legal size class for the fishery.

Tobias (2005) provides an assessment of queen conch densities in backreef embayments on the northeast and southeast coast of St. Croix in the U.S. Virgin Islands (USVI). Data on conch abundance, density and habitat type were collected in 6 shallow backreef embayments (1 to 7 m in depth) on the NE coast (Cottongarden Bay, Teague Bay and Yellowcliff Bay) from October 1998 to September 1999, and 3 sites on the SE coast (Turner Hole Bay, Robin Bay and Great Pond Bay) from July 2000 to September 2001. With the exception of Cottongarden Bay, total conch density was reported to be markedly higher in NE embayments (52.6 conch/ha) than SE embayments (33.6 conch/ha). Seagrass (*Thalassia testudinum* and *Syringodium filiforme*) was the dominant habitat type in embayments with the majority of conch found in seagrass or seagrass combination (with sand and algal plain) habitats. The substantial numbers of juvenile conch found in seagrass habitats by Tobias (2005) indicates that backreef embayments serve as important nursery habitat for this species. Tobias (2005) recommended that adult conch be seeded in protected “no-take” embayments in the East End Marine Park to increase inshore stock abundance.

3.3.3. Reef Fish

In the 2004 EFH-FEIS and the 2005 Comprehensive SFA Amendment, EFH for the Reef Fish FMP in the U.S. Caribbean was defined as all waters from mean high water to the outer boundary of the EEZ – habitats used by eggs and larvae – and all substrates from mean high water to 100 fathoms depth – used by other life stages.

As described in the 2004 EFH-FEIS, the US Caribbean ichthyofauna has been characterized as being composed by three groups (in terms of energetics): large, fast-swimming pelagic apex predators with loose reef affiliations, strongly reef-associated carnivores, and reef-associated herbivores (Opitz 1996). While reef-associated carnivores represent 70-80% of reef fish species in the US Caribbean and herbivores only 10%, the herbivores comprise around 40% of total fish biomass. However, large to intermediate-sized herbivores are not a preferred prey for the larger piscivorous fishes (Opitz 1996). Much of the literature that has been reviewed includes listing of species observed in the study areas but fail to provide information of the life stage of the individuals seen. Often there are no data on the size of the fish, an important variable in determining whether the fish are juveniles or adults. Since 2004, some research projects have addressed this issue (e.g., SEAMAP 2007 surveys, and CCMA Biogeography Branch characterizations of fish assemblages in the U.S.V.I), by measuring or estimating fish lengths and calculating length-frequency distributions by species.

Regarding habitat use by species in the FMU, the 2004 EFH-FEIS noted there is little information on the distribution of reef fish eggs and larvae, but most of the species have planktonic eggs. Also largely unknown, are the distribution, development, settlement, and development of fish larvae. In general, newly settled stages tend to occur at depths of 0-10 m, and primarily at 5-10 m. Grouper species may be less likely than snapper species to have local larval retention due to their longer larval duration. Based on their size and age at settlement, grunts may be considered one of the reef fish groups most likely to exhibit local retention. However, larval duration, larval behavior, variations in current patterns and other factors may play a role in determining the amount of local retention (Lindeman *et al.* 2000). Some of these factors have now been studied in the U.S. Caribbean, although large gaps still exist in the knowledge of reef fish eggs and larvae.

Many species of reef fishes utilize seagrass and mangrove habitats as juveniles, and then migrate to reef areas as they grow larger, showing a clear ontogenetic migration pattern (Table 11). A large percentage of the demersal stages of reef fish species also exhibit a cross-shelf migration to deeper waters as ontogeny progresses. Some reef fishes have been found to use shallow reef areas as juveniles, and then move to deeper reef areas as they mature (Lindeman *et al.* 2000). Ontogenetic migration patterns of reef fishes across mangrove, seagrass, and shallow and mesophotic reef habitats have been examined since 2004. New, detailed information on habitat utilization patterns by some reef-fish species at certain life-history stages may justify more precise definitions of EFH (eg., grunts, snappers, parrotfishes).

Adult reef fish habitat was described in the 2004 EFH-FEIS noting that most commercially important reef fish in the Greater Caribbean area (e.g. groupers and snappers) migrate to specific places at specific times to reproduce in spawning aggregations (SPAGs). Many documented SPAG sites occur largely at reef promontories, and/or the seaward extension of reefs near deep water. In regions where no SPAG fishing has been documented, locations of promontories and reef extension may predict the location of SPAG. Reef fish spawning sites tend to occur near the edge of outer reefs or reef passes over hard sand bottom at depths around 20-50 m. SPAGs are critically important in the life cycle of many reef fishes and reproduction at these sites often represents the total annual reproductive output for specific stocks of a species (Heyman *et al.* 2002, Claro and Lindeman 2003). Several research projects carried out since 2004 focused on the characterization of reef fish communities at mesophotic reefs, reef promontories and areas where SPAGs occur, such as Bajo de Sico, Abrir La Sierra, Mona Island, Desecheo Island, Vieques, the Red Hind Marine Conservation District (MCD).

A large number of studies have been conducted since the 2004 EFH-FEIS that address habitat utilization patterns by reef fish species at different locations and at various stages of their life cycle. The new information and/ or distribution maps resulting from these studies serve to update or complement the reef fish EFH designation (Figure 2.41 in the 2004 EFH-FEIS), and the potential habitat, species distribution, and species-association maps provided the Appendices of that document.

The main findings from these studies are reviewed below, and are presented by the location studied and by author, in alphabetical order.

3.3.3.1. Puerto Rico

Aguilar-Perera (2004) determined the pattern and extent of habitat use in post-settlement reef fishes in southwestern Puerto Rico and how the processes may change during ontogeny. To elucidate the relative importance of coastal shallow-water habitats in terms of nursery value and ontogenetic habitat shifts, the study presents a baseline characterization of the fish community structure along a gradient, evaluates the nursery value of the habitats, and provides evidence for ontogenetic migrations and habitat shifts. Romero Key was identified as an important juvenile fish transition point from bay habitats to coral reef habitats further away.

Appeldoorn (2010) reported on the progress of a multi-year study to assess the ecology, integrity, and status of deep Caribbean coral reefs. Surveys have been conducted for geomorphic and biotic characterizations from depths of ~20 to 160 meters. Mesophotic Coral Ecosystems (MCEs) in La Parguera harbor a rich fish fauna composed of some common species observed on shallow reefs, but also several species confined to deep habitats. Species richness is high, Serranidae is the most speciose family, followed by Pomacanthidae, Haemulidae, Lutjanidae, and Scaridae. The fish assemblage differs between MCEs and shallow reefs because dominant fishes in MCEs are zooplanktivores (63% of fish abundance), and at shallower reefs herbivores are the dominant group.

Among the main conclusions from Appeldoorn (2010) are: The connectivity between shallow and deep coral ecosystems was documented for some species known to be dependent on shallow nursery areas (eg., mutton snapper, great barracuda); Fish abundance and diversity, especially for larger species, is greater over more rugose topography; MCEs serve as habitat for species of concern, particularly hawksbill turtles and reef sharks; The presences of sharks and large snappers and groupers suggests that MCEs have a more intact trophic structure that in shallow areas. This is one of the few research projects that have described MCEs in Puerto Rico at depths greater than 50-100m and it is producing unique results that are will expand the fundamental knowledge on EFH for a number of species in mesophotic coral ecosystems.

Bauer and Kendall (2010) undertook extensive UVC surveys around Vieques in 2009. The fish community observed in the study consisted of 34 taxonomic families and 110 species. While individuals from the families Labridae (wrasses) and Pomacentridae (damselfishes) were the most numerically abundant, surgeonfishes (Family Acanthuridae) and parrotfishes (Family Scaridae) accounted for the highest proportion of biomass.

Cerveny (2006) and Cerveny et al. (2011) mapped reef fish distribution patterns across life stages on a Cross-Shelf Habitat (CSH) framework based on habitat types and geomorphic zones. The study focused on 28 species of surgeonfishes, groupers, snappers, grunts and parrotfishes in La Parguera, Puerto Rico. Visual counts along transects were mapped and patterns were summed across species for different life stages to determine community-scale patterns. Important CSHs for juveniles were vegetated areas (mangrove and *Thalassia*) inside the inner reef line, low relieve dead coral areas on the Inner Shelf, and in the Outer Shelf in coral dominated areas associated with the emergent reef. Important CSHs for adults were sediment and hardbottom/invertebrate habitats and the outer shelf geomorphic zone. The study suggests that the CSH framework can be used as a tool for coastal and marine spatial planning at a variety of scales.

This work by Ceverny (2006) and Cerverny et al. (2011) has particular relevance in the field because it identifies EFH for species of snappers, groupers, grunts and parrotfishes through ontogeny on one scale, and investigates how EFH would be configured if it were examined across all species and stages combined.

Clark et al. (2005) provide preliminary results from an experiment that used 100m gill nets set along habitat boundaries within La Parguera, Puerto Rico to determine fish movements across four habitat types (seagrass/ reef, seagrass/ mangrove, seagrass/ unconsolidated bottom and mangrove/ unconsolidated sediments) along with gut content analysis to inform feeding related migrations between each habitat and the (dietary) functional role of those habitats. The results presented by Clark et al. (2005) provide strong evidence that many fishes exhibit dependencies on the range of habitats available to them for growth and reproductive success. Data collected by Clark et al. (2005) also showed that many species tend to exhibit resting or inactivity among highly structured habitats (reefs, mangroves) and venture into nearby seagrass and/or sand flats for feeding.

García Sais et al. (2005) developed an inventory and atlas of corals and coral reefs of the U.S. Caribbean EEZ, and reported that 872 species of fish inhabit depths greater than 30 m in the waters of Puerto Rico and the U.S. Virgin Islands. The most speciose families were Serranidae, Stomidae and Myctophidae, with 53, 51 and 49 species, respectively. García Sais (2005) concluded that planktonic food webs support the ichthyofauna at deep reefs where zooplanktivorous fish dominate and large numbers of pelagic game fish (including marlin, wahoo, mackerel, tuna and swordfish) commonly occur. The deep reefs at Isla Desecheo, Puerto Rico, provide habitats for Nassau and yellowfin groupers, red hind, cubera snapper, and aquarium trade species such as blue chromis, royal gramma, pigmy angelfish, butterflyfish, jawfish and hawkfish.

García-Sais et al. (2007) mapped benthic habitats down to 50 m, recording associated benthos and invertebrate cover and fish communities to provide a preliminary assessment of commercially important grouper and snapper populations on the Bajo de Sico (BDS) seamount off Puerto Rico. This study found the large reef promontories at BDS to provide important residential and foraging habitat for a group of large, commercially important species of snappers (*Lutjanus cyanopterus, L. jocu*) and groupers (*Epinephelus striatus, Mycteroperca bonaci, M. venenosa, M. interstitialis*) that have virtually disappeared from most reef systems in Puerto Rico. In addition, this site has also been identified as an important spawning aggregation site for red hind (*Epinephelus guttatus*), and possibly other groupers within the Mona Passage. García-Sais et al. (2007) also observed that a deep colonized rhodolith reef area on the slope edge of the seamount appears to serve as residential habitat for the red hind and for an assemblage of fishes that are typical of deep reefs, including some highly valuable for the aquarium trade industry.

The BDS seamount has been identified as an important foraging and residential habitat for endangered hawksbill sea turtles (*Eretmochelys imbricata*) with many large individuals observed on reef promontories. The BDS also serves as an important foraging area for large migratory pelagic fish, including wahoo (*Acanthocibium solanderi*), mahi-mahi (*Coryphaena hippurus*), tunas (*Thunnus spp*.) and marlins (mostly *Makaira nigricans*) making it a popular destination for game fishing vessels based in Puerto Rico. García-Sais et al. (2007) recommended that the entire BDS be permanently closed to fishing for demersal fish species to protect what could be one of the few remaining actively reproducing populations of black, yellowmouth, yellowfin and Nassau groupers in Puerto Rico.

In a report of the Status of Coral Reef Ecosystems in Puerto Rico, García-Sais et al. (2008) noted that the abundance of reef fish and associated species in the coral reef ecosystems of Puerto Rico has declined. Possible causes for this decline could include overfishing, changes in habitats, higher sea surface temperatures which in turn cause coral bleaching and/or mortality and increased use of the marine environment by vessels. Additionally, the report acknowledges that the CFMC has determined the following species as overfished: Nassau and goliath groupers (*Epinephelus striatus* and *E. itajara*), queen conch (*Strombus gigas*), species from the Snapper Unit 1, Grouper Unit 4 and the parrot fish complex. Furthermore, this study concluded that fish communities (density and biomass) were positively correlated to water clarity. This result was independent of the correlation between animal-environment and rugosity or percent of live coral cover. The authors discussed some mesophotic reefs, such as El Seco, east of Vieques, (SPAG for tiger grouper, *Mycteroperca tigris*); Black Jack, south of Vieques; Red Hind Marine Conservation District, south of St. Thomas; as important as SPAG sites for several grouper species.

Garcia-Sais et al. (2010a) conducted a characterization of the mesophotic reef habitats (30–50 m deep) in Abrir La Sierra (ALS), Puerto Rico. A total of 100 species of reef fishes were identified at ALS during this study. The three main benthic habitats associated with mesophotic reef zones at ALS (e.g. rhodolith reef, colonized pavement, and scattered rhodolith and sand) exhibited statistically significant differences of fish community structure. Differences were also noted between colonized pavement habitats of different reef zones, mostly driven by the higher abundance of bluehead wrasse, *T. bifasciatum* and parrotfishes, *S. aurofrenatum*, *S. iserti* at 30 m, whereas masked goby, *C. personatus*, sunshine fish, *C. insolata* and bicolor damselfish, *S. partitus* were most prominent at 50 m. Differences between the rhodolith reef and colonized pavement habitats were mostly associated with higher abundance of *C. argi, S. atomarium, S. tabacarius, S. baldwini* and *P. maculatus* at the rhodolith reef, and higher abundance of *C. personatus, C. insolata, T. bifasciatum, S. iserti and S. aurofrenatum* at slope habitats and inner walls. Red hinds (*Epinephelus guttatus*) were distributed along the entire range of mesophotic reef zones and benthic habitats at ALS, with the highest densities at the top of the insular slope (30 m), at the rhodolith reef (36–40 m) and on the small rock promontories of the scattered rhodolith and sand habitat within the deep terrace. Black groupers were observed at depths of 35–50 m at the insular slope, where they seem to be the most prominent demersal predator. During the 2009 spawning event for mutton snapper (*L. annalis*), it was observed that the dominant north-northwest current patterns may transport disperse fertilized eggs and larvae towards the west-northwest coast of PR and Mona Passage.

García-Sais et al. (2010b) monitored coral reef communities in 15 reefs from seven natural reserves in Puerto Rico. These included reef sites at Isla Desecheo, Isla de Mona, Rincón, Mayagüez, Guánica, Isla Caja de Muerto and Ponce. Visual surveys of species richness and abundance of fishes and motile megabenthic invertebrates were performed along sets of five permanent transects. Fish populations in 2010 presented a general trend of stabilized abundance and species richness relative to the 2008 levels. Significant differences in fish abundance were observed in seven out of the 12 reef stations surveyed. Likewise, differences of fish species richness were observed in some stations at different depth ranges. Abundance variations between surveys are mostly associated with fluctuations of numerically dominant populations that exhibit highly aggregated distributions in the immediate vicinity of live coral heads (e.g., Masked Goby and the Blue Chromis). It is uncertain if reductions of abundance by reef fishes closely associated with coral habitats are related to the massive coral mortality exhibited by reef systems between 2005-2006.

During this study, the authors noted that Lionfishes (*Pterois volitans*) were present in the vicinity of the reef monitoring of Isla Desecheo, Rincón and Mona. Some reductions of both fish species richness and abundance were observed and may be attributed to the presence of lionfish. Although in low abundance, large demersal (top predator) fishes were detected in several reefs. These include Reef Sharks; Yellowfin, Yellowmouth, Tiger, Jewfish, and Nassau Groupers, and the Cubera, Dog and Mutton Snappers (García-Sais et al. 2010b).

García-Sais (2010) reported on quantitative surveys (undertaken in 2004-2005) of sessile benthos and fish populations associated with reef habitats across a 15-50 m depth gradient at Isla Desecheo in the Mona Passage off the west coast of Puerto Rico. This study found fish species richness to be positively correlated with live coral cover however, the relationship between total fish abundance and live coral was weak. The lowest ichthyofaunal abundance and species richness was associated with the rhodolith reef habitat at the deepest section of this study (50 m). Abundance of several numerically dominant fish species varied independently from live coral cover and appeared to be more influenced by depth and/or habitat type and statistically significant differences in the rank order of abundance of fish species at euphotic *vs*. mesophotic survey stations was detected. The authors identified a small assemblage of reef fishes that were most abundant or only present from stations deeper than 30 m, which may serve as indicator species of mesophotic habitats. This included the cherub-fish, *Centropyge argi*, sunshine chromis, *Chromis insolata*, greenblotch parrotfish, *Sparisoma atomarium*, yellowcheek wrasse, *Halichoeres cyanocephalus*, sargassum triggerfish, *Xanthichthys ringens*, and the longsnout butterflyfish, *Chaetodon aculeatus*.

Jiménez (2006) undertook fishing surveys using traps and hook and line to survey fish at shallow and deepwater sites off the west coast of Puerto Rico. Whilst no conclusions could be reached regarding relationships between habitat and species diversity, higher Catch per Unit Effort (CPUE) of sand tilefish (*M. plumieri*) was recorded at deep sites with lower CPUE in shallow sites compared to 2001 data. Jiménez (2006) noted that this trend could suggest a shift in habitat preference of the species towards deeper areas. Further surveys and investigation would be required to verify this result as a shift in habitat preference.

Mateo et al. (2010) used otolith chemistry to determine if mangrove and seagrass habitats served as nurseries for French grunt (*Haemulon flavolineatum*) and schoolmaster (*Lutjanus apodus*) in St. Croix and Puerto Rico. The authors found that mangrove habitats served as nurseries for almost 100% of all schoolmaster subadults in both locations. French grunts, however, seemed to use both mangrove and seagrass habitats as nurseries. The density of schoolmasters and French grunts was greater in mangrove habitat then in seagrass habitat. According to Mateo (2009), schoolmasters and French grunts in mangrove habitats had higher growth rates than those in seagrass habitats. Mangrove habitats, therefore, likely support faster growth and more successful recruitment to the adult population for both schoolmasters and French grunt. To protect reef fish, Mateo et al. (2010) suggested that Marine Protected Areas (MPAs) should include ecologically-linked nearshore habitats including mangroves and seagrass as well as coral reefs. This study contains the first direct evidence of post-settlement fish movement connecting mangrove habitats to the reef using otolith chemistry.

Nemeth et al. (2006) documented spawning aggregations of Red Hind (*Epinephelus guttatus*) and yellowfin grouper (*Mycteroperca venenosa*) at Mona Island between Puerto Rico and the Dominican Republic. Spawning aggregations of these two species occurred simultaneously at focal points approximately 100m apart with the density of *E. guttatus* peaking in January and *M. venenosa* 2 days after full moon in March. Tiger grouper (*M. tigris*) was also observed aggregating in preparation to spawn at this site but this species was not quantitatively surveyed during this project. *E. guttatus* aggregated at 20m on a low relief hard bottom colonized by scleractinian corals (*Montastrea* spp., *Diploria* spp.), gorgonians and barrel sponges (*Xestospongia muta*) whilst *M. venenosa* and *M. tigris* preferred a 25-30m deep site on the high relief shelf edge, characterized by larger coral colonies, promontories and ledges close to a steep drop-off (30-40 degrees) to depths >50m. Nemeth et al. (2006) noted that this site may serve as an important stepping stone for ecological connectivity between Puerto Rico and the Dominican Republic.

Ojeda-Serrano et al. (2006) and Ojeda-Serrano (2007) undertook an interview-based survey to identify unknown reef fish spawning sites throughout the entire Puerto Rican Archipelago including the islands of Mona, Desecheo, Culebra and Vieques. Information was obtained for 61 fish species about 27 past and 93 present "potential" (non-overlapping) spawning aggregation sites, spawning times, changes in species composition in time and space, spawning-site fidelity, as well as 76 sites supporting multiple spawning species. Data from this project, including detailed shape files on fishing aggregations, spawning aggregations, past spawning aggregations, sport fishermen fishing aggregation sites, and observed fishing boat positions during 2002 and 2003 for each site/area, including the type of species, fisher ID, bottom type and comments reported by fisherman can be found in Ojeda-Serrano et al. (2007) and was provided to local and regional fisheries management agencies (DNER and CFMC). Ojeda-Serrano et al. (2006, 2007) noted that these results should be interpreted as preliminary information until field verification and characterization of the sites can be performed.

Pittman et al. (2007b) developed an exploratory seascape approach using the geographical location of mangroves and the structure of the surrounding seascape at multiple spatial scales to explain the spatial patterns in fish density and number of species observed within mangroves of southwestern Puerto Rico. This study found that fish density and species richness in mangrove forests was strongly influenced by the make-up of the seascape in adjacent areas to mangroves, including the presence or absence of nearby seagrass beds and/or coral reefs. Pittman et al. (2007b) emphasize that there is an urgent need to incorporate information on the influence of seascape structure (or make-up) into a wide range of marine resource management activities, such as the identification and evaluation of critical or essential fish habitat, the placement of marine protected areas and the design of habitat restoration projects.

Pittman (2008) conducted a spatial and temporal (1999-2006) characterization of the fish and benthic communities of Buck Island Reef National Monument and the surrounding seascapes of northeastern St. Croix, United States Virgin Islands. The project integrates field data on coral condition, living marine resources and benthic habitats through an ongoing multi-agency collaboration between NOAA's CCMA-BB, NPS, U.S.G.S. and the VI-DPNR. The technical memorandum resulting from this work contains analysis of the first six years of fish survey data (2001-2006) and associated characterization of the benthos. The primary objectives were to quantify changes in fish species and assemblage diversity, abundance, biomass and size structure and to provide spatially explicit information on the distribution of key species or groups of species and to compare community structure inside (protected) versus outside (fished) areas of BIRNM. The integration of the NOAA/NPS lead efforts with data generated by VI-DPNR provides robust spatial and temporal data to characterize St. Croix coral reef ecosystems.

The main findings by Pittman et al. (2008) include the following. A total of 201 fish species/species groups were identified from 56 families. Nine of the 10 most frequently encountered species belonged to the families Labridae (wrasse), Acanthuridae (surgeonfish) and Scaridae (parrotfish). The majority of the most abundant fish across the study region were found in highest densities over hardbottom habitat types, yet most also utilized multiple habitat types including seagrasses and sand. Fish metrics significantly higher on hardbottom habitat inside BIRNM included fish biomass (all fish combined), herbivore biomass, parrotfish biomass, shark and ray biomass, coney (*C. fulva*) density and biomass, blue tang (*Acanthurus coeruleus*) density and biomass, and striped parrotfish (*Scarus iseri*) biomass. Fish metrics significantly higher outside BIRNM included ecologically important predator groups such as piscivore biomass (including sharks and rays), snapper (Lutjanidae) density, and grunt (Haemulidae) density and biomass.

Pittman et al. (2010) reported on analyses of data collected from 2001 to 2007 in the Reserva Natural La Parguera in Puerto Rico as part of the Caribbean Coral Reef Ecosystem Monitoring project (CREM). Underwater visual census (UVC) surveys recorded 210 fish to species level and a further 14 to genera level. Adjacent seagrass and mangrove areas within this region were found to be an important habitat in this region closely linked with nearby coral reefs, providing important recruitment, nursery and feeding habitats. Pittman et al. (2010) found twenty-five of the 30 most abundant fish species in mangroves were also observed over coral reefs indicating a high level of multi-habitat use, but with fish body length markedly smaller in mangroves than on coral reefs. This can be indicative of size dependent ontogenetic habitat shifts, particularly for grunts (Haemulidae), snapper (Lutjanidae), parrotfish (Scaridae) and barracuda (Sphyraenidae). Based on body size, Pittman et al. (2010) observed that mangroves appeared to function as an intermediate habitat type for some grunts and snappers, with smallest fish associated with seagrasses, larger fish in mangroves and the largest mean length recorded for fish on coral reefs. The authors highlighted that efforts to protect and restore mangroves, particularly those that are in close proximity to seagrasses and coral reefs will be beneficial to the diversity and productivity of fish assemblages in this region.

Rodríguez (2006) investigated the relationship between water turbidity and coral and fish communities at 35 reef sites in southwest Puerto Rico. Coral and fish parameters varied with turbidity, showing higher diversities and abundances in clearer waters. Results generally indicated lower percentages of live coral cover, fish densities, species richness and fish biomass with increasing water turbidity. Turbidity, reef rugosity and percentage of live coral were significant variables affecting the reef fish community.

Rosario et al. (2004) conducted fishing surveys using fish traps and hook and line methods off the west coast platform of Puerto Rico from Mayaguez Bay to the southwestern corner of Puerto Rico from April 2000 to March 2001. Catch per unit of effort (CPUE) was consistently the highest at stations on the Bajo de Sico seamount. Whilst this study provided limited definitive data on fish-habitat relationships, the authors did observe that red hind prefers hard bottom substrates with high cover of sponges and corals. Algal plains and seagrass beds were also found to be more productive than sandy or muddy substrates.

Schärer et al. (2008) surveyed sites around Mona Island off Puerto Rico between August 2005 to March 2006 to investigate habitat preferences by grunts (Haemulidae) and snappers (Lutjanidae) at different life stages (early juvenile, juvenile and adult). Mean fork length was found to be significantly different by habitat type for seven species of grunts and snappers. Early juvenile grunts and snappers were found to be more abundant in habitats of depths less than 5 m, mainly in rocky shores and seagrass areas with patches of coral or other hard structures. Larger juveniles were significantly more abundant in depths less than 5m in coral dominated habitats and adults were abundant throughout the habitats of all depth ranges, except for two species *Haemulon chrysargyreum* (small mouth grunt) and *Lutjanus mahogoni*, which were limited to shallower habitats. The authors caution that measuring species abundance without considering their life stage may provide misleading patterns of habitat use since ontogenetic migrations include a variety of habitats which are not necessarily the most abundant. The authors also noted the importance of studying species individually and not pooling them at the family level due to differences in species specific patterns of habitat utilization.

Schärer-Umpierre (2009) conducted research in Mona, Puerto Rico to explore habitat connectivity for reef fish species at an oceanic island where there is a lack of mangroves and seagrasses, habitats known to support the ecological nursery function elsewhere. This study showed that nursery habitats (nearshore seagrass, hardbottom, coral reef) were species-specific and cross-shelf ontogenetic migrations were identified for the coral reef fish assemblage. The presence and abundance of most species at Mona were limited, as compared to other areas with abundant mangroves and seagrasses (i.e., La Parguera). A correlation between habitat metrics and fish density suggested that ontogenetic requirements are species-specific and scale dependent. At landscape scales, areas with small patches (~100 m^2) of coral habitat located in proximity to each other supported higher fish densities, although their arrangement on the shelf influenced this relationship. The distribution and replication of key habitats within Mona Island's marine reserve suggested that this protection is sufficient to encompass inter-habitat connectivity for reef fishes. Using landscape ecology, Schärer-Umpierre (2009) was able to detect patterns of habitat use and ontogenetic connectivity of reef fishes, applicable to evaluating the ecological value of a particular arrangement of habitats within spatial-based protection.

