Literature Search and Data Synthesis of Biological Information for Use in Management Decisions Concerning Decommissioning of Offshore Oil and Gas Structures in the Gulf of Mexico

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LITERATURE SEARCH AND DATA SYNTHESIS OF BIOLOGICAL INFORMATION FOR USE IN MANAGEMENT DECISIONS CONCERNING DECOMMISSIONING OF OFFSHORE OIL AND GAS STRUCTURES IN THE GULF OF MEXICO

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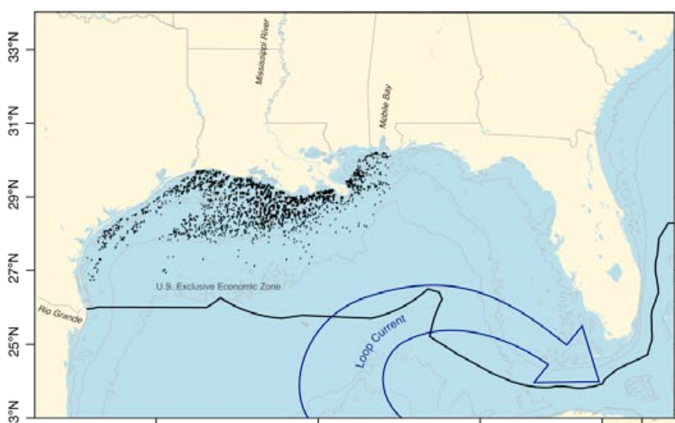

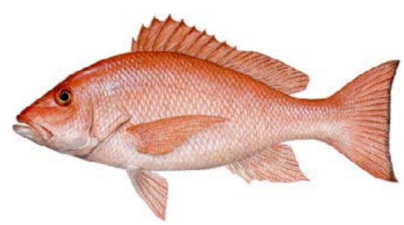

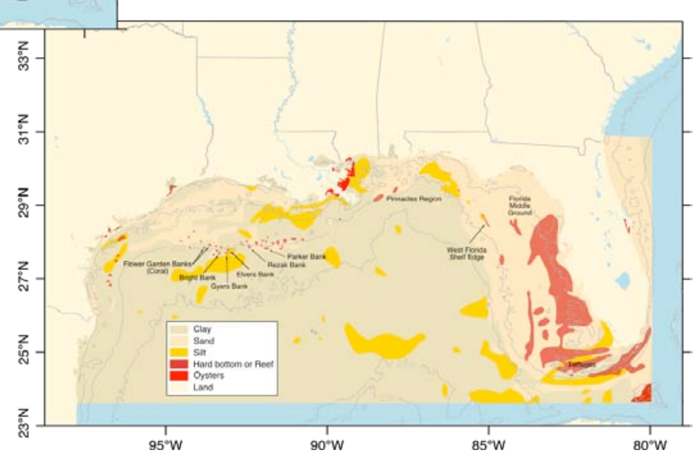

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Prepared for

Minerals Management Service
381 Elden Street, MS 2100
Herndon, Virginia 20170

Prepared by

Versar, Inc.
9200 Rumsey Road
Columbia, Maryland 21045

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FOREWORD

This report is the product of a Project Team effort lead by Versar, Inc. under Contract No. 1435-01-05-39082 from the Minerals Management Service, U.S. Department of Interior. Versar Project Managers over the term of the contract included **Drs. Jon V0lstad, Edward Weber**, and **William Richkus**. Versar had responsibility for overall project coordination, literature search and acquisition, synthesis and preparation of background information, integration of individual contributions from the team Principal Investigators, and summarizing research needs. The Project Team Principal Investigators and their respective project responsibilities included:

- **Dr. Jerald S. Ault,** Professor of Marine Biology and Fisheries at the University of Miami's Rosenstiel School of Marine and Atmospheric Science – Technical Lead for Gulf of Mexico (GOM) natural reefs, co-authored report Section 4.2
- **Drs. James Cowan** and **Kenneth Rose**, Professors at Louisiana State University with a joint appointments in Coastal Fisheries Institute and the Department of Oceanography and Coastal Sciences – Technical Leads for GOM artificial reefs and fisheries population dynamics, authored report Section 5.0 and subsections of Section 7.0
- **Dr. Daniel Sheehy,** Principal at Aquabio – Technical Lead for Decision Analysis and Non-Indigenous Species, authored report Section 6.0 and subsections of Section 7.0
- **Dr. Benny Gallaway**, President of LGL Ecological Research Associates, Inc – Technical Lead for GOM ecosystem characterization - contributed to report Section 3 and provided general technical review, and
- **Dr. Milton Love**, Research Biologist at the University of California, Santa Barbara – provided general technical review.

All Project Team members contributed to general reviews of all report sections. Several of the sections or subsections of this report were authored by specific members of the Project Team based on their interests and areas of expertise, as noted above and specified in the report text. As documented in this report, the role of platforms in the Gulf ecosystem is a matter of considerable scientific uncertainty. Consequently, scientific disagreements existed among some of the Team members on some of the conclusions drawn in report sections prepared by individual authors. For that reason, authors of specific sections that were developed relatively independently are identified in section headings, and conclusions in those sections may not represent the opinions of the project team as a whole.

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1.0 INTRODUCTION AND PROJECT ELEMENTS

More than 4,000 structures associated with oil and gas production are in place on the continental shelf of the Gulf of Mexico. Oil fields of the continental shelf have been developed for more than 50 years, and many of these structures are now reaching the end of their economic lives. When an oil and gas field is retired because operations are no longer profitable, all structures in the field typically are removed by detaching them below the mudline and moving them to shore. The number of removals is expected to far outstrip the number of new platforms constructed in the Gulf during the next ten years (Pulsipher 2001; Kaiser et al. 2005) because development of new fields has slowed as proven oil and gas deposits have been exhausted.

A reduction in the number of offshore structures used for oil and gas production (hereafter referred to as structures or platforms) may have important effects on the Gulf ecosystem because they function as defacto artificial reefs (Shinn 1974; Stanley and Scarborough-Bull 2003). Platforms have created large amounts of hard substrate with high vertical relief in a system that is dominated by soft, muddy bottom with relatively little vertical relief. The habitat created by platforms has promoted biological communities that are very different than those in surrounding area (e.g., Sonnier 1976; Gallaway and Lewbel 1982) and has enhanced commercial and recreational fishing (Stanley and Wilson 1989; 1990). The removal of a large portion of the platforms could affect the environment by changing the distribution and abundance of reef-oriented versus soft-bottom-oriented communities of organisms, which may affect the surrounding ecosystem. The objective of this report is to summarize the known effects of oil and gas structures on the Gulf ecosystem, evaluate the likely consequences of their large-scale removal, and identify gaps in the state of knowledge about potential effects of decommissioning large numbers of platforms.

We addressed this objective by performing several tasks. First, we compiled a database of relevant literature about oil and gas structures, artificial reefs, natural reefs, and associated species, with primary focus on the Gulf of Mexico. The literature database is attached to this report for use by other researchers. We then briefly synthesized the literature related to biological communities associated with platforms and natural substrates in the Gulf (Section 4.0). The major effort of this project consisted of an evaluation of the role of platforms in the ecology of one or more species using these data and information (Section 5.0). We approached this evaluation in several sub-tasks. The main scientific and economic debate about the role of platforms centers around their effect on mobile fishes. We summarized the literature about fish species that occur at platforms, and assessed the degree to which each species requires platforms or other hard substrates. These assessments were conducted using an approach similar to the levels of analysis established by the National Marine Fisheries Service for identification of essential fish habitat. Four levels of assessment were possible depending on the amount of information available for each species. Assessments were limited to level 1 if little process information was available for a species. At the other extreme, level 4 assessments could be conducted for species in which sufficient data were available to allow detailed population modeling. An example level-4 assessment was conducted for one species, the red snapper, *Lutjanus campechanus*. Platforms may also facilitate introduction or range expansion of non-indigenous species that would not occur if the habitat provided by platforms were not available. We described the role of platforms interacting with non-indigenous species in Section 6.0.

We note that some sections or subsections of this report were authored by specific members of the project team based on their interests and areas of expertise. Because the role of platforms in the Gulf ecosystem is a matter of considerable scientific disagreement, even among the authors of this report, we list authors of specific sections that were developed relatively independently in the section headings (Section 4.2 Ault and Swanson; Section 5.0 Cowan and Rose; Section 6.0 Sheehy). These sections may not represent the opinions of the project team as a whole. In the final chapters, we summarize the role of platforms in the ecosystem, likely effects of their large-scale removal, major areas of scientific debate, gaps in the state of knowledge related to effects of platforms, and potential approaches to addressing such gaps (Sections 7.0, Discussion and 8.0, Future Data Needs).

2.0 LITERATURE SEARCH AND BIBLIOGRAPHIC DATABASE

The bibliographic database was compiled from keyword searches of the ISI Web of Science® electronic database, agency documents posted on the world-wide web, theses and dissertations from universities, and literature of which the authors were aware based on their professional experience and contacts with other researchers. The electronic search on Web of Science was conducted for all years available (1900-present) using the keywords “artificial reef”, “reef”, “oil platform”, “gas platform”, “petroleum platform”, “rig”, and “Gulf of Mexico.” Results were screened for relevancy, and any references judged to be unrelated were excluded from the database. Pertinent reports listed on the MMS Environmental Studies Program Information System web page (http://www.gomr.mms.gov/homepg/espis/espisfront.asp) and NOAA web page (http://www.lib.noaa.gov/docs/pubsource.html) also were included in the database. Searches for theses and dissertations related to oil and gas structures were conducted at Auburn University, Georgia Institute of Technology, Louisiana State University, Texas Agricultural and Mechanical University, the University of Houston, the University of Louisiana at Lafayette, and the University of Southern Alabama.

The database was compiled using the Reference Manager bibliography-management software (version 11.01; Thompson ISI ResearchSoft 2005). The bibliography may be searched by title, author, journal, date, and keywords. In addition, we have added searchable fields to the Notes section about the type of manuscript (study or synthesis), species involved, availability of specific data, focus on artificial or natural reefs, and the area, region, coordinates, and time period of the study. Only a small fraction of the bibliography was related directly to platforms (Table 2-1); most sources were related to artificial or natural reefs, but provided information that could be used indirectly to understand the role of platforms in the ecosystem. We note the Literature Cited section of this report contains some references that are not included in the bibliography. This is because some of the material cited is related to the report but not to platforms directly (e.g., statistical references). The database file is attached to this report as a compact disk, and may be obtained directly from Versar.

Table 2-1. Summary of manuscripts included in the Reference Manager electronic bibliography (CD attached).

Subject	Number of References
Directly related to platforms in the Gulf of Mexico	71
Directly related to platforms elsewhere	35
Related to artificial reefs in the Gulf of Mexico	64
Related to artificial reefs elsewhere	284
Related to natural reefs in the Gulf of Mexico	31
Related to natural reefs elsewhere	584
Total references in bibliography	1,037

3.0 BACKGROUND

Five basic types of offshore structures are needed to pump, separate, and prepare petroleum products for transport to land. They are *single-well platforms*, *multi-well platforms*, *production platforms*, *quarters platforms*, and vertical pipes extending to the surface called *flare stacks* (cf, Gallaway and Lewbel 1982). Well platforms are used to recover oil and gas products, which are processed on production platforms before they are transported to land. Typical offshore production areas have some or all of these structures. For example, a working field may have a single production platform and a (living) quarters platform nearby. It may be serviced by several nearby well platforms that are connected by underwater pipes. Structures range in size from small, single pipes (flare stacks) to large multi-well platforms with several decks. The largest platforms have more than 24 legs and occupy several acres. Additional details of platform construction and design are described by the National Research Council (1985; 1996).

Much of the underwater structure used by aquatic organisms is provided by the open-pipe framework of interconnected legs and braces that rests on the ocean floor and extends to the surface, called the *jacket* (National Research Council 1985). Platform jackets support decks on the surface for working and living, and are held in place on the ocean floor by pilings that are driven through the inside of the legs into the substrate. Large platforms provide about 8,173 m^2 (2 acres) of hard substrate (Shinn 1974). Platforms create additional hard substrate on the surface beneath and around themselves as shelled organisms are dislodged, and equipment is accidentally discarded. Stanley and Wilson (1997) estimated that the approximately 4,000 structures in place in 1997 provided a total of about 12 km^2 hard substrate in the Gulf. Although this is a small fraction of the total area in the northwestern Gulf (Figure 3-1), it may constitute a biologically significant amount of hard substrate. Parker et al. (1983) estimated about 1-3% of the habitat in the northwestern Gulf was hard bottom (about 2,800 km2), but nearly all of it was < 1 m high. Recent studies indicate the amount may be greater, covering 15% of the substrate in some areas (Schroeder et al. 1995; Dufrene 2005 Section 4.2). Platforms may provide an important novel habitat feature because they extend to the surface of the water. Because of their high vertical relief, the ecological effects of platforms may be greater than suggested simply by the footprint that they occupy (Gallaway and Cole 1997). Fish biomass has been reported to be more than an order of magnitude greater around a standing platform than around a nearby toppled platform, partially removed platform, or natural coral reef (Wilson et al. 2003).

Oil and gas structures located in federal waters (3-200 miles offshore of the coast) are leased to private companies and managed by the U.S. Department of the Interior Minerals Management Service (MMS). The MMS ensures that when fields are retired, wells are capped and structures are removed so that there are no obstructions to shipping or commercial fishers. Lessees generally are required to remove structures by severing pilings 5 m (16 ft) below the sea floor, and transport structures back to shore (National Research Council 1985). An exception is made for platforms that are converted to artificial reefs as part of the rigs-to-reefs program (Reggio 1989; Kasprzak 1998; Dauterive 2000). Under this program, decommissioned structures are donated to coastal states to serve as artificial reefs. They are toppled in place, partially

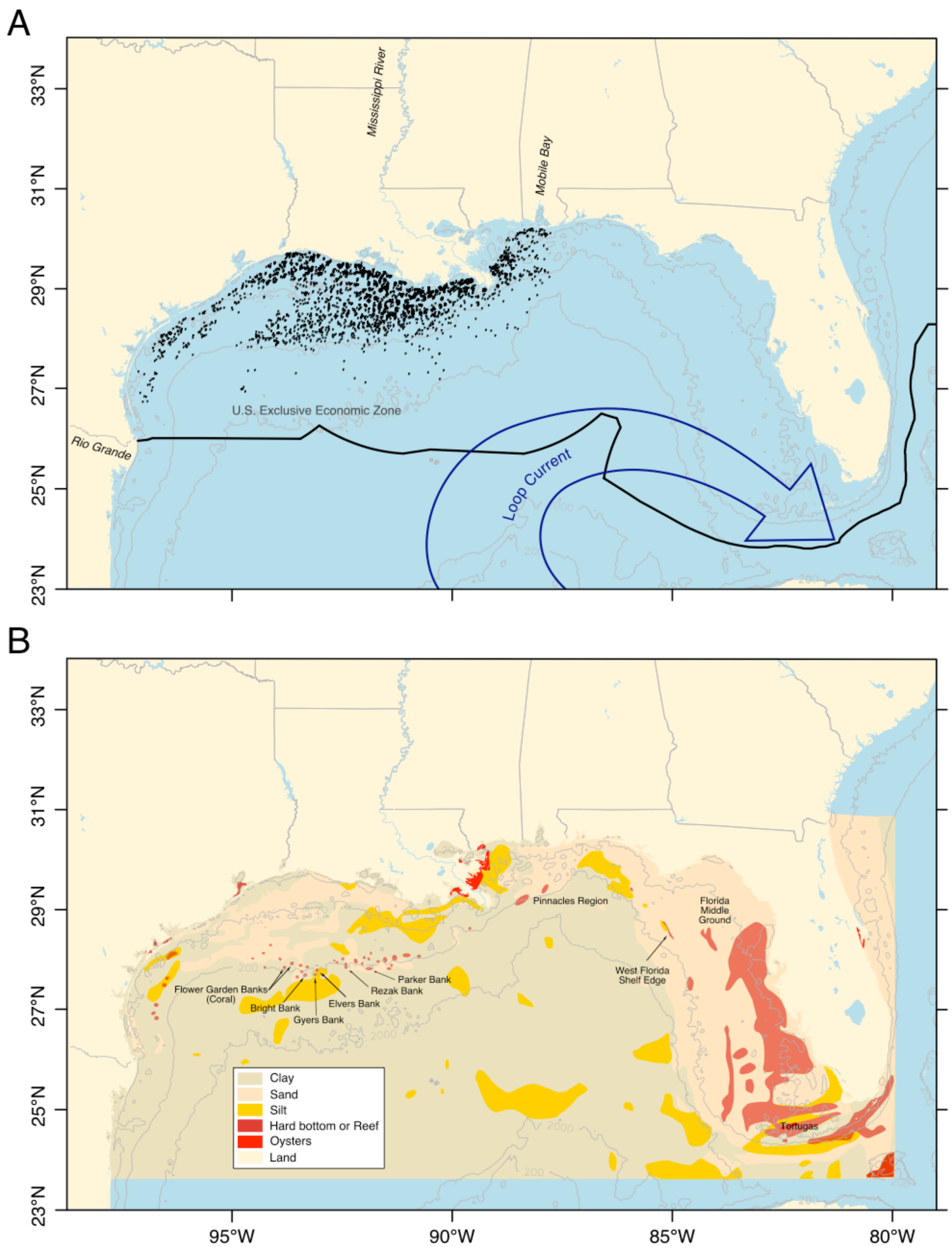

Figure 3-1. Map of the northern Gulf of Mexico. Panel A depicts oil and gas structures currently in place (black dots), the U.S. exclusive economic zone, and depth contours for 20, 200, and 2,000 m. The continental shelf follows the 200-m contour approximately. Panel B (adapted from Gulf of Mexico Fishery Management Council 2005) depicts the primary bottom substrate in the area. Labeled banks were sampled during SEAMAP reef fish surveys in 1992-1996.

removed near the surface, or towed to deeper water so that they do not interfere with navigation. Because of the perceived benefit of oil and gas platforms and related structures to the enhancement of marine fisheries habitat, the MMS announced in 1983, and again in 1993, its support for the conversion of selected obsolete oil and gas platforms for permanent use as artificial reefs (Dauterive 2000). However, a relatively small fraction of the total number of structures decommissioned has been converted to artificial-reef habitat to date (151 of 1,879 as of the year 2000; Dauterive 2000).

Although offshore oil and gas drilling began in the Gulf of Mexico in 1938, large-scale development of offshore fields did not occur until the 1950's. The number of platforms expanded rapidly from 463 in 1960 to 2,737 in 1980, and 4,024 in 2000 (http://www.gomr.mms.gov/homepg/pubinfo/freeasci/platform/freeplat.html). Platforms typically are kept in service for about 25 years (National Research Council 1985). Thus, these numbers reflect many new installations that have outpaced the removal of decommissioned platforms (Figure 3-2). The number of platforms on the continental shelf of the Gulf of Mexico is now probably near its maximum (Pulsipher et al. 2001). Removals are predicted to exceed installations by more than 300 platforms per year by 2020 (Kaiser et al. 2005).

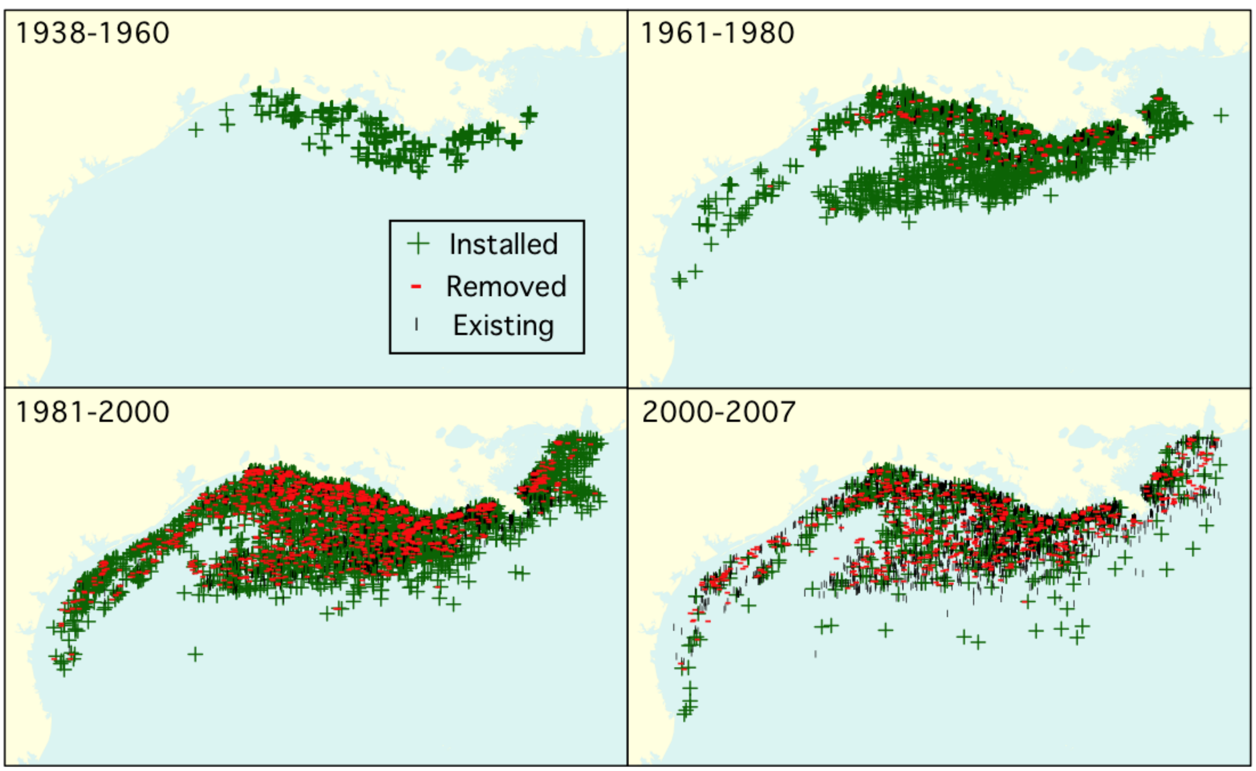

Figure 3-2. Oil and gas platforms installed, removed, and in place in U.S. federal waters of the northwest Gulf of Mexico during the periods 1938-1960, 1961-1980, 1981-2000, and 2000-2007. Source U.S. Minerals Management Service, http://www.gomr.mms.gov/homepg/pubinfo/repcat/arcinfo/index.html.

Most platforms are located in the north-central and north-western portions of the Gulf offshore of Louisiana, Mississippi, and Texas in water depths of 20-200 m (Figure 3-1A). This area is known as the *outer continental shelf* (< 200 m depth; Gulf of Mexico Fishery Management Council 2004). It is relatively shallow with low bottom slope, and is bounded in the offshore direction by much steeper bottom slopes in an area called the *continental slope* (~200-3,000 m depth). Oil and gas development has begun more recently in deeper water on the continental slope (cf, U.S. Minerals Management Service 2000); however, we do not specifically address deepwater platforms in this report. Most of the continental shelf in the northwestern Gulf is covered in deep sediment deposited by river systems, and consisting of sand, silt, and clay (Figure 3-1B). Older calcareous deposits from ancient reefs or shoreline structures are buried beneath the sediment throughout much of the area. Where these structures have not been completely covered, they form hard-bottom topographic features such as the reefs offshore of Alabama and Mississippi known as the pinnacles region, and the Flower Garden Banks coral reefs offshore of Texas (Section 4.2).

The area where most of the deployment of platforms has occurred is part of the Louisianan (or Acadian) zoogeographical province that is characterized by a wide continental shelf with relatively little vertical relief. The shelf experiences high freshwater discharge and sediment inputs from a suite of rivers, most notably from Mobile Bay and the Mississippi/ Atchafalaya River complex in the northern Gulf of Mexico (GOM), and the Grijalva/ Usamucinta/Lagauna Terminos complex in the Bay of Campeche to the south. Discharge rates in the northern GOM (> 22,000 cfs) are sufficient to generate an annual freshwater surplus on the shelf, which extends estuarine-like conditions well offshore in the spring (Deegan et al 1986; Engle and Summers 2000). Fish and invertebrate communities are strongly influenced by the estuarine-like conditions on the shelf, and diversity is low compared to the West Indian zoographical province typical of the southern Florida, and eastern side of the Yucatan peninsulas (Engle and Summers 2000). The Mississippi River system provides more than half of the fresh-water inflow into the Gulf each year, and has deposited much of the sand, clay, and sediment that cover the outer continental shelf in the northwest Gulf (Gulf of Mexico Fishery Management Council 2004). The influx of nutrients from the Mississippi drainage also creates algal blooms that deplete oxygen during summer, creating a “dead zone” with little or no aquatic life (Rabalais et al. 1997) that affects some platforms.