3.3.3.2. USVI

Friedlander and Beets (2008) monitored spatial and temporal trends in reef fish assemblages within the Virgin Islands National Park (VINP) and adjacent reefs around St John with UVC surveys from 1988 to 2006 to provide a comparative data set to assess the status of reef fishes around St. John. This study found similar (low) densities of targeted fish species inside and outside the VINP and concluded that existing management strategies should be reviewed as they do not appear to be adequately protecting resources within the VINP. This monitoring program was referenced in the current 2004 FEIS-EFH.

Friedlander and Monaco (2007) deployed an array of hydroacoustic receivers around the island of St. John to track a variety of tagged reef fishes to determine habitat utilization patterns and residence times inside and outside marine protected areas around the island. Lane snappers and bluestriped grunts showed clear and consistent diel movement from reef habitats during daytime hours to offshore seagrass beds at night corresponding with sunrise and sunset times. Fish on reefs without adjacent seagrass beds were found to make more extensive movements during the night.

Friedlander and Monaco (2007) reported that 21 additional receivers were deployed along much of the south shore of St. John in April 2007 to enable further assessment of the extent of broader-scale reef fish movements among management units and examine the potential benefits of the Virgin Islands Coral Reef National Monument (VICRNM) to provide adult "spillover" into the Virgin Islands National Park and adjacent harvested areas. The results of this work are anticipated to aid in defining fine to moderate spatial scales of reef fish habitat affinities and in designing and evaluating marine protected areas.

Hill et al. (2009) conducted a study in the St. Thomas-St. John and St. Croix reef environments to explore spatial and temporal patterns of the reef fish abundance and density within six habitat types over a five-year period. This study also examined the variation in the composition of species caught with fish traps. Results showed a low abundance fish community, dominated by herbivores and secondary carnivores and with minimal representation of predators and large species. This community structure appeared drastically different compared to studies conducted three decades ago. The authors suggested that the composition of the reef fish caught in traps might also reflect the degradation of the habitat quality caused by natural and human-induced stressors acting synergistically. After 12 years of protection of offshore reefs, reef fishes appeared to be recovering, although clear evidence was not found during this study.

From field observations in the USVI, Kojis (pers. comm. 2011) noted that juvenile tomtate (*Haemulon aurolineatum*) recruit to reefs. She also noted that juveniles <0.5 cm of species such as yellowtail snapper recruit to algae, sponges, seagrass but by 1 cm have moved to small patch reefs within this habitat. This habitat is described in Mateo and Tobias (2006, 2007) and in Adams (2002). Finally, Kojis described that lane snapper and mahogany snapper juveniles (1-4 cm) are often found in rocky shorelines along with juvenile parrotfish. These rocky shorelines may be eroded beachrock with caves and overhangs (west end STX) or volcanic rocks (Lindberg Bay, St. Thomas).This information complements the data provided in Table 11.

Using underwater visual census techniques at St Croix's Southeastern barrier reef lagoon, Mateo and Tobias (2007) found that reef fish use a number of nearshore habitat types as nurseries in addition to seagrass beds and mangrove systems. They also use patch reefs, rubble areas and algal plains. During all four seasons, patch reefs and rubble areas had greater species richness than seagrass beds, algal plains and unvegetated sandy habitats. The density of fish was also highest in patch reefs and rubble areas, but density fluctuated seasonally with peak density occurring in the summer, a secondary peak in the fall and the lowest total density in the winter.

Mateo and Tobias (2007) reported that recruits of newly settled *Haemulon* spp. and *O. chrysurus* were found primarily in seagrass beds and algal plains along with small resident species such as *Halichoeres* spp. and *S. radians*. Juvenile damselfishes, parrotfishes, grunts and surgeonfishes, including *S. iseri* and *A. chirurgus*, dominated rubble areas and patch reefs. *C. roseus* and *H. poeii* were typically found in seagrass beds. *T. bifasciatim*, *H. radians*, *S. aurofrenatum*, *S. viride*, *H. adcensionis* and *M. jacobus* were typically found over patch reefs. *X. martinicensis* and *C. glaucofraenum* were typically found over bare sand. *H. bivittatus*, *S. radians*, *Haemulon spp*., *H. flavolineatum*, *H. plumierii*, *O. chrysurus*, *L. mahogoni*, *A. chirurgus* and *A. bahianus* were often associated with more than one habitat type.

Monaco et al. (2007) conducted UVC surveys of habitat and fishes inside and outside of the VICRNM in 2002-2004. This study found that areas outside the VICRNM had significantly more hard corals, greater habitat complexity, and greater richness, abundance and biomass of reef fishes than areas within the VICRNM, indicating that the administrative process used to delineate the boundaries of the VICRNM did not include a robust ecological characterization of the area before it was established. Monaco et al. (2007) noted that because of the reduced habitat complexity within the VICRNM, the enhancement of the marine ecosystem inside the reserve may not be fully realized and/or increases in targeted reef fish may take longer to detect.

Nemeth (2005) recorded rapid increases in the average size density and biomass of spawning red hind (*Epinephelus guttatus*) following permanent closure to fishing in the Red Hind Marine Conservation District in St Thomas. Spawning density has reportedly more than doubled since the closure, which is believe to be a key contributing factor to the speed of the recovery of this population. Data recorded by Nemeth (2005) suggests that red hind typically arrive early at their spawning aggregation site (e.g. In December) and remain on or close to spawning sites between spawning peaks, with most fish (50-80%) dispersing short distances (at least 100m) into adjacent habitats between spawning peaks. Nemeth (2005) therefore noted that short-term seasonal closures may still expose parts of spawning populations to fishing mortality between spawning peaks.

Nemeth et al. (2008) surveyed habitat and fisheries resources in the Red Hind Marine Conservation District (MCD) in St Thomas in 2007 to validate habitat classifications developed for the CFMC and assess fisheries and non-fisheries resources within the MPA. Coral species richness was high with 37 species or genera recorded from the MCD, including the threatened staghorn coral (*Acropora cervicornis*). Resource surveys of fish and commercially important invertebrates showed a total of 112 fish species. Benthic habitat assessments by Nemeth et al. (2008) also revealed extensive and well developed mesophotic coral reefs at depths of 34 – 47m. Nemeth et al. (2010) recommended as a priority that formal re-assessment of benthic habitat maps be carried out using recently acquired in situ surveys to improve habitat classification models for Caribbean mesophotic systems.

Nemeth et al. (2008) hypothesized that mesophotic reefs such as those observed in St. Thomas may well be widespread on the Puerto Rican Shelf and are likely to serve as important fisheries areas. It was therefore recommended that further surveys be undertaken outside the MCD to establish the extent of these mesophotic reefs and their associated fish assemblages. Other federal marine protected areas in the U.S. Virgin Islands noted by Nemeth et al. (2008) that would benefit from Essential Fish Habitat assessment included Grammanik Bank, Lang Bank, and the Mutton Snapper closed areas.

A NOAA SEAMAP reef fish survey was conducted around Puerto Rico and the US Virgin Islands (USVI) in March and April 2009 to assess reef fish relative abundance, determine length frequency distributions, collect tissues for life history studies and DNA analyses, and collect water quality data (NOAA 2009). Sampling was carried out using video camcorders, chevron fish traps and bottom longlines, and CTD was employed to measure temperature, salinity, dissolved oxygen, fluorescence, and transmissivity profiles of the water column. 11 fish species were captured in the traps (primarily blackfin snapper and lane snapper, but also vermilion snapper, coney and red hind) and 31 taxa were taken with the bottom longlines (primarily smoothhounds, blacknose shark and gulper, but also red hind, lane snapper, red snapper, mutton snapper, dog snapper and silk snapper).

In a review of the status of the coral reef ecosystems of the U.S. Virgin Islands, Rothenberg and colleagues (Rothenberg *et al.* 2008) reported that there was an increase observed in fish density in spring months between 2001 and 2006 in St. Croix; although this trend could not be stated as significant. However, densities of commercially viable grouper species remain at low levels. Between 2003 and 2006 neither total fish abundance nor average species richness changed significantly on reefs in St. Thomas. Rothenberger et al. (2008) found that lane snappers (*L. synargris*) and bluestriped grunts (*Haemulon sciurus*) consistently moved from reefs in the daytime to offshore seagrass habitats during hours of darkness. This was highly predictable and occurred with sunrise and sunset all year round. Additionally, red hind spawning occurs in cooler water temperatures; between 26-27.5°C (Nemeth et al., 2007 in Rothenberger et al., 2008).

3.3.3.3. Other Areas

Cushion (2010) reports the life-history traits of *Epinephelus guttatus* (red hind), *E. striatus* (Nassau grouper) and *Mycteroperca venenosa* (yellowfin grouper) in the Bahamas. This research documented maximum ages (longevity) of 17 years for *E. guttatus*, 22 years for *E. striatus* and 13 years for *M. venenosa* with *E. striatus* estimated to have the slowest growth and *M. venenosa* the fastest growth rate. The peak spawning months were January-February for *E. guttatus*, December-January for *E. striatus* and March-April for *M. venenosa*. Size and age at maturity was determined to be 2.05 years and 235mm Total Length (TL) for *E. guttatus*; 4 years and 435mm TL for *E. striatus* and 4.66 years and 561mm TL for *M. venenosa*. The size and age range of sex change (female to male) for *E. guttatus* was between 257-401mm TL and ~4-5 years old and between 716-871 mm TL and ~8-9 years old for *M. venenosa*. Cushion (2010) noted that the findings of this research highlight that life history traits of the study species differ greatly and the impacts of these differences on population dynamics should be considered when reviewing and/or developing management initiatives.

3.3.4. Corals

In the 2005 Comprehensive SFA Amendment, EFH for the Coral FMP in the U.S. Caribbean was defined as “all waters from mean low water to the outer boundary of the EEZ – habitats used by larvae – and coral and hard bottom substrates from mean low water to 100 fathoms depth – used by other life stages.” Since the 2005 Comprehensive SFA Amendment, numerous studies have examined coral distribution and diversity within the U.S. Caribbean. Particular attention has been given to the study of Mesophotic Coral Ecosystems (MCEs), which represent unique habitats, different from those coral reefs previously described as EFH. Several research projects have studied deepwater coral reefs and their associated fauna within the U.S Caribbean. Some marine protected areas, including spawning aggregation sites and Marine Conservation Districts (MCDs), classified as HAPCs, are located within mesophotic reefs.

Since the edge of the insular shelf of PR and the USVI is typically found at depths between 20 to 30 m, reef systems deeper than 30 m are considered deep reefs for the purpose of this review (as in the zonal review conducted by García-Sais et al 2005). Thus, coral reefs in deep terraces of the outer shelf, rocky outcrops and vertical wall features of the insular slope, submerged volcanic ridges, and oceanic seamounts comprise the deep reef systems in the inventory and Atlas of the US Caribbean EEZ.

The findings of the research on all coral reefs – shallow, deepwater and rhodolith reefs - are presented below, with a separate section dedicated to Mesophotic Reefs. These studies contribute to a better understanding of EFH and HAPCs in the U.S. Caribbean, and, in some cases, propose new areas as possible candidates for the designation of HAPCs or MPAs. The new information and/ or distribution maps produced, thus serve to update or complement the coral EFH designation (Figure 2.42), the habitat distribution mosaic maps (Figures 2.5 to 2.15), and the known and potential habitat maps (Figures 2.16 to 2.22) in the 2004 EFH-FEIS.

3.3.4.1. Puerto Rico

Bauer and Kendall (2010) undertook extensive UVC surveys around Vieques in 2009. This study reported that turf algae accounted for the highest overall mean percent cover, followed by macroalgae, gorgonians, crustose/calcareous algae, hard coral, and sponges. Hard coral cover was generally low, with an overall mean of 3.4 (±0.5)%. Sites with the highest coral cover were generally located on reefs southwest of the island. Bauer and Kendall (2010) noted that Vieques is similar in terms of benthic cover, total fish abundance and biomass to other nearby locations in southwest Puerto Rico, St. Croix, and St. John in the USVI.

In a review of the “State of the Coral Reef Ecosystems in Puerto Rico”, García-Sais et al. (2008) indicate that reef systems in Puerto Botes and Puerto Canoas (Isla Desecheo), Tourmaline Reef (Mayagüez), Cayo Coral (Guánica), West Reef (Caja de Muerto–Ponce) and Derrumbadero Reef (Ponce) have statistically significant reductions of live coral cover. This decline was most notable between 2005 and 2006 with reductions measuring at 59%, 56% and 42% at Derrumbadero Reef, Puerto Canoas Reef at Desecheo Island and West Reef at Caja de Muerto Island respectively. These reductions were most impacted by significant mortality of *Montastraea annularis* complex, a highly dominant species in terms of reef substrate cover in Puerto Rico and the Caribbean.

Pittman et al. (2010) reported on analyses of data collected from 2001 to 2007 in the Reserva Natural La Parguera in Puerto Rico as part of the Caribbean Coral Reef Ecosystem Monitoring project (CREM). The coral reef ecosystem of the La Parguera region of southwestern Puerto Rico is a complex spatial mosaic of habitat types dominated by coral reefs, seagrasses, macroalgal beds, unconsolidated sediments and mangroves. The Natural Reserve is a unique coral reef ecosystem in Puerto Rico, due to its relatively sheltered position on a wide and shallow section of the insular shelf of southern Puerto Rico and may therefore warrant consideration as a habitat area of particular concern (HAPC). This study found that the shelf edge environment and the complex coral reef ecosystems between Margarita Reef and El Palo Reef support the highest fish species diversity and high abundance for many species and should receive special management attention.

Survey data from Pittman et al. (2010) indicates that the coral reef ecosystem within and around the La Parguera Natural Reserve is being impacted by multiple stressors, with low live coral cover, high macroalgal abundance and a depleted population of large-bodied species resulting in shifts in species dominance. Temporal analysis revealed that live coral cover varied significantly among some sampling years, but overall live coral cover decreased over the sampling period (2001-2007), particularly on pavement habitats between fall of 2003 and summer of 2007.

These findings are reportedly consistent with declines in live coral cover recorded in other parts of the Puerto Rico and the US Virgin Islands (USVI). Temporal declines ranging from 40-50% in live coral have been reported at several sites in Puerto Rico including reefs off Isla Desecheo, Mayagüez, Guanica and Ponce, with most of the loss occurring after the 2005 bleaching event (Garcia-Sais et al., 2008). At Buck Island, St. Croix, mean estimates of live coral cover on reefs were lowest in 2006 after four years of observations (Pittman et al., 2008; Clark et al., 2009). Similarly, in St. John, average live coral cover declined from 21.4% in 2005 to 8% by October 2007 (Miller et al. 2009). Much of the reported loss in live coral occurred in a few species, namely *M. annularis* complex, *C. natans* and *Agaricia agaricites* (St. John), *M. annularis* complex (Puerto Rico), and *M. annularis* complex and *Agaricia* spp. (Buck Island, St. Croix). After the drastic decline in acroporid corals, *Montastraea* remained one of the most abundant coral species in La Parguera (per this study) and in other areas of the U.S. Caribbean (Garcia-Sais et al. 2008; Rothenberger et al. 2008; Miller et al. 2009). Given their dominance and key ecological roles as reef-building species, the recent declines in the cover of *Montastraea* species represent a severe degradation to already fragile reef ecosystems.

Acropora species were rarely observed by Pittman et al. (2010) which could be, in part, due to the occurrence of the largest recorded coral bleaching event of 2005, although *Acropora* is not as susceptible to bleaching as many other coral species (B. Kojis, pers.comm). Pittman et al. (2010) also noted that coral disease has contributed to the mortality of *Acropora* corals in Puerto Rico over recent years.

Pittman et al. (2010) updated the habitat maps of the area, which were originally developed between 1998-2001 by the CCMA-BB. Relevant figures from this study are reproduced here, and can be used to complement the figures of the SW coast of Puerto Rico (Figures 2.32 and 2.8 in 2004 EFH-FEIS) (see Figures 16-19). This study also produced maps of species distributions in La Parguera, PR, including live coral cover, macroalgae, seagrasses, and queen conch (examples in Figures 18 and 19).

3.3.4.2. USVI

Armstrong et al. (2006) used an autonomous underwater vehicle (AUV) to survey benthic communities on deep insular shelf reefs (between 32 and 54m) in the Hind Bank Marine Conservation District (MCD) approximately 12km south of St Thomas, US Virgin Islands. Coral species richness was found to be highest on the western side of the MCD, which had mean overall live coral cover of 43%. Overall, *Montastrea annularis* complex (including *M. annularis*, *M. faveolata* and *M. franksi*) plates were the dominant coral representing 92% of live coral cover. Corals of the genus *Agaricia* were the next most common coral group with increasing cover at greater depths (>41m). Maximum coral cover found was 70% at 38-40m depth, where gorgonians were also typically observed in high densities. Also found in abundance was an encrusting sponge, thought to be a species of *Cliona*, which is a black sponge that grows over corals as it dissolves them. Armstrong et al. (2006) note that the presence of this species in such high abundance may account for the high percentage of bare substrate observed in some areas. Although no disease was evident in the Seabed AUV digital imagery obtained during this project, Nemeth et al. (2004) (see below) reported that low levels of disease occurred within the MCD in spring 2003, but higher levels of disease (over 10%) occurred on similar deep reefs outside the MCD. Armstrong et al. (2006) conclude that their initial results show that the deeper reefs of the MCD have been largely unaffected by hurricane disturbances, human impacts and disease and could therefore serve as potential refuge areas and a source of larvae for the recovery of shallower coral reef communities present downstream. In this respect, it was also noted that they may play a critical role in the re-establishment of fish populations in adjacent insular shelf areas.

Clark et al. (2009) reported on spatial and temporal patterns of coral bleaching around the Buck Island Reef National Monument (BIRNM), St Croix, US Virgin Islands between October 2005 and October 2006. Biannual UVC surveys were conducted in this area by scientists from NOAA's National Center for Coastal Ocean Science's Biogeography Branch (BB) and the National Park Service's BIRNM from 2001 to 2006 as part of a larger project to characterize and monitor fishes and benthic composition in coral reef ecosystems in southwestern Puerto Rico and the U.S. Virgin Islands. Bleaching was observed at 86 of 94 (91%) survey sites during Oct 2005 with 51% of the total live coral cover within surveys bleached. Coral cover for *Montastraea annularis* and species of the genus *Agaricia* were the most affected, while other species exhibited variability in their susceptibility to bleaching, including 5 taxa which showed no signs of bleaching.

Monaco et al. (2007) conducted UVC surveys of habitat and fishes inside and outside of the VICRNM in 2002-2004. This study found that areas outside the VICRNM had significantly more hard corals, greater habitat complexity, and greater richness, abundance and biomass of reef fishes than areas within the VICRNM, indicating that the administrative process used to delineate the boundaries of the VICRNM did not include a robust ecological characterization of the area before it was established. Monaco et al. (2007) reported many areas adjacent to the VICRNM to be populated by hard corals including stands of living staghorn coral, *Acropora cervicornis* (Lamarck), which was recently listed as a threatened species. Monaco et al. (2007) noted that because of the reduced habitat complexity within the VICRNM, the enhancement of the marine ecosystem inside the reserve may not be fully realized and/or increases in targeted reef fish may take longer to detect. In addition, due to jurisdictional boundaries the VICRNM was found to offer limited protection for productive areas of the St John mid-shelf reef. Monaco et al. (2007) highlighted the importance of St. John's mid-shelf reef habitat with its high bathymetric complexity, high percentage of live coral substrate and its location in relatively deep water. Deeper reefs such as these may intrinsically carry some buffer to future coral bleaching events as water temperatures generally decrease with increasing depth.

Muller et al. (2008) observed that bleached colonies of *A. palmata* in St. John had higher prevalence of diseases and disease-associated mortality than unbleached colonies following the October 2005 bleaching event.

In a study to characterize the fish assemblage and benthic habitat of Buck Island Reef National Monument in St. Croix, USVI, Pittman et al. (2008) found that 78% of the mapped area inside BIRNM was hardbottom habitat dominated by colonized pavement and 22% was soft bottom (sand and seagrasses); outside BIRNM, 46% was hardbottom and 54% softbottom. Seascapes inside BIRNM also had significantly higher mean habitat richness. Coral cover for all major scleractinian families was significantly higher inside BIRNM and coral reefs had a significantly higher ratio of live coral cover to macroalgal cover than outside BIRNM. Overall, hardbottom habitats of the study area were dominated by turf algae (37%) and macroalgae (11.4%), with mean scleractinian coral cover of only 5.6% ranging from 12.1% on patch reefs to 2% on the less rugose reef rubble. Results and maps generated by this study complement/update the maps produced previously by the NOAA/NOS/Biogeography Program (2001) and available online (http://www.stxeastendmarinepark.org/maps.htm) (Figures 15 and 27).

Nemeth et al. (2008) surveyed habitat and fisheries resources in the Red Hind Marine Conservation District (MCD) in St Thomas in 2007 to validate habitat classifications developed for the CFMC and assess fisheries and non-fisheries resources within the MPA. Coral reefs occupied 65% of the sites sampled. Coral species richness was high with 37 species or genera recorded from the MCD, including the threatened elkhorn coral (*Acropora cervicornis*). Members of the *Montastraea annularis* species complex dominated the coral coverage (91.8%), Resource surveys of fish and commercially important invertebrates showed a total of 112 fish species. Benthic habitat assessments by Nemeth et al. (2008) also revealed extensive and well developed mesophotic coral reefs at depths of 34 – 47m. This study produced a number of relevant maps of the bathymetry and habitat types within the MCD; maps of the percent cover of different species of corals, gorgonians, sponges, macroalgae, non-living substratata (sediment, sand, stone, rubble, etc.); fish species richness, abundance, biomass (Families: Scaridae, Serranidae, Lutjanidae, Haemulidaea, Lutjanidae, Balistidae); and maps of coral diseases and bleaching. These maps complement previous maps of the MCD (examples provided in Figures 20 and 21).

In a review of the status of the coral reef ecosystems of the U.S. Virgin Islands, Rothenberg and colleagues (Rothenberg *et al.* 2008) reported survey results from a series of belt transects over an eight year period and over seven sites. The most notable changes occurred post the warm seas event in 2005. Between 2005 and 2006, 6,061 disease lesions were noted on 23 species of coral. While several diseases were noted, 99% of the lesions and loss of coral cover was due to white plague which was cited as a regular occurrence in areas impacted by bleaching. In St. John, coral coverage also reduced; the mean live coral cover was highest in 2001 (8.4 ±1.8%) and steadily decreased to its lowest value in July 2006 (4.5 ±0.9%). In some sites, coral coverage reduced by 50%.

Benthic habitat mapping of the nearshore marine environment around St. John, USVI by Zitello et al. (2009) showed that the overwhelmingly dominant biological cover was algae, which accounted for 74% of the mapped area (53km^2), whilst the total area of features dominated by live coral cover was only 1.5% of the mapped area (0.81km^2). Zitello et al. (2009) found 83% of the nearshore environment had less than 10% coral cover, with 17% of the area (9km^2) comprising coral cover of 10% - <50% cover. Whilst it was observed that some areas did have >50% coral cover, these areas were smaller than the minimum mapping unit of 1,000m^2 and are therefore not represented on these maps. Zitello et al. (2009) achieved 86% accuracy for the detailed structure in these new St. John benthic habitat maps. An interactive mapping tool for St. John, USVI (BIOMapper- Biogeography Integrated Online Mapper) is available online: (http://ccma.nos.noaa.gov/ecosystems/coralreef/benthic/) (examples in Figures 24 to 26). These maps expand the work done by the NOAA Biogeography Branch, and replace or complement the previous NOAA maps generated by Kendall et al. (2001) (e.g., Figure 2.14 in 2004 EFH-FEIS).

3.3.4.3. Mesophotic Reefs

Several research projects have studied mesophotic and deepwater coral reefs and their associated fauna within the U.S Caribbean.

Appeldoorn (2010) reported on the progress of a multi-year study to assess the ecology, integrity, and status of deep Caribbean coral reefs. This research involves the analysis of the geomorphological features of mesophotic coral ecosystems of the upper insular slope of southwest Puerto Rico, from depths of ~20 to 160 meters. Surveys have been conducted for geomorphic and biotic characterizations. To date, results show that MCEs are more abundant, extensive, and diverse on southwest-facing slopes where the steep, irregular topography provides suitable substrates. The characterization of the coral community shows 18 scleractinian corals, with *Agaricia* and *Undaria* being the most abundant at all depths (47m, 59m and 70m). Some other species *Agaricia undata, A. grahamae, Leptoseris cailleti and Mycetophylia ressi*) were reported in Puerto Rico or at such depths for the first time in this report. Bacterial communities, dissolved nitrogen, and nutrient concentration are also being monitored, and the genetic connectivity of scleractinian corals is being analyzed.

The main conclusions in relation to MCEs from Appeldoorn (2010) are: A low incidence of disease or bleaching among corals within MCEs has been observed; There is a shift in benthic community composition occurring at ~45-50 m, with MCEs below this depth no longer strongly reflecting the shallow coral communities; Most corals in MCEs that also occur in shallow areas (e.g., *Montastraea* spp.) have small size and low density, both of which would limit effective spawning potential; MCEs are areas of high biodiversity, potentially including many new species (several new species of algae and invertebrates have already been documented). This is one of the few research projects that have described MCEs in Puerto Rico at depths greater than 50-100m and it is producing unique results that are will complement EFH information for a number of species in deep water coral reefs.

García-Sais et al. (2005) developed an inventory and atlas of the corals and deep-water coral reefs of Puerto Rico and the U.S. Caribbean. This work was an effort towards characterization of deep reefs and associated marine communities from Puerto Rico (PR) and the United States Virgin Islands (USVI). It included an assessment of their geographic distribution, bathymetric features, benthic habitat types, and a taxonomic inventory of species previously reported from deep reefs in this region, with particular emphasis on corals. Geo-physical, hydrographic and biological information was geo-referenced and included on a GIS map atlas of the US Caribbean. These authors reported that deep hermatypic coral reefs occur along the shelf-edge north of St. Thomas, southwest of St. Croix and east and southeast of St. John as well as along the seamounts and the gently sloping terraces of the outer shelf and oceanic islands of Puerto Rico. On the southeast coast of Puerto Rico, the submerged seamounts, Bajo Investigador, Bajo Grappler and Bajo Whitting are the most prominent deep reef systems. In this region, ahermatypic coral banks have not been reported, but at least 33 species of azooxanthellate (aposymbiotic) corals, including the deep water reef builder, *Lophelia pertusa* have been observed.