The physio-chemical characteristics of the water around platforms and availability of drifting organisms are strongly affected by currents. The major input of ocean water into the Gulf of Mexico comes from the loop current. The loop current enters the Gulf of Mexico between Cuba and the Yucatán peninsula of Mexico, and moves clockwise (Hofmann and Worley 1986: Figure 3-1B). Currents in the northwest Gulf are caused by water that separates from the loop current and drifts westward toward the shores of Texas and Mexico (http://oceancurrents.rsmas.miami.edu/atlantic/loop-current.html), known as the eddy or the loop-current ring.

4.0 BIOLOGICAL COMMUNITY IN THE NORTHWEST GULF OF MEXICO

The habitat in the northwest Gulf of Mexico may be broadly divided into three categories: soft bottom, naturally occurring hard bottom (including natural reefs), and hard substrate associated with platforms, ship wrecks, or other constructed reefs. The community associated with platforms is very different from the soft-bottom habitat that predominates in the northwest Gulf. It is most similar to naturally occurring hard bottom; however, the communities associated with platforms differ from hard bottom because of the platforms' physical structure (i.e., vertical extension to the water surface), geographic distribution, and relatively short time in existence. We summarize the communities that are associated with the three major habitat types below.

4.1 COMMUNITY ASSOCIATED WITH OIL AND GAS PLATFORMS

Many studies have reported the fishes associated with platforms (e.g, Putt 1982, Sonnier et al. 1976, Hernandez et al. 2003, Rademacher and Render 2003, Stanley and Wilson 2003), but fewer studies have described the entire range of organisms that inhabit platforms. The most comprehensive synthesis of community interactions around platforms has been reported by Gallaway and Lewbel (1982) based on a series of studies conducted during the late 1970s and early 1980s. More recent literature describing epibenthic species associated with platforms include Dokken et al. (2000), and Carney et al. (2005). The communities associated with platforms are summarized primarily based on these works.

The numbers and taxonomic composition of bacteria around platforms have been reported to be similar to nearby surrounding waters (Gallaway and Lewbel 1982). The dominant genera of bacteria sampled near Buccaneer oil field offshore of Texas were *Vibrio*, *Pseudomonas*, *Aeromonas*, *Acinetobacter*, and *Moraxella* (Gallaway et al. 1981a). Abundance of hydrocarbon-oxidizing bacteria typically has been reported to be slightly greater around platforms than in other waters, although low densities of hydrocarbon-oxidizing bacteria are present throughout the Gulf indicating exposure to oil and gas products in all areas (Gallaway and Lewbel 1982 and references therein).

Algae are present on nearly all platforms. They are one of the first colonizers of newly exposed hard substrates (Gallaway and Lewbel 1982; Carney et al. 2005). Green algae (*Chlorophyta* excluding *Plantae*) are typically the dominant type in biomass, but red algae (*Rhodophyta*), blue-green algae (*Cyanophyta*), and brown algae (*Phaeophyta*) all occur in various proportions depending on depth and season. Algal cover tends to be greatest near the surface of platforms, probably because ambient light is greatest (Gallaway and Lewbel 1982; Lewbel et al. 1987; Carney 2005); however, the standing crop of algae present may not reflect the level of production because grazing by other species may differentially reduce algae at different depths (Carney et al. 2005). Production rates of algae on platforms have not been quantified well. Algae tend to be more abundant on platforms located farther offshore (e.g., at bottom depths greater than 30m) and away from the Mississipi River, probably because turbidity is lower and light penetration is greater (Lewbel et al. 1987). Despite their lower total biomass at platforms located in shallow water, algae often are the dominant epibenthic organisms; in deeper waters they are often out competed by sponges and other fouling organisms and thus not dominant (Carney et al. 2005).

Sponges (*Porifera*) are sessile filter-feeding organisms consisting of several layers of unspecialized cells. They exhibit a wide range of depth preferences depending on species (Gallaway and Lewbel 1982), although sponges generally have not been identified to this level on platforms because taxonomic classification of sponges is extremely difficult (Gallaway and Lewbel 1982; Carney et al. 2005). Sponges constitute a large portion of the surface cover of nearly all platforms. They are most abundant offshore in depths greater than 30 m (Carney et al. 2005), but less abundant in very deep water greater than 60 m (Gallaway and Lewbel 1982). Sponges tend to grow over shells and barnacles, and can eventually kill them. This can result in chunks of shell material from dead animals shedding from the platform, thereby creating clean surface area that is colonized by other species (Carney et al. 2005). Sponges may also contribute to the patchy surface habitat on platforms because they die back into much smaller groups of cells during the summer months (Gallaway and Lewbel 1982).

Barnacles (*Balanoidea*) are crustaceans that are planktonic as larvae, but attach permanently to solid surfaces as adults. They are extremely fecund, broadcasting large numbers of larvae into the water that settle on any available hard substrate. Barnacles settle in large groups and then develop their characteristic external calcareous plates for protection. They are early colonizers on most platforms and form the dominant biologically created structure (Gallaway and Lewbel 1982; Lewbel 1987). Early-colonizing barnacles sometimes are out competed by other later arriving species of barnacles, or covered with sponges or bryozoans. These changes in species composition, combined with shedding, create a dynamic pattern in species abundance on platform surfaces, as described above. Barnacles exhibit species-specific depth preferences within and among platforms. Stalked barnacles that are attached to the surface by long peduncles tend to dominate on platforms in deeper water greater than 30 m, but unstalked barnacles tend to occur in shallower water (Gallaway and Lewbel 1982; Carney 2005). Gallaway and Lewbel (1982) reported that barnacles became much less abundant in very deep water greater than 60 m; however, Carney et al. (2005) reported that barnacles were still an important component of the epifaunal community in these areas. Barnacles feed on suspended organic material in the water column and serve as food for some invertebrates and fish such as sheepshead, *Archosargus probatocephalus*. The structure that they create also serves an important role as habitat for small invertebrates such as polychaete worms and xanthid crabs, and fishes such as blennies (*Blennioidei*).

Oysters (*Bivalvia*) are commonly found on platforms throughout the Gulf of Mexico in deeper water. Oysters are broadcast spawners, and larvae must attach to a hard substrate within a short period or die. After they attach, oysters remain sessile during their adult lives. They replace barnacles as the dominant epifaunal species on platforms located in waters deeper than 30 m in terms of biomass and structure, but are also common on nearshore coastal platforms offshore from Texas (Gallaway and Lewbel 1982). Gallaway and Lewbel (1982) listed the

Eastern oyster, *Crassostrea virginica*, horse oyster, *Ostrea equestris*, mangrove tree oyster, *Lopha frons*, and a large "pen shell" oyster, *Hyotissa thomasi* as the most common species found attached to platforms in the Gulf. Eastern and horse oysters were most common in shallower water less than 30 m. The leafy jewel box, *Chama macerophylla*, a warm tropical species, also was commonly reported. Oysters fill a similar ecological niche to barnacles, filtering water for organic particles and small bacteria, and providing food for a few fishes and invertebrates. Likewise, their shells provide habitat for small cryptic fish and invertebrates.

Hydroids (*Hydroida*) are small organisms with hollow tube-shaped bodies that contain an opening at one end which functions as both mouth and anus. The mouth is surrounded by tentacles armed with stinging cells that are used to capture small planktonic organisms. Hydroids may occur singly or in colonies. They may reproduce sexually or asexually. Marine hydroids produced from sexual reproduction have a free-swimming medusa stage that settles onto a solid surface and develops into the adult polyp stage. Hydroids exhibit a patchy distribution on platforms but they are extremely abundant in some areas. They tend to be more abundant near the surface of the water, although they constitute a greater proportion of the total biomass at greater depths where other organisms become rare (Gallaway and Lewbel 1982). Hydroids can outcompete and cover sponges and other early colonizers of platforms (Gallaway and Lewbel 1982); however, they are dominated by sponges on platforms located in deep water (Carney et al. 2005). The most common genera reported to occur on platforms are *Bougainvillia*, *Clytia*, *Eudendrium*, *Obelia*, *Sertularia*, *Syncorne*, and *Turritopsis*,

Anemones, stony corals, and octocorals (*Cnidaria*) are small organisms belonging to the same phylum as hydroids. They also have hollow bodies containing a single opening surrounded by tentacles that are armed with stinging cells. Anemones, stony corals, and octocorals may live singly or in colonies, and occupy a similar trophic position to that of hydroids. They rapidly colonize bare substrates, and then secrete a mucus layer that inhibits overgrowth by other epifauna. Stony corals secrete calcium carbonate crystals to form an external skeleton that is characteristic of coral reefs. Octocorals usually contain small unfused calcareous spicules that are characteristic of soft corals. Stony corals and octocorals often form large colorful colonies on platforms, but they constitute a relatively small proportion of the total biomass of the epifaunal community (Gallaway and Lewbel 1982; Carney et al. 2005). Anemones are relatively abundant on some coastal platforms.

Bryozoans ("moss animals;" *Bryozoa*) are very small colonial animals that secrete calcium carbonate skeletons similar to corals. Bryozoans reproduce sexually, and most are hermaphroditic. Larvae of bryozoans settle onto solid substrates, plants, or other animals, and form colonies in thin sheets or erect bush-like growths. Bryozoans feed by filtering suspended plankton from the water. They are patchy in distribution, but can be extremely abundant on some shallow-water platforms. Some species of bryozoans exhibit distinct seasonality, growing rapidly and then dying back; however, the timing these diebacks can vary (Fotheringham 1981; Gallaway and Lewbel 1982). Bryozoans can rapidly colonize exposed substrate in shallow waters, but often they are out competed subsequently by other epifaunal organisms. The most common genera of bryozoans reported on platforms are *Aeverillia*, *Bugula*, *Membranipora*, *Parasmittinia*.

Many types of motile invertebrates dwell on platforms and use the fouling community for shelter or food. Amphipod crustaceans of the genera *Ampithoe*, *Caprella*, *Corophium*, *Elasmopus*, and *Stenothoe* have been reported to occur in the greatest abundance on platforms (Gallaway and Lewbel 1982; Carney 2005). Most amphipods feed by scraping detritus from the epifaunal substrate. Polychaetes (segmented worms), marine spiders (*Pycnogonidae*), ribbon worms (*Nemerteae*) also occur commonly. These animals prey upon polychaetes, crustaceans, mollusks, and animals. Other common predators include brittle stars (*Ophiuroidae*), mud crabs (*Xanthidae*), and flatworms (*Platyhelminthes*). Large invertebrate predators such as shrimp (*Caridea*), and spiny lobsters (*Panulirus*) occupy platforms at lower densities.

Almost 250 species of fishes have been reported to occur at platforms in the Gulf of Mexico. These species range from small, cryptic fishes such as blennies (*Blenniidae*), that depend on platforms for food and cover, to large transient predators such as jacks (*Caranx* spp.). Most of the fish biomass around platforms consists of species that are not trophically dependent on organisms attached to platforms themselves, making it less straightforward to assess the relative importance of platforms for their production, as is discussed at length later in this report. We list each species of fish reported to occur on platforms in the literature, and evaluate the degree to which they are known to depend on platforms, in Section 5.0. The species most commonly reported around platforms in the Gulf include Atlantic spadefish (*Chaetodipterus faber*), blue runner (*Caranx crysos*), lookdown (*Selene vomer*), and red snapper. The species most commonly reported that are trophically dependent on platforms include blennies, gray triggerfish (*Balistes capriscus*), and sheepshead (*Archosargus probatocephalus*).

Other vertebrates such as birds and sea turtles commonly occur on or around platforms. Platforms generally have been reported to benefit migratory birds by serving as stopover points (Russell 2005), although some birds are killed by collisions with platform structures. Sea turtles (*Chelonioidea*) are not strongly associated with platforms but sometimes rest on underwater structures. They can be injured when platforms are removed using explosive devices (e.g., Gitschlag and Herczeg 1993).

Platforms serve as important destinations for fishing and recreational diving. A large proportion of the saltwater fishing trips offshore of the Gulf States occurs near oil and gas platforms (Hiett and Milon 2002), and the proportion is greater than 70% in some areas (Ditton and Graefe 1978; Reggio 1987). More than 90% of the dive trips in the U.S. portion of the Gulf have also been estimated to occur within 300 feet of an oil and gas structure (Hiett and Milon 2002). Biological communities associated with platforms are affected by humans primarily via harvest of large predators. Sportfish such as red snapper that congregate around platforms are harvested in large numbers (Stanley and Wilson 1989; Render and Wilson 1994), which some believe may contribute to their over-exploitation (Gulf of Mexico Fishery Management Council 1981).

The species composition and abundance of platform-associated communities varies with water depth, distance from shore, latitude, currents, and age of the platform. Water depth has been reported to have the greatest effect on community composition. Gallaway et al. (1981b) reported three zones associated with unique assemblages. The coastal zone occurred in water depths of 0-30 m, the offshore zone in depths of 30-60 m, and the bluewater zone in depths greater than 60 m. The most commonly reported distinction between the coastal and offshore zones is that barnacles are the dominant epifaunal organisms in the coastal zone, but bivalves (pelecypods) predominate in the offshore zone (Gallaway and Lewbel 1982; Dokken et al. 2000; Carney et al. 2005). Gallaway and Lewbel (1982) characterized the bluewater zone as having relatively low biomass, algae and stalked barnacles near the surface of the water, and bivalves at greater depths. More recent studies (Dokken et al. 2000; Carney et al. 2005) suggest the bluewater zone may not be distinct from the offshore zone. Motile invertebrates such as amphipods, polychaete worms, crabs, and lobsters generally exhibit less inshore/offshore zonation than the epifaunal community (Gallaway and Lewbel 1982). Mobile fish species exhibit great variation with platform depth. Offshore platforms tend to attract large groups of red and gray snapper, and some tropical species, in addition to the sheepshead, blue runner, and spadefish that are common at coastal platforms. At bluewater platforms, more tropical species occur than at shallower platforms, and large schools of creole fish and almaco jacks tend to replace other schooling fishes such as spadefish and lookdowns.

Platforms strongly affect trophic interactions in the area surrounding them. Primary production is provided by algae that are distributed by currents or attached to epifauna on the platform. Primary production is channeled differently at platforms because they provide substrate for epifaunal organisms such as sponges, hydroids, bryozoans, barnacles, and bivalves that consume bacteria, particulates, and zooplankton. These epifaunal organisms support invertebrates such as amphipods, polychaetes, shrimps, and crabs, and some fishes such as blennies and sheepshead. Zooplankton and planktivorus fishes such as scads and sardines are attracted to platforms by sloughing organic material and meroplankon that epifauna produce. Predators may be trophically supported by increased forage around platforms to different degrees (Section 5.0), or simply use platforms for cover. Platform communities are estimated to export small amounts of carbon (Fucik and Show 1981), indicating that net biomass is produced, although the amount of harvestable sportfish production that occurs is a matter of debate (e.g., Bohnsack 1989; Pickering and Whitmarsh 1997; Section 5.0).

4.2 NATURAL REEFS AND HARD BOTTOMS

This Section was authored by primarily by J. Ault and D. W. Swanson, University of Miami in a report to Versar, Inc. dated 5 October 2000. Additional data pertaining to low-relief hard substrate was provided by J. Cowan, Louisiana State Universit and incorporated into this section by Versar.

4.2.1 Geographic Position of Reefs in the Northern Gulf of Mexico

Naturally occurring hard bottom features in the northern Gulf of Mexico (from Destin, Florida, to Brownsville, Texas) have been estimated to occupy a cumulative area of approximately 2800 km^2 within the depth range of 18 to 91 m (Parker et al. 1983). At depths including and exceeding these, rocky outcrops and hard banks have been found to be common on the continental shelf throughout the Gulf of Mexico (Rezak et al. 1985). Most studies have focused on 2 general areas of the Gulf – northwest (Texas and Louisiana); and, northeast (Mississippi delta to Desoto canyon –offshore of approximately Destin, Florida).

Thirty-eight banks have been mapped in the northwestern Gulf of Mexico including the intensely studied banks of the East and West Flower Gardens. Most of the banks are surface expressions of underlying salt domes from buried Jurassic salt deposits (Amery 1978; Rezak et al 1985). Both geological and biological classifications have been developed from extensive surveys (Rezak et al. 1983; Rezak et al. 1985) from which three categories of banks have been identified: (1) mid-shelf bedrock banks; (2) outer shelf bedrock banks with carbonate reef caps; and, (3) reefs growing on relict carbonate shelfs (i.e., banks of South Texas; (Rezak et al. 1985, Rezak et al. 1990). Mid-shelf bedrock banks are outcrops of relatively bare, bedded Tertiary limestones, sandstones, claystones, and siltstones and are associated with salt domes (Rezak et al 1990). The bases of the outcrops are in depths of 80 m or less and have 4 to 50 m of relief. Named mid-shelf banks are: 32 Fathom, Stetson, Claypile, Coffee Lump, Sonnier, and Fishnet (Rezak et al. 1985; Rezak et al. 1990). Outer shelf bedrock banks with carbonate reef caps are all located beyond the 30 m isobath (with the exception of Fishnet), and east of a line drawn from Matagorda Bay, Texas, to the shelf break (Rezak et al. 1985; Rezak et al. 1990). The base of these banks range from 80 to 300 m and crest at depths 15 to 100 m. Surveys offshore of Louisiana (http://geopubs.wr.usgs.gov/open-file/of02-411) indicate that these mid- and outer-shelf banks generally are shaped like plateaus (Figure 4-1).

In the northeastern Gulf of Mexico, topographic features are common. However, compared to the northwestern Gulf, this region has been less intensively studied. At depths of 18-40 m there are extensive areas of low-relief calcareous outcrops (Schroeder et al 1988a, 1988b). Additional rocky outcrops have been found to occur along shelf edge and continental slope from south of Mobile Bay, Alabama, towards Desoto Canyon, Florida, in depths of 73 to 365 m (Shipp and Hopkins 1978). The outer continental shelf between the Mississippi River and Mobile Bay contains the only topographic highs resulting from salt diapirism. The topographic features, except on outer continental shelf between Mississippi River and Mobile Bay, are not the result of geologic uplift; where pinnacles have been found to be relict reefs and the large flat-topped banks are erosional remnants (Rezak et al. 1989). The greatest proportion of hard substrate in the northern Gulf occurs in this area. Hard substrates cover about 15% of the sea floor in the mid-shelf zone offshore of Alabama (Schroeder et al. 1995; Dufrene 1995). The features in the northeastern Gulf of Mexico have been categorized into 5 groups:

(1) isolated, low (to 2m);

(2) moderate (2-6 m) and high relief (to 20 m) features;

(3) clusters of moderate and/or high relief features;

(4) linear ridges several kilometers in length and up to 8 m relief; and,

(5) clusters of shallow depressions; and banks (i.e., topographic highs resulting from salt diapirism).

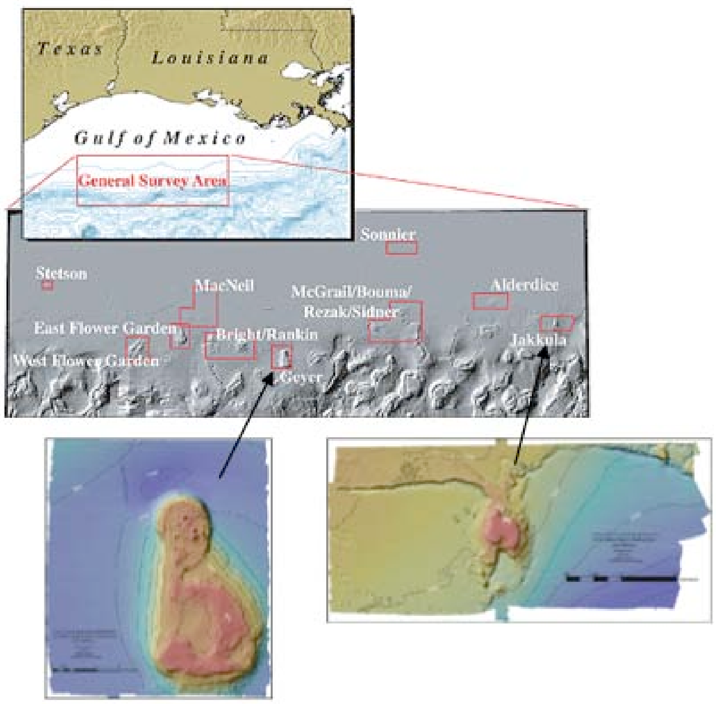

Figure 4-1. Shelf-edge banks on the Louisiana continental shelf. The two bottom panels are enlargements of Geyer and Jakkula banks to illustrate the bathymetry typical of these habitats.

Coral reef community composition in the northern Gulf of Mexico consists of both tropical and warm-temperate species. Instead of a distinct latitudinal boundary between the two groups, transition patterns are subtle. The tropical component of community composition tends to become increasingly larger with progression from estuarine and nearshore habitats to offshore habitats. Tropical species are likely limited to suitable habitats and depths (Bright 1977; Rezak et al. 1985)

Recent surveys conducted by Louisiana State University indicate that additional low-relief hard-bottom habitat exists in shallow waters throughout the northern Gulf of Mexico. On the Louisiana shelf, these low-relief hard-bottoms are derived mostly from lithified deltaic muds, but contain some calcium carbonate in the form of relic oyster shells. East of the Mississippi River off the Mississippi/Alabama coast, these low-relief natural habitats contain more relic calcium carbonate, and were mostly formed by the drowning of beach ridges during sea level transgressions (Dufrene et al. 2005; Patterson et al. 2005). For example, the East Cameron Artificial Reef Planning Area, one of several areas that the State has set aside for the possible placement of decommissioned platforms, contains about 10-15% hard bottom (Figure 4-2 and Figure 4-3). LSU has completed surveys of all of the planning areas, and the results can be found online (http://www.wlf.state.la.us/fishing/programs/habitat/artificialreef.cfm). These areas are not biogenic, but are used by fish species that are also associated with platforms (Wells 2007; Sections 5.0 and 0).

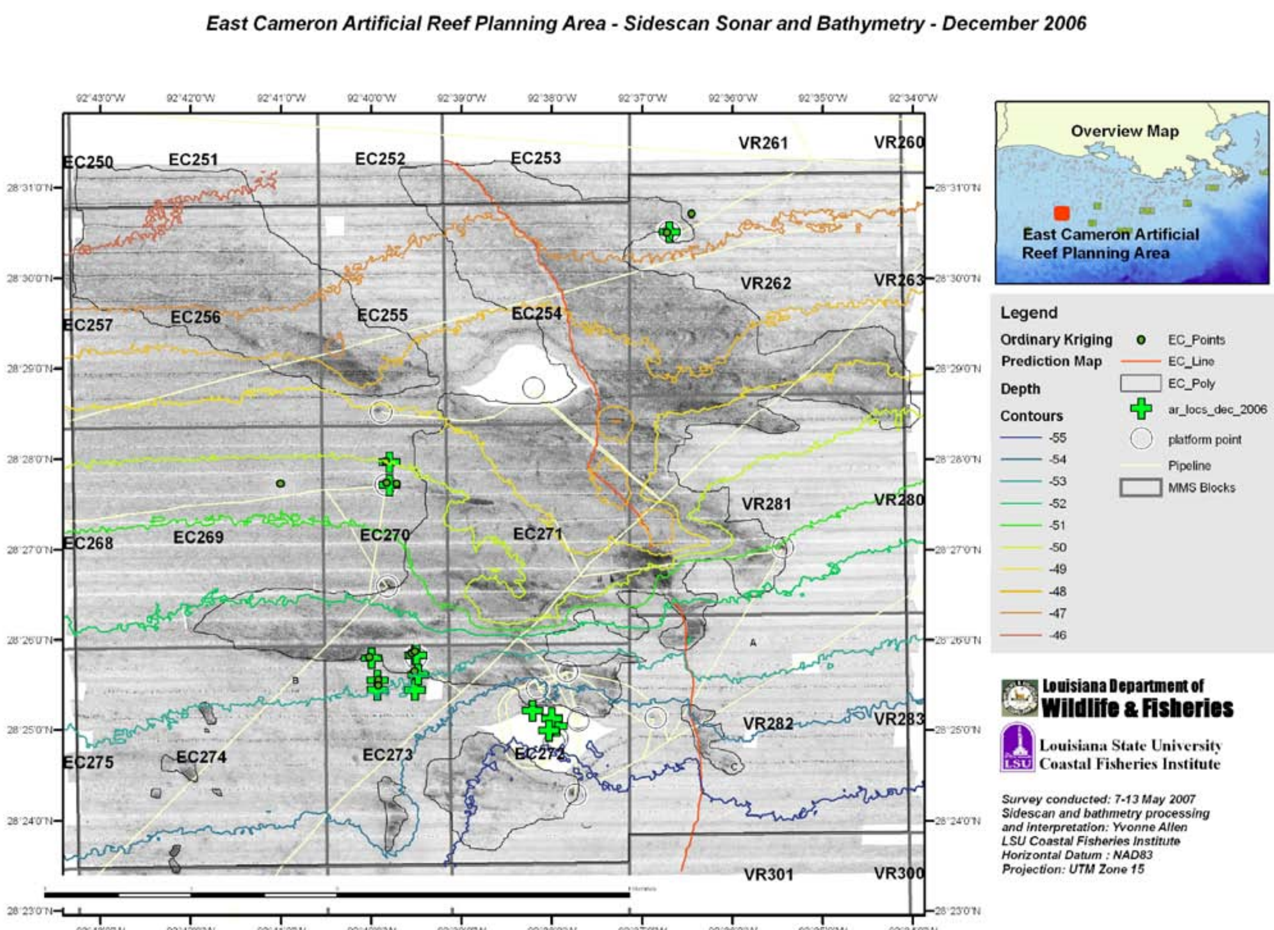

Figure 4-2. Side-scan sonar image of the East Cameron Artificial Reef Planning Area on the Louisiana continental shelf. Dark areas indicate presence of hard, high reflectance substrate. These areas are lithified delta muds and remnant beach ridges that were formed on the shelf during that last glacial period during the Pleistocene (Cowan et al.; Louisiana Artificial Reef Program Final Report, June 2007).