García-Sais et al. (2005) study included a historical review of previous work on deep water coral reefs in the U.S. Caribbean, including La Parguera, PR; the Hind Bank MCD south of St.

Thomas; Black Jack Reef, south of Vieques, PR; and Agelas Reef and SW Wall Reef in the SW coast of Desecheo Island, PR. (Figure 28) The research group also conducted field surveys that provided a detailed characterization of the reefs at Desecheo Island. Characteristics and differences in species composition and structure among different reef formations are highlighted. Below 25m, the authors found that sponges associate with stony corals to form large "sponge-coral bioherms" that serve as important habitat for fish and motile invertebrates. The authors recommended that the distribution of deep hermatypic coral reefs be assessed along the islands of Mona and Monito and along the shelf-edge southwest of St. Croix, north of St. Thomas and St. John, north of Culebra and south of Vieques. Significant contributions from this work include new bathymetric and benthic habitat maps of deep hermatypic reefs in the U.S. Caribbean. This inventory and atlas provide enhanced descriptions of deep coral reef habitats that were not previously included 2004 EFH-FEIS, and should be used to complement the information on Coral EFH (some relevant maps included in this study are illustrated in Figures 28-30).

García-Sais et al. (2007) undertook exploratory surveys of the Bajo de Sico (BDS) in the Mona Passage. This study represented a pioneer effort towards characterization of benthic habitats and associated deep reef communities on a submerged seamount of Puerto Rico. This work formed part of the research program priorities of the CFMC for scientific documentation of closed fishing areas. BDS is a known red hind (*Epinephelus guttatus*) spawning aggregation site that was proposed for seasonal closure (December –February) by west coast fishermen as a management strategy for protection of the commercially valuable grouper stock. The objectives of the study were to understand and map benthic habitats and associated sessile-benthic and fish communities at BDS down to a maximum depth of 50 m and to provide a preliminary assessment of the commercially important grouper and snapper populations associated with BDS down a to depth of 50 meters.

In this study, García-Sais et al. (2007) reported that scleractinian corals (13 species) were the dominant coral species covering the BDS reef top (8%) and that octocorals (gorgonians) were the most dominant coral species covering the BDS reef wall (14%). Black corals (Antipartharians), mostly the Caribbean bushy coral, and octocorals, mostly the deep sea fan (*Iciligorgia schrammi*) cover an average of 17% of the reef. These species provide protective cover for fishes on the reef wall. In terms of reef substrate cover and colony density, lettuce corals (*Agarica lamarki* and *A. grahame*) were the dominant coral assemblage at BDS. Other species such as *Tubastrea coccine*, *Porites asteroids* and *Montastraea cavernosa* were common at the reef top. Results from this work also include detailed bathymetric maps of Bajo de Sico and benthic habitat maps, which are new maps that must be added to the collection of maps describing mesophotic reef habitats of the U.S. Caribbean (example in Figure 31).

In the "State of Coral Reef Ecosystems of Puerto Rico" report, García-Sais et al. (2008) reviewed previous descriptions of reef habitats in Puerto Rico (corals, mangroves, and seagrass communities) and also described deep hermatypic coral formations (Mesophotic reefs), including the "Deep Terrace", "Drop-off Wall" and "Rhodolith" reefs. "Deep Terrace" reefs have been found at depths between 30-90 meters growing over flat or gently sloping terraces in very clear water. The dominant coral species is a flattened plate morphotype of *Montastraea annularis* complex; lettuce corals (*Agaricia lamarki, A. grahame*) and *Porites astreoides* are also common. Examples of "Deep Terrace Reefs" are Black Jack, off the south coast of Isla de

Vieques; El Seco, east of Vieques; Black Jack, south of Vieques; Red Hind Marine Conservation District, south of St. Thomas. They highlighted their importance as spawning aggregation sites for several grouper species. The authors provided the species composition (corals, algae, reef fishes) in each of these reef formations.

García-Sais et al. (2008) also discussed some "Drop-Off Wall Reefs" that have developed on drop-off walls at the upper slope of oceanic islands, such as Isla Desecheo and on the reef top and upper slope of the seamount at Bajo de Sico in Mona Passage. "Rhodolith reefs" have developed along gently sloping terraces below depths of 40 m at Isla Desecheo and Bajo de Sico (Agelas Reef). This study provides a complete review of the status of coral reefs in Puerto Rico up to 2007 and gives an overview of the main stressors impacting each of the components of these fragile ecosystems.

García-Sais (2010) reported on quantitative surveys (undertaken in 2004-2005) of sessile benthos and fish communities associated with reef habitats across a 15-50m depth gradient at Isla Desecheo in the Mona Passage off the west coast of Puerto Rico. These surveys showed highest live coral cover at mid-shelf (20m) and shelf-edge (25m) stations, whilst benthic algae and sponges dominated the sessile benthic assemblage below 25m. In addition, García-Sais et al. (2010) observed marked shifts in the community structure of both corals and benthic algae across the depth gradient (15-50m).

Another assessment of the mesophotic benthic habitats and communities was undertaken by Garcia-Sais et al. (2010a) at Abrir La Sierra (ALS), Puerto Rico This study provided a georeferenced benthic habitat map of the mesophotic zone at ALS within a depth range of 30–50 m, along with a characterization of the predominant sessile-benthic, fish and motile-megabenthic invertebrate communities. Boulder star coral, *Montastraea annularis* was the main structural component of the coral reef habitat and was observed to be in good condition. An assemblage of 20 species of scleractinian corals, 10 octocorals, two hydrocorals and 44 sponges were identified. Differences in community structure between coral reef and other habitats were identified, and assumed to be driven by the proportion scleractinian corals, gorgonians, sponges, abiotic substrates, cyanobacteria, turf and fleshy algae. Of particular importance is the documentation of rhodolith reefs as important habitats for adult queen conch, red hind, and other large, commercially important snappers and groupers. A benthic habitat map of ALS is illustrated in Figure 32.

García-Sais et al. (2010b) monitored coral reef communities in 15 reefs from seven natural reserves in Puerto Rico. These included reef sites at Isla Desecheo, Isla de Mona, Rincón, Mayagüez, Guánica, Isla Caja de Muerto and Ponce. At each reef, quantitative measurements of the percent substrate cover by sessile-benthic categories and visual surveys of species richness and abundance of fishes and motile megabenthic invertebrates were performed along sets of five permanent transects. Results from this study showed that the sessile-benthic communities at most of the reef systems presented significant differences in live coral cover. Differences in live coral cover were also observed between monitoring surveys and were attributed to sharp decline measured during the 2006 survey, after a severe regional coral bleaching event that affected Puerto Rico and the U.S.V.I. This reduction in coral cover during 2006 was largely driven by mortality of Boulder Star Coral, *Montastraea annularis* (complex), a highly dominant species in terms of reef substrate cover and the principal reef building species.

Corresponding increments of reef substrate cover by benthic algae, cyanobacteria and abiotic categories were measured. During this 2009-10 monitoring survey, live coral cover presented a pattern of mild increments relative to 2007- 09 levels for most reef sites monitored, related in part to what appears to be a recuperation response of *M. annularis*. The *Acropora palmata* finging reef of Tres Palmas in Rincón is infected by what appears to be white pox, an infectious disease also known as "patchy necrosis", with a very high prevalence in colonies (>80%). Coral bleaching at the reef community level was not observed on any reef surveyed in the program during the 2007-2010 monitoring period.

Kahng et al. (2010) provide a review the geographic distribution of studies into mesophotic coral reef ecosystems (MCEs) and what is known about their community ecology, outlining essential gaps in our knowledge of these deeper water coral reef ecosystems. According to Kahng et al. (2010), mesophotic coral reef ecosystems (MCEs) are warm water, light-dependent coral reef communities starting at 30–40 m to the bottom of the photic zone, which varies by location and extends to over 150 m in some regions. MCEs represent a direct extension of shallow-water coral reef ecosystems, which support a diverse abundance of habitat building taxa including corals, sponges, and algae. This review noted that the majority of research done to date on MCEs has been performed in the Caribbean. The primary findings from this review were that: (1) many dominant shallow-water species are absent from MCEs; (2) compared to shallow reefs, herbivores are relatively scarce, perhaps due to limited habitat complexity at depth; (3) changes in the dominant photosynthetic taxa with depth suggest adaptation and specialization to depth; (4) evidence regarding the importance of heterotrophy for zooxanthellate corals at depth is conflicting and inconclusive; and (5) decreased light with depth, but not temperature, appears to be the primary factor limiting the depth of MCEs.

Hinderstein et al. (2010) review the ecological characterization, geomorphology, and concept of mesophotic coral reef ecosystems (MCEs) as refugia for shallow-water populations. Hinderstein et al. (2010) state that MCEs are characterized by the presence of light-dependent corals and associated communities that are typically found at depths ranging from 30 to 40 m and extending to over 150 m in tropical and subtropical regions. The dominant communities providing structural habitat in the mesophotic zone can be comprised of coral, sponge, and algal species.

Locker et al. (2010) investigated the known and predicted distribution of mesophotic coral reef ecosystems (MCEs) and reviewed approaches for mapping technologies related to MCEs. Potential MCE sites across the U.S. Caribbean were mapped as the seafloor area occupying the 30-100m depth range to enable scientists to better target more in depth exploratory surveys in the future. This study highlighted that geomorphology of the seafloor can fundamentally influence the occurrence and distribution of MCSs by providing favorable hard substrates for colonization and directing the downslope transport of sediment. Locker et al. (2010) noted that common features such as breaks in slope, submarine terraces, and relic reef structures offer prime locations for MCEs along insular and continental slope environments and represent important targets for future study. In addition, the authors noted that coring studies would also help to understand the formation of these habitats and their response(s) to environmental change over time, to inform how they may be impacted by future environmental change. These authors also undertook a bathymetric mapping exercise to identify potential areas of mesophotic coral ecosystems (MCEs) and identified Grappler Bank south of Puerto Rico as an isolated bank with high potential for MCEs, which warrants further research and exploration in the future.

Benthic habitat assessments by Nemeth et al. (2008) in the Red Hind Marine Conservation District in St Thomas revealed extensive and well developed mesophotic coral reefs at depths of 34–47m. The authors recommended as a priority that formal re-assessment of benthic habitat maps be carried our using recently acquired in situ surveys to improve habitat classification models for Caribbean mesophotic systems. The authors hypothesized that mesophotic reefs such as those observed in St. Thomas may well be widespread on the Puerto Rican Shelf and are likely to serve as important fisheries areas. It was therefore recommended that further surveys be undertaken outside the MCD to establish the extent of these mesophotic reefs and their associated fish assemblages. Other federal marine protected areas in the U.S. Virgin Islands noted by Nemeth et al. (2010) that would benefit from Essential Fish Habitat assessment included Grammanik Bank, Lang Bank, and the Mutton Snapper closed areas.

Sherman et al. (2010) report on research performed to describe the geomorphology and benthic cover of mesophotic coral ecosystems of the upper insular slope of southwest Puerto Rico. These authors noted that this slope is divided into two geomorphic zones separated by a pronounced break in slope gradient at ~90 m water depth. Descending from the shelf break, these are Zone I (20–90 m) and Zone II (90–160 m). This study found that Mesophotic coral ecosystems (MCEs) are largely restricted to Zone I and concentrated on topographic highs removed from the influence of active downslope sediment transport, which inhibits coral recruitment and growth. Accordingly, MCEs are more abundant, extensive and diverse on southwest-facing slopes where irregular topography funnels downslope sediment transport into steep narrow grooves.

3.3.5. Community/ Ecosystem

The majority of the studies described above characterized the habitat and provided the taxonomic composition and density by habitat type and depth gradient. Some studies focused on specific groups (e.g., reef fishes, corals, etc.), and a few provided a characterization of the benthic and pelagic coral reef community as a whole. This section reviews the studies that used a broader, ecosystem-based approach to describe EFH in the U.S. Caribbean.

Appeldoorn, et al. (2011) reviewed the knowledge base of habitats relative to the issues of representation and connectivity to identify what features, and at what scales, should be included in numerical models used to identify fish production centers. The aim of the study was to develop a way to use habitat as a proxy for species distribution in the design of conservation measures by developing a process to include habitat data in the models and evaluate model performance. The study discussed the main considerations related to habitat structure and location, habitat connectivity and ecological function, scale of habitat connectivity, scale of larval connectivity, and mapping habitats.

Burke et al. (2010) characterized the flora and fauna of four lagoons (Puerto Mosquito, Puerto Ferro, Ensenada Honda, and Puerto Negro) on the island of Vieques off Puerto Rico and identified critical ecosystem services provided by these habitats. Lagoons were sampled using a range of methods including quadrats, sediment cores, visual fish surveys and push nets. Burke et al. (2010) found that differences in flora and fauna of lagoons appeared to be driven partly by turbidity and openness or degree of water exchange with adjacent shelf habitats. Seagrass cover was found to be higher in open lagoons and the shelf compared to lagoons with restricted circulation. In contrast seagrass species richness was higher in lagoons with restricted circulation than in open lagoons or the shelf. Soft-bottom faunal communities of both lagoons and the shelf were dominated by juveniles however, lagoon communities were found to be more diverse and included commercially and ecologically important species that were absent as juveniles from the shelf. The high floral and faunal diversity observed in lagoons provided evidence of their role as nursery areas and Burke et al. (2010) emphasized the critical role that lagoons have in the Vieques coastal ecosystem.

A trophic model of the coral reef ecosystem of La Parguera, Puerto Rico was developed by Guénette and Hill (2009). These researchers evaluated fishery policy scenarios using the Ecopath with Ecosim modeling software and information for the year 2000. The model included species of commercial and ecological importance in the ecosystem, grouped by habitat preferences. Guenétte and Hill identified gaps in available data (e.g., diet compositions, metrics of fishing effort, incomplete landings) and applying the model raised interesting ecological and fishery management questions. Results were compared with those of a similar Caribbean modeling exercise conducted in the 1970-1980s, when the estimated total biomass was 5.6 times greater than the biomass in 2000. This model helped the authors to define future data needs, generated hypotheses for further coral reef research, and provided a basis for evaluation of fishery management scenarios in an ecosystem context.

Harborne, et al. (2006) used remotely sensed imagery with a detailed field survey conducted in St. Thomas and St. John, USVI, to generate multiple-scale, two-dimensional maps of beta diversity and show that beta diversity can be modeled using two environmental variables. The study classified benthic communities and mapped them using remote sensing imagery. Bathymetry and wave exposure were also mapped. A beta diversity algorithm was used to model beta diversity based on four explanatory variables for each map pixel. Because inter-habitat differences in diversity were significantly greater than intra-habitat differences, ‘hotspots’ of beta diversity were found where coral and soft-bottom habitats converged. Corals, gorgonians and algae tended to drive the differences between hard-bottom communities, while *Thalassia* and *Syringodium* were particularly important in discriminating seagrass communities. Two variables, depth and exposure, were investigated in a model of beta diversity for each island and were found to explain at least 59% of the variance in the data. Beta diversity increased with increasing variation of depth, as high depth variation corresponded to greater heterogeneity of environmental conditions. Beta diversity also increased with increasing variance of wave exposure, as wave exposure variance increases with increasing variety of habitats. The study concluded by discussing how beta diversity can assist in achieving conservation targets.

A comprehensive review of the feasibility of an ecosystem approach to fisheries management in the U.S. Caribbean was performed by Valle-Esquivel (2006). The CFMC´s interest in adopting this approach stemmed from the recognition that stocks and multi-gear/ multi-species fisheries and habitats should no longer be modeled and managed independently without regard for complex interactions among trophic levels; targeted and non-targeted stocks; spatio-temporal environmental influences; and socio-economic factors.

Valle-Esquivel (2006) provided a comprehensive review of fishery and ecosystem information from the U.S. Caribbean, including biological and fishery data, biological surveys, stock assessments, habitat characterization and mapping, species inventories, trophic interactions, and ecosystem modeling efforts. The author also analyzed the available multispecies and ecosystem models and principles and provided recommendations for future work, based on the temporal and spatial coverage of existing information. The author concluded that full dynamic ecosystem models could not be implemented in the U.S. Caribbean in the near future, given their large data demands and the gaps of information in the existing databases. She recommended that migration to an ecosystem-based approach to fisheries management in the U.S. Caribbean should involve a slow, multi-step transition that builds from single-species to multi-species assessments, and culminates in ecosystem-based models.

4. Review of New Mapping Efforts, Tools and Modeling Techniques in EFH and HAPC Identification and Description

Habitat information has been obtained from a number of sources throughout the years. In 1983, the Council contracted for the first attempt at large scale mapping of the marine benthic habitats of Puerto Rico and the USVI. This original work was done using the satellite remote sensing technology available at the time. This initiative resulted in amendments to the Spiny Lobster and Reef Fish FMPs and allowed for quantification of benthic habitats and mangroves.

Significant information became available from agencies other than NOAA, such as the USGS (1980s, 1990s), EPA (1992), Universities and Research Centers. The EFH Generic Amendment (1998) included most of these references. Among other concurrent efforts to obtain more detailed information, especially for those areas from which data other than presence or absence of species was available, included the efforts of SEAMAP-Caribbean, a fishery-independent program. This program has been continuously sampling for fish since 1989, and later for queen conch and spiny lobster, as well as mapping the benthic habitats of the sampling areas (i.e., West Coast of Puerto Rico and South Coast of St. John). The data include identification of species, distribution and abundance as well as identification of reproductive activity of commercially important species. More details of the habitat later became available through the use of side scan sonar and deep-water video cameras.

The benthic habitat mapping initiatives of the Puerto Rican and USVI insular shelves started in response to the 1996 EFH amendments of the Fisheries Sustainable Act and the National Coral Reef Action Strategy (2002) which demanded comprehensive maps of all U.S. shallow water coral reef habitats. Since the 2004 EFH-EIS, the Council has continued to collaborate with various agencies and institutions, local and Federal, to work on EFH related projects, including the University of Puerto Rico, the Polytechnic University of Puerto Rico, the University of Miami, NOAA Fisheries, NOAA Center for Coastal Monitoring and Assessment/ Biogeography Branch, NOAA Coral Reef Conservation Program, the U.S. Geological Survey, the National Park Service, the PRDNER, USVIDPNR, etc. When finished, all the ongoing projects will complement each other in helping to provide the highest resolution data to elaborate the best maps for use by resource managers and stakeholders.

The next section reviews some of the leading mapping efforts that have taken place since 2005. This new information serves to update Section 2 (Alternatives), sub-sections 2.1.3 (Describing and identifying EFH), 2.1.4 (Designating HAPCs), 2.1.5.2.1 (Mapping efforts) and Section 4 (Environmental Consequences), subsection 4.2.3 (Ongoing work to obtain missing information) of the 2004 EFH-FEIS (Table 1). In addition, the new data and maps produced update and/or complement the majority of the figures provided in the 2004 EFH-FEIS: the habitat distribution mosaic maps (Figures 2.5 to 2.15), the known and potential habitat maps (Figures 2.16 to 2.22), the EFH designation maps for each FMP (Figures 2.38 to 2.46), and the managed areas around Puerto Rico and the U.S. Virgin Islands (Figures 2.31 to 2.36).

4.1. Review of new mapping research, mapping tools, and modeling techniques used in the U.S. Caribbean

4.1.1. Habitat mapping research conducted by the NOAA Biogeography Branch

Since 2002, the NOAA Biogeography Branch (Center for Coastal Monitoring and Assessment-CCMA/NOAA/NOS/National Centers for Coastal Ocean Science) has used optical remote sensing imagery to generate benthic maps at a scale or 1:6,000, with a large percentage of the area (approx. 60%) classified as unknown (Prada and Rivera 2008). Significant improvements in the benthic mapping of these coral reefs have been accomplished using acoustic technology, such as the side scan sonar (SSS) system. These efforts began in 1998, when NOS and the Council collaborated with other agencies, institutes, universities and individuals to prepare a large scale map of the benthic habitats of the US Caribbean (http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_pr_mapping.aspx#products).

This comprehensive project has generated detailed maps (1:1,000) over large sections of Puerto Rico insular shelf at La Parguera and San Juan Bay Estuary (Rivera, 2005, Prada, et al. 2008). Similar habitat maps have been created for the three closed fishing areas in the USVI: the Marine Conservation District (MCD) south of Saint Thomas, the Mutton Snapper (southwest side of Saint Croix) and Lang Bank (northeast of Saint Croix), were also produced using SSS technology, combined with multibeam bathymetry (GPR, Inc 2003). Some of these maps have been discussed in previous sections, where characterizations of coral reefs and reef fish are described. They serve to update or complement previous maps for these MPAs and HAPCs (Figures 2.23 to 2.36 in the 2004 EFH-FEIS).

Links to related projects conducted by the CCMA-BB in the U.S. Caribbean are provided in Table 12 and online at the NCCOS-Biogeography webpage below: (http://ccma.nos.noaa.gov/about/biogeography/proj_region.aspx). Some of these projects include: the Caribbean Coral Reef Ecosystem Monitoring Project; Development of Reef Fish Monitoring Protocols to Support the National Park Service Inventory and Monitoring Program; Coral bleaching and recovery observed at Buck Island, St. Croix, U.S. Virgin Islands; National Coral Reef Ecosystem Montoring Program; Benthic Habitat Mapping of Puerto Rico and the U.S. Virgin Islands; Seafloor Characterization of the U.S. Caribbean - *R/V* Nancy Foster Missions.

The "Seafloor Characterization of the U.S. Caribbean" project, was initiated in 2004 to integrate abiotic data collected from acoustic sonar systems that use multibeam transducers, with biotic information obtained from underwater imagery systems (Remotely and Autonomously Operated

Vehicles and drop/drift camera systems) and SCUBA divers to create accurate benthic habitat maps. Information from this project will contribute to the development of detailed species utilization models linking physical habitats and biological information. Areas mapped in the U.S Caribbean include the National Park Service's (NPS) Buck Island Reef and Virgin Islands Coral Reef National Monuments, Salt River Bay National Historical Park and Ecological Reserve, the fish spawning aggregation site at Grammanik Bank south of St. Thomas, the La Parguera area of southwest Puerto Rico, and areas closed to fishing by the CFMC on the west side of Puerto Rico (Tourmaline Bank, Abrir La Sierra Bank, and Bajo de Sico), and Mona Island (Figure 33). Data, maps and figures resulting from this project can be obtained at the CCMA website: (http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_nps.aspx).

It is important to note that some of the studies reviewed below have already been discussed under Section 3.3. Reviews were divided by topic because the studies generally had multiple goals, including the biological characterization of coral reef communities and the development of benthic habitat and habitat association maps. In this section, only the mapping efforts are highlighted, and the main products (maps and tools) from each study, are referenced again. Relevant new studies by the Biogeography Branch are summarized below.

Detailed high resolution bathymetric surveys of the three closed areas (Bajo de Sico, Tourmaline Bank and Abrir La Sierra) were conducted jointly by the CFMC and CCMA-BB with support from the NOAA Coral Reef Conservation Program (CRCP) in 2007. The use of bottom gears has been banned from these areas. All Coral Reef Ecosystem Studies field data collections, which had started prior to the 2004 EFH-EIS, ended in spring 2007. See **Error! Reference source not found.** for monitoring locations of this project throughout Puerto Rico.

The Coral Reef Early Warning System (CREWS) station, installed in 2005, began transmitting data in January, 2006. The instruments provide measurements on wind speeds and gusts, barometric pressure, relative humidity, precipitation, photosynthetically available radiation (PAR, above and below water), ultraviolet radiation (UV 305, 330, 380 nm, above and below water), state of tide, sea temperature, salinity, and pulse amplitude modulating fluorometry on up to four species of coral (for more information see NOAA's Integrated Coral Observing Network at http://ecoforecast.coral.noaa.gov/)

Bauer et al. (2010) updated benthic habitat maps for the island of Vieques off Puerto Rico mapping 350 km^2 of nearshore seafloor. These higher resolution habitat maps, generated by interpretation of 2006-2008 IKONOS imagery and orthophotography, represent a significant improvement from NOAA's previous digital maps of the U.S. Caribbean (Kendall et al. 2001) due to an expanded habitat classification scheme, smaller minimum mapping unit (MMU), and more recent imagery. Bauer et al. (2010) mapped a larger area of seafloor and were able to classify areas previously marked as "unknown" on the earlier maps, whilst smaller MMUs (1,000m^2 vs 4,046m^2) enabled more accurate depiction of patchy habitats. As different classification schemes and MMUs were used in 2001 and 2009, Bauer et al. (2010) could not provide a quantitative comparison between the 2001 and 2009 maps, however there did appear to be some changes in biological cover on softbottom substrates between the two time periods. In 2009, algae dominated benthic cover on hardbottom substrates whilst seagrass dominated softbottom cover. Live coral cover was generally low with <10% cover over 93% of the mapped area and 10% - <50% live coral cover over the remaining area (Bauer et al. 2010).

Examples of coral cover maps from Kendall (2001) and from Bauer (2010) are illustrated in Figure 35. These maps complement Figures 2.13 and 2.33 in the 2004 EFH-FEIS. The Vieques benthic habitat map and a suite of associated products are available to the public at NOAA Biogeography Branch website devoted to this mapping effort: “An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico” (http://ccma.nos.noaa.gov/ecosystems/coralreef/vieques/) that includes an interactive web tool to view maps and data (“Vieques BIOMapper” at: http://ccma.nos.noaa.gov/explorer/biomapper/biomapper.html?id=Vieques).

Costa et al. (2009) reported on habitat mapping surveys and the creation and assessment of a moderate depth (30-60m) habitat map for the Virgin Islands Coral Reef National Monument (VICRNM) south of St. John, U.S. Virgin Islands. This work conducted by NOAA’s CCMA-BB in partnership with the U.S. National Park Service (NPS) utilized semi-automated and visual interpretation techniques to provide the first acoustically-generated digital map of these moderate depth areas and serves to update Figure 2.14 in the 2004 EFH-FEIS. Spatially-explicit information describing the moderate-depth (30 - 60 m) benthic habitat types and live coral cover present in and around the VICRNM’s southern boundaries is provided. In terms of coral cover, the majority (>96%) of all three areas were colonized by 0% - <10% live scleractinian and/or gorgonians. Individual Patch Reefs and Aggregated Patch Reefs comprised just over 4% of the total mapped area (3% of the mapped area outside the VICRNM and 5% of the mapped area inside the VICRNM). Rhodolith habitat types dominated the entire moderate-depth region south of St. John. Additional maps and data generated by this project are available online at the “Benthic Habitat Mapping off St. John, USVI National Park and VI Reef National Monument” website (http://ccma.nos.noaa.gov/ecosystems/coralreef/benthic/), which also includes an interactive mapping tool, “St. John BIOMapper”: (http://ccma.nos.noaa.gov/explorer/biomapper/biomapper.html?id=StJohn)

Kendall and Miller (2010) utilized data collected from UVC surveys (including quadrat analysis for benthic cover) a remote sensing imagery and habitat maps for the Buck Island Reef National Monument to explore relationships and limitations in the extrapolation of fine scale ecological information from larger scale habitat maps and inversely, predicting larger scale conditions for an area based on smaller scale surveys. Multivariate analyses undertaken by Kendall and Miller (2010) indicated that the local environmental variables that best explained fish assemblage composition at BIRNM were depth, rugosity, live coral, and soft bottom cover. Unfortunately, Kendall and Miller (2010) concluded that these multivariate relationships could not be readily implemented for predicting fish distributions over broad regions since all of these habitat variables are not presently detectable from remote sensing at the required spatial scales (Diaz et al., 2004). The authors noted that estimates of the percentages of specific cover types such as live coral can be mapped with ever-increasing detail and may soon be detectable at scales similar to those regularly measured by divers. Further, as technologies, such as high resolution satellites, hyperspectral sensors, lidar, and multibeam sonar improve, they may achieve the precision and accuracy required to map the distribution of fine-scale environmental variables across entire landscapes, and ultimately be used to predict fish assemblages. However, the analyses presented here indicate that until then, current technologies limit the ability to understand relationships between fish, local habitat variables, and reef types at mapped at broad spatial scales and overcoming these limitations remains a priority for research and management.

Pittman et al. (2007a) combined empirical models, remotely sensed data, field observations and GIS to assess the performance of three different modelling techniques to predict species richness across different habitat types in the U.S. Caribbean. Models developed for the La Parguera region in southwest Puerto Rico were applied to nearshore areas around the island of St. John and Buck Island, St. Croix, USVI. Overall, regression trees outperformed multiple linear regression and neural networks, with the best performing model of fish species richness (high, medium, low) in southwestern Puerto Rico achieving an overall map accuracy of 75% and 83.4% accuracy when simplified to assess only high and low species richness. Areas of high fish species richness were predicted for the most bathymetrically complex areas with high habitat complexity (rugosity) and high bathymetric variance quantified in the surrounding seascape at two different spatial scales ($\geq 0.01 km^2$). Pittman et al. (2007a) found that water depth and the amount of seagrass and hard-bottom habitat in the seascape were the next most influential factors for species richness in the models. Pittman et al. (2007a) concluded that these results demonstrate remotely sensed measures of topographic complexity alone can provide accurate and cost-effective predictions of fish species richness at broad spatial scales.

In 2006, hydrographic Light Detection and Ranging (LiDAR) data were collected by Pittman et al. (2009) to map bathymetry in southwestern Puerto Rico using the ADS Mk II Airborne System. In total, 265 square nautical miles of LiDAR were collected between -20 m (topographic) up to 50 m (depth). This data provided a bathymetric surface and reflectivity surface (example of LiDAR bathymetry in Figure 36). More details on the methods can be found via online metadata files (http://ccma.nos.noaa.gov/products/biogeography/lidar_pr/default.aspx). This study and earlier analyses have revealed that measures of surface complexity are useful and cost-effective predictors of the distribution of fish species, fish diversity and biomass and coral diversity and abundance (Pittman et al. 2009). To highlight the changes in surface complexity across the region this study measured surface rugosity (or structural complexity) as the ratio between the horizontal surface and the actual convoluted 3-dimensional surface bathymetry.

Pittman et al. (2010) reported on analyses of data collected from 2001 to 2007 in the Reserva Natural La Parguera in Puerto Rico as part of the Caribbean Coral Reef Ecosystem Monitoring project (CREM). In 2005, spectral analysis of Landsat Thematic Mapper data (CCMA-BB) and locally available side-scan sonar data (Prada 2002) was used to classify the deeper water “unknown” area to provide a complete coverage for the La Parguera study site. This benthic habitat map (Figure 17) includes coral reef ecosystems to a depth of approximately 35 m, and serves to update Kendall et al (2001) maps for SW Puerto Rico and La Parguera (Figures 2.8 and 2.32. in the 2004 EFH-FEIS).

Zitello et al. (2009) completed benthic habitat mapping, field validation and accuracy assessment of maps for the nearshore marine environment of St. John as part of a multi-year interagency project and ongoing mapping and monitoring efforts by NOAA’s CCMA-BB and the U.S. National Park Service (NPS). Benthic habitat maps were created through visual interpretation of remotely sensed imagery. Updated habitat maps produced by Zitello et al. (2009) replace previous NOAA maps generated by Kendall et al. (2001) for the waters around St John. Key results in relation to coral cover reported by this study are provided under section

3.3.4 – Corals. Also, as already described in that section, an interactive mapping tool (St. John BIOMapper) is available online (examples in Figures 23 to 26 complement Figure 2.14 in the 2004 EFH-FEIS).

4.1.2. Habitat mapping research conducted by other groups

Some of the research studies reviewed below have already been discussed under Section 3.3. because they generally had multiple goals, including the biological characterization of coral reef communities and the development of benthic habitat and habitat association maps. In this section, only the mapping efforts are highlighted, and the main products (maps) from each study, are referenced again.

Appeldoorn, et al (2011) reviewed the knowledge base of habitats relative to the issues of representation and connectivity to identify what features, and at what scales, should be included in numerical models used to identify fish production centers. The aim of the study was to develop a way to use habitat as a proxy for species distribution in the design of conservation measures by developing a process to include habitat data in the models and evaluate model performance. The study discussed the main considerations related to habitat structure and location, habitat connectivity and ecological function, scale of habitat connectivity, scale of larval connectivity, and mapping habitats.

García-Sais (2005) developed a digital map of the bathymetric, hydrographic and biological information pertaining to the deep reefs off Puerto Rico and the U.S. Virgin Islands using geo-referenced data. These data included side-scan sonar images of Bajo de Sico, hydrographic data of the insular slope of Puerto Rico and the USVI produced by the Johnson Sea Link submersible and benthic images of the upper insular slope off the La Parguera shelf-edge of Puerto Rico produced by the SeaBED Autonomous Underwater Vehicle.

García-Sais et al. (2007) mapped benthic habitats down to 50m, recording associated benthos and invertebrate cover and fish communities to provide a preliminary assessment of commercially important grouper and snapper populations on the Bajo de Sico (BDS) seamount in the Mona Passage off Puerto Rico. Several pieces of information were integrated to produce a benthic habitat map of BDS, including side-scan sonar images of reef promontories, bathymetric and backscatter data produced by a multibeam survey of the reef. The main bathymetric features and benthic habitats were field verified by divers using re-breather technology. The new maps resulting from this study must be added to the collection of maps describing mesophotic reef habitats in the U.S. Caribbean (examples in Figures 28-31).

Using the same technology and methods, García-Sais et al. (2010) developed georeferenced benthic habitat maps of the mesophotic zone at Abrir La Sierra (ALS), Puerto Rico within a depth range of 30– 50 m, along with a quantitative, qualitative and photographic characterization of the predominant sessile-benthic, fish and motile-megabenthic invertebrate communities associated with these mesophotic habitats. Production of the benthic habitat maps was based on a series of field observations and habitat classifications of the main reef topographic features by rebreather divers, as suggested from a multi-beam bathymetry footprint produced by the R/V Nancy Foster (NOAA). The new maps resulting from this study must be added to the collection of maps describing mesophotic reef habitats in the U.S. Caribbean (example in Figure 32).

Harborne, et al. (2006) used remotely sensed imagery with a detailed field survey in St. Thomas and St. John, USVI to generate multiple-scale, two-dimensional maps of beta diversity and show that beta diversity can be modeled using environmental variables. The study classified benthic communities and mapped them using remote sensing imagery. A beta diversity algorithm was used to model beta diversity based on four explanatory variables for each map pixel. Beta diversity increased with increasing variation of depth, as high depth variation corresponded to greater heterogeneity of environmental conditions. Beta diversity also increased with increasing variance of wave exposure, as wave exposure variance increases with increasing variety of habitats. The study concluded that modeling beta diversity can assist in achieving conservation targets.

Locker et al. (2010) reviewed existing and emerging mapping technologies available for the exploration and survey of mesophotic coral reef ecosystems (MCEs). This included acoustic instruments such as multi-beam and side-scan sonar and seismic-reflection profilers (to provide data on underlying geological make-up) and underwater still and video cameras. Locker et al. (2010) noted that in-situ photography and videography are the most effective means of acquiring the high resolution imagery needed to characterize and monitor MCE habitats, as well as ground truthing associated acoustic data. Combinations of the above instruments can be deployed on remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs) and/or towed underwater vehicles or sleds. New emerging mapping instruments reported by Locker et al. (2010) included pulsed-laser line imaging that can construct a 3D representation of the seafloor with spatial resolutions finer than 3cm, laser line scanning (LLS) with 2-5mm resolution and multispectoral imaging that can measure fluorescence signatures to classify and map benthic habitats. Locker et al. (2010) concluded that future investigations and mapping efforts need to utilize more cost-effective and remote methods (such as AUVs and acoustics) to assess the distribution and extent of MCE habitats.

In a characterization of deep water reef communities within the St Thomas MCD, Nemeth et al. (2008) noted that sonar imagery was able to distinguish major blocks of benthic habitat, but could not always correctly identify the habitat type. The authors recommended that benthic habitat maps be formally re-assessed using recent in situ surveys so that all habitat types are included in benthic habitat algorithms. The bathymetric map and habitat association maps resulting from this study (examples in Figures 20-22) should serve to update Figure 2.23 and species distribution maps in the EFH-FEIS Appendices.

Potter (2008) reviewed a number of new emerging underwater acoustic technologies in advanced stages of development that may be applied to mapping of MCEs in the future. These included (1) passive-phase conjugation, which allows both bathymetry and sub-bottom profiles to be retrieved from ambient noise in the ocean; (2) synthetic-aperture sonar, which produces acoustic images of higher resolution than that attainable with side-scan systems; and (3) diver-based multibeam sonar, which enables the collection of bathymetry for areas difficult to access from other deployment platforms.

Prada and Rivera (2008) used side-scan sonar imagery to map the habitats of the West Coast shelf of Puerto Rico. This project addressed the need of spatial characterization of the benthic communities of the west coast by examining detailed habitat knowledge at a landscape scale. The objectives were to compile existing SSS data from the western section of the Puerto Rico shelf; to collect and post-process new SSS imagery to generate high resolution habitat mosaics needed to generate maps; and to adjust the existing SSS hierarchical classification scheme to delineate and quantify benthic habitats within the Cabo Rojo shelf and generate detailed habitat maps in digital format, ready to use in a GIS format by resource managers and researchers. Results from this project consisted in four detailed habitat maps (Añasco, Mayagüez, Guanajibo and Boquerón), produced from the available UNCW SSS bottom mosaics covering a total of 6,975 ha (20.6 nm^2) of classified benthic habitats (Figure 37). This project allowed mapping 5,455 ha of the previously unidentified bottom coverage from the 1998 aerial photographs utilized by the NOAA Biogeographic Team (2002), and the maps produced significantly enhance the resolution of previous mosaics (eg., Figure 2.8 in the 2004 EFH-EIS).

4.1.3. Integrated GAP Analysis Program

The GAP Analysis Program was initiated in the 1980s as a landscape approach to conservation and planning, with the purpose of identifying the distributions of species and habitats, identifying conservation areas, and assessing how well species and habitats are protected. The original mission of the National GAP program undertaken by the U.S. Geological Survey was to prevent conservation crises by providing conservation assessments of plant communities and native animal species and to facilitate the application of this information to land management activities (see http://gapanalysis.usgs.gov/).

A GAP Analysis consists of mapping three data layers: land cover, predicted distributions of vertebrate species, and a stewardship layer. This data is then assessed to determine how much of a target species' (plant or animal) habitat is in conserved areas. From this assessment, planning decisions can be made about whether further protection is necessary.

The importance of GAP Analysis is to provide information about the conservation status of common species that is important for decision makers, planners, researchers, private interests and others. GAP Analysis information can help to: match biodiversity goals to protected area programs; target the most effective areas for biodiversity conservation to offset some of the effects of habitat loss; plan habitat mitigation corridors to protect species from climate change; plan renewable energy projects; and to provide tools to improve protected area management practices that support continued biodiversity.

About six years ago Puerto Rico became a member of a biodiversity and conservation mapping effort known as the National GAP Analysis Program, implemented by the USGS, Biological Resources Division. With a commitment to assess the current knowledge of Puerto Rico's biological resources, the USDA Forest Service International Institute of Tropical Forestry (IITF) agreed to lead the Puerto Rico GAP Analysis Project (PRGAP) with the collaboration of the DNER. The goals of the PRGAP were recently accomplished with the publication of the PRGAP-Final Report (Gould et al. 2008).

Gould et al. (2008) report on the terrestrial GAP analysis project conducted in Puerto Rico. This report documents Puerto Rico's land cover, vertebrate occurrences and natural history information, and land stewardship. The report has four major components: land cover mapping, documentation of vertebrate species distributions, documentation of land stewardship practices with respect to conservation, and an integrated analysis of these three elements. The current reserve system protects a number of important habitats and species, but includes only 7.6 percent of the territory, when 15 percent is the internationally accepted proportion to meet conservation goals. This study found that abandoned agricultural land has excellent potential for restoration, serves as habitat for a number of species and buffers older forests, wetlands, riparian areas, and reserves. Recommendations include expanded reserves in the coastal plain, particularly coastal hills and the matrix of wetland and upland vegetation; regulation of development in the periphery of existing reserves; and developing viable corridors to connect the upland and coastal reserves.

The PRGAP report (Gould et al. 2008) provides a number of terrestrial maps including geoclimatic zones, topography, landscape units (using climate, substrate and topography), land cover, and occurrence and predicted distribution of important vertebrate species.

The Integrated Gap Analysis Program (Aquatic Gap, PRUSVI-I-GAP) was initiated to include the freshwater, estuarine, and marine habitats of Puerto Rico and the U.S. Virgin Islands in the biodiversity and conservation analyses. The primary objective of PRUSVI-I-GAP is to identify aquatic species habitat, species ranges and distributions throughout the islands, and to assess the level of conservation protection of their habitats. This program is following the methodology and guidelines provided by the National GAP and modified for tropical islands by PRGAP (Gould 2011). Research is based within the exclusive economic zone of PR and the USVI, focusing on protected coastal land and marine reserves and federally protected critical habitats for a number of species.

The components of the Aquatic GAP analysis include (Gould 2011, Rincón-Díaz et al. 2011):

1) Develop an aquatic species database and conduct extensive literature-review and compilation to describe species taxonomy, geographic distribution, conservation status, residency status, habitat associations, and natural history.
2) Map vegetation and benthic cover using recent satellite imagery and using existing datasets. This step involves gathering land and seascape geospatial data: GIS and remote sensing layers showing the attributes of habitats.
3) Identify and map species ranges for species classified as endemic, endangered, resident, breeding migratory, or common non-breeding migratory, sport fishes, and keystone species. This step involves compiling species occurrence records and mapping the occupancy of the species within a hexagon grid adapted for Puerto Rico and the USVI to provide a uniform unit area for further analysis and to produce range maps.
4) Map all governmental, non-profit, and private managed conservation areas of Puerto Rico and US Virgin Islands with conservation objectives and determine the management status each has for the conservation of biodiversity. This step involves interviews with land and marine reserve managers to determine the effectiveness of assigning protected status to designated areas, and classification and mapping of areas based on the protection level offered to biodiversity.

5) Map species predicted habitat distributions across their range based upon habitat-association and micro-habitat variables identified through the literature-review process. Overlapping GIS layers will show the attributes representative of habitat affinities of individual species within the hexagon occupancy network.
6) Conduct a spatial analysis (i.e., GAP analysis) to identify the "gaps" in species protection across the landscape. This step consists in combining species predicted habitat maps and protected area analysis to establish the conservation status of individual species' habitats.

An example of the process was illustrated by Rincón-Díaz et al. (2011), where they analyzed the distribution and conservation status of Sea Turtles in marine and coastal conservation areas around Puerto Rico. To illustrate the scope and applicability of the PR-USVI GAP project to the description of EFH and beyond, some graphics from this study are reproduced in Figures 38 to 41.

The PRUSVI-I-GAP has compiled an annotated list of 846 species associated with aquatic habitats in Puerto Rico and added these to the existing Puerto Rico Gap taxonomic database, which now includes 1217 species. This database will contain information on each species taxonomy, conservation status, geographic distribution, habitat associations, life history, and specific threats to conservation. The species associated with aquatic habitats are primarily fishes (714) but include birds (100), marine mammals (9), turtles (7), rays (1), corals (2), crustaceans (11), conch (1), and sea urchins (1). From these 846 species, the Gap project is evaluating the conservation status of 246 prioritary animal species and habitats; 57 are recreational fish species of importance to the PR DNER to include in the *Sportfish Gap* analyses and over 200 aquatic species to include in the *Integrated Gap* analyses. Distribution models for 246 aquatic species are in development (Gould 2011, Solórzano, pers. comm.).

The project has identified 201 protected areas (8% of Puerto Rico) that have an aquatic component and developed a database of the attributes of these protected areas. Virtually all of the terrestrial protected areas identified in the Puerto Rico Gap project have streams, reservoirs, estuarine, or coastal components so these have been included in addition to marine reserves. The goal is to identify and classify aquatic habitats from simple to complex and to capture spatial and temporal variation. The three main aquatic systems include: marine, estuarine, and freshwater. Modeling the marine habitats will require the combination of geospatial layers that consistently cover the extent of the study area with higher resolution information that is available for specific sites.

The PRUSVI GAP Program is currently acquiring information on species occurrences and natural history. GAP researchers are developing a protected area database identifying all areas with potential conservation management goals and are acquiring satellite imagery and ancillary data for benthic habitat and freshwater habitat mapping. To this date, habitat distribution models have been developed for the following sea turtle species: *Eretmochelys imbricata* (Hawksbill turtle), *Dermochelys coriacea* (Leatherback turtle), *and Chelonia mydas* (Green turtle), as well as for *Epinephelus guttatus* (Red hind) and for some shark species (M. Solórzano, pers. comm.).

The project will have a webpage by the end of 2011 and results are expected to be completed in 2013. The PRUSVI GAP is collaborating with government agencies, non-governmental organizations, research institutions and independent researchers to consolidate existing data bases and to develop multi-layer maps for priority species and priority aquatic ecosystems. The GAP process incorporates state-of-the art methodologies to conduct spatial analyses and develop habitat-suitability maps, which will complement the mapping efforts and EFH studies reviewed in this report. Given the scope and coverage of the PRUSVI GAP Program, the expected products will consolidate and enhance the knowledge-base for essential fish habitat in the U.S. Caribbean.

4.1.4. EFH Mapper

The NOAA-NMFS Office of Habitat Conservation recently launched the latest version of the EFH Mapper (v2.0) and EFH data inventory. This mapper gives users newly available data on EFH areas protected from fishing. These data represent areas where steps have been taken to minimize the impact that fisheries have on EFH by geographic area of interest. These steps may include anchoring restrictions, required fishing gear modifications, or a ban on certain types of gear, among others.

The EFH Mapper v.2.0 features improved spatial representations of essential fish habitat (EFH) and habitat areas of particular concern (HAPCs), a pop-up instruction page, a user-friendly display that can be zoomed in and out, and an organized data inventory. Users can query information from multiple fishery management plans at once to view habitat maps and lists of species for a specific location (see http://www.habitat.noaa.gov/protection/efh/habitatmapper.html).

The purpose of this interactive, online mapping application is to provide the public and other resource managers an interactive platform for viewing a spatial representation of EFH, or those habitats that NMFS and the regional fishery management councils have identified and described as necessary to fish for spawning, breeding, feeding or growth to maturity.

Information available for viewing in the EFH Mapper includes EFH, habitat areas of particular concern (HAPCs), and EFH areas protected from fishing, where NMFS and the regional fishery management councils have used the EFH provisions established in Section 303 (a)(7) of the Magnuson-Stevens Fishery Conservation and Management Act to prevent, mitigate, or minimize adverse effects from fishing on EFH.

The GIS data inventory for the U.S. Caribbean includes links to EFH and HAPCs designations (in the 2004 EFH-EIS); links to EFH areas protected from fishing in the 2005 Comprehensive Amendment, 50 CFR (Federal Register 2005) (EEZ gear restrictions, Abrir La Sierra Bank, Bajo de Sico, Grammanik Bank, Lang Bank Red Hind Spawning Aggregation Area, Mutton Snapper SPA, Tourmaline Bank); and information and GIS data downloads for conch, coral, and reef fish, including shapefiles and metadata (see http://www.habitat.noaa.gov/protection/efh/newInv/index.html). Examples of maps created with EFH Mapper are illustrated in Figures 8-11.

4.1.5. MPA Mapping Tool

The National Marine Protected Areas Center of NOAA was established in 2000, after Executive Order 13158 went into effect. The National MPA Center is a division of NOAA's Office of Ocean and Coastal Resource Management. Its mission is to facilitate the effective use of science, technology, training, and information in the planning, management, and evaluation of the nation's system of marine protected areas. The National MPA Center works in partnership with federal, state, tribal, and local governments, and stakeholders to develop and implement a science-based, comprehensive national system of MPAs. These collaborative efforts are intended to ensure more efficient, effective use of MPAs now and in the future to conserve and sustain the nation's vital marine resources.

The National MPA Center has three goals: 1) Build and maintain the National System of MPAs; 2) Improve MPA stewardship and effectiveness; and 3) Facilitate international, national, and regional coordination of MPA activities. To carry out these goals, the MPA Center conducts several activities, including consultations with Fishery Management Councils and collecting data for the MPA inventory, and information to inform the National System of MPAs and other coastal and marine spatial planning needs (http://www.mpa.gov/aboutmpas/mpacenter/).

The National MPA center has several tools available online, including an interactive mapping tool, tabular data, GIS spatial data, maps, and documents and related resources for the MPA inventory. The Interactive Mapping Tool (Map Viewer) is an application that provides online access to the MPA Inventory data from 1,600 MPAs in the U.S. through an interactive map environment. This tool can be used to view the MPA Inventory sites and associated data, query sites by specific conservation attributes or to search and view sites by region. MAP Viewer was designed to provide managers, scientists, and the public with an increased understanding and technical capacity for ocean resource protection, management and stewardship.

Maps for most of the MPAs in the U.S. Caribbean can be obtained with Map Viewer and with different criteria: national system (eligible, member, not eligible); level of protection (no access, no impact, no take, uniform /zoned multiple use, zoned with no take areas); government level (federal, local, partnership, state, territorial); fishing restrictions (commercial/ recreational fishing restricted/ prohibited); and by management agency (PR-DNER, VI-DPNR, NOAA, USFWS, etc.). Figures can be seen as maps, satellite, hybrid or terrain maps, and all maps can be zoomed in and out (see http://www.mpa.gov/dataanalysis/mpainventory/mpaviewer/). An example of a terrain map of all the MPAs in the U.S. Caribbean is provided in Figure 7.

4.2. Review of Alternative Methodologies for use in EFH Designation in the U.S. Caribbean

Habitat assessments, in combination with habitat-specific fish distribution and vital rates, should form the underlying scientific basis for decisions on habitat management and protection, including EFH designation. Limited habitat data and the lack of integration of such data into most stock assessment models constrain the ability of regulatory agencies to effectively designate EFH and prioritize habitat protection, restoration, and mitigation (NMFS, 2010).

EFH regulatory guidance provides an approach to organize and use the best available science for describing and identifying EFH. EFH rule (600.815(a)((1)(iii)(A)) identifies four levels of habitat data: presence/absence data (EFH Level 1) and habitat-specific densities, growth, reproduction and survival data (EFH Levels 2-4). The Habitat Assessment Improvement Plan (HAIP) (NMFS, 2010) identified the essential elements of comprehensive habitat assessments: habitat-specific biological information, geospatial information on habitat characteristics, and development and application of indices to monitor habitat condition related to fish production.

Less than half of Federal FMPs contain information above EFH Level 1 for even one life stage of one species, and therefore most Fishery Management Councils (FMCs) have adopted the precautionary approach for initial EFH designations. Because the science centers have different capacities to include these elements in habitat assessments, the FMCs have used a variety of approaches to conduct habitat assessments in their respective EFH-Final Environmental Impact Statements. More detailed data and habitat assessments will improve the ability to distinguish EFH from other habitats for each managed stock/species and to minimize the effects of fishing on EFH (NMFS, 2010).

This section expands the options to describe and identify EFH and HAPCs and to address the adverse effects of fishing on EFH (Sections 2.1.3., 2.1.4, 2.1.5 and in particular 4.2.3.6- Fish-habitat modeling) in the 2004 EFH-FEIS (more detail provided in Table 1).

4.2.1. Habitat models

Habitat assessments have been refined and improved in the last decade and have been used by some Fishery Management Councils (FMCs) to inform Final Environmental Impact Statements on EFH designation and minimization of fishing impacts to habitats. In recent years the use of correlation-based statistical or machine-learning models that link habitat attributes with species abundance or distribution patterns have increased rapidly in both scope and complexity and could aid in the identification of EFH (GMFMC 2010). The application of these new techniques could improve EFH designation and analysis of factors that impact habitat quality (Knudby et al. 2010).

To facilitate the development and implementation of improved tools to identify EFH, the Northeast Fisheries Science Center completed an extensive review of current EFH designation methodologies and investigated alternative methods for the identification of important habitats (HEWG 2005). The report compared 14 potential EFH designation methods and developed recommendations based on model performance, data requirements, software and technical expertise requirements. It recommended the use of generalized additive models (GAMs) because of their ability to provide quantitative and testable species-level foundations for ecosystem analyses. However, since the 2005 study, methodologies have continued to evolve. Knudby et al. (2010) reviewed several modern approaches to modeling fish-habitat relationships compared to these methods with a variety of other methods including GAMs. The review suggested that novel methods, such as regression tree based boosted techniques, may substantially improve predictions of fish distribution and abundance with lower error rates than linear models or GAMs.

The Pacific FMC developed a Bayesian model that relates the likelihood of occurrence of a species or life stage to habitat characteristics (GMFMC 2010, HEWG 2005). It included innovative habitat suitability and risk models and seafloor habitat maps, provided information on the status of habitats important to groundfishes and the impact of fishing on those habitats, and proposed management measures to protect EFH from fishing, such as area closures and reductions in effort (NMFS, 2005). The New England and Northwest Pacific FMCs have used spatially explicit habitat models to analyze fishing impacts to habitats, but not for EFH designation.

Similar but more qualitative or less spatially explicit approaches have been used by the North Pacific, New England, Gulf, and Caribbean FMCs in EFH designation. These assessments have often been limited by the lack of data on the spatial distribution of habitats, the value of habitats to fish production, and the distribution and magnitude of fishing effort. More comprehensive habitat assessments are needed nationwide to support the protection of EFH from fishing impacts (NMFS, 2010).

This section presents the modeling approaches used in the Pacific, the Gulf of Mexico and Caribbean for EFH designation, outlines the potential role of habitat models in fish stock assessments and ecosystem models, and discusses modeling approaches used by the Northwest Pacific and New England FMCs to analyze fishing impacts on EFH.