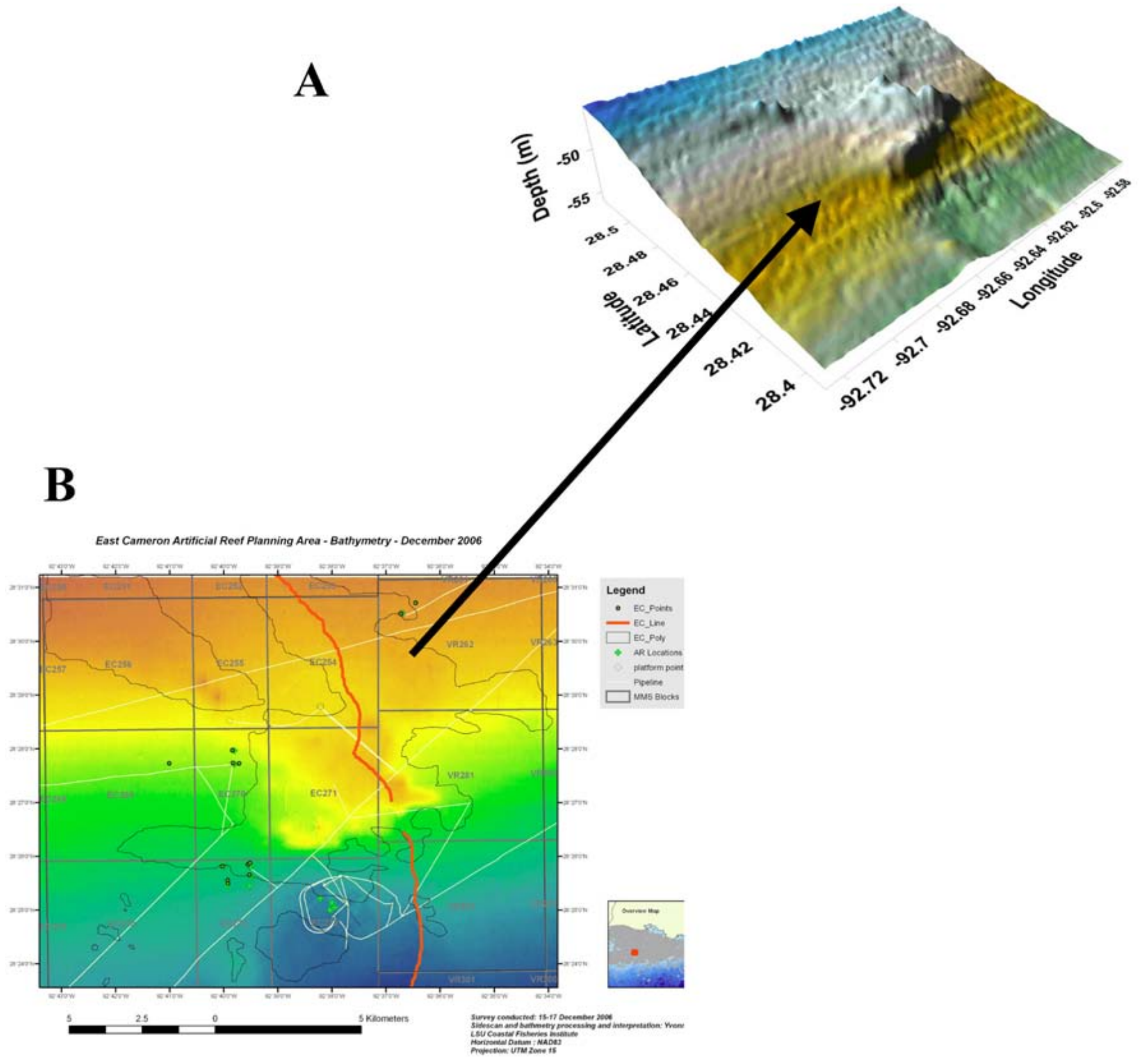

Figure 4-3. P anel A is a 3-D enlargement of a small portion of the (B) bathymetry within the Eastern Cameron Artificial Reef Planning Area. These areas routinely exhibit relief of 1 to 3 meters, and occasionally reach as high as 5 meters from the sea floor as shown here. This type of habitat is common on the mid-shelf east and west of the Mississippi River delta, and may cover as much as 10-15% of the inner- or mid-shelf.

4.2.2 Status

4.2.2.1 Northwestern Gulf of Mexico

The biological categorization of the banks in the Northwestern Gulf of Mexico has been organized into 7 characteristic biotic zones classified within 4 general categories by Rezak and coauthors (1985). The four general categories were based on the degree of reef building and primary productivity that include the following:

(1) zones of major reef-building activity and primary production (4 zones);

(2) zone of minor reef-building activity (1 zone);

(3) transitional zone (1 zone); and,

(4) zone of no reef-building activity (1 zone).

These zones included benthic zonation and depth ranges distinct for the banks in the region.

The first category – zones of major reef-building activity and primary production – contains four biological zones which include the *Diploria-Montastraea-Porites* zone, the *Stephanocoenia-Millepora* zone, the *Madracis* zone and leafy algae (macroalgae) zone (occur in the same depth range) and the algal-sponge zone. The *Diploria-Montastraea-Porites* zone exists above 36 m and encompasses living, high diversity coral reefs where hermatypic corals are dominant, coralline algae are abundant, and macroalgae are limited. Surveys conducted almost entirely on the West Flower Garden Banks have identified 253 species of reef invertebrates and 103 species of fishes (Bright and Pequgnat 1974). However, the West and East Flower Garden banks are nearly identical in species composition within the *Diploria-Montastraea-Porites* zone (Bright and Pequgnat 1974). The fish community include several species of grouper and hind, *Mycteroperca* and *Epinephelus*; amberjack, *Seriola*; great barracuda, *Sphyraena barracuda*; red snapper, *Lutjanus campechanus*; vermilion snapper, *Rhomboplites aurorubens*; cottonwick, *Haemulon melanurum*; porgy, *Calamus*; and, creole fish, *Paranthias furcifer*. In addition, three species of lobster have also been recorded (*Panulirus argus*, *Panulirus guttatus*, and, *Scyllarides aequinectialis)*.

At depths ranging from approximately 36 to 46 m, the *Stephanocoenia-Millepora* zone consists of living, low diversity coral reefs where hermatypic corals are dominant, coralline algae are abundant, and macroalgae are limited. In general, live coral cover is lower and coralline algae are more conspicuous compared to the *Diploria-Montastraea-Porites* zone. There are 12 conspicuous corals found in this zone in relative order of abundance – *S. michelini*, *M. cavernosa*, *Colpophyllia* spp., *Diploria* spp., *Agaricia* spp., *M. angulosa*, *Scolymia* spp. The fish community is qualitatively less diverse that the *Diploria-Montastraea-Porites* zone. In addition the American thorny oyster, *Spondylus americanis*, is present here.

The *Madracis* zone and leafy algae (macroalgae) zone was named specifically for an area at the East Flower Garden in depths between 28 and 46 m. Large knolls exists where some are dominated by the small branching coral *Madracis mirabilis* and other knolls by macroalgae growing on *M. mirabilis* rubble mounds. Typically, thickets of *M. mirabilis* are found with conspicuous macroalgae and sponges. Also *M. mirabilis* rubble mounds usually overgrown by CCA and corals found at tops of mounds from shallow zone common. Knolls with “leafy” algae (macroalgae) include species of *Stypopodium*, *Caulerpa*, *Dictyota*, *Chaetomorpha*, *Lobophora*, *Rhodymenia*, *Valonia* and *Codium*. The fish community structure in this zone is similar in species composition to *Stephanocoenia-Millepora* zone.

The algal-sponge zone is located between 46-82 m and can extend to 88 m. It includes a number of biotope types and is dominated by crustose coralline algae that actively produces large quantities of carbonate substratum, including rhodoliths (algal nodules). Toward the deeper end of the depth range algal nodules diminish in abundance and coralline algal crusts are known to cover a substantial percentage of the hard substratum. This zone encompasses the greatest area of the reef-building zones. Macroalgae are abundant among nodules and reefal structures and include the genus *Stypopodium*, *Lobophora*, *Halimeda*, and *Udotea*. Hermatypic corals reported in the algal-sponge zone are *Leptoseris cucullata*, *Madracis mirabilis*, *M. formosa*, *M. myriaster*, *Montastraea cavernosa*, *Millepora alcicornis*, and *Agaricia fragilis*. Deep-water alcyonarians (primarily Ellisellidae and Paramuriceidae) are abundant in the lower part of the zone as well as Cirrhipathes (*Cirripathes* and *Antipathes*). The most distinctive sponge species is *Neofibularia nolitangere*. Additional invertebrates include cromatulid crinoids, a number of asteroid species (i.e., *Linckia nodosa*), and small gastropods and pelecypods. The fish community consists of small yellowtail reef fishes, *Chromis enchrysurus*, sand tile fish, *Malacanthus plumieri*, cherubfish, *Centropygeargi*; orange back bass, *Serranus annularis*. Coarse carbonate sand and gravel surround living coral reefs here (coral debris facies) and represent the geobiological transition between coral reefs and surrounding platform.

The second general category is the zone of minor reef-building activity which contains the Millepora-sponge zone found in depths ranging from 18 to 52 m. The zone is best described as composed of crusts of Millepora that share the tops of siltstone, claystone, or sandstone outcrops with sponges and other epifauna. Isolated scleractinian coral heads and crustose coralline algae are present but rare. The two most conspicuous sponges are Neofibularia nolitangere and Ircinia spp.

The transitional zone is the third general category represents only the Antipatharian zone. The zone is located at depths between 52 and approximately 123 m. The community is composed of limited crusts of coralline algae and several species of coral exist within sizable population of antipatharian corals (usually *Cirrhipathes* (bedspring shaped). Banks with algal-sponge zones usually have a zone of transition similar to Antipatharian zone between algal-sponge zone and nepheloid zone of lower bank.

The final general category, zone of no reef-building activity, contains only the nepheloid zone. High turbidity, sedimentation, resuspension of sediments, and resedimentation dominate this zone. It is composed of rocks and drowned reefs usually covered with a veneer of fine sediment. Although deep-water octocorals and solitary corals are often conspicuous, epifauna are generally depauperate and variable. This zone occurs in some form on lower parts of all banks below the depths of the Antipatharian or transitional zone.

In a more recent study of reef fish assemblages on the bank in the Northwestern Gulf of Mexico, four assemblages in order of species richness were found: (1) coral reef; (2) mid-shelf; (3) algal-sponge; and, (4) drowned reefs (Dennis and Bright 1988). Fish assemblages on 18 banks closely paralleled the benthic community. Dennis and Bright (1988) used depth to distinguish assemblages. The coral reef assemblage occurs at depths less than 45 m and includes all the zones of major reef-building activity and primary production described above except the algal-sponge zone. The mid-shelf and algal-sponge zones are consistent with the previous descriptions. Drowned reefs are defined as "reefal" structures present at depths too great for hermatypic corals to exist and where crustose coralline algae are insignificant (Rezak et al. 1985). The zones within this definition are the Antipatharian and nepheloid zones.

No single bank contains all zones; however, the Flower Garden banks contain all but *Millepora*-sponge zone. Table 4-1 is replicated from Rezak et al. (1985) and lists zones and depths for each bank. Only the East and West Flower Garden banks have high-diversity coral reefs. Three of six mid-shelf bedrock banks peak at depths shallow enough for the *Millepora*-sponge zone (Claypile, Sonnier, and Stetson), while the remaining mid-shelf bedrock banks are shallowest at approximately 52-73 m (Antipatharian zone). Lower diversity reefs (*Stephanocoenia-Millepora* Zone) are present at East and West Flower Gardens, 18 Fathom, and Bright Banks. The shallowest area of the relict carbonate reefs (south Texas) is 56-70 m. These are occupied by benthic assemblages comparable to Antipatharian zone found at similar depths in mid-shelf and somewhat deeper on outer shelf banks. The nepheloid layer is at about 70 m around South Texas Banks. Carbonate patch reefs occur on these banks. These patch reefs are the primary location where epifaunal communities are best developed and around them the greatest numbers of fish congregate. Although there are variations among the relict carbonate reef, they typically have fish and invertebrate species and abundances typical of the Antipatharian zone found at the other banks.

4.2.2.2 Northeastern Gulf of Mexico

Topographic features in the northeastern Gulf of Mexico are dominated by suspension feeding invertebrates such as gorgonians, ahermatypic scleractinian corals, antipatharians, sponges, comatulid crinoids, oysters, and the alcyonacean, *Sipohogorgia agassizii* (in overall relative order of abundance; Gittings et al. 1992). Coralline algal crusts are common on relatively shallow features (above 78 m) but are dependent on light penetration and vertical relief to avoid deleterious effects of sedimentation. Only a few colonies of the hermatypic corals *Agaricia fragilis* and *Stephanocoenia* spp. were found on features no greater than 67 meters in depth.

Table 4-1. List of 35 banks from northwestern Gulf of Mexico replicated from Rezak et al. (1985) and Rezak et al. (1990). MS = mid-shelf bank, ST = South Texas (relict carbonate reef); OS = outer shelf bank. [a] = zone present, but depth range uncertain; [b] = Weakly represented, stressed; [c] = Clear water, but biota typical of nepheloid zone.

Banks	Category	Biotic Zones							
		***Millepora*-sponge**	***Diporia*-*Montastraea*-*Porites***	***Madracis***	***Stephanocoenia***	**Algal-sponge**	**Antipatharian transitional**	**Nepheloid**	**Soft bottom**
Claypile	MS	40-45						45+	50+
Sonnier	MS	18-52						52+	60+
Stetson	MS	20-52						52+	62-64+
Small Adam	ST						60?	P[a]	64+
Big Adam	ST						60?	P[a]	66+
North Hospital	ST						58-70	70+	68-70+
Aransas	ST						57-70	70+	70-72+
Baker	ST						56-70	70+	70-74+
Blackfish	ST						60?	P[a]	70-74+
Hospital Rock	ST						59-70	70+	70-74+
Mysterious	ST						70?	P[a]	74-86+
Southern	ST						58-70	70+	80+
Dream	ST						62-70	70+	80+
South Baker	ST						59-70	70+	80-84+
32 Fathom	MS						52?	P[a]	55+
Coffee Lump	MS						62-68	68+	70+
Fishnet	MS						66-73	73+	78+
Alderdice	OS					55-67	67-82	82+	84-90+
Ewing	OS					56-72	72-80	80+	85-100+
Bouma	OS					60-75	75-84	84+	90-100+
Parker	OS					60-82	82-?	P[a]	100+
Sackett	OS					67-82[b]	65-85	85+	100+
East Flower Garden	OS		15-36	28-46	36-52	46-82	82-86	86+	100-120+
Applebaum	OS					76?	P[a]	P[a]	100-120+
Bright	OS				37	52-74	74-?	P[a]	110+
West Flower Garden	OS		20-36	P[a]	36-50	46-88	88-89	89+	110-130+
Diaphus	OS						73-98	98+	110-130+
18 Fathom	OS					45-88	82-?	P[a]	110-130+

Table 4-1. (Continued)

Banks	Category	Biotic Zones							
		***Millepora*-sponge**	***Diporia-Montastraea-Porites***	***Madracis***	***Stephanocoenia***	**Algal-sponge**	**Antipatharian transitional**	**Nepheloid**	**Soft bottom**
28 Fathom	OS					52-92	92-100	100+	100-140+
Jakkula	OS					59-90	90-98	98+	120-140+
Rezak-Sidner	OS					55-93	93-100	100+	120-150+
Sweet	OS					75-80+	P[a]	P[a]	130-200+
Elvers	OS					60-97	97-123	123+	180+
Geyer	OS	37-52				60-98	98-123?	123+	190-210+
Phleger	OS						?	122+[c]	200+

[a] zone present, but depth range uncertain
[b] Weakly represented, stressed
[c] Clear water, but biota typical of nepheloid zone

Overall, the northeastern region of the Gulf of Mexico has not been as intensively studied as the Northwestern region. However, quantitative assessments of the following topographic features have been described by Gittings and coauthors (1992): (1) patch reefs - isolated, low (to 2m), moderate (2-6 m), and high relief (to 20m) features; (2) pinnacles - clusters of moderate and/or high relief features; and (3) flat-topped reefs - linear ridges several kilometers in length and up to 8 m relief. There is not a distinct group for diapiric banks because the variation in relief among the banks sample, stations were included among stations with similar relief characteristics. In general, abundance and richness of benthic organisms varied between topographic features. These values increased with the amount of exposed hard bottom, substrate rugosity, and complexity (number of habitat types available for colonization). When stations with large topographic features were compared latitudinally, benthic community development was poorest at stations closest to the Mississippi River and increased progressively eastward (Gittings et al 1992).

Low relief patch reefs (to 2 m) are composed of comatulid crinoids, sea whips, Antipatharians (*Cirrhipathes* spp. and *Antipathes* spp.), and associated invertebrates. Populations were depauperate and a layer of fine sediment was present. On intermediate relief patch reefs (2-6 m) populations were more abundant and species richness was higher than low relief features. Intermediate abundances of comatulid crinoids, Antipatharians, octocorals, ahermatypic corals, encrusting and erect sponges, and sometimes coralline algae were present. Species richness and the development of benthic communities varied with habitat complexity on high relief patch reefs (6-18 m). Within this relief category, assemblages were distinguished by erect sponges, gorgonians (sea fans; *Nicella* spp.), comatulid crinoids, Antipatharians, bryzoans, ahermatypic corals, coralline algae as well as holothuroids and gorgonocephalid ophiuroids (basket stars) on patch reefs with extensive reef flats on their summits.

On large pinnacles and reef faces of flat-topped reefs, ahermatypic corals, both solitary and colonial, were abundant. Ahermatypic species recorded were *Rhizopsammia manuelensis*, *Paracyathus pulchellus*, *Madrepora carolina*, *Oculina* spp., and several unidentified species. Crinoids, gorgonians, oyster clumps, sea urchins, and basket stars were also present. Sponges and gorgonians were much less abundant on pinnacles. Species richness was high on both of these topographic features but flat-topped reefs have a distinct community structure that distinguishes it from pinnacles (Gittings et al. 1992).

These topographic features from the northeastern Gulf of Mexico have fish and hard-bottom community compositions similar to the deeper portions of the banks in the northwestern Gulf of Mexico and northern rim of DeSoto Canyon (Shipp and Hopkins 1978; Rezak et al. 1985; Gittings et al. 1992). The biological assemblages of both the northwestern and northeastern regions are predominately tropical in origin. Specifically, the features described above are consistent with the deeper areas of the algal-sponge, Antipatharian, and nepheloid zones on the banks of the northwestern Gulf with some exceptions.

4.2.3 Dynamics

4.2.3.1 Environmental factors

Regional patterns of community structure, distribution, abundance and zonation of tropical epibenthos, both the northeastern and the northwestern regions of the Gulf of Mexico, are correlated to and likely controlled by environmental factors such as: distance from shore, substrate type, bottom depth, bank relief, water temperature, salinity, river runoff, turbidity, sedimentation, currents, and seasonal variation (Rezak et al. 1990, Gittings et al. 1992). Conditions are favorable for tropical reef development beyond the 80 m isobath. Seasonal movements of the 16° and 18° C isotherms may have influence on tropical biota where minimum temperature for reef growth is 18° C. Water masses are influenced by river outflow (Mississippi, and other rivers in Louisiana and north Texas). An enormous amount of sediment from rivers, in addition to reduced salinity, adversely affects community development. In the northwestern Gulf, river outflow and coastal water masses are held onshore and shunted west for most of the year. This keeps turbidity beyond 80 m isobath incredibly low. In the northeast Gulf, the Mississippi River plume may limit hard-bottom community development up to 70 km east of the river delta. In addition to sedimentation from river outflow, the degree of light penetration and effects of turbidity from nepheloid layer control depth distribution where high turbidity decreases light penetration and sedimentation smothers benthic organisms. The effects of turbidity and sedimentation from nepheloid layer are more pronounced on mid-shelf. The amount of relief above the bottom is important for biota to escape turbidity and sedimentation stress of the nepheloid layer.

4.2.3.2 Connectivity

Currents in the northern Gulf of Mexico are oceanic and come from the southwest. These currents carry larvae, spores, juveniles from the southern Gulf of Mexico (Gulf of Campeche and Yucatan shelf) and possibly the Caribbean. Larvae from the Gulf of Campeche are transported via the Western Boundary Current (Vidal et al. 1999) while those from the Yucatan shelf are transported by the Caribbean current into the Gulf and then west by the Loop current (Sturges and Blama 1978; Hamilton et al. 1999). Sammarco and coauthors (2004) provide unpublished data (molecular genetics of brooding coral spat) to suggest that the Flower Garden Banks are not being seeded from the eastern Gulf, and further state that the transport of larvae from the Florida Keys, namely, the Dry Tortugas and Pulley ridge, are not likely.

4.3 COMMUNITY ASSOCIATED WITH SOFT-BOTTOM HABITATS

The soft-bottom habitat that predominates in the northwestern Gulf of Mexico is characterized by less habitat complexity and fewer species than natural or artificial hard-bottom areas. This is because there is much less substrate suitable for epibenthic organisms to attach to.

The nepheloid layer, a semi-permanent layer of suspended sediment (Boehm 1987), also blocks light penetration and may smother benthic organisms (Dokken et al. 1993). Almost no algae are present on the predominantly mud and clay substrates (Bert and Humm 1979). Likewise, sponges, barnacles, bivalves, hydroids, anemones, and bryozoans all are rare in their sessile adult stages (Gulf of Mexico Fishery Management Council 2004); however, their early-life planktonic stages are present throughout the Gulf, and occupy any available patches of hard substrate. The bacterial community in the open water and sediment is similar to that around platforms. The most commonly occurring taxa reported are Acinetobacter, Aeromonas, Alcalgenes, Bacillus, Moraxella, Pseudomonas, and Vibrio (Schwarz et al. 1977; Oujesky et al. 1977; Gallaway and Lewbel 1982).

Shrimp are the most abundant and trophically important invertebrate in soft-bottom communities. White shrimp, Litopenaeus setiferus, occur primarily in estuaries and shallow water up to 22 m (Pattillo et al. 1997). Brown shrimp, Farfantepenaeus aztecus, occupy mud and other soft sediments in deeper waters of about 22-91 m. Worms (e.g., Sabellaria), crustaceans, and sea pens (Pennatulacea) also occupy sand and other soft sediments. They act as ecosystem engineers, creating small areas of structured or hard bottom (Gulf of Mexico Fishery Management Council 2004).

The distribution of fish species in soft-bottom habitats of the northwest Gulf is closely related to the distribution of shrimp. Brown-shrimp grounds are dominated by porgies (Sparidae). Other common species include drums (Sciaenidae), searobins (Triglidae), sea basses (Serranidae), lefteye flounders (Bothidae), lizardfishes (Synodontidae), snappers (Lutjanidae), jacks (Carangidae), butterfishes (Stromateidae), cusk-eels (Ophidiidae), toadfishes (Batrachoididae), batfishes (Ogcocephalidae), scorpionfishes (Scorpaenidae), goatfishes (Mullidae), and puffers (Tetraodontidae; Hildebrand 1954; Chittenden and McEachran 1976). White-shrimp grounds are dominated by Drums. Also common are Snake mackerels (Trichiuridae), threadfins (Polynemidae), sea catfishes (Ariidae), herrings (Clupeidae), jacks, butterfishes, bluefishes (Pomatomidae), and lefteye flounders. All fish species found at platforms also occur in the open ocean over soft sediments, at least during their planktonic stages. This is because platforms are effectively islands of hard substrate that are settled initially by colonizing species (Dokken et al. 2000). Although some fishes occupying platforms are reef dependent (e.g., blennies; Chapter 5.0), their larvae are also dispersed over large areas of unsuitable habitat. Those that do not locate appropriate hard substrates die.

5.0 ASSESSMENT OF FISH SPECIES ASSOCIATIONS WITH GOM PLATFORMS

This Chapter was authored by J. Cowan and K. Rose, Louisiana State University in a report to Versar, Inc. dated 7 December 2007

5.1 APPROACH AND METHODS

Stakeholder support of Rigs-to-Reefs and associated programs appears to be based on documented enhanced abundance and catch of fish at GOM structures. Firms that own these structures also experience cost savings when structures are left in place. However, the extent to which structures have influenced the status of exploited fish stocks, either directly via population production rates or indirectly through changes in fishing mortality rates, is less well understood. The structures may alter fish populations and communities as a result of altering ecosystem structure and function. The effects on exploited fish stocks could also be detrimental if the high levels of fishing and catch at the structures result in increased fishing mortality rates not compensated by increased stock production. In contrast to fish communities, the epibenthic communities that colonize artificial structures would simply not exist if the structures did not exist (Dokken et al. 2000). Thus, the issue of greatest scientific interest, and the primary focus of our analyses regarding the consequences of platform removal, is how such removal might affect current fish communities and populations.

Our approach to addressing this issue was to first establish the levels of evaluation of a species complex or individual species, as a function of the amount and adequacy of information on that entity established in our literature and data search. Four levels of assessment were established, analogous to the levels of analysis established by NMFS for identification of Essential Fish Habitat (EFH). For species regarding which little process information is known, a Level One evaluation was deemed appropriate and was based simply on whether the species has been observed in association with platforms or artificial reefs. Level Two and Three evaluations were appropriate for species for which more process information was found. Some process information allows Level Two qualitative assessment to be made, while additional information allows for a somewhat quantitative Level Three analysis. A Level Four evaluation was the most process oriented, and consisted of a detailed species Individual-Based Model (IBM). A level Four analysis requires synthesis and process-level understanding across a variety of temporal and spatial scales, and explicit detail about most of the rates and processes that are implicit in Levels One to Three. Thus, it was only possible in this project to explore its application to a single species, red snapper, for which the most extensive life history information was available.

5.1.1 Level One Methods

Our Level One evaluation consisted of identifying all GOM fish species reported to have been captured in samples collected at a platform, or seen during visual surveys at platforms. That is, the Level-One analysis consisted of simple presence or absence data.

5.1.2 Level Two Methods

For the Level Two evaluation, we used the conceptual model of Bohnsack (1989; qualitative) shown in Figure 5-1. This conceptual model centers on the attraction vs. production issue, which encompasses much of the debate about the ecological role of artificial reefs (including structures and platforms) in a complex and dynamic coastal geography. The difference between level-one and level-two assessments is the degree of inference at the process level about the species in question, even if numbers such as estimates of fishing mortality and site fidelity are poorly documented. As such, relative knowledge of where along the continuum for each of several variables a species falls provides significant insight into how it may be affected by platforms and their removal. The Level Two evaluation presented here is based on information reported In FishBase® (http://www.fishbase.org/)[1], combined with expert opinion, and is used to provide relative species-specific assessments of:

- Site fidelity (High, Moderate, Low);
- Whether or not a directed fishery exists for this species (Yes or No, includes recreational fishing);
- Whether diet is derived directly from reef habitat (Reef, Benthic, Pelagic);
- Whether population size is believed to be limited by recruitment or habitat limitation (Habitat limited, Recruitment limited);
- Type of behavior of adults (Reef, Demersal, Pelagic, Highly Migratory); and,
- A summary judgment about whether the species is reef or habitat dependent, and the type of habitat on which some dependent species are most often found (e.g., Sargassum, Sea Grass, Hard Bottom).

[1] Most of the information about whether the species can be considered to be reef-dependent, reef-associated or transients/ migratory were taken from FishBase® (http://www.fishbase.org/ search.php). These data were not based directly upon results from platform studies, although some of the information in FishBase may have come from studies at artificial reefs. Specific references in the primary literature are listed in FishBase for each species.

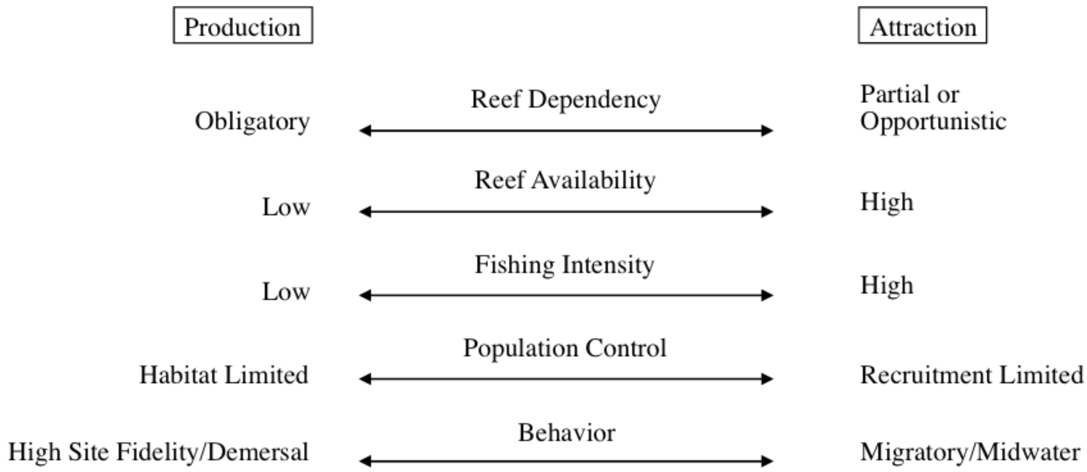

Figure 5-1. Bohnsack's (1989) conceptual model for addressing the role of reefs in fisheries

We summarize the data collected in support of Level-1 and Level-2 assessments in Table 5-1. Red highlights in the table indicate that a species has been judged by management agencies to be overfished, and a yellow highlight indicates that the species is most likely a Caribbean expatriate (i.e., Caribbean species that occasionally reach the northern Gulf through transport by the loop current, but are unlikely to establish reproducing populations). Applying the concepts presented by Bohnsack (1989), a species that is directly fished or overfished, exhibits low site fidelity, is less or not dependent upon the reef for food, is not dependent upon the reef for completion of its life cycle, and is pelagic and/or migratory is less likely to have its population size limited by the amount of structures available.

Population sizes of species that fall on the opposite end of the continuum described by Bohnsack's conceptual model (Figure 5-1) are more likely to be affected by changed in the availability of structures.

5.1.3 Level Three Methods

Level Three assessments (Tables 5-2, 5-3, and 5-4) are based upon the semi-quantitative model described in Powers et al. (2003) which uses the species-specific fish biomass production of a population on a reef (here a platform) weighted by the degree to which growth (biomass production) is attributable to prey resources produced on the reef. To accomplish this, the production estimate for each species is multiplied by an index of reef exclusivity (IRE: Peterson et al. 2003) derived from quantitative diet data. Applying the IRE, annual production (P) of a species attributed to a platform (AP; kg platform^{-1} yr^{-1}) is calculated by:

$$AP_i = IRE_i \ x \ P_i \qquad (1)$$

Table 5-1. Fish taxa reported to occur on Gulf of Mexico oil and gas platforms: SF=Site Fidelity (High, Moderate, Low); DF = Directed Fishery (Yes or No, includes recreational fishing); Diet (Reef, Benthic, Pelagic); PC = Population Control (Habitat limited, Recruitment limited; Behavior (Reef, Demersal, Pelagic, Highly Migratory); Dep = Reef or Habitat Dependent (Yes, No, Reef Associated, Sargassum, Sea Grass, Hard Bottom). Red highlight = overfished; Yellow highlight = Caribbean expatriate.

Taxa	**SF**	**DF**	**Diet**	**PC**	**Behavior**	**Dep.**
Abudefduf saxatilis	H	N	R	R?	R, D	Y
Abudefduf taurus	H	N	R	R?	R, D	Y
Acanthocybium solandri	L	Y	P	R	P, HM	N
Acanthurus chirurgus	H	N	R	R	R, D	Y
Acanthurus coeruleus	H	N	R	R?	R, D	Y
Achirus lineatus	L	N	B	R	D	N
Albula vulpes	L	Y	B	R	D	N
Aluterus schoepfii	H	N	R, B	R?	R, D	Y
Aluterus scriptus	H	N	R, B	R?	R, D	Y
Amblycirrhitus pinos	H	N	R, B	R?	R, D	Y
Anchoa cubana	L	N	P	R	P	N
Anchoa hepsetus	L	N	P	R	P	N
Anchoa mitchilli	L	N	P	R	P	N
Anchoa nasuta	L	N	P	R	P	N
Anchoviella perfasciata	L	N	P	R	P	N
Ancylopsetta dilecta	L	N	B	R	D	N
Ancylopsetta ommata	L	Y	B	R	D	N
Antennarius ocellatus	H	N	R, B	H	R, D	Y
Apogon maculatus	H	N	R, B	R?	R, D	Y
Apogon pseudomaculatus	H	N	R, B	R?	R,	Y
Archosargus probatocephalus	M	Y	R, B	R	R, D	RA
Ariomma regulus	L	N	B	R	P	S
Arius felis	L	N	B	R	D	N
Bagre marinus	L	Y	B, P	R	D	N
Bairdiella chrysoura	L	N	B, P	R	D	N
Balistes capriscus	H	Y	R, B	H	R, D	Y

Table 5-1. (Continued)

Taxa	SF	DF	Diet	PC	Behavior	Dep.
Bodianus rufus	H	Y	R, P	R?	R, P	Y
Bollmannia communis	L	N	B	R	D	N
Bregmaceros cantori	L	N	B	R	D	N
Brevoortia patronus	L	Y	P	R	P	N
Brotula barbata	L	N	B	R	D	RA (juv)
Callionymus bairdi	M?	N	B?	R?	D	RA, SG
Cantherhines pullus	H	N	B	H?	R, D (adults, juv=P)	Y (adults)
Canthidermis sufflamen	L	N	P	R	D, P	N, SG, RA
Canthigaster rostrata	H?	N	B	H?	R, D	Y?, RA & SG
CarangoidesCaranx bartholomaei	L	N	P	R	HM	RA
Caranx crysos	L	N	P	R	P	RA
Caranx hippos	L	N	P	R	P	RA
Caranx latus	L	N	P	R	P	RA
Caranx lugubris	L	N	P	R	P	RA
Caranx ruber	L	N	P	R	P	RA
Carcharhinus plumbeus	L	Y	P	R	P, HM	N
Caulolatilus intermedius	L	Y	P, B	R	D	N
Centropristis melana	M?	Y	P, B	R	D	RA
Centropristis ocyurus	M?	N	B	R	R, D	HB
Centropristis philadelphica	M?	N	B	R	P, D	HB
Cephalopholis cruentatus	H	N	P	H?	R, D	Y
Chaetodipterus faber	H	N	B, P	R	P, P	Y?
Chaetodon ocellatus	H	N	R	H?	R, D	Y
Chaetodon sedentarius	H	N	R	H?	R, D	Y
Cheilopogon cyanopterus	L	N	P	R	P	N
Cheilopogon furcatus	L	N	P	R	P	N
Chilomycterus schoepfii	M	N	B	R	D	RA, SG
Chlorophthalmus agassizi	L	N	B	R	D	N
Chloroscombrus chrysurus	L	N	P	R	P	N

Table 5-1. (Continued)

Taxa	SF	DF	Diet	PC	Behavior	Dep.
Chromis enchrysura	H	N	P	H	D	Y
Chromis mutilineata	H	N	R	H	D	Y
Chromis scotti	H	N	R	H	D	Y
Citharichthys spilopterus	L	Y	B	R	D	N
Clepticus parrae	H	N	P	H	D, P	Y
Coryphaena equiselis	L	Y	P	R	P, HM	N
Coryphaena hippurus	L	Y	P	R	P, HM	N
Coryphopterus punctipectophorus	M	N	?	R	D	RA
Cubiceps pauciradiatus	L	N	P	R	P	N
Cyclopsetta chittendeni	L	Y	B	R	D	N
Cyclopsetta fimbriata	L	Y	?	R	D	N
Cyclothone braueri	L	N	P	R	P	N
Cynoscion arenarius	L	Y	P	R	P	N
Cynoscion nebulosus	L	Y	P	R	P	N, RA
Cynoscion nothus	L	Y	P	R	P	N, RA
Decapterus punctatus	L	Y	P	R	P, D	N
Decodon puellaris	H?	N	R?	H	D	Y, HB
Dermatolepis inermis	H	Y?*	R, P	H?	D	RA, HB
Diplectrum bivittatum	L	N	B	R	D	N
Diplectrum formosum	L	N	P	R	D	SG, HB
Diplogrammus pauciradiatus	H	N	B	R	D	SG
Diplophos taenia	L	N	P	R	P	N
Diplodus holbrooki	L	N	B	R	D	N, SG
Dormitator maculatus	L	N	P (omnivore)	R	D	N
Echeneis naucrates	L	N	P	R	P	N, RA
Echeneis neucratoides	L	N	P	R	P	N
Echiophis intertinctus	L	N	B	R	D	N
Elagatis bipinnulata	M	Y	P	R	P, HM	RA
Elops saurus	L	N	P	R	P	N
Engraulis eurystole	L	N	P	R	P	N

Table 5-1. (Continued)

Taxa	SF	DF	Diet	PC	Behavior	Dep.
Engyophrys senta	L?	N?	?	R	D	N?
Epinephelus adscensionis	H	Y?*	R, P, B	H	D	Y, HB
Epinephelus itajara	M	Y	R, P, B	R	D	RA
Epinephelus morio	M	Y	R, B	R	D	RA, HB
Epinephelus nigritus	M	N	R, P, B	R	D	RA, HP
		(closed)				
Epinephelus niveatus	M	Y*	P, B	R	D	RA, HB
Equetus iwamotoi	M?	N	B	R?	D	RA?
Equetus lanceolatus	M	N	B	R?	D	RA?
Etropus crossotus	L	N	B	R	D	N
Etrumeus teres	L	N	P	R	P	N
Euthynnus alletteratus	L	N	P	R	P, HM	N, RA
Foetorepus agassizi	L	N	B	R	D	N
Ginglymostoma cirratum	M?	N	B	R	D	N, SG
						(sometimes found on coral reefs)
Gobiesox strumosus	M?	N	B	R	D	N, SG, HB (common on oyster reefs)
Gobionellus oceanicus	L	N	B?	R	D	N
Gymnothorax nigromarginatus	H	N	P, B	R?	D	SG, HB (absent from coral reefs)
Haemulon aurolineatum	H	N	P, B	R	D	Y?, SG, HB
Haemulon plumierii	M	Y	P, B	R	D	
Halichoeres bivittatus	H	N	P, B	H?	D	Y, HB
Halieutichthys aculeatus	L	N	B?	R	D	N
Harengula jaguana	M	N	P, B	R	P	RA
Holacanthus bermudensis	H	N	B	R?	D	Y
Holocanthus ciliaris	H	N	B	R?	D	Y
Holocanthus tricolor	H	N	B	R?	D	Y, RA
Holocentrus ascensionis	H	N	B	R?	D	Y
Hoplunnis macrura	L?	N	B?	R?	D	N?, RA
Hyperoglyphe perciformis	L	N	P	R	P	N

Table 5-1. (Continued)

Taxa	SF	DF	Diet	PC	Behavior	Dep.
Hypleurochilus geminatus	H	N	B?	H (nest-builder)	D	RA, HB
Hypleurochilus multifilis	H	N	B?	H (nest-builder)	D	RA, HB
Hypsoblennius hentz	H	N	B?	H (nest-builder)	D	RA, HB (common on oyster reefs)
Hypsoblennius invemar	H	N	B	H (nest-builder)	D	RA, HB
Hypsoblennius ionthas	H	N	B?	H (nest-builder)	D	RA, HB
Ioglossus calliurus	L	N	P	R	D	N
Katsuwonus pelamis	L	Y	P	R	P	N? (associated with objects drifting at surface)
Kyphosus incisor	M?	N	P? (plants, including Sargassum)	R	P	Y?, HB. S
Kyphosus sectatrix	M?	N	P, B (plants, including Sargassum, some benthic crustaceans)	R	P	Y?, HB, S
Lachnolaimus maximus	M?	Y	B	R	D	Y?, HB
Lactophrys quadricornis	L	N	B	R	D	SG
Lagodon rhomboides	M	N	B	R	D	RA, SG, HB
Larimus fasciatus	L	N	B	R	D	N
Leiostomus xanthurus	L	Y	B	R	D	N
Lepophidium profundorum	L	N	B	R	D	N
Lepophidium staurophor	L	N	?	R	D (deep water)	N
Lestrolepis intermedia	L	N	?	R	P (bathypelagic)	N
Lobotes surinamensis	M	Y	P, B	R	P	RA (often found associated with flotsam)
Lutjanus apodus	M	Y	P, B	R	D	RA
Lutjanus campechanus	M	Y	P, B	R	D, P	RA, HB

Table 5-1. (Continued)

Taxa	SF	DF	Diet	PC	Behavior	Dep.
Lutjanus griseus	M	Y	P	R	P	RA
Lutjanus jocu	M	Y	R, P, B	R	P	RA, HB
Lutjanus synagris	M	Y	R, P, B	R	D	RA, HB
Lutjanus vivanus	M	Y	R, P, B	R	D	RA, HB
					(common on shelf-edge banks)	
Magnisudis atlantica	L	N	P	R	P (bathypelagic)	N
Makaira nigricans	L	Y	P	R	P, HM	N
Megalops atlanticus	L	Y	P	R	P	N, RA
Membras martinica	L	N	P	R	P	N
Microdesmus lanceolatus	L	N	B?	R	D	N?
Microdesmus longipinnis	L	N	B?	R	D	N
Micropogonias undulatus	L	Y	B	R	D	N
Monolene sessilicauda	L	N	B	R	D (bathydemersal)	N
Mugil cephalus	L	Y	B (plants)	R	P	N
Mugil curema	L	Y	B	R	P	N
Mullus auratus	L	N	B	R	D	N
Mycteroperca microlepis	M	Y	P	R	P, D	RA, SG, HB
					adults offshore on rocky bottoms)	
Mycteroperca phenax	M	Y*	R, P	R	D	RA, HB
				(high-relief rocky bottoms, often found on Oculina reefs)		
Mycteroperca rubra	M	Y*	R, P, B	R	D	RA, HB
						(rocky and sandy bottoms)
Mycteroperca venenosa	M	Y*	R, P	R	P, D	RA
					(rocky and coral reefs, shelf-edge banks in GOM)	
Myrophis punctatus	L	N	B?	R	D	RA, SG
Neoconger mucronatus	M	N	B	R	D	RA (offshore banks)

Table 5-1. (Continued)

Taxa	**SF**	**DF**	**Diet**	**PC**	**Behavior**	**Dep.**
Ocyurus chrysurus	M	Y	R, P, B	R	P	RA
						(mostly coral reefs)
Ogcocephalus declivirostris	L	N	B?	R	D	N, HB
Ogcocephalus radiatus	L	N	B?	R	D	N, HB
Oligoplites saurus	L	N	P, B	R	P	RA
Ophichthus gomesii	L	N	B	R	D	N
					(common on shrimp grounds)	
Ophidion nocomis	L	N	B?	R	D	N
					(uncommon, shallow sandy bays)	
Ophidion robinsi *(rare)*	L?	N	B?	R?	D	N
Ophidion selenops *(uncommon)*	M?	N	B?	R?	D	RA
Ophioblennius atlanticus	H	N	B (plants)	H	D	RA (rocky reefs and corals)
Opisthognathus aurifrons	H	N	R, P	R?	D	Y?
Opisthognathus lonchurus	H	N	R?	R?	D	Y?
Opisthonema oglinum	M?	N	P	R	P	RA
Opsanus beta	M	N	B	H?	D	RA, SG (common on oyster reefs)
Opsanus pardus	M	N	B	H?	D	RA, HB
Orthopristis chrysoptera	L	N	P, B	R	D	N
Parablennius marmoreus	H	N	B (mostly algae)	H	D	Y
Paralichthys albigutta	L	Y	P, B	R	D	N, HB
Paralichthys lethostigma	L	Y	P, B	R	D	N
Paranthias furcifer	H	N	P	R	P	RA, HB (coral reefs, hard bottoms)
Pareques umbrosus	L	N	B	R	D	N
Parexocoetus brachypterus	L	N	P	R	P	N

Table 5-1. (Continued)

Taxa	**SF**	**DF**	**Diet**	**PC**	**Behavior**	**Dep.**
Peprilus alepidotus	L	N	P?	R	P (bathypelagic)	N
Peprilus burti	L	Y	P	R	P, D (benthopelagic)	N
Pogonias chromis	L	Y	B	R	D	N
Polydactylus octonemus	L	N	B	R	D	N
Pomacanthus paru	H	N	R, B	R?	D	Y
Pomatomus saltatrix	L	Y	P	R	P	N
Pontinus longispinis	L	N	B	R	D	N
Priacanthus arenatus	H	N	R, P, B	R?	D	Y
Prionotus roseus	L	N	B	R	D	N
Pristipomoides aquilonaris	L	N	P (small fishes)	R	D	N
Prognathodes aya	H	N	R?	H	D	HB (offshore banks)
Pseudupeneus maculatus	M?	N	B	R?	D	RA, HB
Rachycentron canadum	M	Y	P, B	R	P (found associated with structure of all types)	RA
Raja eglanteria	L	N	B	R	D	N
Remora remora	H?	N	P	R	P	RA? (usually attached to sharks, turtles)
Rhomboplites aurorubens	M	Y	P, B	R	P	RA, HB (HB on shelf-edge)
Robia legula	L	N	P	R	P (bathypelagic)	N
Ruvettus pretiosus	L	N	P, B	R	P (bathypelagic)	N
Rypticus maculatus	M?	N	B	R	D	RA?
Sardinella aurita	L	Y	P	R	P	RA
Saurida brasiliensis	L	N	P (nekton)	R	D	N

Table 5-1. (Continued)

Taxa	SF	DF	Diet	PC	Behavior	Dep.
Saurida normani	M	N	P	R	D	RA
Saurida suspicio		L		N	P	R
Scartella cristata	H	N	R, B	H	D	Y
Schedophilus medusophagus (GOM record is doubtful)	L	N	P	R	P	N
Sciaenops ocellatus	L	Y	P, B	R	D, P	N
Scomber japonicus	L	Y	P	R	P, HM	N
Scomberomorus cavalla	L	Y	P	R	P, HM	RA
Scomberomorus maculatusL	Y	P	R	P, HM		RA
Scorpaena brasiliensis	L	N	B	R	D	HB (most common over soft bottom)
Selar crumenophthalmus	L	N	P	R	P	RA
Selene setapinnis	L	N	P, B	R	P (benthopelagic)	N
Selene vomer	L	N	P, B	R	P	N
Seriola dumerilii	M	Y	P	R	P, HM	RA
Seriola fasciata	M	Y	P	R	P, HM	RA
Seriola rivoliana	M	Y	P	R	P, HM	RA
Seriola zonata	M	Y	P	R	P, HM	N
Serranus subligarius	L	N	B	R	D	N
Sphoeroides parvus	L	N	B	R	D	N
Sphoeroides spengleri	L	N	B	R	D	RA (SG, reef flats)
Sphyraena barracuda	M	Y	P	R	P	RA, SG
Sphyraena borealis	M	N	P	R	P	RA
Sphyraena guachancho	L	N	P	R	P	N
Stegastes partitus	H	N	R, B	R?	D	Y
Stegastes variabilis	H	N	R, B	R?	D	Y
Stellifer lanceolatus	L	N	B	R	D	N
Stenotomus caprinus	L	N	B	R	D	N
Stephanolepis hispidus	H?	N	B	R?	P, D	RA

Table 5-1. (Continued)

Taxa	SF	DF	Diet	PC	Behavior	Dep.
Syacium gunteri	M	N	B, P	R	D	RA
Syacium papillosum	M	N	B	R	D	RA
Symphurus civitatium	L	N	B?	R	D	N
Syngnathus louisianae	H	N	P	R	D	RA
Synodus foetens	L	N	B	R	D	HB
Synodus poeyi	L	N	B	R	D	RA, HB
Synodus synodus	M	N	P (nekton)	R	D	RA, HB
Tetragonurus atlanticus	L	N	P (jellyfish)	R	P	N
Thalassoma bifasciatum	H	N	R, B	R	D	RA, SG
Thunnus albacares	L	Y	P	R	P, HM	N, RA
Thunnus atlanticus	L	Y	P	R	P, HM	N, RA
Thunnus thynnus	L	Y	P	R	P, HM	N
Trachinocephalus myops	M	N	B, P	R	D	RA, HB
Trachinotus carolinus	L	Y	B, P	R	D (benthopelagic)	N
Trachinotus falcatus	M	Y	B	R	D	RA
Trachinotus goodei	M	Y	B, P	R	P (benthopelagic)	RA
Trachurus lathami	M	Y	P	R	P (minor, bait)	RA
Trichiurus lepturus	L	Y	P, B	R	P, D	N
Trichopsetta ventralis	L	Y	B	R	D	N
Trinectes maculatus	L	N	B	R	D	N
Upeneus parvus	L	N	P, B (zoobenthos, small fishes)	R	D	N
Urophycis floridana	L	N	B, P	R	D	N
Vinciquerria nimbaria	L	N	P	R	P (bathypelagic)	N
Xyrichtys novacula	H	N	B	H?	D	Y?