4.2.1.1. The Pacific Fishery Management Council Modeling Approach

In 2004, a comprehensive risk assessment (understood as the integrated use of the best scientific information available in the development and guidance for the policy development process) of groundfish habitat on the west coast was undertaken as part of the EFH FEIS to evaluate the degradation of habitats caused by anthropogenic and environmental inputs, to identify essential areas and areas at risk of impaired function, and to evaluate management alternatives to mitigate the effects of fishing on habitats.

The data analysis included spatial and temporal analysis of the distribution of habitat types, distribution of fish species, habitat use by fish, sensitivities of habitat to perturbations, and the dynamics of fishing effort. The five main types of data available for the comprehensive risk assessment and how they feed into the decision-making framework are shown in Figure 1. Data types included:

1. Habitat preferences of species and life stages.
2. Use of habitat by groundfish- Suitability of habitat (estimated from trawl surveys).
3. Effects of fishing gears on habitat
4. Non-fishing activities that affect groundfish habitat
5. Existing habitat protection measures

Many of these data types can be analyzed and presented in GIS maps and overlays to indicate where the most important and vulnerable habitats are distributed in relation to the activities that may be impacting them (fishing and non-fishing). This is represented by the arrows that feed directly from the green data boxes into the Comprehensive Risk Assessment box (Figure 42).

Thorough analysis of these types of data, however, involves substantially more than creating maps and visual overlays in the GIS. To represent better the processes that make a particular piece of habitat more or less “essential” for managed species, and the risks posed to that habitat by fishing and non-fishing activities, a sophisticated modeling framework was created (represented by the red boxes in Figure 1). Two models are shown: the EFH Model and the Impacts Model, which are integrated but need to be treated separately in the modeling process due to the complex and wide ranging scope of the issues they address (MRAG Americas 2004).

The EFH Model

The EFH Model was developed to assess the likely importance of habitats for each species and life stage in the FMP (called Habitat Suitability Probability- HSP). This was done by evaluating the probability that particular habitats are suitable for particular species and life stages, based on available data sources; the NMFS groundfish surveys for as many species and life stages as possible, and information on habitat associations from the habitat use database for other species and life stages. The model was required to provide a scientific method for assessing Pacific coast groundfish habitat and developing management alternatives for identification of EFH.

A Bayesian Belief Network (BBN), a particular type of network model, was chosen as a suitable analytical tool for developing the EFH Model. A computer program reads the polygon data from a GIS based data file, passes them to the model, which calculates the HSP values, and writes these values back to the GIS data file. These HSP values are then plotted for the entire coast in the form of a contour plot. These maps can be used to identify EFH for each species and life stage and an overall EFH for all species and life stages. Details of the EFH model are available in the Risk Assessment for the Pacific Groundfish FMP (MRAG Americas, 2004).

The Impacts Model

The measurement of impacts to EFH caused by fishing gears is a complex process that requires substantial amounts of information. The diagram in Figure 43 indicates some of the relationships between the factors listed in the EFH Final Rule, the types of data available and the types of impacts assessment tools that could be derived from these.

Two other factors are needed to understand the process by which fishing and non-fishing activities can impact EFH: 1) the relationship between fishing effort and habitat modification, and, 2) the relationship between habitat modification and ecosystem productivity (fish productivity). Two indices were developed to provide a quantitative measure of the degree of habitat modification resulting from a unit of fishing effort: the Sensitivity Index (provides a relative measure of the sensitivity of habitats to the action of fishing gears) and the Recovery Index (provides a measure of the time taken for a habitat to recover to a pre-impacted state).

A second Bayesian Network model (the Impacts Model) was developed to examine relative changes over time and space in the relative level of impacts to EFH resulting from different management regimes or different intensities of gear use. In essence, the input data are the sensitivity and recovery matrices and the fishing effort data. Details of the Impacts Model model are available in the Risk Assessment for the Pacific Groundfish FMP (MRAG Americas, 2004).

4.2.1.2. Florida Habitat Suitability Models

Habitat Suitability Index (HSI) modeling was developed by the U.S. Fish and Wildlife Service (USFWS) in the early 1980s to support rapid decision-making in data-poor situations. Expert-opinion and literature sources were used to develop suitability indices (SI) indicative of habitat preferences across gradients. These indices were then combined to produce the index. The geometric-mean algorithm is most commonly used to determine the index. In 1997, NOAA and the USFWS developed HSI models with geographic information systems (GIS) using qualitative methods to predict spatial distributions of estuarine and marine species in Maine and Florida. This effort was expanded to develop quantitative HSI models (Rubec et al. 1998), through the analysis of FWRI's Fisheries-Independent Monitoring (FIM) data by species, life stage and season in Tampa Bay and in Charlotte Harbor (Rubec et al. 1999, 2001).

Environmental data were averaged within sampling grids across each estuary on a monthly basis. Aerial photography was used to determine the distribution of submerged aquatic vegetation for the creation of maps of bottom type. Soundings data were interpolated to create bathymetry maps. Data points for temperature, salinity, and dissolved oxygen were interpolated to produce monthly surface and bottom habitat layers. Then, monthly habitat layers were averaged using the ArcView GIS Spatial Analyst to create seasonal maps for each habitat type (Figure 44) (Florida Fish and Wildlife Conservation Commission, 2011, see http://myfwc.com/research/gis/projects/biogeographic/habitat-suitability-modeling-fl-estuaries/).

Habitat preferences for each species life stage were determined by fitting polynomial regressions to mean CPUEs across environmental gradients. Higher mean CPUEs indicate that the species is more abundant in parts of the gradient. Hence, the life stage has a habitat affinity for the peak in the suitability curve. Mean suitability values from the curves (Figure 5a) were used as input to habitat suitability models. The HSI model was used to calculate the geometric mean of the SIs associated with each habitat layer across grid cells to create a predicted HSI map in each estuary (Figure 45). The HSI model was used to create seasonal maps (spring, summer, fall, winter) depicting the spatial distribution of each species life stage (FWC-FWRI, 2011).

Raw CPUE data were overlaid within four zones (Low, Moderate, High, and Optimum) of the predicted map and mean CPUEs calculated to create a histogram. The model was verified when mean CPUEs were found to increase across the zones. Hence, the Optimal zone should have the highest mean CPUE.

Suitability indices from a nearby estuary were also used with the habitat layers from the first estuary to test transferability of the model. For example, Charlotte Harbor SIs were transferred to Tampa Bay to create a second map. Statistics were used to compare the similarity of each pair of seasonal maps within each estuary. Suitability indices transferred from another estuary can also be used to infer species distributions and relative abundance of species in estuaries lacking fisheries monitoring. The spatial modeling can be used to define which habitats are most important for each species. The Optimum zones have the potential of being designated Habitat Areas of Particular Concern (HAPC) associated with Essential Fish Habitat (Rubec et al. 1998).

The approach can assist decision-making associated with habitat protection and fisheries management (FWC-FWRI, 2011).

4.2.1.3. Texas Habitat Utilization Model

A model was developed between NOS/NCCOS Biogeography Program and NMFS/SEFSC Galveston Laboratory to help estuarine resource managers in the identification of EFH (Clark *et al.*, 1999). An analysis of nekton density data in Galveston Bay, Texas was conducted to quantitatively isolate patterns of habitat utilization, based on species abundance that could potentially be used to define EFH by the Gulf of Mexico Fishery Management Council. Results of this analysis were coupled with a geographical information system (GIS) to provide a spatial mosaic of potential EFH.

Nekton densities from drop samples taken over a 16 year period were analyzed to evaluate habitat utilization between vegetated marsh edge, submerged aquatic vegetation, and shallow non-vegetated bottom by brown shrimp, white shrimp, and pinfish. The analysis was further partitioned along seasonal temperature and salinity gradients to explore the extent to which deterministic and/or stochastic factors influence habitat selection. Multiple regression (GLM) was used to develop predictive models based on classified data. Prediction formulae were then applied to habitat geographies in the GIS. The resultant density estimates provided a measure of habitat selection, and subsequently, enabled spatial representation and assessment of potential EFH.

The model was applied in adjacent estuaries (Aransas, Matagorda, and San Antonio Bays) and regression analysis revealed similar habitat utilization patterns in these systems. Mapped model results in Galveston Bay revealed a more spatially resolved delineation of potential EFH than existing EFH maps based on ELMR relative abundance data (Clark *et al.*, 1999).

4.2.1.4. Caribbean Habitat Suitability Model Prototype

The NOS developed a prototype Habitat Suitability Model applied to 14 species in the US Caribbean for the 1998 Generic EFH Amendment. The model linked the life history of the 14 species and habitat distributions. The results included potential habitat maps by species and for some life-history stages. These were considered to represent a conservative estimate of the species distribution across habitats. The use of qualitative information, lack of confirmation of habitat utilization and the application of the model to only a few areas limited the model applicability. It can, however be expanded to more areas and species/life histories with the wealth of new information that has since become available (CFMC and NOAA, 2004, Kendall *et al* 2001).

4.2.1.5. Gulf of Mexico Shrimp Model

A pilot study of brown shrimp (*Farfantepanaeus aztecus*) was conducted by the Gulf of Mexico FMC to explore the efficacy of correlation-based habitat models for EFH designation. Catch per unit effort of brown shrimp was related to depth, longitude, latitude, and season (summer or autumn) using generalized additive models (GAMs). Spatially explicit predictions of the GAMs were produced for both seasons. Predicted catch rates from the fitted model were compared to catch data using simple linear regression to determine the model's predictive accuracy. The study determined that despite the modest complexity of the model, results were informative and could be used to inform EFH decisions. Current brown shrimp EFH is broad; however, the model results suggested that not all area currently considered EFH may be equivalent in terms of shrimp density, and there may be important seasonal components to habitat value. (GMFMC 2010)

4.2.2. Habitat Models in Stock and Ecosystem Assessments

The HAIP (2010) investigated the potential to incorporate habitat data into stock assessment models. A questionnaire of NMFS scientists revealed that some types of habitat data would be more difficult to integrate: habitat-specific vital parameters, information on habitat associations by life stage, and maps of dynamic oceanographic features and anthropogenic impacts would require modified or new models. In contrast, time series of oceanographic and climate variation, bathymetry and habitat-specific catch, effort and biomass data could be incorporated with little or no modification to existing stock assessment models. Elements of stock assessment models that could incorporate habitat data include habitat-specific vital rates, stock-recruit parameters, and movement formulations. The greatest challenges to this process are the lack of useful habitat and habitat-specific data. (NMFS HAIP 2010)

One of NOAA's goals is to "protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management" (NOAA, 2008). Integrated Ecosystem Assessments (IEAs) are an emerging tool for NMFS to use in meeting ecosystem-based fisheries management (EBFM) objectives. Habitat assessments are at the core of an IEA and therefore EBFM, contributing to each of the five stages: (1) *scoping*, by identifying threats to EBFM goals; (2) *developing ecosystem indicators*, through indicators of habitat processes, distribution and impacts; (3) *risk analysis and assessment of ecosystem status*, through integration of habitat data into conceptual risk models; (4) *management strategy evaluation*, using spatially-explicit ecosystem models; and (5) *monitoring*, by using habitat assessments to verify predictions and determine the effectiveness of management. Habitat assessments have been successfully incorporated into the spatially-explicit ecosystem model Atlantis (Figure 46). (NMFS HAIP 2010)

4.2.3. Modeling Impacts of Fishing

The New England and North Pacific FMCs have used modeling approaches to analyze the impacts of fishing on EFH.

The New England Fishery Management Council's (NEFMC) Habitat Plan Development Team created the Swept Area Seabed Impact (SASI) Model to estimate and visualize the impacts of fishing on EFH. The SASI provides a framework for managers to understand: 1) the nature of fishing gear impacts on benthic habitats, 2) the spatial distribution of benthic habitat vulnerability to particular fishing gears, and 3) the spatial and temporal distribution of realized adverse activities on benthic habitats.

The model combines fishing effort data with substrate data and benthic boundary water flow estimates in a geo-referenced, GIS compatible environment. Contact and vulnerability-adjusted area swept, a proxy for the degree of adverse effects, is calculated by conditioning a nominal area swept value, indexed across units of fishing effort and primary gear types, by the nature of the fishing gear impact, the susceptibility of benthic habitats likely to be impacted, and the time required for those habitats to return to their pre-impact functional value. The model components, including fishing effort, the various grids, and habitat feature vulnerability, are combined as described in Figure 47.

The North Pacific FMC developed a mathematical model of the effects of fishing on EFH, presented in the 2005 EFH EIS (NMFS 2005). The model provided spatial distributions of an index of the effects of fishing on several classes of habitat features. The index, termed the Long-term Effect Index (LEI), estimated the eventual proportional reduction of habitat features from a theoretical unaffected state using estimates of fishing intensity, sensitivity of habitat features, and feature recovery rates. The model was applied on a 5-by-5 km spatial scale in GIS for all Alaska fisheries managed through the North Pacific FMP. Based on the risk assessment recommended in Chapter 5 of the National Academy of Sciences' review of the Effects of Trawling and Dredging on Seafloor Habitat, the model described the nature, severity, and distribution of the risk to features of the habitat relevant to the marine fish population of Alaska. (NMFS 2005)

The major limitations of the model were the developing state of the model and the limited quality of available data. Parameter estimates were not well-resolved and there was high uncertainty due to the paucity of data. The Center for Independent Experts (CIE) reviewed the methodology and concluded that the model was well-conceived and useful in providing estimates of the possible effects of fishing on benthic habitat, but that results must be viewed as rough estimates only due to the high uncertainty. The CIE recommended validation using data from Alaska and other regions (NPFMC 2010)

5. Review Changes in the Human Environment

This section serves to update Sections 3.3 (Affected-Human Environment) and 4.3, 4.4 and 4.5 (Consequences of alternatives to the Human Environment) in the 2004 EFH-FEIS (specific subsections provided in Table 1).

In 2006 a new interdisciplinary Center for Coastal Studies (CIEL) was created at the University of Puerto Rico (http://amp-pr.org/ciel/) to contribute to the understanding of coastal and ocean processes in tropical-insular environments. CIEL emerged as an initiative for addressing interdisciplinary aspects concerning the integration of sociology and ecology into the coastal management of Puerto Rico. CIEL incorporates aspects of conservation of coastal and marine resources, promotes the enforcement of Marine Protected Areas integrating society, economy, and traditional ecological knowledge and CIEL underscores the importance of the human dimensions of marine conservation. Lessons learned from case studies in Puerto Rico and the U.S. Virgin Island are used in the design of conceptual blueprints for the development and implementation of Marine Protected Areas, capacity building of conservation officials, and the incorporation of policy issues in fisheries and human factors into the analysis of the health of the coral reef ecosystem. Some of the projects developed at CIEL contribute to the knowledge of the human dimension of EFH in the U.S. Caribbean:

Garcia and Valdes-Pizzini (2010) reported on the development of a socio-economic monitoring agenda for MPAs in Puerto Rico. The main goal of this project was to raise awareness of the human dimension of MPA management and to foster a greater understanding of the need for sound research on socioeconomic indicators. It aimed at improving the capacity of management leaders to address socioeconomic trends and incorporate human dimensions data for improved conservation management. The project implemented the SocMon (Social Monitoring) protocol in four marine reserves in Puerto Rico: Jobos Bay National Estuarine Research Reserve, Tortuguero Lagoon Natural Reserve, Boquerón Wildlife Refuge and the Mosquito Bay (Vieques) Natural Reserve.

Another project led by Valdez-Pizzini (2005-2006), dealt with strategies for the development and implementation of MPAs in Puerto Rico (http://www.uprm.edu/ccri/researcher/Valdes-Pizzini/). This project researched the legal, social, economic and policy processes and framework that configure the process of MPA design, development and implementation in Puerto Rico. The analysis led to the construction of a set of guidelines for the establishment of MPAs. CIEL disseminated information on this project through web logs: MPA in Puerto Rico and the Caribbean (http://amp-pr.org/blog) and Spawning Aggregations in the Wider Caribbean (http://amp-pr.org/spag). In collaboration with R. Appeldoorn (2006), these authors also conducted research for an integrated ecosystem assessment of La Parguera, Puerto Rico, including a socioeconomic and environmental analysis to assess ecosystem health.

Another team that has addressed socioeconomic aspects of fisheries in the US Caribbean is the Social Science Research Group from NOAA-SEFSC. This team has produced a number of technical papers, described below (http://www.sefsc.noaa.gov/ssrg_techmemo.jsp):

Agar et al. (2005) conducted a socio-economic study of the U.S. Caribbean fish trap fishery. The survey was stratified by geographical area (island) and trap tier (number of traps). It produced information on household demographics, annual catch and revenue, number and size of vessels, trap usage (type, number, design), number of fishing trips, capital investment on vessels and equipment, fixed and variable costs, behavioral response to a hypothetical trap reduction program and the spatial distribution of traps. Their results showed a large heterogeneity in the industry, including the various economic surpluses generated. There were positive and negative economic profits which suggested that the fishery is overcapitalized and that steps need to be taken to ensure the long-run economic viability of the industry. The presence of positive financial returns could provide managers with an opportunity to adopt policies that can strengthen the biological and economic performance of the fishery while minimizing any adverse impacts on local fishing communities.

Griffith et al. (2007) conducted a comprehensive research project to collect baseline socio-economic data for the fisheries of Puerto Rico, analyze the socioeconomic profiles of fishers, their communities, and their responses to marine protective measures. This project derived from the recognition by NOAA Fisheries that success of coral reef conservation strategies hinged on the ability to reconcile the need to protect coral reef and associated environments with the local cultural, economic, political and social requirements of coastal communities. The three-volume report by Griffith et al. (2007) was based on two years of ethnographic and survey research, and focused on assessing the socio-economic impacts of MPAs upon fishing communities.

Griffith et al. (2007) emphasize that there have been cumulative social and economic effects resulting from the various area closures on the west coast of Puerto Rico (i.e., Tourmaline Bank, Bajo de Sico, Abrir la Sierra, Desecheo, and La Mona/Monito), as well as the other seasonal closures for numerous commercially important species (e.g., several deepwater snapper species between October and December and several grouper species between February and April). The data collected from this survey (characteristics of the fishing fleets; socio-economic profiles of fishermen, number of fishermen by sector, area, and fishery; market strategies; species fished, catch, etc.) will help update and refine the Human Environment information contained in the 2004 EFH-FEIS.

As part of the same effort by NOAA Fisheries to collect socio-economic information from the U.S. Caribbean fishing communities, Impact Assessment, Inc. (2007) analyzed the community profiles and conducted a socioeconomic evaluation of the marine conservation districts of St. Thomas and St. John, USVI. The goals of the project involved identification and description the fishing communities on these islands and evaluation of the economic and social effects of the Hind Bank MCD, established in 1999, by assessing relationships between the user groups, communities, resources, and area closures. Results from this research showed that area closures have affected fishermen around the islands in different ways and to varying extents, with the most significant effects being intense and cumulative political reaction to closures and other regulatory measures. The authors noted that closures have disillusioned the very fishery participants who may benefit from actions taken to conserve the region's fishery resources and that this problem is likely to be perpetuated unless the well-being of individual fishers and user groups is prioritized in resource management decision-making processes. Consultation with the fishermen prior to a given management action was recommended.

The last document in the NOAA series on U.S. Caribbean fishing communities was written by Valdés-Pizzini et al. (2010). Their research consisted of a rapid assessment of the historical, social, cultural, and economic processes that shaped the dependence on fishing of the coastal communities of St. Croix, USVI. This study contributes to the description of these communities and to the understanding of their levels of engagement and dependence on fishery resources. It discusses how homesteading and gentrification limited fishing communities' access to the shore, transforming them from placed-based communities to network-based communities. In addition, the manuscript describes how declining stocks, government regulations, user conflicts and habitat degradation are threatening the livelihoods of Cruzan fishermen.

The 2010 ACL Amendment (NOAA and CFMC 2010) produced by the Council contains a regulatory impact review and a social impact assessment, that describe the possible effects of the proposed ACL rule on the economic and social environments. The regulatory review analyzed the regulations that affect reef fish and queen conch fisheries in Puerto Rico and the USVI. If Puerto Rico and/or the USVI established landings quotas consistent with the proposed ACLs, there could be cumulative adverse impacts on fishers, their families, and fishing communities; however, that would be dependent on the ACLs and the levels of annual landings at the time such quotas could be established. If the ACLs are greater than or equal to annual landings, there would be no additional adverse impact.

The environmental impact statement in the 2010 and 2011 ACL Amendments (NOAA and CFMC 2010, 2011) provide comparisons of the physical, biological, and ecological effects, as well as the socioeconomic-administrative effects of each alternative within the amendments. The social impact assessments examine the consequences of each of the proposed rules to people and their way of life. The draft Regulatory Impact Review (RIR) in the 2010 ACL Amendment assesses the alternative management measures from the standpoint of determining the resulting changes in costs and benefits to society.

The islands of Puerto Rico, St. Croix, St. Thomas and St. John comprise the affected area; the people directly affected are commercial fishermen, charter fishing operators and recreational and subsistence fishermen of these islands who harvest and are dependent on parrotfish, snapper, grouper and queen conch from federal waters. The people indirectly affected are fish wholesalers, restaurants, households and others who make use of and are dependent on these fishermen's landings of parrotfish, snapper, grouper, queen conch, and other reef fish species. If the proposed rule diminishes their use of any of these fishery management units, it would have an adverse social impact on them. The baseline social conditions (i.e., food insecurity and poverty, population size, race, origin, income, education, occupation, the characteristics and number of licensed fishermen by coastal municipality, etc.) and the possible effects of each proposed rule were analyzed in the ACL EIS assessments. The direct and indirect effects on the economic and social environments described in the 2010 and 2011 ACL Amendments (NOAA and CFMC 2010, 2011) are important to update the human environment sections of the 2004 EFH-FEIS (Table 1).

In essence, the 2010 and 2011 ACL Amendments have unavoidable adverse effects on the economic and social environments. Constraining the harvest of reef fish, spiny lobster, conch resources, and coral and reef associated plants and invertebrates in the U.S. Caribbean, as mandated by the MSFCMRA, is expected to have some negative short-term effects on the social and economic environment, and will create some burdens with respect to the administrative environment. No alternatives were considered in the amendments that would avoid those negative effects because they are a necessary cost associated with setting annual catch limits (ACLs) for the affected fisheries. The range of alternatives has varying degrees of economic costs and administrative burdens. Some alternatives have relatively small short-term economic costs and/or administrative burdens, but would also provide smaller and more delayed long-term benefits. Other alternatives have greater short-term costs, but provide larger long-term benefits. Therefore, it is difficult to mitigate these measures and managers must balance the costs and benefits when choosing management alternatives for the reef fish, spiny lobster, conch resources, and coral and reef associated plants and invertebrates fisheries (NOAA and CFMC 2011).

6. Review Changes and New Information on Fishing Impacts That May Adversely Affect EFH

The purpose of this section is to review research that has occurred since the previous fishing impacts to EFH analysis in 2004 to find out if our knowledge on the way that fishing may impact EFH has changed. A brief summary of the articles and reports detailing possible impacts to EFH in the Caribbean is provided below. The new information encountered during this review serves to update Sections 3.5.1 (Threats to habitat- Fishing Impacts) and 4.7.2 (Conservation recommendations concerning fishing impacts) in the 2004 EFH-FEIS.

A preliminary study by Hill et al. (2004) to assess the effects of trap fishing in coral reef habitats in Florida and the US Caribbean began mapping the distribution of traps and quantifying trap densities by habitat and the damage to corals and other structural organisms. Preliminary findings suggested that a relatively small percentage (<20%) of the traps set in shallow water (<30 m) actually contact hard corals. More were found in contact with gorgonians or sponges, and patchy damage was documented mainly on hard corals.

Hill et al. (in revision) developed a hierarchical approach to search for spatial patterns and impacts of the trap fishery on essential fish habitat in southwestern Puerto Rico. They examined patterns of fish trap abundance and associated impacts on benthic habitats at two scales: 10´s-kilometers and 1-meter. This study notes that proportion of the catch derived from fish traps has dropped significantly, from 72% in 1974 to 67% by the early 1980's and to 34% by 1988. Results showed that fishers set traps among various benthic habitats, and considered reef proximity as a key factor in trap placement. The majority of fish traps were deployed in mid-shelf areas within 2 km of emergent reefs or within 5-10km of deeper coral environments. At the 1m-scale, 84% of the traps were reported on unconsolidated sediments, where hard corals and octocorals also represented 19% of the benthos. Damages to coral communities from trap deployment, mostly octocorals, consisted of scrapes, crushes, uprooting, or bent colonies and were reported at 50% of the survey sites. It was estimated that around 16 to 42 km^2 are potentially impacted by the trap fishery annually. This study provides quantitative estimates and dynamics on the habitat composition and impacts from the trap fishery with a hierarchical scheme that accounts for marine system complexity. It also provides innovative maps and tables that clearly depict the spatial and temporal distribution of fish traps, their use, the essential habitats they impact, and the nature and scale of those impacts. The authors concluded that the use of traps is generating short-term impacts on the benthic communities and relative recovery is expected, but that the long-term cumulative effects of natural and anthropogenic stressors need to be addressed.

From 2002 to 2006, Hill et al. (in prep.) examined the temporal patterns in the distribution and abundance of Antillean fish traps in La Parguera, Puerto Rico. Further understanding of trap fishery patterns were obtained by using information collected from 1996 to 1999 and compared to sparse information available for the 1970´s and 1980´s. Results indicated a reduction in the trap fishery over time and higher trap abundance during the winter and spring seasons. Additionally, the more frequent use of inner-shelf sites as observed at the beginning of the fishery shifted to increased fishing intensity at mid and outer-shelf sites during the 1990´s and current effort concentrations at mid-shelf zones. Trap movement was estimated in the order of 10-27 km in the 1990´s and in the order of 5-10 km in recent years. This work fills important information gaps and denotes the importance of the geo-spatial analysis in the improvement of ecosystem based fisheries management (Hill et al., in prep.). The data confirmed a weak tendency of reduced intensity of the southwest Puerto Rico trap fishery with time. In addition this research produced innovative maps that clearly illustrate the spatial and temporal distribution of fish traps in SW Puerto Rico, their use, the essential habitats they impact, and the nature of those impacts (example in Figure 48).

In a similar study conducted by Hill et al. (2009) in the St. Thomas-St. John and St. Croix reef environments, the authors examined spatial and temporal patterns in reef fish abundance and density within six habitat types over a five-year period. This study also examined the variation in the composition of species caught with traps. Results showed a low abundance fish community, dominated by herbivores and secondary carnivores and with minimal representation of predators and large species. This community structure appeared drastically different compared to studies conducted three decades ago. The authors suggested that the composition of the reef fish caught in traps might also reflect the degradation of the habitat quality caused by natural and human-induced stressors acting synergistically.