Table 5-2. Literature values for mean number per platform, size range at platform (cm FL), mean length of individuals observed (cm FL), mean weight per individual, age range (yrs), and biomass per platform (kg wet wt) for four abundant species of fishes collected from Gulf of Mexico oil and gas platforms. Source numbers correspond to articles in the assembled reference library (attached on CD-ROM).

Species	Mean Number	Size Range	Mean Length	Age Range	Biomass (kg)	Sources
Red snapper	1,884 (range 905-4,632)	25.5 - 79.1	295.3	2 to 10	886	101, 1384, 1283, 1491, 1456, 1380
Bluefish	1,438 (range 282-4,000)	45 - 50	475	1 to 6	1,489	15, 101, 1489, 1384, 1505
Atlantic spadefish	4,177 (range 10 -5,323)	10 - 50	30.0	1 to 8	2,618	1283, 1505. 1456, 1489
Sheepshead	2,250 (range 150-17,000)	22 - 50	360	2-5	1,774	15, 101, 1505, 1283, 1514
Blue runner	6,260 (range 427-25,188)	30 - 36	33.5	2-6	4,152	15, 1514, 1384, 1314, 1283

Table 5-3. Literature values for maximum age, estimated growth and mortality rates, and Von Bertalanffy length-at-age parameters used in production calculations. T_{max} = maximum age, M = natural mortality rate, G = specific growth rate (yr), L_{∞} (cm TL) is the asymptotic maximum length, K is a constant (the Brody growth coefficient), and t_0 is a constant representing the age (yr) at 0 length. Letters in parentheses following L_{∞} indicates sex if males and females were dimorphic. Fish length is converted to wet weight using a length-weight equation with constants a and b. Age distributions of fish (AD) were derived from empirical data for size ranges at age of fishes observed at platforms, except for red snapper that are most abundant from ages 2 to 6 (Wilson and Nieland 2001).

Species	**T_{max}**	**G**	**M**	**AD**	**L_{∞}**	**K**	**t_0**	**a**	**b**	**Source**
Red snapper	57	0.31 (at T_{max} G=0.05)	0.10 (at T_{max} M=0.07)	2-10	94.1	0.18	-0.55	0.0165	3.03	1, 2, 3
Blue runner	11	0.39	0.38	2-4	41.2	0.35	-1.17	0.0524	2.690	4
Sheepshead	20	0.23	0.22	2-5	41.9 (M) 44.7 (F)	0.417 0.367	-0.901 1.025	0.000448 0.000530	2.88 2.85	5
Atlantic spadefish	8	0.41	0.58	1-8	49.0	0.340	-0.18	0.0927	2.64	6
Bluefish	8	0.41	0.58	1-6	94.4	0.18	1.033	-10.02	2.80	7

1 Wilson, C. A. and D. L. Nieland. 2001. Age and growth of red snapper, *Lutjanus campechanus*, from the northern Gulf of Mexico off Louisiana. Fish. Bull. 99: 653-664.

2 Fischer, A., M. S. Baker, Jr. and C.A. Wilson. 2004. Red snapper (*Lutjanus campechanus*) demographic structure in the northern Gulf of Mexico based on spatial patterns in growth rates and morphometrics. Fish. Bull., US 102: 593-603.

3 SEDAR 7. 2005. Southeast Data, Assessment, and Review: Stock Assessment Report of SEDAR 7: Gulf of Mexico Red Snapper. SEDAR7. One Southpark Circle #306, Charleston, SC 29414

4 Goodwin, J. M., IV and A. G. Johnson. 1986. Age, growth, and mortality of blue runner, *Caranx crysos* from the northern Gulf of Mexico. Northeast Gulf Sci. 8: 107-114.

5 Beckman, D. W., A. L. Stanley, J.H. Render and C.A. Wilson. 1991. Age and growth-rate estimation of sheepshead *Archosargus probatocephalus* in Louisiana waters using otoliths. Fish. Bull., US 89: 1-8.

6 Hayse, J.W., 1990. Feeding habits, age, growth, and reproduction of Atlantic spadefish *Chaetodipterus faber* (Pisces: Ephippidae) in South Carolina. Fish. Bull., US 88:67-83.

7 Barger, L.E. 1990. Age and growth of bluefish *Pomatomus saltatrix* from the northern Gulf of Mexico and the U.S. south Atlantic coast. Fish. Bull., US 88: 805-809.

Table 5-4. Estimated relative production attributable to oil and gas platforms (AP). The index of reef exclusivity (IRE) is an estimate of species utilization of resources associated with platform habitat compared to resources from nearby natural habitat (Powers et al. 2003). The IRE is based upon diet information from the sources provided. Trophic level for each species was obtained from FishBase (http://www.fishbase.org/), T°C is the annual averaged sea surface temperature in degrees centigrade obtained from the NOAA Data Buoy Center for years 2004 and 2005 at SPLL1 (28.87 N, 90.48 W) and MRSL1 (29.44 N, 92.06 W) on the Louisiana Shelf. P_r = annual biomass production in kg platform^{-1} yr^{-1} based upon calculations using Ricker (1975). P_e = annual biomass production in kg platform^{-1} yr^{-1} estimated by using the empirical relationship in Edgar and Shaw (1990). AP_r = IRE*P_r, AP_e = IRE*P_e. Source numbers correspond to papers in the assembled reference library (attached CD-ROM). Numbers proceeded by * refer to additional literature resources listed below the table.

Species	**Trophic Level (SE)**	**Diet Composition**	**IRE**	**T°C**	**P_r**	**P_e**	**AP_r**	**AP_e**	**Source of Diet Data**
Red snapper	4.01 ± 0.59	Benthic inverts, demersal fishes, squid, pelagic zooplankton	0.05	25.9	306	115	15	6	1489, 1505, *1, *2
Blue runner	4.40 ± 0.77	Fish, decapods, hyperid amphipods, chaetognaths, other	0.10	25.9	1,627	333	163	33	1276, 1264, 1378
Sheepshead	3.53 ± 0.53	Portunid crabs, shrimp, barnacles, fish, copepods, bryozoans, amphipods, sargassum	0.90	25.9	410	185	369	167	1538, 1505, 1489
Atlantic spadefish	3.50 ± 0.47	Sponges and tunicates, cnidarians, worms, ascidicans, plants, benthic inverts., echinoderms, zooplankton	0.95	25.9	987	243	938	231	1382, 1384, 1420, 1489, 1505, 1514. *3
Bluefish	4.50 ± 0.55	Demersal fish and macrocrustaceans from soft bottoms	0.01	25.9	561	164	6	2	1489, 1505

*1 McCawley, J.R., J.H. Cowan, Jr. and R.L. Shipp. 2006. Diel feeding periodicity and prey habitat preference of red snapper, Lutjanis campechanus, on Alabama artificial reefs. Gulf Mexico Sci. 24: 14-27.

*2 McCawley, J. and J.H. Cowan, Jr. Seasonal and size specific diet and prey demand of red snapper on Alabama artificial reefs: Implications for management. Pages in W. F. Patterson, J. H. Cowan, Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper Ecology and Fisheries in the US Gulf of Mexico. American Fisheries Society, Symposium XX, Bethesda, Maryland. In press.

*3 Randall, J.E., 1967. Food habits of reef fishes of the West Indies. Stud. Trop. Oceanogr. Miami 5: 665-847.

where AP is a measure of relative species-specific production attributable to a platform. Annual production for each species (5) for which sufficient data were available was calculated in two ways. The first was based upon methods described in Ricker (1975) where annual production is estimated by:

$$\hat{P} = \overline{B} * (G) \qquad (2)$$

where $\hat{P}$ is biomass production, $\overline{B}$ is annual mean biomass, and G is specific growth rate yr^{-1}. Annual mean biomass is estimated by using:

$$\overline{B} = B\frac{(1-e^{-(Z-G)})}{Z-G} \text{ when G > Z} \qquad (3)$$

$$\overline{B} = B\frac{(e^{(G-Z)}-1)}{G-Z} \text{ when Z> G} \qquad (4)$$

where $\overline{B}$ is annual mean biomass, B is biomass per platform in kg, G is specific growth rate yr,^{1} and Z is specific mortality rate yr.^{1} In actuality, Z is the sum of F, annual fishing mortality rate plus M, annual natural mortality rate. In our Level Three assessment, we ignore F in calculations, but will discuss the implications of this omission in a later section.

The second method of estimating annual production is from upon an empirical method in Edgar and Shaw (1995) that is based on data obtained from published literature on the biomass, estimated daily somatic production and ambient water temperature for 62 species distributed worldwide. The equation is:

$$P = 0.00051 * B^{0.69} * T^{1.04} \qquad (5)$$

where P is production (g dw d^{-1}), B is biomass (g), and T is temperature (^{o}C). We assumed that g dw = g wet weight * 0.20. Both methods of estimating production required an estimate of biomass on a platform. To make this estimate, we first calculated the simple arithmetic mean number of fish by species on a platform by summing all of the available estimates of numbers observed, based mostly upon visual surveys using scuba. In addition to numbers of individuals, length ranges (cm) also were reported for each species. The means and range of numbers, the largest reported length range, and the sources of these estimates for each species are reported in Table 5-3.

Biomass estimates were calculated based on age and growth relationships reported in the literature from samples collected in the GOM for all species except Atlantic spadefish. For Atlantic spadefish, we used data collected in South Carolina (Hayse 1990). To estimate length at age, we used Von Bertalanffy growth models:

$$TL_t = L_\infty(1-e^{-k(t-t_0)}) \quad (6)$$

where TL_t is total length (TL) at age t, L is the asymptotic TL, k is the Brody growth coefficient, t is age in yr, and t_0 is a hypothetical age when TL is zero. Using this equation specific for each species (Table 5-5), we determined the age range of each species observed on platforms that correspond to observed length ranges (Table 5-4 and AD in Table 5-5) Length-length relationships available for each species allowed for conversion between TL, fork length and standard length as necessary for consistency among units of length. Length at age was converted to wet weight at age using:

$$TW_i = a * TL^b \quad (7)$$

where TW_i is wet weight in g of species i, TL (cm) and a and b are constants derived for each species. The values for a and b for each species are reported in Table 5-5.

Table 5-5. Equilibrium biomass (E*), production rate (r), and energy density (e_p) of the prey groups represented in the individual-based model. The value of r of 0.00197/hour is equivalent to a P/B of 17.3/year; the value of 0.00046/hour is equivalent to a P/B of 4/year.

Prey Type	**E* (g ww/m^2)**	**r (1/hour)**	**e_p (calories/g ww)**
Zooplankton	6.7	0.00197	3511
Crabs	4.0	0.00046	3138
Shrimp	4.0	0.00046	3894
Pelagic fish	17.0	0.00046	4947
Benthic fish	17.0	0.00046	4947

Because we ignore fishing mortality, Z = M. We used Hoenig's (1983) method to estimate M, which is based upon longevity (T_{max}) and is estimated by:

$$\ln(Z) = 1.46 + -1.01 * \ln(T_{\max}) \qquad (8)$$

where Z is specific mortality rate yr^{-1}; results are reported in Table 5-5.

Estimates of mean length of individuals on a platform assume a stable age distribution and are based upon an exponential decline in numbers over time:

$$N_t = N_0 * e^{-(z*t)} \qquad (9)$$

where N_t is numbers a time t in yr, N_0 is numbers at t = zero (beginning of the time series), and Z is the total annual specific mortality rate yr^{-1}.

To estimate numbers at age, equation (9) was solved for each species so that estimated numbers at age summed to the mean number of individuals reported in Table 5-4, and mean length was estimated by summing lengths over all age classes, then dividing by the mean number in Table 5-4. Mean length per individual was converted to weight per individual as described above, then multiplied by mean number to derive an estimate of mean biomass (kg) per platform.

Finally, to compute the final number necessary to estimate production, specific growth rate for each species over itís age range observed at platform, we used:

$$W_t = W_{t-1} * e^{(G*t)} 1 \qquad (10)$$

where G is specific growth rate yr^{-1}, W_t is weight at year t, W_{t-1} is weight at t-1, and t is time in years. This equation was solved for each species based upon the estimated weights of the youngest and oldest age classes observed on platforms, and the number of years between estimates.

5.2 LEVEL FOUR METHODS—MODEL DESCRIPTION

5.2.1 Overview

The tool employed for a level-four analysis consists of a detailed, spatially explicit individual-based model (IBM). This IBM tracks the hourly weight, growth, mortality, and movement of individuals of multiple species groups on a 2-dimensional spatial grid of cells for up to 20 years. Any number of different species can be included, although practical and data considerations likely would limit to the number of species to five or less. Each model year is 365 days from July 1 to June 30. The model uses differences equations that are updated hourly, with the first 12 hours considered nighttime and the second 12 hours considered daylight. The model was coded in FORTRAN 90 and typical 20-year simulations take less than one hour on a high-end personal computer.

Red snapper comprise about 15-20% biomass of fish on large artificial structures (Appendix II). We include two additional “species” in this version of the model to illustrate how one could account for the remaining 60-80% of the biomass of fish that rely on benthos and smaller fish nearby, but not on the structures themselves. We refer to these other two species simply as “species A and “species B.” The biomass represented by species A and B represents the biomass of fish competitors of red snapper for prey during their residence in and around artificial structures. Even if red snapper biomass is not large enough for red snapper to affect their prey (little density-dependent effect), moving or removing structures can affect how the total fish community affects the prey available to red snapper. In this demonstration version, the model was configured very roughly based upon red snapper growth and mortality information; the two additional species were then derived from the red snapper model parameters by only changing a few of the red snapper parameter values. Future versions of the model will use refined parameter values that reflect species differences among red snapper and functional groups such as grunts, groupers, and bluefish beyond the few simple adjustments made here. Thus the results presented here are only for illustrative purposes.

Spatial cells are designated as benthic or hosting an artificial structure (platform). Water temperature is assumed to vary daily, and to be uniform over all spatial cells on any given day. Simple logistic population growth models that include a mortality term from fish consumption are used to follow the biomass of each of 5 prey types (zooplankton, mantis shrimp, crabs, pelagic fish, and benthic fish). Prey dynamics are simulated on each benthic cell, and the dynamics are independent of neighboring cells (no advective or diffusive exchanges of prey biomass between cells). Platform cells are assumed to have no prey.

During the nighttime hours, individual fish start from their location (often a platform cell reached during the previous daylight) and move among neighboring cells going toward the cell in which the greatest growth rate can be achieved. Individual fish consume prey in the cell they reach each hour as they move towards the desired cell; the desired cell can change every hour as the fish changes its location. Prey consumed is combined with a bioenergetics model, and the growth rate of the individual for each hour is computed. The individual's weight is updated based on the computed growth rate. At dusk (hour 13), the individual fish begin to move back to towards the nearest platform cell where they do not feed and they wait until sunrise to begin foraging again. Natural mortality is applied every hour, and is assumed higher during the daylight hours as long as the individual is away from a platform cell. Fishing mortality is applied during the 12 daylight hours. The model loops over years, 365 days, 24 hours, and the growth, mortality, and movement of individuals of red snapper, species A, and species B. Much of the information for model parameters is from Shipley (2008).

5.2.2 Environmental variables and the spatial grid

The spatial grid consists of 50 x 50 square cells, each cell measuring 200 m on a side. A cell is located on the grid by a column number (1 to 50) along the x-axis and a row number (1 to 50) along the y-axis. The origin of the grid is at the lower left corner. For convenience, we assume the orientation of the grid is north is towards the top, and west is towards the right (Figure 5-2). Any number of specific cells on the grid can be designated as being platform cells. Water temperature varies daily and assumed the same for all cells. Water temperature reaches it warmest in mid-August at about 26^o C, and it coldest in January at about 13.5 ^{o}C.

Five prey groups are simulated on each benthic cell (i.e., all cells not designated as a platform cell). The five groups are: zooplankton, crabs, mantis shrimp, pelagic prey fish, and benthic-oriented prey fish (Table 5-2). Each hour of the 24 hours the density of each prey type (Z, g ww/m^2) on each cell is updated:

$$Z_{k,j,t+1} = Z_{k,j,t} + 2.0 \cdot Z_{k,j,t} \cdot r_j \cdot (1 - Z_{k,j,t} / E^*_j) - \sum_{i=1}^{nfish} C_{i,j} \Big/ Area \qquad (11)$$

Equilibrium biomasses (E*) and prey turnover rates (r) were obtained from Shipley's (2008) Ecopath model (Table 5-2). The multiplier of 2.0 is so that the turnover rate occurs when prey density is one-half of the equilibrium density, rather than at zero for the logistic equation without the 2.0. Summed consumption (rightmost term in equation 11) is the biomass of the prey type eaten by all individuals of red snapper, species A, and species B who foraged in the cell for that hour. Area is 4,000 m^2; the area of each 200 m by 200 m cell.

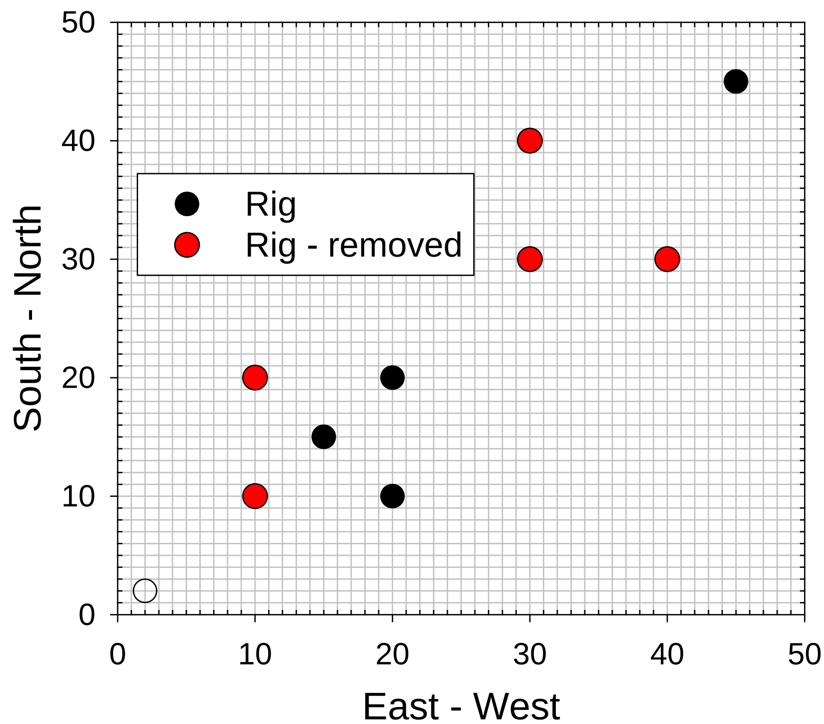

Figure 5-2. Location of the ten rig cells used in the baseline simulation. The rig cells in red were removed for the second simulation involving a reduction of 10 rigs cells to 5 rig cells.

5.2.2.1 Growth

The change in weight of each individual red snapper, species A, and species B every hour is computed based on a difference form of a bioenergetics model:

$$W_{t+1} = W_t + [(C - Ex - F - SDA - R) \cdot \frac{e_p}{e_f} - S] \cdot W_t \qquad (12)$$

where C is consumption, Ex is excretion, F is egestion, SDA is specific dynamic action, R is respiration, and S is spawning. All rates except spawning are in g ww prey/g ww fish/hour; S is in units of g ww fish/g ww fish/hour. Weight is updated for the 12 hours of nighttime each day, so all rates reported as per day in Shipley (2008) were divided by 12 so the correct daily amounts are computed but within the 12 hourly time steps during the nighttime of each day. Consumption is determined each hour of nighttime. Consumption stops when either all 12 nighttime hours are used for foraging and the individual switches to movement towards the nearest platform or until the daily maximum consumption rate is exceeded which causes foraging to stop (but not movement) prior to dawn. Because egestion, excretion, and SDA depend in consumption, they also are zero for nighttime hours after which consumption exceeds the maximum consumption rate. Respiration and spawning losses are imposed for all 12 hours of nighttime, regardless of if and when maximum consumption is reached, so that the correct daily rates are obtained. Energy densities of the prey (e_p) are shown in Table 5-2; energy density of red snapper, species A, and species B (e_f) is 4186 calories/g ww.

Consumption is determined from a maximum daily consumption rate and the densities of each of the five prey groups in the cell the individual is located in. Daily maximum consumption (g ww prey/g ww fish/day) is:

$$C_{\max} = 0.182 \cdot W^{-0.274} \cdot f(T) \quad (13)$$

where f(T) is a slowly rising function of temperature, reaching a value of one at 27 ^{o}C and dropping to zero at 35 ^{o}C. f(T) acts like a Q10 effect in simulations because the warmest temperature experienced by fish is 27 ^{o}C (i.e., just before f(T) starts to decline from a its peak value of one). Hourly consumption of each prey type by an individual (C_j) is then computed from a type 2 functional response that is dependent on the maximum consumption rate and prey densities:

$$C_j = \frac{C_{MAX} \cdot \frac{Z_j \cdot v_j}{K_j}}{1 + \sum_{k=1}^{5} \frac{Z_k \cdot v_k}{K_k}} \qquad (14)$$

where v_j is the vulnerability of the jth prey type to individual fish, and K_k is the half-saturation parameter of the kth prey type to the individual fish. Vulnerabilities were set *a priori* based on diet information; K values were then determined by calibration until weights at age were roughly close to desired values (see Figure 5-8). Vulnerabilities and K values were first specified for red snapper, and then modified for species A and species B (Table 5-6). Species A is assumed to grow slower than red snapper (C_{max} was multiplied by 0.9 and K values lowered) with a similar diet (i.e., similar vulnerabilities). Species B is assumed to grow larger than red snapper, and to only eat the pelagic and benthic fish prey groups (true piscivore).

Table 5-6. Vulnerabilities and feeding efficiency parameter values (K in equation 4) by prey type for red snapper, Species A, and Species B. Parameter values are likely age-specific but were not in this version of the model.

Parameter	Prey type	Red snapper	Species A	Species B
Vulnerability	Zoop	1.0	1.0	0
	Crab	0.2	0.2	0
	Shrimp	0.8	0.8	0
	Pelagic fish	0.1	0.1	1.0
	Benthic fish	0.1	0.1	1.0
K value	Zoop	130.0	40.0	
	Crab	130.0	60.0	
	Shrimp	130.0	60.0	
	Pelagic fish	150.0	69.0	31.0
	Benthic fish	150.0	69.0	31.0

The sum of the consumption rates over the five prey groups is the total hourly consumption for the individual fish.

$$C = \sum_{j=1}^{5} C_j \qquad (15)$$

If summed hourly total consumption (cumulative sum of C) as an individual progresses through hours 1 to 12 of nighttime exceeds C_{max}, then the individual stops feeding and excretion, egestion, and SDA, all of which depend on consumption, are also zero. This means the individual has reached its maximum daily consumption, and thus that losses in weight due to excretion, egestion, and SDA have also accumulated to their specified daily values. If an individual does not reach its maximum daily consumption after 12 hours of foraging, then the rates of excretion, egestion, and SDA are appropriately less than their specific daily values. Respiration and spawning cause weight loss every hour of the 12 hours of nighttime, even for hours with no consumption.

Excretion (E) and egestion (F) are related to water temperature and consumption. The proportion of consumption that is egested decreases with temperature and how close consumption is to maximum consumption.

$$F = \left(\frac{0.212 \cdot WTEMP^{-0.222} \cdot e^{0.631 \cdot \frac{C}{C_{MAX}}}}{0.9} \right) \cdot C \qquad (16)$$

Excretion is represented as a proportion of net assimilated energy (consumption minus egestion). The proportion increases with temperature and how close consumption is to maximum consumption.

$$Ex = \left(0.031 \cdot WTEMP^{0.58} \cdot e^{0.3 * \frac{C}{C_{MAX}}} \right) \cdot \left(C - F \right) \qquad (17)$$

Respiration depends on body weight and water temperature.

$$R = 2 \cdot 0.0045 \cdot W^{-0.2} \cdot g(T) \cdot 5.258 \qquad (18)$$

g(T) has the same shape as the f(T) temperature effect function used to adjust maximum consumption in equation (3). g(T) slowly rises, reaching a value of one at 32 ^{o}C and then declines to zero at 35 ^{o}C. Because 32 ^{o}C is warmer than temperatures experienced by the fish, g(T) acts like a Q10 effect on respiration. Hourly respiration is increased by 30% for every hour an individual is not in platform cell during day light hours. SDA is assumed zero in this version of the bioenergetics model.

Spawning is computed as a weight loss on a single day (day 201) by subtracting an additional weight loss of 8% of each individual's body weight (none for age-1 and 4% for age-2), spread over the 12 one hour time steps during the nighttime period. The same spawning is assumed for all three species.

5.2.2.2 Movement

Each individual is tracked in x-y continuous space as their distance in meters from the origin (lower left corner) of the grid. Each hour, the x and y values are incremented, and then the cell that the individual is located in is updated. During the hour, individuals experience the environmental conditions of their cell.

Movement is different between daylight and nighttime hours. Nighttime movement (hours 1-12) is considered foraging time, and individuals go to cells in their local neighborhood that offer the highest growth rate. Daytime movement (hours 13-24) is considered the time when individuals return to a nearby platform to "hide" from visual predators.

Nighttime movement begins at hour 1 (dusk) and continues for each of the next 12 hour time steps. Each individual evaluates the cells in the 2-cell neighborhood of their current cell. Growth is predicted (but the individual's weight is not updated) using the bioenergetics calculations and the prey densities that ended at the previous hour in all cells within 2 cells of the current cell, including in the four diagonal directions. The 17 cells (16 in the neighborhood plus their current cell) are evaluated in random order. The angle between the fish's current location and the center of the cell that offers the highest growth rate (θ) is determined. In this version of the model, we require that the projected growth rate in the cell be greater than 20% faster than the present best cell's growth rate in order for the cell to become the best cell. The individual's x and y locations are then updated such that the individual moves the allowed distance during foraging (*nightdist*, m/hour) on a track headed from its present location to the center of the cell with the highest potential growth rate (equations from Robert Humston, Virginia Military Institute, personal communication). We compute the angle θ (in radians) based on the current location of the individual fish at hour t (X_t, Y_t) and the center of the cell within its neighborhood with the highest growth rate (X^c, Y^c):

$$\theta = \arctan\left(\frac{\left|Y^c - Y_t\right|}{\left|X^c - X_t\right|}\right) \qquad (19)$$

We add a random component to θ by adding a uniform random value between -0.5 to 0.5 to the value determined with equation (9). We then adjust the angle for possible negative signs that were lost by taking the absolute values in equation (9). Negative values of the numerator imply the best cell is south (down) from the current cell and a negative denominator implies the best cell is west (left) of the current cell:

$$\theta = \begin{cases} \pi - \theta & if\ Y^c - Y_t > 0\ and\ X^c - X_t < 0 \\ \pi + \theta & if\ Y^c - Y_t < 0\ and\ X^c - X_t < 0 \\ 2\pi - \theta & if\ Y^c - Y_t < 0\ and\ X^c - X_t > 0 \end{cases} \qquad (20)$$

The x axis position and y axis position is then updated:

$$x_{t+1} = x_t + nightdist \cdot \cos(\theta) \qquad (21)$$

$$y_{t+1} = y_t + nightdist \cdot \sin(\theta) \qquad (22)$$

A random component is added to the value of *nightdist* for each fish each hour by varying the *nightdist* value by ±30% separately for the x direction and for the y direction. This also affects the angle of movement because the final angle actually moved depends on how far an individual moves in the x and the y directions. We use values of *nightdist* of 200 m/hour for red snapper, 400 m/hour for species A, and 100 m/hour for species B. If the individual would move off the grid, then the individual reflected back as if the individual bounded off the wall.

An individual may: (a) travel far enough to actually get to the desired cell, (b) travel in the correct direction but not far enough to leave their current cell, (c) may get to the next cell on the desired track but not the desired cell that could be two cells away, or (d) may overshoot the desired cell and end up in the cell past the desired cell. Individuals evaluate platform cells within their neighborhood but platform cells have zero prey and are not desirable because they offer negative growth rate. However, individuals may move into a platform cell during nighttime because the platform cell is between their current cell and the cell that offers the highest growth rate. No feeding takes place for any hour an individual is on a platform cell.

Upon reaching hour 13 in each day (i.e., dawn), the closest platform cell is determined for each individual fish and they move towards this cell. The nearest platform cell is determined by computing the distance between the individual's current x and y location and the center of all platform cells that are on the grid. The angle for the track from the individual's current location and the center of the nearest platform cell is determined the same way as for foraging (i.e., equation (9) with X^c and Y^c now the center of the nearest platform cell). The individuals x and y locations are then updated using equations 10-12, but with *daydist* substituted for *nightdist*.

The parameter *daydist* is the assumed distance moved in an hour when fish are returning to a platform cell. For daytime movement, we add a random component of ±0.25 radians to the value of θ, and ±20% to the *daydist* value used for the x direction and the y direction. Values of daydist were assumed to be 200 m/hour for red snapper, 100 m/hour for species A, and 400 m/hour for species B. Each hour of daylight (hours 13 to 24), the individual is moved and if it reaches a platform cell, movement stops and the individual waits there for the dusk to begin foraging again starting from the platform cell. The nearest platform cell is determined every hour of daylight in case the individual's actual movement changes which platform cell is closest.

5.2.3 Mortality

Natural, movement, and fishing mortality rates are imposed on model individuals. Natural mortality rate (1.14 $x10^{-5}$/hour) is applied for all 24 hours (equivalent to a rate of 0.1/year). Movement mortality is assumed the same as the natural mortality rate, and a doubling in natural mortality is imposed for hours when individuals are not in a platform cell during daylight hours. Fishing mortality ($5.71x10^{-5}$/hour, or 0.5/year) is imposed during all 12 daylight hours for age-3 and older individuals. Identical rates were assumed for red snapper, species A, and species B.

5.2.4 Initial conditions and annual recruitment

The initial population of each species is started by specifying a total number of individuals per species per platform. The initial values were roughly estimated from the information summarized in Table 5.2. The number at each of 10 ages is then determined from the total number using the natural mortality rates and assuming a stable age-distribution

distribution. The calculated number of age-1 individuals is then added each year on July 1 as new recruits to the population on the grid.

Initial weights, ages, and locations are assigned using mean weights-at-age and randomly placing individuals throughout the grid. Birthdays occur on June 30 (end of each model year), when age-10 individuals are removed from the population and new recruits are added to the population as age-1 individuals. New recruits are assigned an initial weight equal to the mean weight of age-1 and randomly placed on the grid. Prey densities are started at their equilibrium densities.

5.2.4.1 Numerics

We use a super individual approach so that we can easily manage array dimensions in the computer code and for computing speed (Scheffer et al. 1995). Tracking every individual could involve millions of individuals, which can vary year to year dependent on the assumed recruitment. Instead, we follow a fixed number of model individuals per age-class of each species. Each model individual is treated like its own cohort; individuals are assigned initial worths that specify how many identical population individuals are represented by the model individual.

The initial worth of model individuals is determined when they first enter the simulation as new age-1 recruits. Initial worth is computed as the population number of recruits (age-1 in the stable age distribution) divided by the number of model individuals used to represent the age-class. For example, if we add 1000 recruits using 20 model individuals, then each model individual is worth 50 population individuals. For initial conditions, we do the same for each of the 9 other age-classes. Natural, habitat, and fishing instantaneous mortality rates are added together and converted to a fraction surviving one hour, and the worth is reduced by multiplication of the worth by the fraction surviving. If the worth of individual gets less than 0.1, then the individual is removed from the simulation. Worth is incorporated into demand for prey consumption rates and outputting.

5.2.5 Example Simulations: Design

We show some results from simulations to illustrate how the model operates and how the model could be used to evaluate the impacts of platform location and removal on red snapper productivity. The model is still under early development so the results are not meant to be interpreted beyond simply illustrating the model and some of its capabilities. Some parameter values were guessed, and many of the red snapper parameter values were also used for species A and species B.

Two simulations were performed. First, we report results of a 20-year baseline simulation that used 10 platforms distributed throughout the grid (Figure 5-2), with initial value of 2,000 individuals of red snapper, 10,000 individuals of species A, and 4,000 individuals of species B assumed at each platform. Second, we show how the model can be used to compute how red snapper production would change with the removal of 5 of the ten platforms (shown as red in Figure 5-2). We forced the same number of initial fish as used on the 10 platforms onto the 5 platforms. Both simulations used 50 model individuals per age class per species (i.e., a total of 500 individuals per species). We ignored the first 10 years of simulation to minimize the effects of initial conditions. The simulations reached steady state results by year 10.

We use the baseline simulation to illustrate the model. We first show the hourly positions of 3 model individuals (one of each species) for 4 days during year 20. By adding up all of the individuals (multiplied by their worths) and multiplied by their individual weights we obtain values of biomass. We show biomass of red snapper on the spatial grid for each of four hours during a particular day in year 20. We also show daily biomass of the three species for years 10 to 20. Biomass is comprised of numbers of individuals and the weight of individuals. We show mean weights per individual by age-class and numbers of individuals by age-class for each day between years 10 to 20.

We used averaged red snapper biomass and production to compare the effects of removing the 5 platforms. We averaged total biomass of red snapper during year 20 to obtain a daily average biomass. Production is computed as growth production (sum of the change in weight every hour for all surviving individuals) and mortality production (sum of weights of individuals at their death). We average growth production over the days during year 20 to obtain a daily average production (g/day) for the modeled grid, and we add and average growth and mortality production rates to obtain a daily average total production (g/day).

5.3 RESULTS

5.3.1 Level One and Two Results

In all, a total of 246 species have been reported from oil and gas platforms in the GOM. Of these, 33 species are Caribbean expatriates (23 of which are reported to be reef dependent) that occur sporadically in low numbers, and are not believed to contribute to overall stock productivity because their larvae are nearly absent in waters of the northern GOM (Hanisko and Lyczkowski-Shultz et al. 2001, Hanisko and Lyczkowski-Shultz 2003). One hundred-two (102) species have life history strategies that conclusively exclude them from being reef associated or dependent (N in Table 5-1), even though these species have been reported in collections of fishes from platforms. Thirty-six (36) species are conclusively considered to be reef dependent (Y in; note that Y=reef dependent, Y plus habitat descriptor HB, SG, S are habitat dependent on a specified habitat), which here indicates that reef habitat is required for these species to complete their life cycles, or that their diet is almost exclusively derived from the reef (Hoese and More 1977; Robins et al. 1986; Carpenter 2002; Richards 2006). Reef dependent species that are not expatriates are: *Balistes capricus*; *Cantherhines pullus*; *Cephalopholis cruentatus*; *Chaetodipterus faber*; *Clepticus parrae*; *Parablennius marmoreus*; and *Xyrichthys novacula*.

Thirteen species have life history strategies that appear to preclude reef dependency, or are documented to occur on structured, non-reef habitats, but are listed in FishBase as reef associated. In 5-1, these are listed under the Dep category with an N, followed by the habitat type that is reported to be of greatest importance.

Of the 246 species reported from platforms, the 102 species to which we assigned an N would likely experience little impact attributable to platform removal. An effect of some magnitude would be more likely for the 36 species that are conclusively reef dependent (assigned a Y in Table 5-1). The species for which we assigned an N in 3 have life history and behavioral characteristics that are qualitatively similar to the attraction end of the continuum described by Bohnsack (1989): they are directly fished or overfished, exhibit low site fidelity, are less or not dependent upon the reef for food, are not dependent upon the reef for completion of their life cycles, and are pelagic and/or migratory, thus less likely to have its population size limited by the amount of structures available. In contrast the species for which we assigned a Y in Table 5-1 have life history and behavioral characteristics that are qualitatively more similar to production end of Bohnsacks (1989) continuum, having higher site fidelity, the need for reef or structured habitat to complete the life cycle, and a significant fraction of diet that is reported to be derived directly from reef-associated prey.

There are numerous species for which expectations are more difficult to describe, even qualitatively. To provide some interpretation, we use both a qualitative assessment relative to the Bohnsack (1989) conceptual model, and insight derived from the Level-3 assessments to make comparisons among the reef-associated species in Table 5-1. Where possible, we identify species that are comparable with respect to ecology, life history and behavioral characteristics to the Level-3 species. It is fortunate that the latter group is comprised of species that appear to differ significantly in their relative ecological dependence on reefs and, by extension, platforms. We believe the Level 3 assessments provide some information by to which inform the interpretation provided below. We consulted the following additional reference material to make our determinations: Bohlke and Chaplin 1968; Hoese and Moore 1977; Robins et al. 1986; Humann 1994; Randall 1996; Carpenter 2002.

In all, forty-six species are listed as reef associated (RA in Table 5-1). Of these, many are known to be pelagic and/or highly migratory. Among this group are several species of jacks (fm. *Carangidae,* genus *Caranx* (6 species), genus *Seriola* (3 species), *Elagatis bipinnulata*, *Selar crumenophthalmus*, *Oligoplites saurus* and *Trachurus lathami*)), mackerels (Scomribdae, *Scomberomorus* (2 species), clupeids (*Harengula jaguana, Opisthonema oglinum, and Sardinella aurita*), barracudas (genus *Sphyraena* (3 species)), cobia (*Rachycentron canadum)*, and ocean triggerfish (*Canthidermis sufflamen*). Although listed as reef associated in FishBase, they exhibit life history and behavioral characteristics that are more typical of fishes at the attraction end of Bohnsacks continuum, and appear to be most comparable in their use of reefs and platforms to bluefish and/or blue runner. As such, these species may not be significantly affected by platform removals.

Thirty of the fotty six species listed as reef associated (RA) have other habitats listed as primary (*Carangidae*, mackerels family Scombribdae, and clupeiods herrings and anchovies). Many of these species are reported to primarily associate with hard-bottom (HB) habitats (25 species including most of the groupers). This makes sense given the nature of most of the natural reef habitat in the GOM. Others are reported to associate with sea grass (SG) meadows. Where possible, we have included additional detail in Table 5-1 about primary habitat associations reported for many of the reef associated species; these habitats are consistent with natural habitats reported to occur in the GOM and include reef flats, rocky reefs, coral reefs, oyster reefs, floatsam, shelf-edge banks, offshore rock bottoms, offshore banks, *Oculina* reefs, structure of all types, and sharks and turtles. This group is clearly the most difficult to assess. We note that the lack of habitat-specific, process-level data makes the following interpretations speculative.

Most of the grouper species reported in Table 5-1 in the genus *Epinephelus,* with the exception of *E. itajara,* and in the genus *Mycteroperca,* with the exception of *M. microlepis,* are managed as a complex in the GOM referred to as the "deep-water groupers." Relatively little is known about the ecology and behavioral characteristics of these fishes, although they are believed to be long-lived and exhibit relatively low stock productivity (SEDAR 2004; Grouper Assessment Review). Assessment of the role that platforms play in their life histories would be speculation on our part, but it is likely that association with platforms does not significantly increase their vulnerability to fishing, especially to recreational anglers, given their preferred depth distribution. It also is unlikely that a significant number of platforms are available as habitat for these groupers for the same reason; these fishes are likely to occur only on those structures near or on the shelf-edge banks. In contrast, *E. itajara,* the goliath grouper, and *M. microlepis*, the gag grouper, are found inshore on a variety of habitats ranging from platforms to artificial reefs, to bridge pilings, piers, docks, seawalls, and other hard structures (Kingsley, M.C.S. ed. 2004). Juvenile goliath groupers are most often found in mangroves, which appear to be its primary nursery ground. Goliath groupers are severely overfished in the US GOM, and harvest currently is prohibited. They are confined mostly to Florida Bay and the southern portion of the Florida peninsula and the Bay of Campeche (where they are harvested in great numbers as juveniles) in the GOM, but have been observed occasionally by scuba divers around platforms. As the stock rebuilds and expands northward in the GOM, however, it is plausible that platforms will contain increasing numbers of goliath groupers. The relative role of platforms as sources of stock productivity and fishing mortality should be closely monitored as the stock increases.

Gag grouper are more widely distributed in the GOM, but also are overfished. They are extremely vulnerable to overexploitation because they are haremic as adults, and aggregate to spawn at just a few locations in the northeastern GOM. Juvenile gag groupers are mostly associated with sea grass meadows as nursery areas. To our knowledge, the ecology of gag grouper on platforms has received little or no study. However, the work of Lindberg and coworkers on the west Florida shelf has demonstrated that the value of artificial reefs as habitat is effected both by size and spatial arrangement of reef modules. The net effect on stock production of reefs is negative when fishing mortality is considered (Lindberg and Loftin 1998;

Lindberg et al. 2006). Despite these results, we caution against drawing inference about the role of platforms as habitat for gag groupers because the aforementioned work was done on relatively small, low-relief, reef modules. Two other species reported as reef-associated in Table 5-1 (*Neoconger mucronatus* and *Ophidion selenops*) also are found in deep waters on or near the shelf edge.

There are several species in Table 5-1 that are reported as reef-associated, but also occur on a wide variety of habitats including inshore waters, bays, estuaries and sea grass meadows. Qualitatively, these species have life history and behavioral characteristics that are more similar to those found at the production end of Bohnsack's continuum. These include *Chilomycterus schoepfii, Lagodon rhomboides*, two members of the genus *Opsanus*, *Sphoeroides spengleri*, two members of the genus *Trachinotus,* and *Stephanolepis hispidus*. However, given the ubiquity of these fishes, especially in inshore waters, it seems unlikely that platform removal will significantly affect stock biomass and reproductive potential. This group appears to be most like Atlantic spadefish and sheepshead in the group for which Level 3 assessments were made.

Similarly, there is another group that qualitatively appears to have life history and behavioral characteristics that are more similar to those found at the production end of Bohnsack's continuum, but also appear to be more restricted in their distribution than the group described immediately above. These species are reported to occur in coastal waters, and on shelf-edge banks, but are explicitly identified as not being found on coral reefs. This group includes two members of the genus *Equetus*, *Gymnothorax nigromarginatus*, two members of the genus *Hypleurochilus,* two members of the genus *Hypsoblennius*, *Myrophis punctatus, Pseudupeneus maculatus, Saurita normani*, two members of the genus *Syacium*, *Syngnathus louisianae*, three members of the genus *Synodus,* and the blue phase of *Thalassoma bifasciatum*. These species are generally less widely distributed. Furthermore, blennies are nest builders that depend on hard substrate. Removal of platforms would likely affect this group more than the species described above. This group also appears to be most like Atlantic spadefish and sheepshead in the group for which Level 3 assessments were made.

There are several small, cryptic species listed in Table 5-1 as reef-associated that we believe to be more strongly associated with reefs than the species described in the preceding two paragraphs, and whose life history and behavioral characteristics appear to place them solidly at the production end of Bohnsack's continuum. Although information about the ecology and life history of this group on platforms is lacking, and there are no analogues for these among the group for which Level 3 assessments were possible, we believe that platform removal would reduce the distribution or productivity of these species in the northern GOM. This group includes *Callionymus bairdi*, *Coryphopterus punctipectophorus*, *Ophioblennius atlanticus, Prognathodes aya*, *Rypticus maculatus*, the yellow phase of *Thalassoma bifasciatum,* and *Trachinocephalus myops.*

There are several species listed in Table 5-1 as being reef-associated in FishBase, whose life history and behavioral characteristics, qualitatively, do not strongly support placement near either endpoint of Bohnsack's continuum. This group is has been reported from a wide variety of natural hard-bottom habitats in the GOM, including platforms, but appear to have only moderate site fidelity. Many support directed commercial fisheries, and all appear among the list of species harvested by recreational anglers. This group includes six members of the genus *Lutjanus*, including the northern red snapper which is severely overfished, *Rhomboplites aurorubens*, *Brotula barbata*, three members of the genus *Centropristis*, *Haemulon plumierii*, and *Paranthias furcifer*. Of this group, only the red snapper has been reasonably well studied, but almost all of the work on adults at ages that recruit to platforms has been done on small, low-relief, artificial reefs in the northeastern GOM. Similar to the results reported by Linberg and coworkers for gag grouper, studies of red snapper indicate that the value of artificial reefs as habitat is effected both by size and spatial arrangement of reef modules, and that the net effect on stock production of reefs is negative when fishing mortality is considered (Strelcheck et al. 2005; Strelcheck et al. 2007). In addition, diet studies in the northeastern GOM indicate that adult red snapper rely very little on prey derived explicitly from reef habitats, whether collected on artificial (McCawley et al. 2006; McCawley and Cowan 2007) or natural (Wells 2007) reefs. Despite these results, we caution against drawing inference about the role of platforms as habitat for red snapper given that the aforementioned work was done on relatively small, low-relief, reef modules.

Vermilion snapper, *Rhomboplites aurorubens,* also is overfished in the GOM, and the other lutjanids are much less abundant than are red and vermilion snappers. Of the lutjanids reported in Table 5-1, the dog snapper *L. jocu* is likely to be the most strongly reef associated, as is the creole fish, *Paranthias furcifer*. We believe the remainder of the species in this group to be reef-associated, rather then reef dependent, thus it is difficult to assess how platform removals will affect stock dynamics, especially for the species that are overfished. This group as a whole is most similar to red snapper among the Level 3 species.

5.3.2 Level Three Results

Sufficient life history information was available for five species to conduct a Level Three analysis: red snapper, blue runner, sheepshead, Atlantic spadefish and bluefish. Tables 5-2 and 5-3 present data used in the assessment and their sources. Calculated estimates of biomass production per year per platform using Rickers's method ranged from 306 kg platform^{-1} by sheepshead to 1,627 kg platform^{-1} for blue runner (Table 5-4). Estimates using Edgar and Shaw's empirical approach were consistent in pattern, but averaged less than half of the values derived from Rickers' methods (Table 5-4). This difference was largely because we estimated specific growth rates (G) for each species over a period that was shorter than their reported life span. For red snapper, blue runner and sheepshead, the age classes we used were those in which high growth occurred during that period of their life cycle. Biomass production in the Ricker equations is sensitive to the ratio of G/Z (or G/M), and the ratio was close to, or less that 1 for all but red snapper (Table 5-3). When the ratio is less than one, there is a net loss in population biomass. It is also important to note that the often highly productive pre-recruit period was not included in our calculations, which could have large effects on the overall production estimates.

The annual production for each species, however, was more dependent upon the index of reef exclusivity, suggesting that species for which platforms provide only a small fraction of prey resources (e.g., red snapper, blue fish and blue runner) may be less affected by platform removal than for species such as Atlantic spadefish and sheepshead that depend heavily upon the fouling community for food. Low annual production values also imply that platforms are more likely acting to attract individuals from surrounding natural habitats rather than producing new population biomass. However, the lack of quantitative diet data from fishes collected around platforms, especially red snapper, and the unknown effects on relative predation vulnerability associated with different habitats, limits the confidence we place on this interpretation, especially given the sensitivity of production estimates to subtle changes in the G/M ratio.

5.3.3 Level Four Results

5.3.3.1 Baseline

As described in Section 5.1.3, the model was exercised using three species: red snapper and two hypothetical species, A and B. Consistent with the species differences in movement assigned to the three species, hourly distances moved by red snapper was intermediate between species A and B (Figures 5-3 through 5-5). Species A was assigned the longest *nightdist* value and the shortest *daydist* value; species B was assigned the shortest *nightdist* and the longest *daydist* values. As expected, species A showed large hourly jumps in distance moved during the night time foraging and shorter distances moved during daylight when moving towards the nearest platform (Figure 5-5). Species A individual required almost all of the 12 hours of day time (hours 13-24) to get back to a platform cell. During one day, the species A individual wandered so far from the nearest platform cell during nighttime foraging that the closest platform cell became a cell of a different nearby platform. The individual of species B showed the opposite behavior; short movements during night time and large distances moved hourly when moving to a platform during the day time (Figure 5-5). This individual of species B never wandered far enough from the platform cell during nighttime foraging to put itself closer to another platform cell, and was able to return to the platform cell within a few hours of daylight movement (never a label for hour of day greater than 10). Red snapper was intermediate with relatively moderate and similar distance movements during the night time and day time (Figure 5-3), and like the individual of species A, wandered far enough from a platform cell to then move the next day time to a different platform cell.