Hill et al. (2010) conducted a multi-year and multi-scale study in the U.S. Virgin Islands, similar to the one carried out in La Parguera (Hill et al., 2010), to examine the impacts of Antillean fish traps on essential fish habitats. The spatial distribution of the traps (as indicated by trap buoys) was surveyed by navigating transects around the main islands covering coastal and mid-shelf areas between 2002 and 2006. A total of 1,215 trap buoys were found in the USVI, with an annual mean of 304 traps (195 from STSJ and 110 from STX). Results of this study are very comprehensive in scope and coverage, and include: trap buoy abundance by area, year, and season; trap location (within and outside protected areas); location by habitat; seasonal movements; legal status (color coded or not); seasonal movements; habitat use; and habitat damages caused by the trap fishery by island.

Specific results from Hill et al. (2010) varied by island, but this research produced innovative maps for the USVI, that clearly illustrate the spatial and temporal distribution of fish traps, their use, the essential habitats they impact, and the nature and scale of those impacts. At STSJ the majority of the habitat damages were classified as injured (45%), scraped (29%) and broken (18%). Octocorals suffered the majority of the impacts, but hermatypic coral colonies were also impacted. Damages to habitats were 45% injured, 29% scraped, and 18% broken. In STX the majority (78%) of the trap were found to be inside protected areas, and most of habitat damages were classified as broken (50%), crushed (23%) or bleached (10%), differing from habitat damages found in STSJ and PR. No damage to habitats was reported in 53% of the observations. Habitat damages affected mainly sponges, followed by hermatypic corals, and on third place, octocorals.

Marshak et al. (2006) reported on a study started in 2002 to monitor the impact of Antillean fish traps in coralline habitats of southwest Puerto Rico. This research found that most traps (63%) were found within colonized hard bottom habitats dominated by soft corals at intermediate depths (12-18 m). Fishes composed 78% of the total individuals caught, of which butterflyfishes, surgeonfishes, grunts, and parrotfishes were most abundant. Snappers and groupers composed only 7% of all observed fishes and the Caribbean spiny lobster was the most frequently observed invertebrate (85%). found within 22% of all observed traps, made up of all observed invertebrates, and the highest percentage of all observed individuals (20%). The majority of individuals (81%, n=316) were observed within colonized hard bottom and reef areas of high damage potential. Although sampled less frequently, traps within more barren areas (27%, n=44) of lower damage potential (algal sand and mud habitats), consisted mostly of trunkfishes (19%, and grunts (15%). Within these habitats, *P. argus* was the most frequently observed species (32%), of which 58% were observed in algal sand. Due to the presence of spiny lobster within barren habitats, and the higher percentage of commercially valuable fish species observed within areas of lower damage potential, these results suggest that fishers could prosper well by fishing traps only within areas of low damage potential. However, given the potential to catch higher numbers of lobster and fishes of the snapper/grouper complex within coralline habitats, it is unlikely that such a change in practice would occur

Scharer et al. (2004) evaluated the use of fish traps and their effects on fish habitat, based on fisher knowledge and quantitative field surveys. This study included 5 regions in Puerto Rico (north, south, east, west, and islands) and showed that despite its traditional dominance in artisanal fisheries, the individual effort in number of traps per fishermen is declining. Coral reefs were not reported as a preferred fish trap location, but rather areas adjacent to reefs (sand, seagrass, gorgonian. and algal habitats) are targeted.

Sheridan et al. (2004) examined the fishing patterns of the trap fishery in the U.S. Virgin Islands. Their results showed that preferred fishing areas were SW and NE St. Croix, and SW and NW St. Thomas, with spiny lobster, parrotfishes and triggerfishes being the main catch. St. Croix fishermen concentrated off the south coast in relatively shallow waters (averaging 17.7 m, max. 30.5 m), while St. Thomas / St. John fishermen concentrated effort off southern St. Thomas in moderate to deep waters (mean 47.5 m, max. 183 m). Fishermen moved traps regularly and seasonally. The type of trap construction, use and soak time by area was evaluated. This study found that fishing times were shorter off St. Croix than off St. Thomas/ St. John (means 3.2 days vs. 7.2 days, respectively). Traps were most often deployed in vegetation (seagrass or algae), sand, or rubble habitats, but some fishermen targeted corals.

The previous study was expanded by Sheridan et al. (2005). They looked at the use of fish and lobster traps in the U.S. Virgin Islands, Puerto Rico, and the Florida Keys. The researchers found that less than 20% of the traps set in shallow water (<30m) actually contacted or impacted corals, gorgonians, or sponges. The damage mainly affected hard corals and was considered patchy and less than the total trap footprint. In addition, half of the traps caused no apparent damage and seasonal shifts in trapping effort and habitats used were observed.

While researching the differences in reef substrate between areas damaged by anchorage as opposed to those not, Toller (2005) found that Rugosity Indices (RI) were significantly lower at damaged sites than non-damaged sites. This difference in RI also caused the greater levels of rubble coverage (37.6%) in damaged sites than non-damaged sites (6%). At damaged sites, the average percentage cover of *Montastraea annularis* was reduced by 97 % and *M. faveolata* had been reduced to 0%. Through these studies it was found that reef structure now consisted of *M. franksi* (30.4 %), *A. agaricites* (19.8 %), *P. astreoides* (16.7 %), *M. annularis* (12.3 %), *M. cavernosa* (8.9 %), and *S. siderea* (4.6 %). However, at non-damaged sites, all coral species had a lower percetange of average abundance except for *S. siderea* and *Stephanocoenia intersepta*. In addition to greater coral abundance at non-damaged sites, higher fish densities were also observed (10, 305 fish) than at damaged sites (8,508 fish). While the average abundance differences was not significant (using the t-test), once the five most common species were removed – creole wrasse (*Clepticus parrae*), blue chromis (*Chromis cyanea*), bicolor damselfish (*Stegastes partitus*), bluehead wrasse (*Thalassoma bifasciatum*), and brown chromis (*Chromis multilineata*) – the difference was significant. The most notable reductions in abundance observed for graysby (*Cephalopholis cruentata*), mahogany snapper (*Lutjanus mahogoni*), and schoolmaster (*L. apodus*) showed 65%, 81% and 100% reductions respectively. The overall spatial extent of coral damage is considered to be large at the Frederiksted Reef (16.1>21.2 hectares).

7. Review Changes and New Information on Non-Fishing Impacts That May Adversely Affect EFH

The review of non-fishing activities focuses on Sections 3.5.2 (Threats to Habitat-Non-fishing impacts) and 4.7.3 (Non-fishing project-specific conservation recommendations) of the 2004 EFH-FEIS. That section of the EIS identifies non-fishing activities that have the potential to adversely impact EFH in order to support recommendations provided in accordance with the requirements of the Magnuson-Stevens Act.

A number of non-fishing impacts to EFH occur throughout the US Caribbean region, and include a variety of physical, water quality, and biological effects. The majority of these impacts are directly related to anthropogenic activities and these vary throughout the region. The relative measures of these effects (activities) are an important factor in determining all of the potential anthropogenic impacts on EFH in the US Caribbean. Therefore, an analysis of non- fishing effects and their relative intensity would ideally be performed and used in concert with fishing impacts for the EFH risk analysis for assessing cumulative impacts. Table 13 ranks natural and anthropogenic factors which stress reef ecosystems in the US Caribbean according to their level of concern for reef managers EFH-FEIS (CFMC 2004).

7.1. Review of Maritime-Related Factors

In February 2008, NOAA published Technical Memorandum NMFS-NE-209 entitled “Impacts to Marine Fisheries Habitat from Non-fishing Activities in the Northeastern United States” (Johnson et al. 2008). The report was the outcome of a technical workshop intended to assist the Northeast and Mid-Atlantic Fishery Management Councils in updating non-fishing impact analysis within their Fishery Management Plans. During that workshop, it was recognized that the information being generated was applicable to a larger audience and the scope of the report was expanded. Although produced for the northeast United States, the comprehensive nature of the report provides a framework to evaluate the information included in the 2004 EFH-FEIS and updated in this report. To update and add detail to Table 13, all the available information for the US Caribbean can be ranked against the scoring tables for the northeast provided in the TM NMFS-NE-209 (see Habitat impact category tables, pp. 14-26 in: http://www.nefsc.noaa.gov/publications/tm/tm209/tm209.pdf).

The following activities were analyzed in the 2004 EFH-FEIS and conservation measures identified in the Council’s original EFH Amendment (CFMC 1998) to satisfy the EFH guidelines:

- Docks and piers
- Boat ramps
- Marinas
- Bulkheads and seawalls
- Cables, pipelines, and transmission lines
- Transportation

- Navigation channels and boat access canals
- Disposal of dredged material
- Impoundments and other water-level controls
- Drainage canals and ditches
- Oil and gas exploration and production
- Other mineral mining/extraction
- Sewage treatment and disposal
- Steam-electric plants and other facilities requiring water for cooling or heating
- Mariculture/aquaculture

From the review of the NOAA Technical Memorandum (NOAA 2008), the new information can serve to enhance the information, associated risks, and conservation recommendations concerning non-fishing activities in Sections 3.5.2.1 (Non-Fishing Impacts- Maritime-related factors) and 3.5.2.2 (Coastal development and related threats), including:

- Navigation channels: temporal impacts to water quality (e.g., turbidity) and benthic species composition; losses of submerged aquatic vegetation, intertidal habitats and wetlands; impacts associated with different dredging methods.
- Docks and piers: impacts associated with vessels including mooring, grounding, prop-dredging, and wave-induced erosion; shading affects of floating structures, and water quality considerations of anti-fouling agents.
- Housing developments: alteration of local hydrodynamics including natural filtration of runoff, groundwater recharge, and floodwater retention.
- Bulkheads and seawalls: nearshore groins, jetties, and breakwaters.
- Offshore mineral mining for beach nourishment and other purposes.
- Municipal and industrial discharges.
- Non-point source discharges.
- Water intakes: impingement and entrainment of larval and juvenile life stages.
- Marine debris: abandoned and derelict vessels and intentional vessel disposal.
- Global effects: effects of climate change, including alteration of temperature and hydrological regimes, alteration of weather patterns, and changes in community structure.

During this review, only a few new studies conducted in the U.S. Caribbean addressed non-fishing impacts to EFH, such as pollution, diseases, bleaching, etc. They are described below. Other impacts that have become increasingly important in recent years: global warming and lionfish invasions, are described in separate sections.

7.2. Review of Natural Impacts

The literature reviewed in this section will contribute to enhance the information in Section 3.5.2.3 (Non-fishing impacts to EFH-Natural Factors) of the 2004 EFH-FEIS (Table 1)

7.2.1. General Impacts

The NOAA Technical Memorandum cited above (NOAA 2008) also addresses other impacts to habitat. One chapter includes climate change and natural disasters as global effects on marine habitats. According to this report, the main impacts caused by climate change are: alteration of hydrological regimes, alteration of temperature regimes, changes in dissolved oxygen concentrations; nutrient loading and eutrophication; release of contaminants; loss of wetlands and fishery habitat; shoreline erosion; alteration of salinity regimes; alteration of weather patterns; changes in water alkalinity; changes in community and ecosystem structure, and changes in ocean/coastal uses. The report also lays out conservation measures and best management practices for climate change impacts to aquatic habitats.

According to the NOAA report (2008), natural disasters and events include hurricanes, floods, and drought. These events may impact water quality, alter or destroy habitat, alter hydrological regimes, and result in changes to biological communities. Natural disasters have the potential to impact fishery resources, such as displacing plankton and fish from preferred habitat and altering freshwater inputs and sediment patterns. Conservation measures and best management practices for natural disasters are recommended are provided by NOAA (2008).

In the U.S. Caribbean, Bauer and Kendall (2010) concluded that whilst it has been hypothesized that naval activities negatively impacted marine environments around Vieques, a converse lack of residential and commercial development on two-thirds of the island formerly owned by the U.S. Navy may have been a positive influence by preventing anthropogenic activities that are well documented elsewhere to harm marine environments. Although there were some differences found in biota among sampling strata and some elevated levels of contaminants and nutrients around the island, the results of this study did not support either of those hypotheses as a major factor structuring the marine environment of Vieques. Bauer and Kendall (2010) found that biota, nutrients, and contaminant levels around Vieques generally match those for other coral reef ecosystems in the Puerto Rico and US Virgin Islands region and appear to be shaped primarily by regional-scale processes rather than local factors.

Eakin et al. (2010) undertook the most comprehensive documentation of basin-scale bleaching to date for the 2005 mass bleaching event in the Caribbean. Collaborators from 22 countries, estimated over 80% of corals were bleached with over 40% mortality observed at many sites between June and October 2005. This study found that thermal stress during the 2005 event exceeded any observed from the Caribbean in the prior 20 years, and regionally-averaged temperatures were the warmest in over 150 years. Eakin et al. (2010) also documented a significant relationship between accumulated heat stress (measured using NOAA Coral Reef Watch's Degree Heating Weeks) and bleaching intensity.

The biological review team in García-Sais et al. (2008) determined that ecosystem elements which are dependent on coral reefs have most likely had their growth ability significantly marred by the reduction of elkhorn and staghorn corals. This was linked to the large coral bleaching event in 2005 followed by the mass mortality of 2006. The bleaching occurred through record sea surface temperatures between 31.8^0C and 33.1^0C where a significant number of corals in La Parguera, Mayaguez, Boqueron, Rincon and the offshore islands of Desecheo and Mona Island showed signs of bleaching. Furthermore, reefs which were leeward of ocean currents showed greater susceptibility to bleaching. However, all sightings of *A. palmata* indicated that this coral was not susceptible to bleaching through warming.

García-Sais et al. (2008) also found that as a result of a 228 m tanker running aground in 2006 on reefs off Guayanilla caused significant reef structure damage. Thousands of scleractinian corals and gorgonians were reattached using hydraulic cement, however it will require monitoring to determine the success of these actions. Additionally, a large oil spill in 2007 in Guánica went unreported and caused damage to mangrove forests, beaches, and coral cays.

A review of "The State of Coral Reef Ecosystems in Puerto Rico" (García-Sais *et al.* 2008) suggested that 69% of projects involved interactions which could adversely impact fishery habitats. For example, water resource projects around Puerto Rico have caused losses to wetlands and seagrass beds and changes in sea temperatures. Currently, regulations state that water effluents must not be higher than 32.2^0C (which is already above optimal growing temperatures for coral). However, actual temperatures which are released are sometimes at 43.3^0C which far exceeds this regulation.

A recent study by NOAA Fisheries and the U.S. Army Corps of Engineers (Shafer *et al*., unpub. data, in García-Sais *et al.* 2008) found that 63% of docks in Fulladosa Bay were not authorised and their construction and use resulted in loss of at least 5% of seagrass beds. This occurred through shading of areas by dock structures. Furthermore, at least 7, 14, and 21% of seagrass habitats have been negatively impacted by boat traffic in Palominito, Palomino and Icacos respectively.

Nemeth et al. (2008) reported an extensive coral mortality event referred to as "unknown necrosis" within the MCD. The disease occurred primarily in a basin in the western-central portion of the MCD. Unknown necrosis covered one fifth (about 9km^2) of the total benthic habitat of the MCD shallower than 50m. Within this area, unknown necrosis had a prevalence of 42.4% and affected 32.8% of the colony, possibly leading to a loss of more than half the coral coverage. The disease seems to have peaked in October 2007 and mostly dissipated within three month. Nemeth et al. (2008) noted that this unknown necrosis was probably the result of a response to a common abiotic driver, rather than a pathogen. The mean prevalence of coral disease (excluding bleaching) in the MCD was 18.5% with a mean severity (measured as the percent of a colony affected) of 26.9%. Unknown necrosis was the most common coral disease, followed by white plague, which had a mean prevalence of 0.8% and a mean severity of 11.6%. Nemeth et al. (2008) noted level 2 bleaching (bleaching of 10 – 50% of a coral colony) within the MCD. The mean prevalence of bleaching was 12.4% with a mean severity of 1.9%.

Pait et al. (2010) undertook an assessment of chemical contaminants in sediments and corals in nearshore waters and lagoon areas on the island of Vieques off Puerto Rico to identify differences in contamination based on former land-use, establish baseline values for change detection, and identify sites where sediment contamination exceeded established guidelines. Chemical contaminants (150 types) including metals, pesticides, and energetic compounds (explosives) were analyzed. Overall, contaminant concentrations were found to be below established sediment quality guidelines. Sediments from lagoons typically had higher concentrations than offshore sites, and sediments had higher concentrations of trace and major elements (mostly metals) than corals. DDT (at four sites) and chromium (at one site) were detected in sediment samples above established sediment quality guidelines. At one site near Blue Beach, the concentration of DDT was over an order of magnitude higher than the established sediment quality guideline. Sediment concentrations of polycyclic aromatic hydrocarbons were significantly higher in the strata that included the former Naval Ammunition Support Detachment and the concentration of cadmium was significantly higher in the former Live Impact Area. However, Pait et al. (2010) concluded that no sites had concentrations that were likely to affect sediment-dwelling biota.

Rothenberger et al. (2008) found that during the bleaching event in 2005, 90% of coral coverage was impacted in St. John. Whilst *Montastraea annularis* continues to be the dominant species at these sites, its abundance was reduced by 7%.

7.2.2. Spiny Lobster Disease

Spiny lobsters have few reported pathogens, parasites or other naturally-occurring sources of disease. Most reported syndromes are associated with lobster culture (Shields 2011). Only one pathogen, *Panulirus argus* virus 1 (PaV1), is thought to have potential impacts on wild Caribbean Spiny Lobster populations. The first naturally-occurring pathogenic virus found infecting a lobster, PaV1 was first reported in Florida in 1999 (Shields and Behringer 2004) and now may be widespread in the Caribbean with high local prevalence in some areas (Ehrhardt et al. 2010).

PaV1 is an unenveloped, icosahedral, DNA virus that develops within the nuclei of host cells. The virus initially infects the fixed phagocytes in the hepatopancreas, which lyse and allow the virus to spread to spongy connective tissues and hemocytes. In late stages of infection, the hepatopancrease and other tissues lose glycogen reserves and the host probably dies from metabolic wasting (Li et al. 2008, Shields 2011). Lobsters heavily infected with PaV1 become lethargic or slow, and studies indicate that the virus causes lobsters to stop feeding, resulting in a lack of glycogen reserves, poor nutritional condition and eventually death (Behringer et al. 2009, Shields 2011). The virus is lethal, with infected individuals typically dying within one month to 200 days (Behringer et al. 2009, Shields 2011). The sublethal effects (reduced mobility) also result in greater predation on infected individuals (Behringer et al. 2009). In Florida and Mexico study locations, the disease is most prevalent in the smallest juvenile lobsters (16-25%) and declines in prevalence among larger juveniles (5%) and adults (<1%) (Shields and Behringer 2004, Ehrhardt et al. 2010). This inverse relationship between PaV1 prevalence and lobster size is thought to result from the combined effects of increasing immunological resistance with size, decreasingly effective water-borne transmission with size, and the ability of healthy lobsters to detect infection in conspecifics (Behringer et al. 2009). Small juveniles have been shown to be more susceptible to infection when exposed to the virus by direct contact (Butler et al. 2008), and to exhibit more rapid mortality once infected (Behringer et al. 2009).

PaV1 can be transmitted via a number of pathways, but contact and water-borne transmission appear to be the main pathways in nature (Shields 2011). Because the virus is not viable in seawater for more than a few days, it is thought that the disease is primarily spread by contact, and that larvae and post-larvae can be carriers over potentially large distances (Behringer et al. 2009). Heavily infected lobsters become less active than healthy individuals; however, lightly infected lobsters are still highly active, and are thought to facilitate dispersal of the virus to new habitats (Shields 2011).

The virus has a profound impact on lobster behavior and ecology, with significant implications for nursery habitats. PaV1 has been shown to induce a remarkable behavior in healthy, infected lobsters. Such lobsters can detect and avoid diseased lobsters (Behringer et al. 2006), the first example of avoidance of diseased individuals by healthy conspecifics other than in humans (Shields 2011). Avoidance behavior commences prior to the time infected lobsters become infectious, and appears to be effective at reducing contact transmission and limiting the local spread of the disease (Behringer et al. 2009). In the wild, healthy lobsters are normally social and more than half (54%) co-occupy dens, while virtually all diseased lobsters (94%) occupy solitary dens (Behringer et al. 2006). The size and dimensions of available shelter may affect the frequency of shelter cohabitation, as healthy lobsters co-occurred more frequently with diseased lobsters in larger than in smaller natural shelters (Lozano-Alvarez et al. 2008, Behringer et al. 2009). The avoidance of shelters containing diseased lobsters has implications for healthy lobsters attempting to find shelter from predation, especially when shelter is limited, which may occur in locations where structure for juveniles is naturally sparse or where it has been eliminated by a catastrophic event such as a harmful algal bloom or a disease outbreak (Behringer et al. 2009).

PaV1 infections have been confirmed in the Florida Keys, US Virgin Islands (St. Croix), Mexico and Belize, and there are anecdotal reports from the Bahamas and Cuba (Behringer et al. 2009). There were no reports or confirmation of PaV1 in Puerto Rico at the time of writing. In Florida and Mexico, where the disease has been studied, benthic juvenile mortality due to the disease is four times higher than the natural mortality rate assumed for the recruited age classes (Ehrhardt et al. 2010). The discovery of PaV1 coincided with a decline in landings of *P. argus* from the Florida Keys fishery; however, it is not known whether the virus was a factor that contributed to the decline (Behringer et al. 2009, Shields 2011). Field studies have found no relationship between disease prevalence and lobster density at smaller spatial scales (Behringer et al. 2009), but there are no known studies over larger spatial scales, probably due to the fact that the disease has only been studied in two locations. It is therefore not possible to determine the disease's impact on *P. argus* populations at present.

PaV1 is widespread in the Florida Keys and Florida Bay, particularly in the shallow juvenile nurseries (Shields 2011). Mean prevalence in the Florida Keys has been stable since 1999 at 5-8%, but has risen from 2.7% to 10.9% in Puerto Morelos, Mexico (Behringer et al. 2009). In a review of PaV1, Shields (2011) suggests that the differences in nursery habitat between the Florida Keys and the Puerto Morelos area are large enough to justify further attention to the potential impacts of habitat features on the host-pathogen association. Neither nutritional condition of the individual nor exposure to different seawater salinities has been found to affect lobster susceptibility to PaV1 (Behringer et al. 2009, Shields 2011). Although no seasonal patterns of disease prevalence have been found in the wild, laboratory studies indicate that high seawater temperatures increase susceptibility of early benthic juveniles (Behringer et al. 2009, Shields 2011). There does not appear to be any obvious management mechanism to contain the spread of this disease (Ehrhardt et al. 2010).

7.2.3. Review of Likely Climate Change Impacts to Habitat

Impacts of Climate Change

Climate change is expected to have an impact in the Caribbean by affecting marine ecosystems and habitats such as coral reefs, mangrove forests and seagrass beds. Climate change will likely lead to significant changes in the structure, function, and productivity of these habitats. Climate change is also expected to impact the availability, stability, access, and utilization of aquatic food resources (Cochrane et al. 2009). Most of the research to date on the impacts of climate change in tropical areas has focused on coral reefs.

Coral reefs are important globally, with nearly 500 million people depending on them for food for protein, income from fishing and tourism, and coastal protection from storms (Wilkinson and Souter 2008). Approximately 30 million people depend solely on these resources for food and protection (Wilkinson and Souter 2008). Despite their importance, coral reefs are threatened by various impacts, one of which is climate change. In 1992, scientists estimated that 10% of the world's coral reefs had already been lost, and an additional 60% were threatened if management measures were not implemented immediately to conserve coral ecosystems (Wilkinson and Souter 2008). However, coral reef degradation continued in subsequent years. Bleaching of coral is expected to become a regular event by 2030 and an annual one by 2100 if emissions of greenhouse gases are not reduced significantly (Wilkinson and Souter 2008).

Coral bleaching occurs when coral becomes stressed or overheated; they often respond by expelling zooxanthellae, algae with which they form a symbiotic relationship. The loss of the zooxanthellae causes coral to become pale or white, which is known as bleaching (Rogers and Beets 2001, Hughes et al. 2003). During this state, corals are weakened and have lower reproductive capacity and slower growth rates, and are more prone to disease (Wilkinson and Souter 2008). When this state is prolonged, coral will begin to die. Bleaching can occur in response to increased water temperatures or ultraviolet radiation (Rogers and Beets 2001).

Bleaching that lasts for an extended period of time can impact the productivity or survivability of coral, leading to biological impacts on the coral ecosystems and economic impacts on the services they support (citations in Clark et al. 2009). Yet, as carbon dioxide in the atmosphere increases and temperatures rise, coral reefs are more likely to change than to disappear altogether (Hughes et al. 2003, Santer et al. 2006). Bleaching, for instance, can lead to changes in the composition of coral communities. Since coral species have differing tolerances to heat and to ultraviolet radiation, they will begin to bleach at different times; those that are able to endure higher temperatures or more ultraviolet radiation have a greater chance of survival as do the species that are able to colonize new areas rapidly (Hughes et al. 2003, Hoegh-Guldberg et al. 2007). As a result, it is possible that coral reefs will become more homogeneous.

Coral bleaching can also affect fish species that inhabit these ecosystems. Fish associated with bleached corals have been found to be more vulnerable to predators due to increased visibility and thus, susceptibility (Coker et al. 2009). This increased susceptibility to predators can lead to declines of fish associated with bleached corals (Coker et al. 2009).

In addition, other species that inhabit coral reef ecosystems are impacted by the increasing water temperatures associated with climate change. In both marine and freshwater ecosystems, fish and plankton have shifted their distributions away from low latitudes and towards the poles in response to rapid temperature increases (*In* Brander 2007). The effects of distributional changes can include the spread of competitive and potentially invasive species, as well as diseases, to new areas (Brander 2007). These changes can have significant impacts to ecosystem composition.

In low-latitude regions where temperature changes will be most significant due to climate change, fish production will likely decline (Brander 2007). These declines will result as vertical mixing, which is responsible for recycling of nutrients from deep depths, subsides. Reproductive capacity of fish stocks is also likely to be reduced, making them vulnerable at fishing levels that they once could sustain. Fish production will be greatly impacted by the loss of structural complexity in coral reefs (Graham et al. 2006). Many fish species rely on live coral reefs for food and shelter. Since reefs provide specialized niches for various species, the loss of these areas will lead to competition for remaining shelter and to increased predation (Graham et al. 2006). As a result, fish species richness will decline, and local extinctions could increase within reef ecosystems (Jones et al. 2004, Sano 2004, Graham et al. 2006). Local extinctions are already occurring at the edge of distributions for various species, including freshwater and diadromous species such as salmon and sturgeon (*In* Brander 2007). The Caribbean region is at high risk from these impacts of climate change.