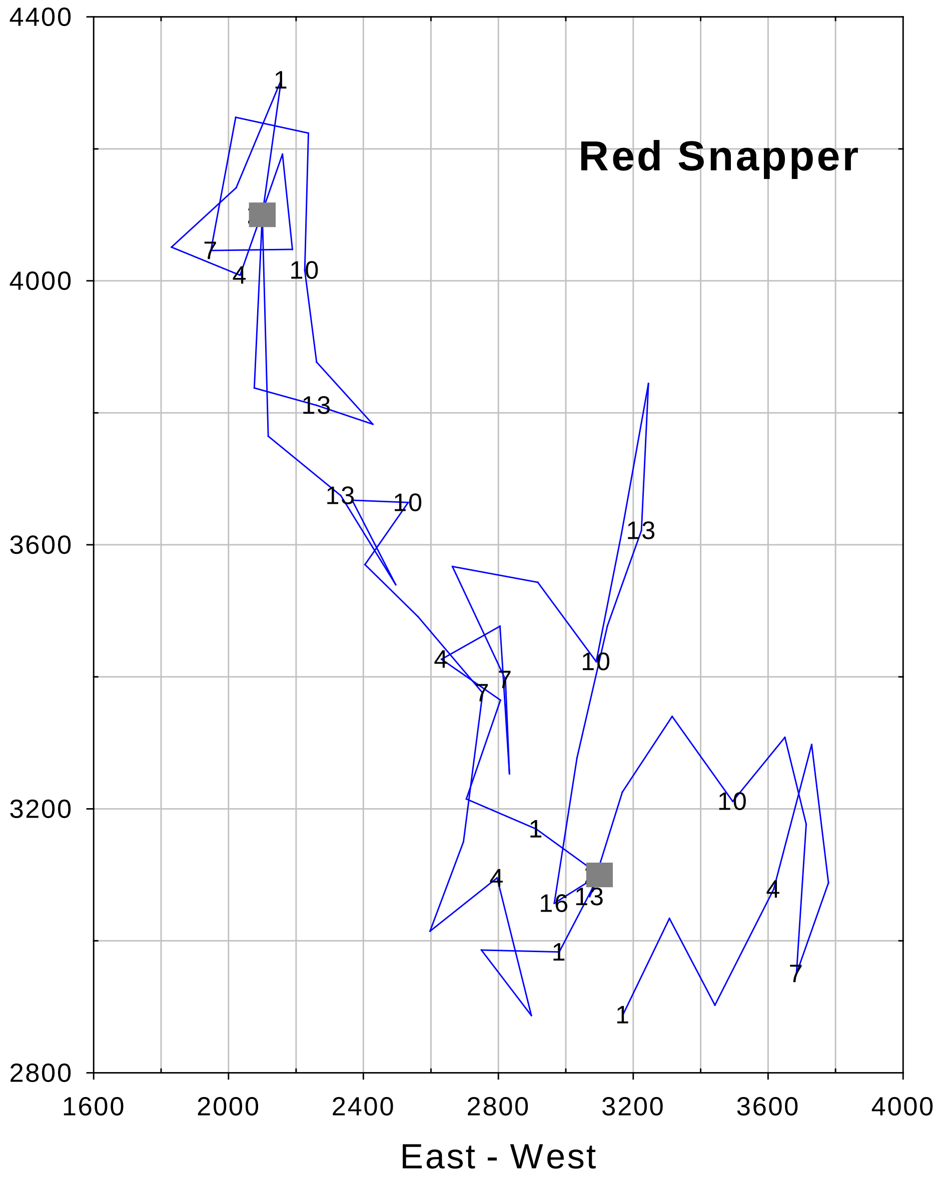

Figure 5-3. Hourly position of an individual red snapper during four days in year 20 in the baseline simulation. The numbers on the track line are hours within each day (1-12 is night time and 13-24 is day light). Rig cells are shown with a grey square.

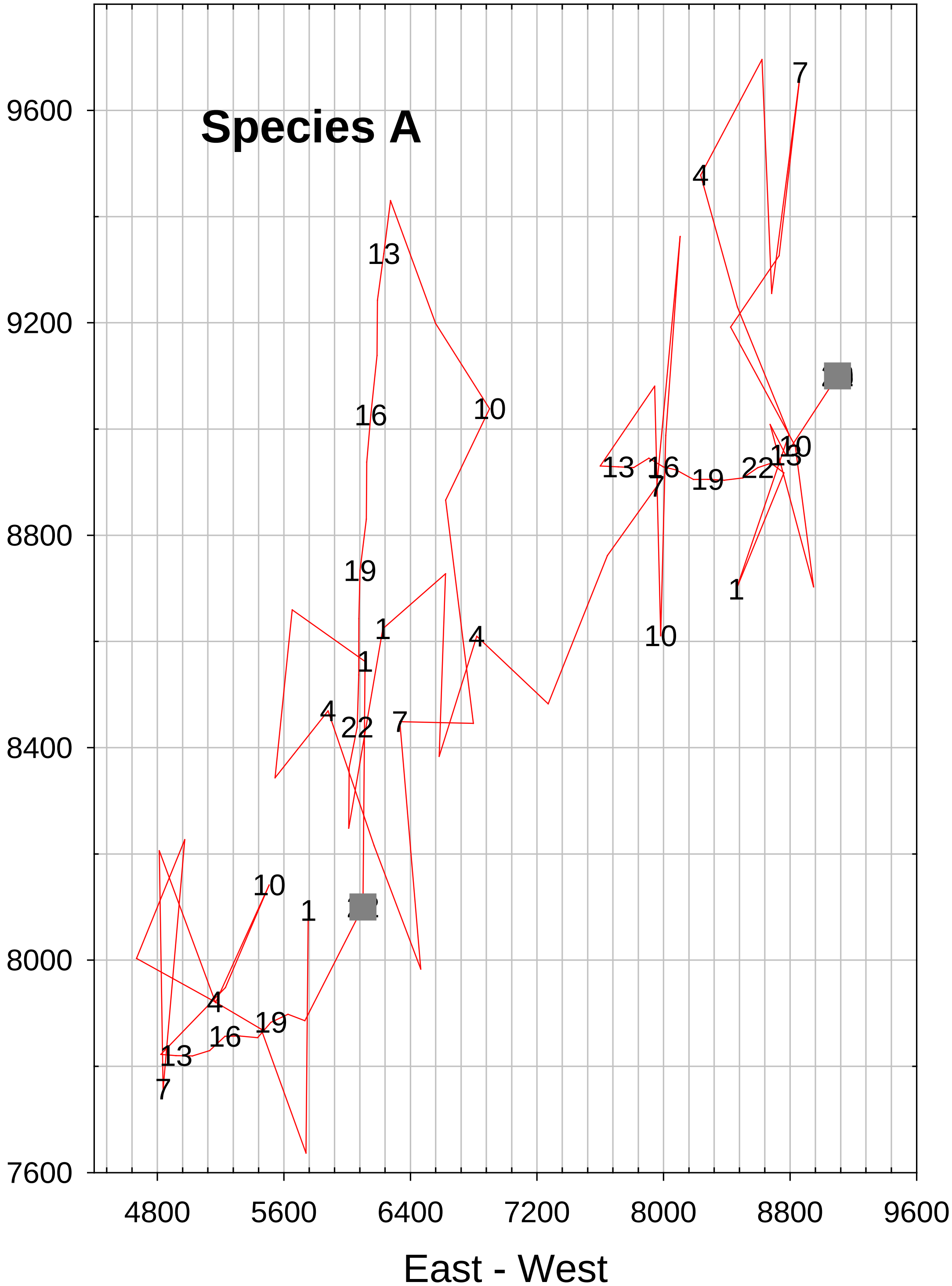

Figure 5-4. Hourly position of an individual of species A during four days in year 20 in the baseline simulation. The numbers on the track line are hours within each day (1-12 is night time and 13-24 is day light). Rig cells are shown with a grey square.

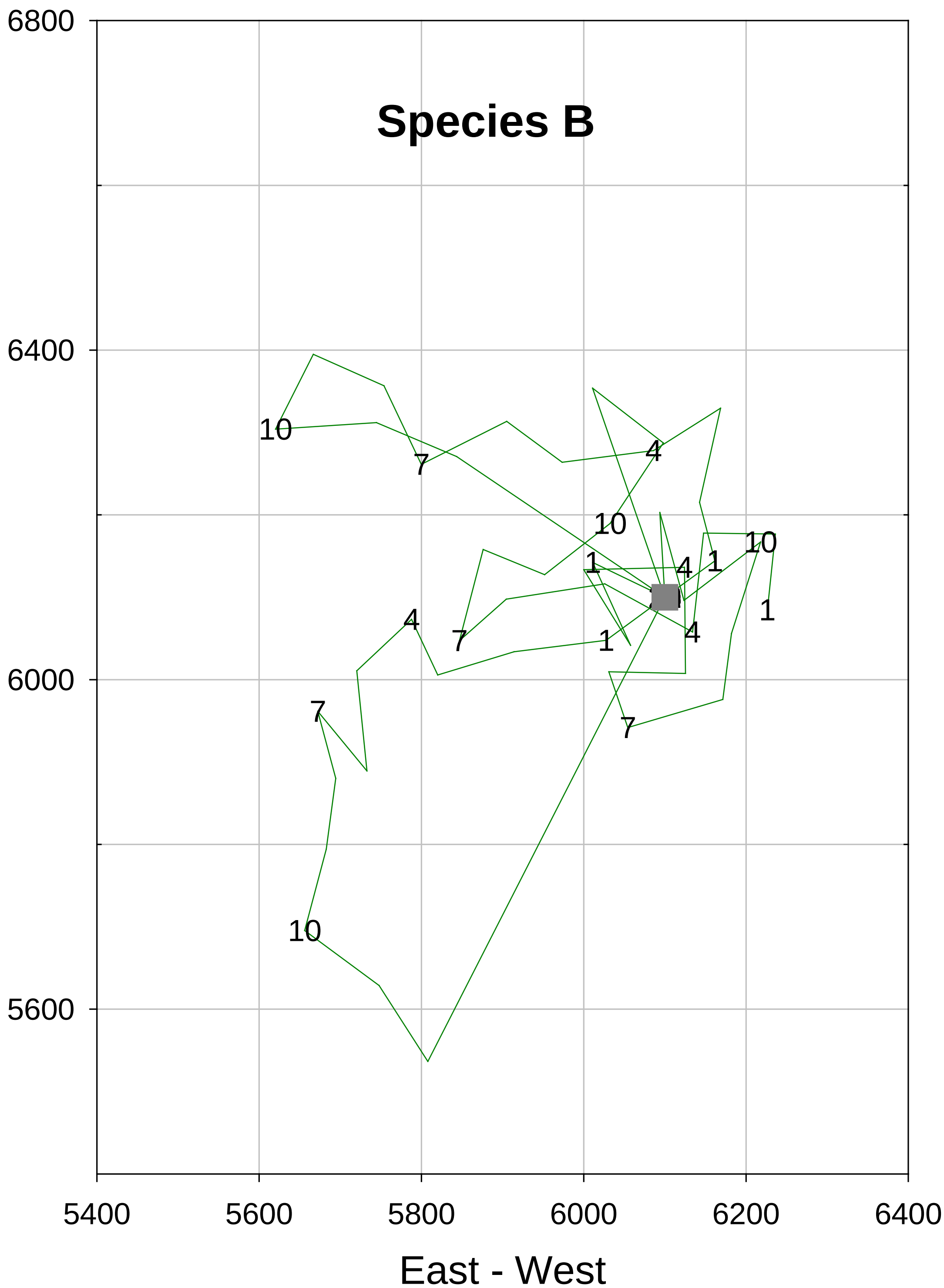

Figure 5-5. Hourly position of an individual of species B during four days in year 20 in the baseline simulation. The numbers on the track line are hours within each day (1-12 is night time and 13-24 is day light). Rig cells are shown with a grey square.

Hourly snapshots of biomass of red snapper during Julian day 56 of year 20 illustrate the day versus night differences in spatial distributions (Figure 5-6). Individuals begin to wander off of platforms cells in hour 2 as they start night time foraging movements, and continue to show a spreading out from the platform cells in hours 6 and 11. By hour 11 (just before sunrise), individuals are clustered around the platform cells but quite spread out. Beginning in hour 13, individuals move towards platform cells with all biomass becoming located on platform cells by hour 24 (just before sunset). The apparent diffusion-like process of biomass spreading out from platform cells during the night time reflects that prey were distributed evenly throughout the gird (except the platform cells that had zero prey). With only a very small effect of red snapper, species A, and species B consumption on prey densities, the 20% threshold in growth rate needed for a cell to be considered "better" than the other cells is rarely invoked. Thus, individuals move essentially in random directions from the platform cells, mimicking a diffusion process. With higher densities of fish and non-uniform spatial distribution prey densities, movement would become less random and fish biomass would show other spatial patterns during the night time foraging period.

Total biomass of the three species showed consistent cycles year after year that reflected the effects of decreasing numbers of individuals during the year with increasing weight per individual (Figure 5-7). The higher numbers of recruits assumed for species A (Figure 5-8) more than offset its slower growth and smaller body size (Figure 5-9) and resulted in species A showing the highest biomass. Species B had the second highest biomass (Figure 5-7) as a result of assumed higher recruitment and similar growth for species B compared to red snapper (Figure 5-8 for recruitment and Figure 5-9 for growth). Red snapper showed the lowest biomass of the three species, despite similar growth rate as species B because of the lower recruitment of new individuals assumed for red snapper.

5.3.3.2 Ten to Five Platform Reduction Simulation

The removal of the five platforms resulted in lowered biomass and growth production of red snapper. Based on year 20, average daily biomass of red snapper was 16.14 MT under baseline compared to 15.09 MT with the 5 platforms removed, and average daily growth production was 24,024 g/day compared to 22,553 g/day. This reduction in growth production was due to increased respiration assumed for individuals when they were not in a platform cell during daylight hours. The fewer platforms forced individuals to travel farther, which required more hours, in order to reach the safe haven of a platform cell. In this particular configuration of the model, the mortality penalty of being in non-platform cells during day light was relatively small compared to the respiration penalty. Thus, the reduction in total production (growth plus mortality) mimicked the approximately 6% reduction predicted in growth production alone that reflected respiration. Average daily total production of red snapper went from 384.9 MT under baseline to 357.9 MT under the 5 platforms removed.

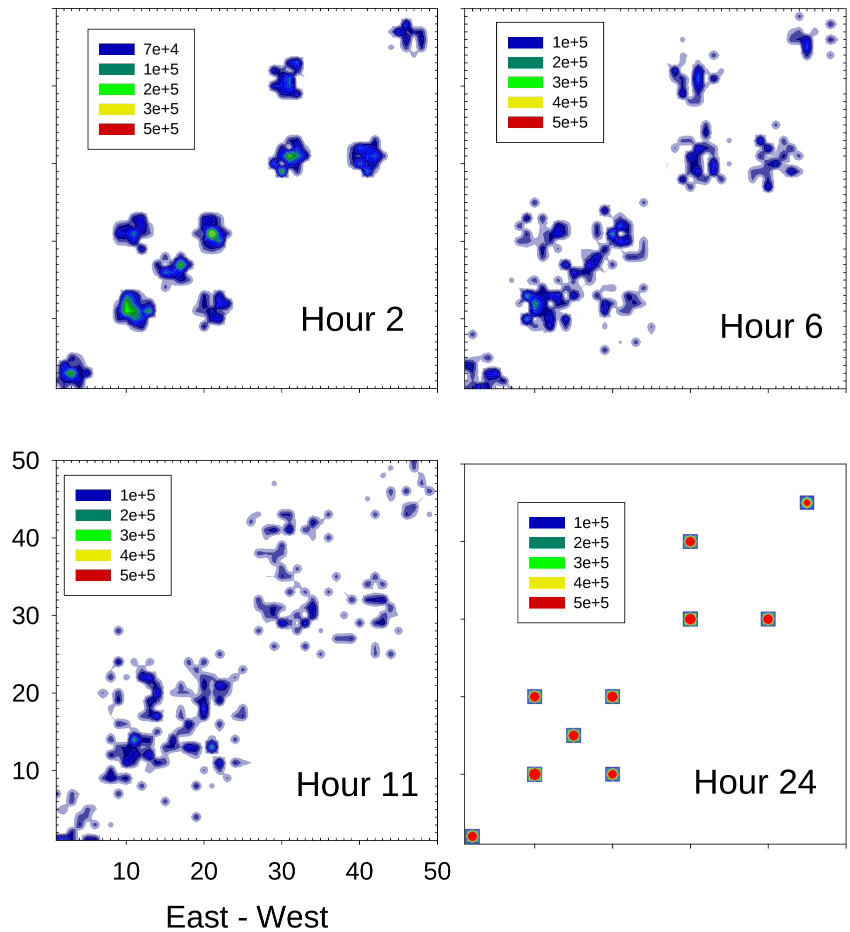

Figure 5-6. Red snapper biomass (g) at four hours during Julian day 56 of year 20 in the baseline simulation.

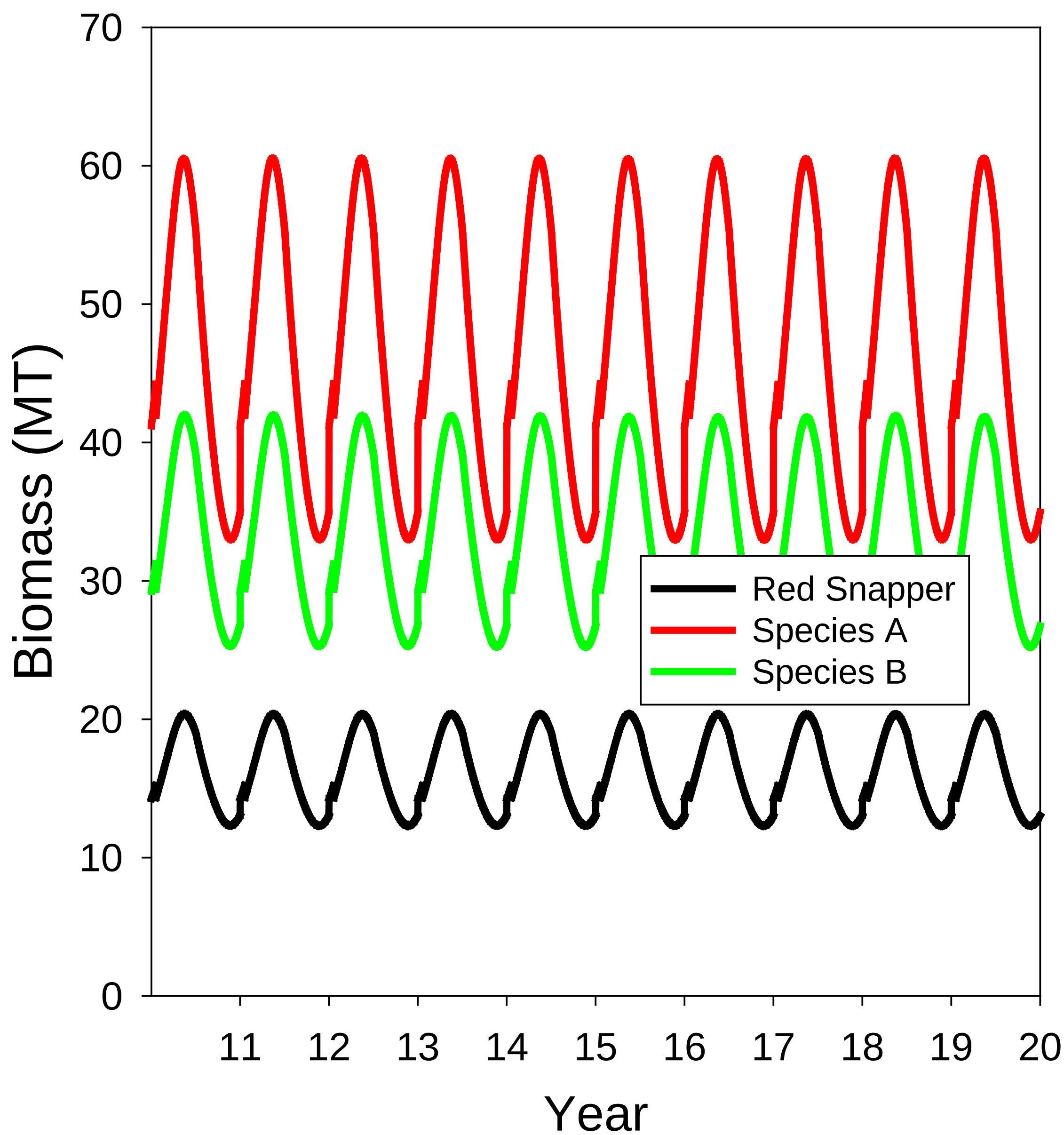

Figure 5-7. D Daily total biomass of red snapper, species A, and species B for years 10 to 20 in the baseline simulation.

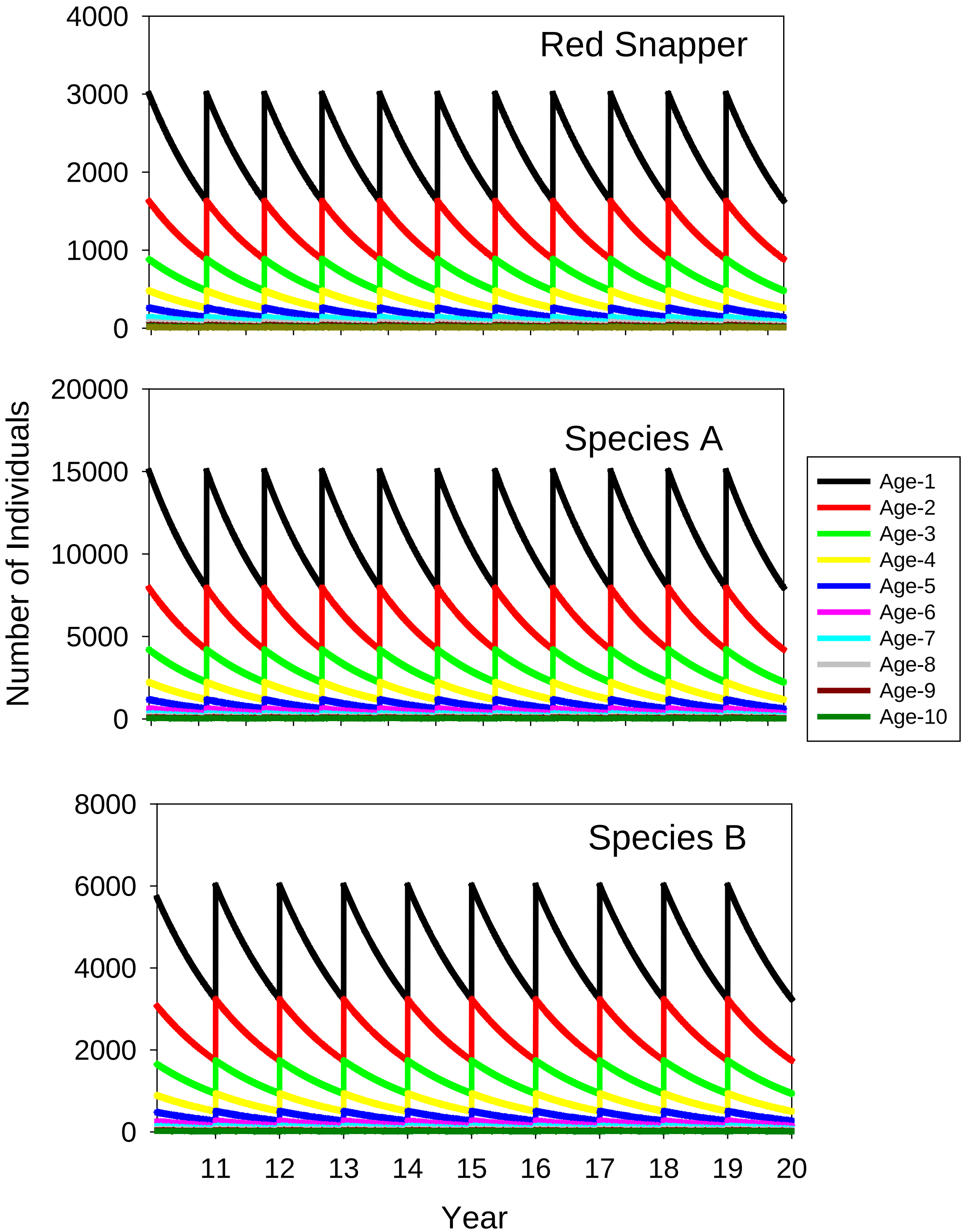

Figure 5-8. Numbers of individuals in each age class of red snapper (top), species A (middle), and species B (bottom) for years 10 to 20 in the baseline simulation.