In addition to coral communities, mangrove forests and seagrass beds are also likely to be impacted by climate change. These habitat types provide food resources and other ecosystem services to local communities. Mangroves are harvested for wood which provides fuel and timber. They also provide habitat for multiple species, both aquatic and terrestrial, at varying life history stages; filter and trap pollutants from run-off; stabilize coastal land by trapping sediment; and protect against storm damage (McLeod and Salm 2006). While some changes that result from climate change, such as increased levels of carbon dioxide, may be beneficial to mangroves by enhancing photosynthesis and growth rates (UNEP 1994), other changes can cause damage. Sea-level rise is likely the greatest threat of climate change to mangroves, particularly to mangroves on low relief islands and those deprived of sediment (McLeod and Salm 2006). Mangroves can adapt to changes in sea-level when those changes occur slowly (Ellison and Stoddart 1991), or if adequate room for inland expansion exists (McLeod and Salm 2006). Otherwise, the mangroves will become smaller until they no longer have room, and they will perish (UNEP 1994).

Seagrasses, which provide among the highest number of services of any ecosystem on earth, may also be impacted by climate change (Bjork et al. 2008). Among the services provided by seagrasses are shelter for multiple species, stabilization of sediments, prevention of erosion, and filtration of suspended sediments and nutrients. Like mangroves, seagrasses may be positively impacted by increases in carbon dioxide, which would lead to increases in photosynthesis. Increasing temperatures, on the other hand, can lead to stress in addition to changes in distribution, sexual reproduction patterns, seagrass growth rates and metabolism, and carbon balance (Short and Neckles 1998, Short and Coles 2001). Plants may begin to die at their upper thermal limit (Coles et al. 2004). In addition, increased temperatures may increase growth rates of competitive algae and epiphytes, leading to overgrowth of seagrasses and reduction of available sunlight needed for survival (Bjork et al. 2008). Sea level rise can also reduce the availability of light, thus negatively impacting seagrasses.

Rising sea surface temperatures caused by climate change are also believed to contribute to the intensification of storms and hurricanes (Santer et al. 2006, Rogers et al. 2008). Intense storms can damage the structure of coral reefs and communities in seagrass beds and mangrove areas (Rogers and Beets 2001). These three diverse ecosystems provide habitat and nursery areas for marine organisms. Because marine species utilize diverse habitats throughout their various life history stages, degradation of the habitat types can have significantly adverse effects on associated marine communities (Rogers and Beets 2001). Community structure can also be impacted by differential responses to storm damage and varying rates of regeneration after storms (Roth 1997, McLeod and Salm 2006). Storm surges, especially combined with sea level rise, can flood mangroves and lead to destruction (McLeod and Salm 2006). Intense storms can also impact human health and well-being.

As discussed in relation to impacts on mangrove forests and seagrass beds, sea level rise will also occur as climate change continues. Estimates that include ice melt in their considerations predict that sea levels could rise anywhere from .5 to 2 meters by the end of the 21st century (Rahmstorf 2007; Pfeffer, Harper, and O'Neel 2008). Sea level rise is not likely to occur equally around the world, and thus, will have varying impacts in different regions (Bamber et al. 2009; Yin, Schlesinger, and Stouffer 2009). In addition to storm intensity and sea level rise, climate change is expected to exacerbate issues related to water quality and overexploitation of ocean resources (Hoegh-Guldberg et al. 2007).

Coral Reef and Climate Change Research in the Caribbean

Coral bleaching has occurred in the Caribbean a number of times in response to unusually high water temperatures; bleaching events have been documented in 1987, 1990, 1995, 1998, and most recently in 2005, each with increasing severity (Goreau et al. 2000, Rogers and Beets 2001, Rogers and Miller 2001, Goldberg and Wilkinson 2004, Miller et al. 2006, Muller et al. 2008, Rogers et al. 2008, Clark et al. 2009). In 1998, shifts in climate resulted in massive coral bleaching and mortality of approximately 16% of the world's coral reefs (Wilkinson and Souter 2008). Extensive bleaching was observed in the USVI (Rogers and Beets 2001). While some corals had recovered fully by 1999, others had only partially recovered or had died (Rogers and Miller 2001). This bleaching event occurred during a period when the seawater temperatures from 1989 to 1999 were the highest on record, exceeding 30°C, at Newfound and Great Lameshur Reefs in St. John. During the fall of the same year, extensive bleaching also occurred at the Buck Island Reef National Monument off of St. Croix when water temperatures reached 29.9°C (Rogers and Beets 2001). In this area, it was estimated that 60-80% of coral colonies bleached (Goreau et al. 2000), but less than 5% of the colonies died (Goldberg and Wilkinson 2004).

Another major bleaching event occurred in 2005, the hottest year on record in the Northern Hemisphere since 1880 (Wilkinson and Souter 2008). Mean reef water temperatures were found to be significantly higher than in the previous 14 years (Miller et al. 2006, Muller et al. 2008, Rogers et al. 2008, Clark et al. 2009). During this year, large areas of warm surface water developed in the Caribbean and in tropical areas of the Atlantic, which led to temperature-related stress among corals. The greatest amount of coral mortality was observed in the USVI where approximately 51.5% died as a result of bleaching and disease (Wilkinson and Souter

2008). This observation was the most extensive damage seen in forty years of observations (Wilkinson and Souter 2008).

In St. John, water temperatures ranged from .6-1.6^{o}C higher than the monthly means for the previous 14 years (Muller et al. 2008). Reports vary as to when bleaching peaked (April-September by Miller et al. 2006, October-November by Muller et al. 2008) and how much of the coral cover was affected. It has been estimated that in the USVI, over 90% of the coral cover demonstrated some degree of bleaching (Miller et al. 2006). Muller et al. (2008) found that 50% of monitored *Acropora palmata* colonies exhibited a loss of pigmentation. Between October and December, 17% of the *Acropora* colonies died from bleaching or a combination of bleaching and disease (Muller et al. 2008).

Disease prevalence in coral colonies was found to be related to bleaching events. Muller et al. (2008) studied *Acropora palmata* (elkhorn coral) and *Acropora cervicornis* (staghorn coral) colonies in Hawksnest Bay, St. John. These two species have been the primary shallow-water reef-building coral species in the Caribbean during the last 200,000 years (Pandolfi 2002). There have been unprecedented declines in the habitat ranges of these two species in recent years (Precht et al. 2004). Muller et al. (2008) found a high prevalence of disease during three years of studying these coral species; however, the linear relationship between temperature and disease, meaning that as temperature increased so did disease prevalence, only occurred during 2005. This relationship suggests that the prolonged period of high water temperatures increased the likelihood of disease in coral communities (Muller et al. 2008). Bleached coral colonies exhibited significantly more tissue loss from disease than non-bleached communities (Muller et al. 2008). Miller et al. (2006) found that coral mortality from November 2005 to April 2006 occurred as a result of White Plague Disease that occurred after the 2005 bleaching event, resulting in 26-48% losses in coral cover.

Montastraea annularis (boulder star coral) was also studied in 2005 throughout the USVI. *M. annularis* and *A. palmata* are among the most significant in the USVI because of their structural role in building of reef ecosystems, due to their large colony sizes, and as a result of their complex morphology (Rogers et al. 2008). Rogers et al. (2008) noted that the fate of the USVI reef ecosystems depends on these species since they are the main reef builders and provide shelter and habitat for other species. Contrary to *A. palamata* which is a found at shallow depths less than 8 meters, *M. annularis* is the most abundant deep-water coral species in waters 5-20 meters deep. It also can be found in depths over 40 meters (Rogers et al. 2008). *M. annularis* decreased in abundance as a result of the 2005 bleaching event and subsequent disease, primarily White Plague (Rogers et al. 2008). An average of about 96% of the total coral cover bleached in the USVI, with over 90% of this consisting of the *M. annularis* complex. Approximately 60% of the coral in the USVI died the 2 years during and following the 2005 bleaching event; a significant portion of this coral mortality was attributed to disease instead of the bleaching itself (Rogers et al. 2008).

A. palmata was impacted to a lesser extent than *M. annularis* by the high water temperatures and disease outbreak that began in 2005. An estimated 48% of the monitored *A. palmata* colonies in the USVI bleached; of these colonies, 13% died partially and 8% died completely (Rogers et al. 2008). The species is a threatened species, and this was the first bleaching on record for it in the USVI. *A. palmata* has a faster growth rate and a lower vulnerability to bleaching than *M. annularis*; thus, it is expected to recover more quickly. By January 2006, the colonies had regained color in many areas around St. John while *M. annularis* colonies remained pale until October 2006 at the earliest (Rogers et al. 2008). Despite the ability of *A. palmata* to recover quickly, no evidence has been observed of increases in number or size of colonies in the USVI in the past five years (Rogers et al. 2008). In addition *A. palmata* has been extensively impacted by white band disease, with very high mortality in the 80's because of this disease, and colonies still bing affected by it (B. Kojis, pers. comm.).

In St. Croix, coral colonies were also affected by water temperatures that were above average in 2005 from March through November (Clark et al. 2009). In a study of areas in and around Buck Island Reef National Monument, off of St. Croix, about 64% of the surveyed area was classified as a hard substrate (Clark et al. 2009). Coral colonies in this study exhibited bleaching at 91% of the survey sites in October of 2005. Overall, 51% of the total live coral cover within the surveyed areas was bleached (Clark et al. 2009). As seen in other studies, different species responded differently to the increased water temperatures. Four species (*Acropora cervicornis*, *Eusmilia fastigata*, *Dendrogyra cylindrus*, *Madracis decactis*) and one genus (*Scolymia* spp.) exhibited no signs of bleaching; however, their occurrence in the study area was low (Clark et al. 2009). Other coral species – 19 species within 16 genera – did bleach, with *Montastraea annularis* and species of the genus *Agaricia* being the most affected. Coral in all depths, ranging from 1.5-28 meters, were affected, although bleaching was negatively correlated with depth. Most of the bleaching that was observed occurred east of Buck Island with a few observations northwest and southeast of the protected area. Bleaching decreased as water temperatures began to return to normal temperatures, and by October 2005, bleaching was infrequently observed.

In addition to coral bleaching, hurricanes and storms, possibly intensified by rising sea surface temperatures of climate, have caused extensive damage to USVI coral reefs, significantly decreasing coral cover and creating fragmented colonies in some circumstances (Rogers and Beets 2001). A record-breaking number of hurricanes occurred in 2005 – 13 in total – in addition to extreme storms (Wilkinson and Souter 2008). These storms damaged corals through wave action and run-off of muddy and polluted waters. Branching species such as *Acropora palmata* and *Acropora cervicornis* were the most vulnerable to storm damage, and also are the species most threatened by coral diseases (Rogers and Beets 2001).

Intense storms and hurricanes can also cause damage to seagrass beds in the form of 'blowouts' or scoured depressions, as were observed as a result of hurricanes in the USVI in 1989, 1995 and 1999 (Rogers and Beets 2001). Hurricane Hugo in 1989, subsequent storms, and a drought (1994-1995) caused well-documented damage to mangroves areas of St. John (Rogers and Beets 2001). However, seagrass beds and mangrove forests have not received the research attention that has been directed towards coral reefs.

Mitigation measures

A number of management measures have been recommended to mitigate the impacts of climate change. While direct management action will not prevent climate change from impacting benthic habitats, effective management can minimize the damage from direct anthropogenic effects and promote resilience in these ecosystems (Wilkinson and Souter 2008). Marine protected areas (MPAs) have been suggested to be the most effective method to conserve coral reefs and other benthic habitats from degradation (Rogers and Beets 2001, Bjork et al. 2008). MPAs or other forms of no-take areas, or areas where extractive use of resources is prohibited, cannot stop bleaching. They also may not be able to prevent declines in fish biodiversity in areas where degradation occurs (Jones et al. 2004). Instead, they can enable the partial recovery of areas that have been repopulated with resistant species (Hughes et al. 2003). They can also minimize degradation from some impacts such as fishing.

In the Caribbean, MPAs have been found to have a larger biomass of both herbivorous and carnivorous fish, but the MPAs have had no effect on the survival or abundance of coral or macroalgae (Mora 2008). To date, these areas have not been designed with climate change or other external threats such as sewage in mind; the failure to include these potential threats to ecosystems may explain why MPAs have not prevented coral mortality (Mora 2008).

To optimize the benefits of MPAs and their effectiveness against climate change stressors, a number of considerations can be taken into account. Wilkinson and Souter (2008) recommend protecting areas that act as refugia, provide for diverse representation and replication, allow for connectivity, and support good overall ecosystem condition. Refugia are sites that provide natural resistance or tolerance to coral ecosystems from mass coral bleaching events; these areas also may serve as source locations for coral larvae which can replenish more vulnerable sites (Bjork et al. 2008). For mangroves, areas should be protected that demonstrate resilience or are naturally positioned to survive threats, such as those that have the potential for landward migration if sea levels rise or that possess abundant mature trees that would be important for repopulating (McLeod and Salm 2006).

MPA networks should also be designed around sites that provide representation and replication and allow managers to protect diverse habitat types and maximize biological diversity (McLeod and Salm 2006, Bjork et al. 2008). This approach will buffer against uncertainty associated with climate change (Wilkinson and Souter 2008). Connectivity will allow for rebuilding and recovery after mass bleaching as organisms can disperse between sites. Healthy ecosystems are better able to adapt to global changes in climate (Bjork et al. 2008). Those that are healthy boast diverse and dense benthic cover, diverse and abundant fish populations, and good water quality, all of which allow for recovery following disturbances.

In the case of corals, they are in a weakened state during bleaching, and reducing local stressors, including tourism activities, water pollution, and fishing, will also help in preventing coral mortality during bleaching events (Wilkinson and Souter 2008). Conservation measures such as reducing fishing mortality or developing precautionary, ecosystem-based approaches to fisheries management will also likely have positive effects in mitigating the impacts of climate change. By reducing fishing mortality, managers can make fisheries more resilient to potential impacts of climate change (Brander 2007). Developing precautionary, ecosystem-based approaches would also make fisheries resilient to changes caused by increasing water temperatures; however, this type of approach should go beyond incorporating a few commercially important stocks, as has been done in the past, and instead should consider the entire ecosystem (Brander 2007). Finally, to prepare for negative impacts of climate change, management measures should be developed that are flexible and adaptive to allow for changes in management as new information becomes available (Brander 2007). Engaging stakeholders that rely on coral reefs will help promote effective and adaptive management efforts.

Improving land use practices will also lead to healthy seagrass and mangrove habitats that are better equipped to adapt to global changes. These practices should be designed to decrease nutrient and sediment run-off, limit unregulated felling, eliminate persistent pesticide usage, and increase filtration to improve water quality (McLeod and Salm 2006).

In addition to effective management measures, an expanded knowledge base will assist in planning for uncertainty related to climate change and increasing storm intensity (Cochrane et al. 2009). Baseline maps of benthic habitats should be created to allow for monitoring of changes in distribution and abundance (Bjork et al. 2008). Monitoring programs should also be implemented. Likewise, storm surge/vulnerability maps, such as those produced by the Army Corps of Engineers or the SLOSH program (http://slosh.nws.noaa.gov/) could also be useful in determining which areas to protect. Research efforts should also focus on improving current understanding of future levels of fish production, predicted impacts of climate change on fisheries and aquaculture processes, the use and effectiveness of decision-making tools under uncertainty, and socio-economic impacts related to food security issues (Cochrane et al. 2009).

Finally, community outreach programs should be developed. Raising the awareness of the value and threats to benthic ecosystems can lead to valuable protections and programs. Community restoration projects have also been successful in restoring habitats, such as mangrove trees. Encouraging communities to develop non-destructive uses of mangrove forests can prevent communities from converting these areas to ports and from removing mangroves for private development of homes, docks, hotels, oil refineries, etc. These projects can thus be effective to mitigate deforestation (McLeod and Salm 2006). Developing an ecosystem valuation of these areas can encourage support for conservation efforts.

Ocean acidification

In addition to the impacts of climate change on tropical ecosystems, ocean acidification will also lead to and exacerbate changes in these areas (Raven et al. 2005). About one quarter of carbon dioxide that is emitted into the atmosphere by human activities is absorbed into the ocean (Canadella et al. 2007). The carbon dioxide mixes with water to produce carbonic acid, which breaks down into bicarbonate ions and protons. This process decreases the pH of the ocean, making it more acidic, and it reduces the availability of carbonate in the water to shell- and reef-forming organisms (Brander 2007, Hoegh-Guldberg et al. 2007). Due to the importance of shell-forming species to marine food chains, ocean acidification can impact food webs and threaten food security (Hoegh-Guldberg et al. 2007). Phytoplankton and zooplankton are additional calcifying organisms that may be affected, and these organisms are important prey species for fish and other marine animals (Raven et al. 2005).

In addition to making it difficult for organisms to utilize carbonate, increased carbon dioxide in the ocean may also weaken coral skeletons and reduce the accretion of reefs (Hughes et al. 2003). A panel of 155 marine scientists found that “ocean acidification may render most regions chemically inhospitable to coral reefs” by 2050 (Prince Albert II of Monaco Foundation 2008).

Ocean acidification also threatens biodiversity, tourism, and coastal protection, the latter provided by coral reef ecosystems.

Coral reefs in tropical and subtropical areas are expected to be most impacted by ocean acidification, leading to negative ramifications for reef ecosystems in these areas; however, cold-water corals are also likely to be affected, though less information about these ecosystems is known (Raven et al. 2005). Unfortunately, the acidification process of our oceans is irreversible; it will take tens of thousands of years to revert the chemistry of the ocean to pre-industrial times (Raven et al. 2005). The only way to manage the effects of ocean acidification is to minimize the emissions of atmospheric carbon dioxide (Raven et al. 2005).

7.2.4. Review of Likely Impacts of Lionfish Invasions

Introduction

Lionfish (*Pterois miles* and *Pterois volitans*), finfish native to tropical coral reefs in the South Pacific and Indian Oceans, have recently been introduced to waters along the U.S. east coast and in the Caribbean. More recently, they have been documented in the Gulf of Mexico. Lionfish inhabit depths between 10 and 175 meters (Schofield et al. 2010). While most scorpionfish are colored to blend in with their environment, lionfish are not and instead have long fin spines and a striking coloration. Their dorsal, ventral, and anal spines are venomous and can not only deter predators but also injure humans (Schofield 2009).

Lionfish live in small groups as juveniles but are typically solitary as adults (Fishelson 1997). During the day, lionfish shelter in reef crevices while at night they forage in deeper waters. They are voracious predators that prey on large quantities of small fish and crustaceans (Albins and Hixon 2008). Particularly problematic in regards to their introduction to new habitats is that they are able to adapt quickly to new prey types and to learn which prey are noxious and should be avoided (Fishelson 1997). They have no native predators in habitats to which they have been introduced. Lionfish have been found in the stomachs of groupers in the Bahamas, but it is unclear how often this type of predation occurs (Maljković et al. 2008). Lionfish can also reproduce year-round (Morris et al. 2008), are relatively resistant to parasites (an advantage over native species), grow quicker than native species, and compete with native species for food and space (Albins and Hixon 2008).

Lionfish are popular in the marine aquarium trade (Morris et al. 2008). While reports vary as to when the first lionfish was spotted in waters off Florida along the U.S. east coast (early 1990s by Albins and Hixon 2008 and Morris et al. 2008, 1985 by Schofield 2009 and Aguilar-Perera and Tuz-Sulub 2010), some believe that they may have been introduced to Florida waters when six individuals were released from an aquarium during Hurricane Andrew in 1992 (Schofield 2009). These individuals are believed to have made their way into Biscayne Bay. Lionfish were not observed again until 2000 when they were observed off of Florida, South Carolina, and North Carolina (Schofield 2009). Since 2000, the species has increased rapidly in numbers and spread throughout the western North Atlantic and into the Caribbean Sea and Gulf of Mexico (Whitfield et al. 2002, 2007; Freshwater et al. 2009a). By 2002, lionfish were distributed continuously between Miami, Florida to Cape Hatteras, NC, and populations in these areas are now considered established (Schofield 2009). They have been seen north of Cape Hatteras, presumably swept there in the Gulf Stream, but intolerance to cold water temperatures is believed to limit their survival in northern waters (Kimball et al. 2004). Lionfish apparently became established in the Florida Keys by January 2009 (Schofield 2009) and Dry Tortugas National Park in 2010 (Schofield 2010).

In addition to the Atlantic coast of the U.S., lionfish are believed to be established in the Greater Antilles, Lesser Antilles (Leeward Islands), Bermuda, Bahamas, Cayman Islands, Turks and Caicos, Mexico, Honduras, Costa Rica and Venezuela (Schofield 2009, Schofield 2010). Reports from the Netherlands Antilles, Belize, Nicaragua, Panama, and Colombia have also been documented, but lionfish are not believed to be established in these locations yet, though further invasion is likely imminent (Schofield 2009, Schofield 2010).

The spread of lionfish into the Northwest Atlantic Ocean and Caribbean Sea represents one of the fastest distributional expansions of a non-native marine finfish in history (Morris et al. 2008) (see Figures 49 to 51). In Bermuda, the first lionfish was discovered in 2000 in a tide pool on the southern shore of the island (Whitfield et al. 2002). It is believed that lionfish persisted here at low levels for several years as only a few sightings occurred each year between 2001 and 2003. However, by 2004, lionfish sightings became more numerous in Bermuda. It is unknown if lionfish can survive winters in Bermuda; thus, it is unknown if the population is truly self-supporting or transient, being repopulated by recruitment from the Gulf Stream (Schofield 2009).

Lionfish first appeared in the Bahamas in 2004 and became established and distributed among the different islands by 2005 (Whitfield et al. 2007). They now inhabit coral reef habitats in addition to mangrove, seagrass, sandy beach, and even occasionally canal habitats in the Bahamas (Freshwater et al. 2009a). Densities of lionfish recorded off of reefs on the southwest coast of New Providence, Bahamas were found to greatly exceed documented densities of lionfish in both its invaded and native ranges (Green and Cote 2008). For instance, lionfish densities in the Bahamas were 18 times higher than those previously reported in invaded areas of North Carolina (Green and Cote 2008). Due to the cryptic nature of the species, lionfish densities are difficult to assess and should be considered conservative (Morris et al. 2008).

In the U.S. Virgin Islands, the first report of lionfish came from a diver off of two sites on the north shore of St. Croix in June of 2008 (Schofield 2009). A juvenile lionfish was collected on the western side of St. Croix off of Frederiksted Pier in November of 2008 (Schofield 2009). An additional seven lionfish were either observed or collected from St. Croix between January and July of 2009 (Schofield 2009). The first confirmed report of lionfish from St. Thomas was in January 2010, and two months later the first lionfish from St. John was captured (Schofield 2010). Lionfishes are now established in all three islands (Schofield 2010).

In the Netherlands Antilles, the Leeward Antilles (off the coast of Venezuela) were invaded by lionfishes in 2009 and quickly classified as established (Schofield 2010). Lionfishes invaded other leeward islands of the Lesser Antilles in 2010, including Saint Martin (July 2010), Anguilla (August 2010), Guadeloupe (September 2010) and St. Kitts (October 2010) (Schofield 2010). In the Gulf of Mexico, a dead lionfish was retrieved off the coast of Florida in October 2006 during a toxic red-time bloom of the organism, *Karenia brevis*; however, testing of the lionfish revealed minimal exposure to the toxin (Schofield 2009). This result suggests that the fish was in the Gulf of Mexico for a short period of time. By 2009, several unconfirmed reported sightings of lionfish had occurred in the northern Gulf of Mexico between Texas and the Florida panhandle (Schofield 2009). In 2010, there were confirmed reports of lionfish off the west coast of peninsular Florida and from the northern Gulf of Mexico in Florida, Alabama and Louisiana. However, a lionfish has been collected in the southern Gulf of Mexico, approximately 130 km off of the northern Yucatan Peninsula (Aguilar-Perera and Tuz-Sulub 2010). This lionfish was one of two individuals sighted in December 2009 at 38 m depth over a reef, 58 km northwest of Alacranes Reef National Park (Aguilar-Perera and Tuz-Sulub 2010). It is believed that this sighting of lionfish in the Gulf of Mexico is the first that has arrived via larval transport (Aguilar-Perera and Tuz-Sulub 2010).

A lionfish sighting occurred in early 2009 off of Cozumel Island in the Mexican Caribbean by the eastern Yucatan Peninsula. Subsequent sightings and collections have occurred along the mainland Mexican coast. Thus, it is possible that the lionfish larvae has been dispersed through the Caribbean current to the Yucatan Current, passing through the Yucatan Channel, and are now being transported by the Loop Current of the Gulf of Mexico (Aguilar-Perera and Tuz-Sulub 2010).

Lionfish have been observed in the Turks and Caicos, Haiti and Cuba beginning in 2007, in Jamaica, the Dominican Republic, the Cayman Islands, and Puerto Rico beginning in 2008, and in Mexico, Honduras, Costa Rica, Nicaragua, Panama, Colombia and Venezuela beginning in 2009 (Chevalier et al. 2008, Guerrero and Franco 2008, Morris et al. 2008, Schofield 2009, Aguilar-Perera and Tuz-Sulub 2010). They were established in the Turks and Caicos by 2008 and in the Cayman Islands by 2009 (Schofield 2009) and in Venezuela by 2010. Lionfishes are well established along the Venezuelan coastline as well as along the northern islands near the Netherlands Antilles (Lasso-Alcalá and Posada, 2010). Lionfishes are expected to continue their geographic expansion and eventually close the loop of the Caribbean, including the entire Gulf of Mexico and the island chain from the US Virgin Islands to Grenada, and it is probable that the invasion will spread south through Trinidad and Tobago, Guyana, Suriname, French Guyana and Brazil (Schofield 2010).

It was originally thought that only one species of lionfish, *Pterois volitans*, was present in the Atlantic Ocean and Caribbean Sea, but genetic evidence has shown that a second species, *P. miles*, is also present in some locations (Hamner et al. 2007; Morris and Freshwater 2008; Freshwater et al. 2009a,b) citations in Schofield 2009). It is not clear whether both species are present in all locations though research has found that *P. volitans* comprises 93% of the introduced lionfish population (Hamner et al. 2007). In the Bahamas, only the presence of *P. volitans* has been confirmed (Morris et al. 2008, Freshwater et al. 2009a in Schofield 2009). Low genetic diversity has been found among sampled lionfish specimens in the Atlantic (Hamner et al. 2007) and the greater Caribbean (Betancur, et al. 2011). Mitochondrial DNA screening has shown that *P. miles* is restricted to the northernmost locations (Bermuda and the US east coast) (Betancur, et al. 2011).

The lionfish invasion has spread quickly and is expected to continue to do so of *P. volitans* and possibly of *P. miles* as well. This invasion is likely to threaten ecosystems, and is a concern for coastal and fisheries managers due to the potential of lionfish to impact fisheries resources, native communities, and even human health (Morris et al. 2008).

Impact

Lionfish have voracious appetites, feed on both fish and crustacean species, can adapt to novel prey, can learn which prey to avoid, and have no native predators in their non-native habitats; thus, they possess ability to significantly impact ecosystems to which they have been introduced. Lionfish stomachs can expand in volume over thirty times when consuming large quantities of prey. They also can withstand periods over 12 weeks with no food (Fishelson 1997). Removals of large amounts of forage fish are a great concern to fisheries managers. In many areas, there is also a concern that lionfish may out-compete native predators which are already in low abundance due to overfishing (Hare and Whitfield 2003).

In the Bahamas, Albins and Hixon (2008) performed an experiment using translocated coral and artificial patch reefs to determine the short term effects of lionfish on the recruitment of native reef fish species. They found that lionfish significantly reduced recruitment by an average of 79% over a five week period, compared to reefs without lionfish. The results suggest that lionfish may already have negatively impacted coral reefs in the Atlantic (Albins and Hixon 2008). Analysis of stomach contents and observations of feeding lionfish demonstrated that reductions in native fish density were likely due to lionfish predation. The size of the prey in lionfish stomach contents suggested that lionfish may be preying upon adult fish (Albins and Hixon 2008). They may compete with native predators for important prey species. Further studies suggest that lionfish may decrease the abundance of ecologically important species such as parrotfish and other herbivorous reef fish which play an important role in preventing seaweeds from overgrowing corals (Williams and Polunin 2001, Mumby et al. 2006). Many of these fish species may also have economic importance to local fishing communities (Morris et al. 2008).

Arias-González, et al. (2011) modeled the invasion of lionfish in a coral reef community based on pre-invasion fish community data. The model suggests that lionfish may have a strong impact on biomasses and fluxes: small and intermediate carnivorous-omnivorous fish showed strong decreases in biomass (although there was a slight increase in some small and intermediate carnivorous-omnivorous fish and scarids), sharks, rays, jacks and scombrids decreased and turtles and corals also declined. The model suggests that lionfish may impact the ecosystem by both releasing competition and producing competition. The model also investigated eradication scenarios, comparing short term and long term fishing pressure, and found that lionfish would bounce back after short term pressure but could be reduced to a very low level through long term fishing pressure.

Johnston and Purkis (2011) found that the lionfish invasion occurred in a series of three stages as illustrated in the stage map (Figure 52). Stage one was largely current driven, Stage two was more radial and proximity based, and Stage three was again current driven.

Mitigation efforts

Prevention of lionfish establishment is the least expensive and most effective management option (Morris et al. 2008); however, due to the widespread geographic extent and fast expansion of lionfish distribution, it is unlikely that complete eradication of lionfish from the

Atlantic and Caribbean regions is possible (Albins and Hixon 2008). Instead, for areas that already have established populations, efforts are needed to decrease densities and to stop further expansion of lionfish distribution. Albins and Hixon (2008) recommend targeting areas with vulnerable or valuable reefs or areas that can be used to stop further expansion, or “choke” off growth. Another possible mitigation effort is maintaining or rebuilding populations of potential predators such as grouper or sharks that are native to the areas with lionfish (Albins and Hixon 2008, Mumby et al 2011). Mumby et al. (2011) found that grouper serve as lionfish biocontrol at high grouper biomass levels that are only found in protected marine reserves.

A number of mitigation measures are being attempted to either reduce lionfish densities or to prevent establishment of the species. The Cayman Islands which had its first lionfish sighting in 2008 has begun an aggressive removal program by training and licensing local divers to remove the species. By June of 2009, over 200 lionfish had been captured and removed (Schofield 2009). A collection program is also underway in Mexico under the Yucatan Peninsula Program. More than 100 individuals have been collected in the area by local divers (Aguilar-Perera and Tuz-Sulub 2010). In Bermuda, a culling program began in 2008 that consisted of training and licensing which allowed certain commercial and recreational fishermen to spear lionfish on nearshore reefs (Morris et al. 2008). In 2007, Bahamian fisheries managers institute a lionfish kill order to fishermen. They have also tried to engage the public with education seminars in an effort to promote lionfish for human consumption and to encourage the development of a fishery for the species (Morris et al. 2008).

Other mitigation attempts have included grassroots “adopt a reef programs” to encourage local citizens to take responsibility for local reefs and to protect them from lionfish. In some areas, tourists are also getting involved in removal of lionfish using spears and handnets to avoid injury (Morris et al. 2008). NOAA has also developed gear to trap lionfish in deeper waters, in larger areas, or at higher densities than are practical for reliance on divers (Morris et al. 2008).

The US Virgin Islands published a Lionfish Response Management Plan in October 2009. The Plan aims to reduce lionfish throughout the USVI through (1) education, outreach and training, (2) opportunistic and targeted detection and removal of lionfish, (3) monitoring and data gathering, and (4) data analysis and reporting. The Plan focuses on educating communities about lionfish and implementing reporting and capture programs with the goal of removing lionfish whenever they are sighted, as well as implementing scheduled monitoring programs.

8. Review Habitat Area of Particular Concern (HAPC) Designations (Addition or Removal of HAPCs)

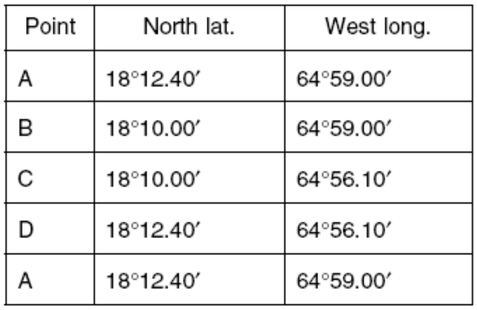
The 2005 Comprehensive SFA Amendment (CFMC 2005) identified several areas as HAPCs. Each proposed site is discrete, and meets one or more HAPC criteria:

1. Importance of ecological function provided by the habitat;
2. Extent to which the area or habitat is sensitive to human induced degradation;
3. Whether and to what extent development activities are stressing the habitat; and
4. Rarity of the habitat type.

The HAPCs identified are provided in Section 1.5. Since the 2005 Comprehensive Amendment, there have not been any directed studies to look at the effectiveness of the Council's HAPCs. The purpose of designating HAPCs was to help provide additional focus for conservation efforts for these areas. Some of these areas are already afforded protection through other means (see MPA Section 1.6). Some of the studies described in the Biological Environment (Section 3 of this report), in particular those related to Reef Fish and Coral EFH, have looked at the effectiveness of protecting habitat in the areas designated as HAPCs and have provided further insight into the distribution, abundance and habitat preferences of the species protected in HAPCs (eg., studies by Armstrong 2006; Clark *et al.* 2009; García-Sais *et al.* 2007, 2008, 2010; Monaco *et al.* 2007; Nemeth *et al.* 2005, 2006, 2008, 2010; Ojeda-Serrano *et al.* 2006, 2007). There was no information in the literature reviewed that reported any habitat damage to HAPCs. All the new data produced by those reports enhance the fundamental knowledge for the description of HAPCs in the U.S. Caribbean, which, along with this part, updates Sections 2.4 (Alternatives to designate HAPCs) and 4.4 (Consequences of alternatives for identifying HAPCs) of the 2004 EFH-FEIS.

On January 4, 2005 a new HAPC was designated by NMFS (50 CFR Part 622), the Grammanik Bank Seasonally Closed Area which is managed by NOAA through the CFMC. This rule prohibits fishing for or possessing any species of fish, except highly migratory species, within the Grammanik Bank closed area from February 1 to April 30, each year. The intended effect of this rule is to protect an important spawning aggregation of yellowfin grouper, to help arrest the decline in the resource, reduce overfishing and to support its recovery.

The Grammanik Bank closed area is bounded by rhumb lines connecting, in order, the following points:



Point	North lat.	West long.
A	18°12.40′	64°59.00′
B	18°10.00′	64°59.00′
C	18°10.00′	64°56.10′
D	18°12.40′	64°56.10′
A	18°12.40′	64°59.00′

Details and locations of additional managed areas in the USVI are illustrated in Figures 13-14. HAPCs in the U.S. Caribbean include marine reserves, national monuments, national parks, wildlife refuges, fishing closures, and the Red Hind Marine Conservation District (MCD) (Figure 4). It is worth noting that The Nature Conservancy (TNC), with local stakeholders, is developing a management plan for the Mangrove Lagoon, Cas Cay, St. James, Marine Reserves on the east end of St. Thomas (Figure 14). Some regulations will include prohibiting fishing in the Mangrove Lagoon and part of Cas Cay and limiting fishing to handlining in the St. James part of the reserve. This is a local government initiative (B. Kojis, pers. comm.).

9. Conclusions and Recommendations on Updating EFH Information

This report represents the first periodic review of EFH information as required by Section 600.815(a)(10) of the EFH Final Rule. Although a pre-defined process was not in place the authors utilized guidance provided by NMFS through the Caribbean Fishery Management

Council, the Caribbean Office of Habitat Conservation, and the Southeast Regional office. Substantial guidance was also provided by a similar report produced by the Gulf of Mexico Fishery Management Council in 2010.

The 2004 EFH-FEIS resulted from a court order to NMFS to complete a new and more thorough NEPA analysis of actions to minimize adverse effects of fishing on EFH. NMFS and the Councils decided the scope of the EIS should address all required EFH components of Section 303(a)(7) of the MSFCMA, rather than a limitation to fishing impacts. This Section requires a “periodic review” of EFH information (Section 600.815(a)(10) of the EFH Final Rule).

9.1 Description and Identification of EFH

The literature review provided new information on some managed species’ habitat utilization, on descriptions of mesophotic coral reefs, and on spawning aggregations. This new information suggests that the Council could consider revised descriptions of EFH for coral reefs and for reef fish species that use mesophotic reefs and spawning aggregations. New mapping efforts underway (see Section 4.1), when complete, would provide maps to update habitat distributions and species-specific habitat utilization for use in descriptions of EFH. However, the new literature did not provide information that would dramatically alter current aggregate EFH designations and descriptions.

9.1.1. Spiny Lobster EFH.

Most of the new studies describing EFH for spiny lobster focused on postlarval stages. In general, they provided information on pueruli settlement on different habitats, and on the distribution and abundance of spiny lobsters at different locations over a period of time. In essence, habitat utilization by spiny lobsters at the life stages analyzed remains unchanged from the original EFH-FEIS identification, but more detailed information is now available on the type, characteristics, location, and depth of the preferred habitats. New regulatory documents, specifically the draft 2011 Comprehensive ACL Amendment, provide new alternatives for reference points or proxies and proxies for OFL, ABC, ACL and OY definitions; when finalized, the 2011 ACL Amendment will provide information that updates the 2004 EFH-FEIS.

9.1.2. Queen Conch EFH.

There were few studies conducted since the 2004 EFH-FEIS that described EFH for the species in the Queen Conch FMU. The main research efforts in recent years have focused on stock assessments and surveys of juvenile and adult queen conch distribution and abundance. Recent exploratory surveys of mesophotic benthic habitats and associated fish and shellfish communities have identified rhodolith deposits at depths between 35-50 m at Abrir La Sierra as preferred grazing and reproductive habitats of adult queen conch. Other new habitat associations have not been found; however, new studies expand the understanding of the spatial distribution of conch juveniles and adults by area, depth, and habitat type and contribute to the characterization of conch populations and their habitat-utilization patterns in the U.S. Caribbean.

9.1.3. Reef Fish EFH.

The new literature on reef fish habitat associations in the U.S. Caribbean produced since 2004 is extensive and varied. Some studies explored new methodologies and addressed important ecological questions of different species at different life-history stages or at new locations, while others deepened the knowledge generated previously regarding the distribution, abundance, and habitat affinity of reef fish species at known locations.

New research on mesophotic and deep water reefs in the U.S Caribbean (including Bajo de Sico, Abrir La Sierra, Mona Island, and Desecheo Island) has uncovered new information on habitat utilization by reef fish species. Reef promontories provide residential, foraging, and spawning habitat for many large, commercially important species (e.g., large snappers and groupers) that have virtually disappeared from most other reef systems in the U.S. Caribbean. Mesophotic reefs also serve as foraging areas for large migratory pelagic fish and as residential areas for many smaller aquarium trade species. The study of mesophotic (15-50 meters) and deep reefs (up to 150 m) revealed new habitats for a few species, as well as new data about their distribution along depth gradients. Mesophotic reefs also serve as spawning aggregation sites and transport routes of fertilized eggs and larvae across the U.S. Caribbean for multiple reef fish species (e.g., red hind; mutton snapper; black, yellowfin, tiger grouper, etc.).

A large proportion of the literature reviewed described spatial patterns in fish density, richness, and abundance at multiple spatial scales and along depth gradients, over different habitats and periods of time. Some of these focused on the analysis of spatial and temporal trends in reef fish assemblages inside and outside marine reserves to evaluate their effectiveness. Yet another group of studies revealed species-specific patterns of habitat utilization (i.e., nursery areas) and ontogenetic habitat requirements for important reef species (e.g., French grunt and lane snapper), as well as the possible configuration of EFH across all species and stages combined (Ceverny 2006, Ceverny et. al., 2011). One study (Pittman et al., 2007b) highlighted the need to incorporate the influence of seascape structure in the identification and evaluation of EFH, HAPCs, MPAs and restoration projects.

References to new distribution ranges (horizontal and vertical), habitat associations, ontogenetic shifts, and possible shifts in habitat preferences for a number of reef fish species were encountered during this review, in particular in the new studies that characterized mesophotic coral reef systems and spawning aggregation sites. The new information on mesophotic reefs and spawning aggregations suggests sufficient change from the 2004 EFH FEIS that the Council could consider revision of the description of EFH for reef fish that use mesophotic reefs and spawning aggregations. While such a revision would affect EFH for individual species, it would not affect the aggregate EFH for reef fish.

9.1.4. Coral EFH.

The new literature on coral reefs of the U.S. Caribbean produced since 2004 uncovered a wealth of new information, particularly in regard to the characterization of sessile-benthic and fish communities at mesophotic coral reefs, natural reserves, and habitat areas of particular concern.

New and deeper areas have been explored and described, including the mesophotic reefs at Bajo de Sico, Abrir La Sierra, Mona Island, Desecheo Island, the Red Hind MCD; other MPAs around in Puerto Rico (Rincón, Guanica, Ponce, Caja de Muerto and Mayagüez) and the U.S. Virgin Islands (Buck Island in the East End Marine Park, St. Croix; U.S. Virgin Islands National Park and Virgin Islands Reef National Monument in St. John).

In general, the research studies on coral reefs carried out in recent years involved:

- The characterization of shallow water, moderate depth, and mesophotic reefs and associated communities from PR and the USVI
- Community assessments of mesophotic reefs, including corals, fish, and invertebrates.
- Description of bathymetric features, benthic habitat assessments, taxonomic inventory of species, species-habitat utilization, distribution and abundance by habitat and life-history stage.
- Geo-referenced information on geo-physical, bathymetric, hydrographic and biological reef features on GIS maps.
- Production of benthic habitat maps and information of taxonomic composition of corals and other benthic and pelagic taxa from each habitat for new locations and at different depths.

The composition and structure of corals and associated benthic and fish communities at mesophotic reefs were found to differ significantly from shallow coral reefs. Given the wealth of new information on mesophotic coral reefs from the U.S. Caribbean, the Council could consider a revision of the identification and description of coral EFH. Furthermore, given the ecological importance of these reef formations, some of the study sites have been proposed as potential habitat area of particular concern (HAPCs). Thus, the revision (expansion) of existing HAPCs and/or the designation of new ones is also justified based on the new information generated since the 2004 EFH-FEIS.

According to Pittman et al (2010) and to García-Sais (pers. comm., 2011) respectively, La Parguera Natural Reserve and El Seco Reef off Vieques are other unique coral reef ecosystems in Puerto Rico that may also warrant consideration as a HAPC.

As noted Section 3.3.4, where new information of corals is reviewed in detail, and Section 4.1, where new mapping research and mapping tools are discussed, a number of studies generated new bathymetric, habitat, and habitat-association maps that would update, replace or complement those provided in the 2004 EFH-FEIS. Mapping efforts underway (Section 4.1) will provide more details when complete.

9.2 Identification of Habitat Areas of Particular Concern (HAPC)

The Council did not designate HAPC by FMP in the Generic EFH Amendment. In the 2004 EFH-EIS, several alternatives for HAPCs were presented to the Council as a means of designating HAPCs. In the 2005 Comprehensive SFA Amendment, Alternative 3 (Preferred) (numbered Alternative 4 in 2004 EFH-FEIS) was selected to designate HAPCs in the Reef Fish and Coral FMPs based on confirmed spawning locations and on areas or sites identified as having particular ecological importance to managed species. This preferred alternative and the corresponding HAPCs are described in Section 1.4 of this document. The designation of HAPCs thus occurred after the 2004 EFH-EIS, although the specific areas in the selected alternative were not modified from those described and mapped in that document.

Habitat Areas of Particular Concern seem to be working effectively in the U.S. Caribbean, and, as noted in the conclusions and recommendations in Section 9.1 above, there have been a large number of studies that directly or indirectly measure their effectiveness (see for example Sections 3.3.3 and 3.3.4, describing research on fish spawning aggregations around mesophotic reefs). Recommendations from regional experts suggest that the Council could consider adding such locations as La Parguera Natural Reserve and El Seco reef as HAPC.

9.3 Fishing Activities That May Adversely Affect EFH

A number of new studies assessed the impacts of fishing on coral reef habitats in the U.S. Caribbean. They focused, in particular, in the analysis of spatial and temporal patterns of fish trap utilization, and the associated impacts on habitat. Results from these studies provide qualitative or quantitative estimates and dynamics on the habitat composition and impacts from the trap fishery in Puerto Rico and the U.S. Virgin Islands. Most studies have also produced innovative maps and tables that clearly depict the spatial and temporal distribution of fish traps, their use, the essential habitats they impact, and the nature and scale of those impacts.

In general, results from these studies showed that trap damage mainly affected octocorals, scleractinian coral colonies, and sponges. Main damages were classified as broken, crushed, bleached, scraped, or injured. An important conclusion from these studies is that the composition of the reef fish caught in traps might also reflect the degradation of the habitat quality caused by natural and human-induced stressors.

In essence, the literature review of fishing impacts on habitat produced new evidence and understanding on how current trap fisheries in the U.S. Caribbean are impacting habitat. This information confirmed that current measures taken by the Council to avoid adverse fishing impacts are adequate. Additional measures do not appear necessary at this time. It is recommended that similar assessments on the extent and amount of habitat damage produced by other main gears be conducted.

In addition to the new fundamental knowledge on fishing impacts on EFH generated since the 2004 EFH-FEIS, the 2005 Comprehensive Amendment set new gear restrictions in the U.S. Caribbean EEZ, including anchoring restrictions, buoy restrictions, and the year-round prohibition to use pots, traps, bottom longlines, gillnets or trammel nets in Federal closed areas (see Table 4). In territorial waters, the U.S.V.I has also banned gillnets and trammel nets, and Puerto Rico has set restrictions on these gears. All these measures contribute to the protection of EFH in the U.S. Caribbean.

9.4 Non-fishing Activities That May Adversely Affect EFH

A review of recent literature (NOAA 2008) identified some information gaps regarding non-fishing threats to EFH that could be incorporated into the 2004 EFH-FEIS discussion of non-fishing impacts. Additionally, several new sources of threats to EFH have emerged since the 2004 EFH-FEIS including new and emerging industries as well as invasive exotic species, diseases, and the increasing effects of climate change on coral reefs. Incorporation of these new threats into the Council's FMPs would be necessary to satisfy Section 600.815(a)(4) of the EFH Final Rule.

9.5. Prey Species

Prey species were identified, as required, for each fishery management unit in the 2004 EFH-FEIS (Section 3.12. Affected Biological Environment- Fishery resources under FMPs- Prey Species). During the course of conducting literature searches and communicating with the CFMC and researchers around the Southeast Region and the U.S. Caribbean, only one study (Guénette and 2009) addressed the trophic relationships among species in the coral reef ecosystem of La Parguera, Puerto Rico. These authors evaluated fishery policy scenarios using the Ecopath with Ecosim modeling approach. They recommended further research on diet compositions to improve the understanding of predator and prey species in these ecosystems.

No other new information regarding prey of the managed species became available during the preparation of this document. Thus, no changes to the prey species discussed in the 2004 EFH-FEIS are anticipated.

9.6 Research and Information Needs

This section complements Section 4.7.5 (Recommendations for improving habitat information) of the 2004 EFH-FEIS.

9.6.1. NMFS' Research and Information Needs

In May 2010, NMFS published a Habitat Assessment Improvement Plan (NMFS 2010) which provides a general description of national and regional habitat related research programs and an assessment of regional staffing needs to meet identified tiers of habitat assessment excellence in the plan. Also in May 2010, the 1st National Habitat Assessment Workshop was held jointly with the National Stock Assessment Workshop. The main goals of the meeting were to: 1) Improve communication and coordination within the community of NOAA Fisheries habitat ecologists, stock assessment scientists, and resource managers; 2) Produce the first steps towards building a coordinated, national habitat research program and community; 3) Address issues of national concern; 4) Begin implementing the key recommendations of the Habitat Assessment Improvement Plan (HAIP); and, 5) Integrate habitat science with other areas of research and promote interdisciplinary research.
(see http://www.st.nmfs.noaa.gov/st4/HabitatAssessmentWorkshop.html). The 2nd National Habitat Assessment Workshop is tentatively planned for 2012.

The proceedings (Blackhart, K. (ed.) 2010) from this meeting include a series of top recommendations to improve habitat research within NMFS, of which the following stand out:

- Habitat data should be integrated into resource survey sampling design where available to improve the precision and efficiency of surveys;
- NMFS should expand its capacity to collect habitat information and develop a comprehensive repository for existing and new habitat information. Expanded habitat mapping and classification has the highest priority.
- Regional entities should establish defined processes to: 1) jointly identify habitat research priorities on a periodic basis; 2) align habitat research funding decisions with the identified priorities; and 3) maintain open lines of communication regarding research planning, research results, and evolving management information needs.
- Regional entities should work together to support implementation of the Habitat Assessment Improvement Plan (HAIP) by supporting development of national HAIP budget initiatives and by incorporating the HAIP into regional habitat research plans and developing regional HAIP implementation plans.
- NMFS' Restoration Center should have an increased role in the regional habitat dialog.

9.6.2. CFMC's Research and Information Needs

In the 2004 EFH-FEIS (Section 4.7.5.2), a list of Council's information and research needs were identified, in general and for the four FMPs. Significant progress toward those goals has been made since.

At that time, the first recommendation was related to the four levels of information listed in the NOAA Fisheries EFH Final Rule with which to describe and identify EFH: Level1- Distribution; Level 2- Density; Level 3- Growth, reproduction or survival rates; Level 4- Production rates. It was then noted that only information for Level 1 existed. A large number of the documents in this review showed that most habitat assessments now measure density and abundance (Level 2) of at least the most important species in the FMUs. In addition, many population-dynamic studies of main species in the U.S. Caribbean, various stock assessment analyses (via SEDAR), and scientific literature from other areas in the Caribbean largely support Level 3 information. Level 4 information is still needed, but will likely emerge from the successful integration of data and analyses for the other three tiers of information.

A second observation in the 2004 EFH-FEIS was that habitat mapping had only occurred for nearshore areas, limited to depths of visibility of aerial photography. It was recommended that the level of information had to be increased for complete habitat mapping of deeper areas. As described in the Coral and Habitat Mapping Efforts sections of this report (Sections 3.3.4 and 4.0), the major mesophotic reefs of the U.S. Caribbean have now been mapped and characterized.

A third recommendation noted that preventing, minimizing, or mitigating adverse fishing impacts required knowledge of gear-specific effects on habitats, and of the relationships between habitat and fish production. Section 9.3 (above) highlights the progress achieved in the understanding of gear effects (particularly fish traps) on habitat. The damage caused to coral reefs and associated EFH by traps has now been quantified, mapped and tracked over time for some areas in the U.S. Caribbean. The impacts of other gears on habitat are yet to be assessed, as well as the overall effects of fishing on coral reef ecosystems and habitats. The relationships of fish production and habitat have now been assessed in many areas, through direct (surveys) and indirect (catch) measurements of species density and abundance over different habitats and depth gradients. Further research is needed to expand this knowledge to other areas, as fish production by habitat is specific to each reef complex.

The final recommendation in the 2004 EFH-FEIS consisted in the need to monitor the fishery in each FMP to determine the effectiveness of the management measures implemented by the Council and NOAA Fisheries. At that time, the need for fisheries-dependent and -independent monitoring programs was highlighted, with an emphasis on tagging studies of both target and non-target species. While tagging studies have not specifically been pursued, fishery monitoring programs and SEAMAP surveys have been enhanced. Continuous recommendations to these programs are now provided through SEDAR and data-procedures workshops, whose goal is to produce robust assessments that will lead to sustainable management of the fishery resources of Puerto Rico and the U.S. Virgin Islands. Furthermore, since 2004 the Council has devoted significant effort and resources to increasing the effectiveness of management measures through the enhancement of the regulatory framework (e.g., the 2005 Comprehensive Amendment and the 2010-2011 ACL Amendment initiatives).

A large number of the high-priority recommendations for each FMP discussed in the 2004 EFH-FEIS have now been addressed, but medium and low priority recommendations (short and long-term) from that report still hold (see Section 4.7.5.2, CFMC 2004).

9.7 Summary of Recommendations

1. After a review of all the relevant literature presented in this document, and after an examination of the contents of this report, a comprehensive or generic EFH amendment does not appear warranted at this time.
2. It is the recommendation of the preparers that the Council's EFH information be updated as fishery management actions are developed for FMP amendments in the U.S. Caribbean.
3. The Council could consider expansion of the definitions and descriptions of EFH for reef fish and coral to include mesophotic coral reefs and spawning aggregations.
4. Additional HAPC designations can be considered based on the recommendations of regional experts.
5. The new information on the impacts of traps and anchors on coral reef habitats confirmed that current measures taken by the Council to avoid adverse fishing impacts are adequate. Further actions do not appear necessary at this time.
6. Ongoing mapping efforts in the region will allow refining EFH maps species and life-stages and provide higher resolution of spatial EFH representation.
7. Other methods for describing EFH, such as habitat modeling described in Section 4.2, can be explored over time with a possible refinement of EFH for applicable species and life stages.

10. List of Preparers

MRAG Americas

Mónica Valle-Esquivel, Ph.D., Senior Fishery Biologist
Robert J. Trumble, Ph.D. Vice President
Elizabeth Clark, M.Sc., Marine Scientist
Erika Zollet, Ph.D., Senior Marine Scientist
Jill H. Swasey, M.Sc., Marine Scientist

MRAG Ltd.- MRAG Asia-Pacific

Carl Harris, Fisheries Consultant
Christian McDonald, Fisheries Consultant

11. List of Reviewers and Contributors

NOAA Fisheries, Habitat Conservation

José A. Rivera, M.Sc.

CFMC Scientific and Statistical Committee (SSC)

Richard Appeldoorn, Ph.D.
Jorge García-Sais, Ph.D.
Barbara Kojis, Ph.D.
Michael Sissenwine, Ph.D.
Van Vicente, Ph. D.

CFMC Staff

Graciela García-Moliner

Contributors

Jorge García-Sais, Ph.D, University or Puerto Rico
Mariano C. Solórzano, USDA Forest Service International Institute of Tropical Forestry
Iván Mateo-Rabelo, Ph.D., NOAA Fisheries

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