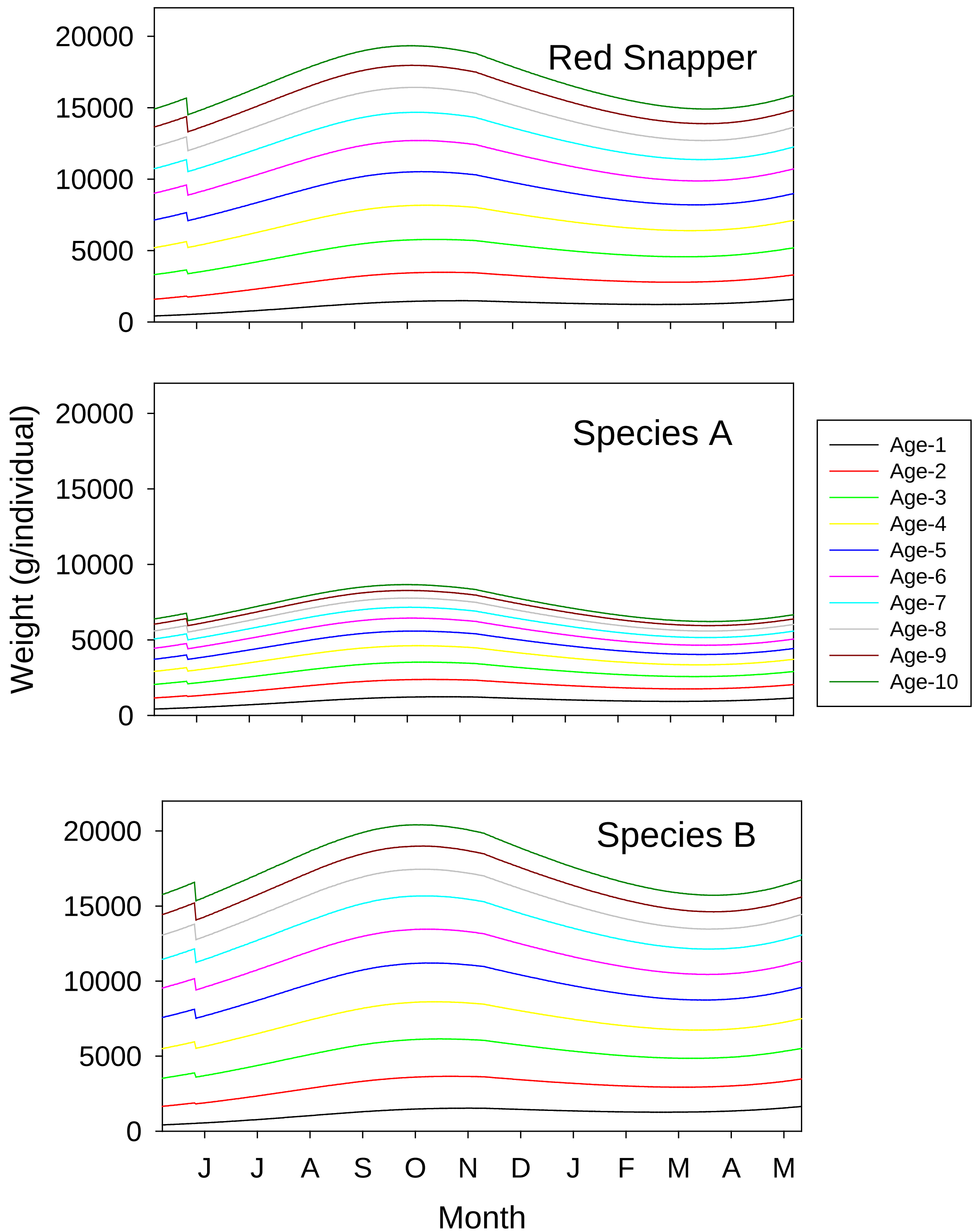

Figure 5-9. Mean daily weight at age of red snapper (top), species A (middle), and species B (bottom) for year 20 of the baseline simulation.

5.4 DISCUSSION

5.4.1 Ecological Context

The effects of oil and gas platforms on the fish populations are largely determined by the natural habitats on which these structures have been placed. What should be expected to happen when artificial reefs are deployed? The area in the GOM where most platforms occur is dominated by muds and quartz sand, and diversity is relatively low (Sections 4.0 and 4.2). Hermatypic, reef-building corals are rare. They are found primarily on the Flower Garden Banks, offshore of the Texas-Louisiana boarder, and a few platforms near the shelf-edge. Unlike true coral reefs, corals did not build the Flower Garden Banks; rather they are geologic formations that were formed during the last sea level transgression. Fish and invertebrate communities found there more closely resemble those typical of the Florida reef tract and Caribbean coral reefs than elsewhere in the northern and western GOM, but are considerably less diverse (Rooker 1997; Gittings 1998).

This has led some to argue that the northern GOM continental shelf resembles a blank slate, where placement of artificial reefs on areas where hard bottom is limited has resulted in a fundamental transformation of habitat, and a fundamental change in biota (Shipp 1999). He suggested that on the Alabama shelf, placement of artificial reefs displaced a fish fauna dominated by small benthic species with larger reef related forms, thus vastly improving fishing opportunities for Alabama citizens (Minton and Heath 1998). Based upon this improvement in fishing, it was further argued that while this change in habitat may or may not have resulted in a net change in fish biomass (or biomass production), it would not be of importance in management of GOM fisheries.

We believe this argument to be flawed. Hard-bottom habitat is far from absent in the northern GOM, and there is no conclusive evidence this habitat is limiting to the fishes that naturally occur in the region. However, most of the natural high-vertical relief habitat in the northern GOM occurs farther offshore than is convenient for most recreational and some commercial fishers to exploit. Moreover, these habitats are not typical reefs; rather, most occur offshore as shelf-edge banks. As described in Section 4.2, there is a large amount of hard substrate of model relief (10's of meters; Figure 4-1). These reefs are not biogenic and support very little hard coral. They are comprised mostly of soft-corals such as *Oculina*, some sponges, bryozoans and gorgonians, all of which are able to exist in an ecosystem that is frequently exposed to high sediment loads. Total numbers of fishes are dominated by a relatively small suite of species, most notably snappers (northern red and vermillion) in the western GOM, and deepwater groupers in the eastern GOM off Florida.

Perhaps of more relevance to this report is recognition of the presence of additional hard-bottom habitats on the shelf in much shallower water than at the shelf edge. Recent studies conducted by Louisiana State University, as summarized in Section 4.2 and illustrated in Figure 4-2, indicate that there may be a much larger amount of low-relief hard-bottom than generally has been acknowledged. In recently completed studies of biological communities associated with these habitats (Wells 2007; UWF student paper; Wells et al. in press), data indicate that a wide variety of fishes and invertebrates use them. It is also clear that natural communities in the northern GOM are not dominated by species of fishes and invertebrates that are strongly dependent upon “reefs” in a strict sense, and this should be expected given the information provided. It does not make sense ecologically that native species would be dependent on reef habitat in a region of an ocean that is mostly free of reefs. This point is hardened by the fact that, despite the relatively large amount of artificial habitat that has been added, none of the truly reef-dependent Caribbean expatriates reported in Table 5-1 have established self-sustaining populations in the northern GOM outside of the Flower Gardens region.

This is not to say that the natural, low relief hard-bottoms that do exist are not important. Several species of recreational and commercial importance, most notably northern red and lane snapper, and numerous species of ground fishes, utilize these habitats during ontogeny, progressively favoring more structured habitats as they grow older. However, contrary to the assertion made by Shipp (1999), Wells (2007) found that recently settled juvenile red snapper, and adults to at least age 5+, were using the low relief habitats. Moreover, red snapper apparently use this habitat as a refuge from predation because ~95% of the prey found in the guts of red snapper collected from low relief natural habitats, higher relief natural reefs and artificial reefs alike, were obtained by foraging in the soft sediments found nearby (Wells 2007; McCawley and Cowan in press).

It is probably true that large-scale deployment of artificial reefs off the coast of Alabama (maybe as many as 20,000 have been deployed) has resulted in a fundamental transformation of habitat, leading to a fundamental change in biota. It is also true that these actions have displaced a fish fauna dominated by small benthic species in favor of larger reef related forms, thus vastly improving fishing opportunities for Alabama citizens (Minton and Heath 1998). However, should the success of such programs be judged solely upon whether these actions improve fishing opportunities? Should success be judged by whether this change in habitat may have resulted in a net change in fish biomass (or biomass production) of a few, but important species?

We can not answer these questions directly in this report, but we note that opinions about the value of platforms are not shared by fisheries management in the State’s of Louisiana or Florida, both of which are struggling to decide how to proceed given the strong public support for artificial reef programs. Managers in these states are concerned about the effects of artificial reefs on natural fish communities, and when construction of reefs to “enhance” habitat becomes more of a vehicle for “transformation” as lauded by Shipp (1999). Louisiana has placed a moratorium on construction of new reefs of any kind on, or adjacent to, natural hard bottoms. In Alabama, there is substantial evidence that the deployment of reefs there has resulted in a biomass sink for red snapper (Strelcheck et al. in press), and the addition of artificial reef habitat Gulf-wide does not appear to have increased red snapper stock productivity. In contrast, results concerning the few well studied species in the GOM show that the relative value of artificial reefs as habitat is dependent on their spatial arrangement on the shelf, and appear to make fishes such as red snapper and gag grouper more vulnerable to exploitation (Strelcheck et al. 2005;

Strelcheck et al. in press, Lindberg et al. 2006). However, there also is anecdotal evidence that platforms may differ significantly from low-relief reefs with respect to how they affect vulnerability to fishing. Off the Alabama coast, oil and gas platforms have been deployed through out the Artificial Reef Permit Zone, so both types of habitat are available. Charter boat Captain's that depend upon red snapper for their livelihood seldom frequent oil and gas platforms (Charter Captains Mike Theirry, http://captainmikeonline.com/, and Bob Zales http://www.interoz.com/bobzalesfishing/, personal communication), preferring to fish on low-relief artificial reefs where catch rates are reported to be much higher. In addition, data complied by the Marine Recreational Fisheries Statistics Survey (http://www.st.nmfs.noaa.gov/st1/ recreational/ overview/overview.html) report that most anglers who fish at platforms in this area list red snapper as their primary target. There has been considerable speculation as to the explanation for these reports; some have suggested that platforms are more heavily fished and are thus depleted in this area where recreational fishing pressure is high, and the locations are public. Other large public reefs also become seasonally depleted in this region (Theirry and Zales, personal communication). The former would suggest that these large, easy to locate, structures are contributing disproportionately to fishing pressure. It also is possible that, given a choice, reef associated species such as red snapper prefer artificial habitats that more closely resemble natural structures with respect to vertical relief. There are many more unknowns than knowns, particularly regarding the effects of platforms on the population dynamics of GOM fishes. The State of Louisiana has recently funded LSU to determine to examine how biomass and community composition scales to reef size, and whether oil and gas platforms affect foraging dynamics in the same way that smaller, low relief reefs do in the aforementioned studies of red snapper and gag grouper.

The answers may depend upon two issues with respect to oil and gas platforms in the GOM. First, what fraction of the populations in question is actually associated or affected by the presence of platforms? Second, how does association directly or indirectly effect growth, mortality, and other vital rates?

5.4.2 Influence of Vital Rates on Population Size

It is generally recognized that cohorts (a population is comprised of many cohorts) of fishes initially lose biomass immediately after spawning, reach a point during the late-larval to juvenile stage where G=M, after which the cohort gains biomass for some period of time depending upon life history, followed by another period of net loss as members of the cohort age (Houde 200?). The end result is a delicate balance between factors that influence growth and mortality rates, and a population is stable if G=M over the entire life history. So it is not surprising that evaluation of how a particular habitat type will affect population dynamics and long-term stability is challenging, given the almost immeasurable number of ways that habitat can affect vital rates. Unfortunately, the majority of information about how artificial reefs effect fish populations in the GOM is based upon studies of low-relief, relatively small structures. This is most likely attributable to the logistical difficulties of studying structures as large as platforms, and the ease at which smaller structure can be manipulated in experiments (see Strelcheck et al. 2005 and Lindberg et al. 2006 for examples).

There are fundamental differences in the way platforms and low relief, small artificial reefs affect fish populations, so we must be careful not to make inferences based upon studies of the latter. One of the key differences is that low relief reefs in the northern GOM appear to support a much less complex fish assemblage – red snapper, gray triggerfish, and gag grouper account for > 80% of the fish numbers biomass (about 75% is red snapper), and large piscivores do not appear to be overly concentrated around these structures (Frazer and Lindberg 1994; Strelcheck et al. 2005; Lindberg et al. 2006); predators are present, and probably in somewhat higher numbers than over unstructured bottoms. Of note is that these small structures usually have about 1,500-2,000 red snapper around them, ranging in age from 2-6, with a steeply declining catch curve once they become legal size (~40 cm). Annual site fidelity ranges between 25-60% per year. As such, intraspecific competition for food appears to have a significant effect on site fidelity, growth rates, and other vital rates, and results are consistent with the resource mosaic hypothesis (Strelcheck et al. 2005; Shipley in preparation). Similar results have been reported for gag grouper (Lindberg et al. 2006).

It is surprising that platforms also appear to support, on average, ~1,500-2,000 red snapper, but on these structures they make up < 15-20% of the numbers and biomass of the fish assemblage, and there usually is a rich and diverse concentration of large predators around the structures (king mackerel, amberjack, barracuda, blue fish, large Spanish mackerel, several grouper species, jack crevalle, lesser amberjacks, small coastal sharks, etc.). Our best estimate of is that site fidelity around platforms is very low, and we have always assumed this difference to be attributable to foraging dynamics---i.e., bigger foraging halos, hence longer distances to travel to find food, and greater potential to wander to adjacent platforms or artificial reefs. This assumption may or may not be true, but recent results from an MMS funded telemetry study appear to support this hypothesis. Figure 5-10 is a composite that shows the locations of an acoustically tagged red snapper on a platform in the “Circle Rigs” south of Port Fourchon. The upper left panel shows the movements of the individual in 2-D space, with high numbers of detections at the point 0,0 (the platform). The bottom left is a 3-D representation of the same data---each dot is a 3-D position, and dots of similar color are positions taken in short time intervals relative to one another. Note the red dots near the sea floor, indicating long distance movements away from the platform, presumably to forage; these occurred mostly at night. The upper right panel is a feather diagram---each line is a vector representing distance (length) and direction (angle 90 from line towards top = due N). The x-axis is time in hours over which positions were obtained for this fish, suggesting that after some time period of recovery following implantation of the acoustic tag, the fish began to make regular movements away from the platform at night to forage, returning to the platform during the daytime. Over the course of the 2-year study, distances traveled during presumed foraging bouts ranged from ~100 to as high as 600 m away from the platform each night, indicating that a conservative estimate of the of the size foraging halo around this 6-leged platform (relatively small, unmanned) is between 300,000 to 800,000 m^{-2}. We know this estimate is conservative, because we often observed fish that moved outside our limits of detection, only to return several hours later as morning approached.

Figure 5-11 is a periodgram (Fourrier transformed to change the time domain to frequency) of the total the number of detections by hour during 2006. These results indicate a strong periodicity in the number of detections at 24 hours, suggesting that fish moved close the platform and were more frequently detected during daytime hours each day. Finally, red snapper site fidelity estimates from Louisiana oil and gas platforms (< 2 % yr-1; Peabody-Westmeyer et al. in press, McDonough and Cowan (unpublished) are an order of magnitude less than from the smaller reefs that we have studied off Alabama (25 to >60% yr^{-1}; Patterson and Cowan 2003; Strelcheck et al. 2005), suggesting that foraging opportunities around platforms are less than optimal, or that long distance movements away from the platforms to forage expose individuals to high predation risk. If indeed foraging dynamics explain these movements, it is likely that interspecific competition is the principal process at work. As such, the strength of the interactions may be specific to the community composition (and its variability) around individual platforms.

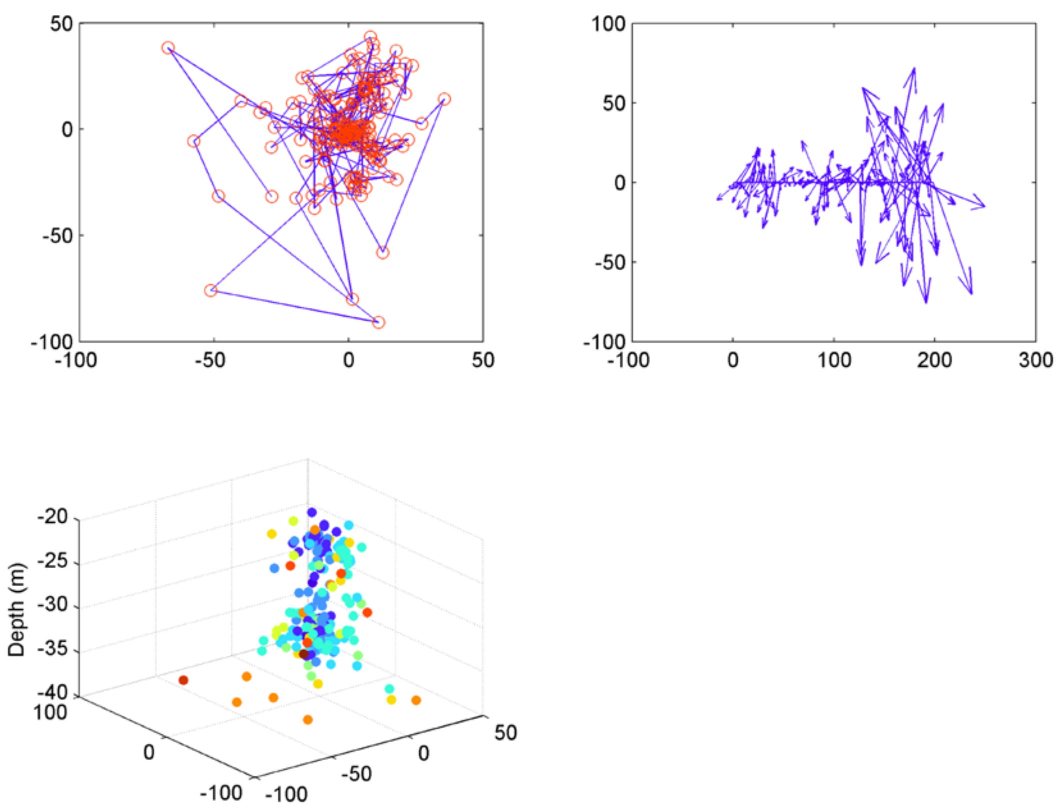

Figure 5-10. Telemetry data from red snapper #213 on a Louisiana platform (McDonough and Cowan, unpublished).

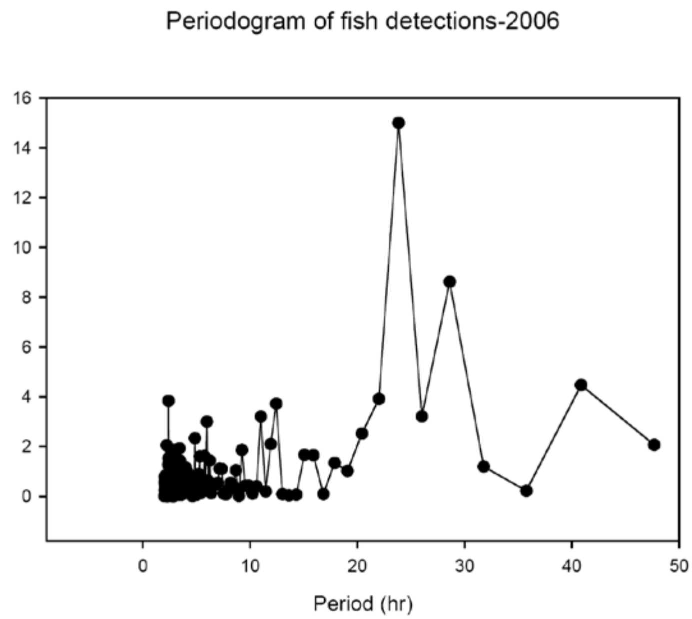

Figure 5-11. Periodogram of fish detections in 2006 on a Louisiana platform.

It is also possible that toppled platforms, which more closely resemble large offshore natural habitats with respect to vertical relief, may affect fish populations differently still, compared to the extremes of large, standing platforms and small, low-relief prefabricated reef modules and piles of materials of opportunity commonly deployed off Alabama and Florida.

In the red snapper IBM, it is apparent that there is a very delicate balance between the benefits of foraging in the benthic communities around the platforms, and the risk of being preyed upon while fish are away from the structure. It is also apparent that large artificial habitats are very different from most of the natural habitats in the GOM (e.g., low relief shell ridges, shelf edge banks, exposed tops of salt domes, other shelf edge features created during previous sea level transgression) with respect to vertical relief. In addition, their distribution on the shelf in more inshore waters has created the potential for significant increases in overlap between predators and their prey, and may have put juvenile snapper (0 &1) and other ground fishes at higher risk to predation on nursery grounds because they generally don't recruit to natural reefs or platforms until a size refuge is reached, if at all. So it may be that deployment of artificial reefs (high and low relief) has created a predation “trap” that has resulted in increased vulnerability to a whole suite of predators that infrequently encountered and consumed juvenile and adult reef associated fishes in the past, and our findings regarding site fidelity on platforms compared to low-relief reefs reflect relative predation risk, rather than foraging behavior. The degree to which the above scenario is important is likely dependent upon whether a significant fraction of the population is exposed to higher predation, and the degree to which an increase in vulnerability during early life prior to recruitment to platforms is offset by increased shelter and a foraging advantage for older fishes after they recruit to the structures. Both are unknown, but could be significant. However, there are numerous examples in ecological studies of such “traps”, where artificial cues draw animals into maladaptive situations; prominent high profile examples include manatees in warm water discharge canals from cooling operations in power plants, the deployment of fish attraction devices to concentrate highly migratory fishes prior to harvest, and the use of power poles by raptorial birds as nesting sites.

It is important to note, however, that commercial fishing for reef fishes began in the northern GOM off Mobile, AL and Pensacola, FL in the late 1800's, long before the first platform was constructed. Historical annual landings of red snapper prior to the 1940's were frequently as high 8-10 million pounds. Over this period, landings were highest in the eastern GOM, and this pattern remained unchanged until ~1964 when catches in the western Gulf began to exceed those from east of the Mississippi River (Porch et al. in press); the shift in the ratio from east to west coincides in time with large scale construction of platforms west of the Mississippi River. It is unfortunate that we cannot say for certain whether higher catches in the west are attributable to an increase in stock productivity, or an increase in vulnerability to fishing, because we are unable to disentangle the two factors, even though our Level 3 analyses seem to indicate that relatively little red snapper production is derived from platforms However, we cannot rule out the possibility that platforms could have large positive effects on species that more clearly derive prey resources from platforms or other types of artificial reefs. One such species may be the gray snapper, *Lutjanus griseus*. Historically, GOM landings of gray snapper have been highest on the Florida west coast. Over time, however, landings in the eastern GOM have declined to less that half of levels in the late 1980's, whereas Louisiana landings of gray snapper have increased by more than 10-fold (Figure 5-12). Some have attributed this increase to their use of platforms as shallow water habitat that is functionally similar to mangrove roots, which is preferred habitat for this species in Florida; others believe that gray snapper have always been abundant in Louisiana waters, and increasing catches are occurring because of changes in fishing practices in response to reduced availability of red and vermilion snappers. It also is possible that changes in the global climate have allowed black mangroves (*Avicennia germinans*) to become established and proliferate along Louisiana's coastline thus changing the nursery function of coastal wetlands. Wetland fisheries ecologists once widely assumed that *Spartina* and black mangroves provided equally valuable nursery habitat (Manson et al. 2005) and that primary production from both habitats was readily transferred to higher trophic levels, but this paradigm has been seriously challenged. Evidence indicates that mangrove detritus may not contribute significantly to basal resources and that use by decapods and fin fishes of mangrove habitats may not be equally advantageous across habitat types and latitudes (Lee, 1995; McIvor and Smith, 1995; Marguillier et al., 1997; Sheridan and Hays, 2003) but some species may benefit as nursery functions change. The effects of continued expansion of black mangroves on nursery-ground function and fisheries production in Louisiana are therefore unknown. Similarly, the role that platforms play in the GOM fishery ecosystem could change with climate in ways that cannot now be predicted, but should not be ignored.

Figure 5-12. Gray snapper landings in the Gulf of Mexico Florida west coast and Louisiana, 1985-2005.

The role of platforms as habitat for reef fishes is complex, and considerably more work at the process level will be needed before we can disentangle the relative affects of platforms with respect to the attraction vs. production debate. IBM’s are one such tool for sorting out the vagaries we have described above, as new process level data becomes available.

The IBM was developed to illustrate an extreme example of a Level Four analysis, and will be used to evaluate some of the scenarios above as data become available. The version of the model presented here is a first step in a much longer process of model development. Although the overall structure of the model is sound, many parameter values were educated guesses, species differed by only a few parameter values, and no model validation was performed. The model and analyses do illustrate how a detailed, population modeling approach could be used to assess the effects of removing artificial structures for the select few species for which extensive data are available. We demonstrated how a modeling approach like the model presented here can be used to predict the change in production with the removal of specifically located artificial structures.

Other population approaches are also possible that are simpler to apply. For example, it is conceivable that a spatially-explicit age or stage-structured matrix projection model could be developed (like those in stock assessment), and the effects of the removal of artificial structures be simulated via clever tweaking of model parameters. These simpler approaches may be applicable to more species than the detailed, individual-based model described because of fewer data requirements. The individual-based model is an example of one of the most complex approaches to Level Four analysis.

There are advantages and disadvantages to the individual-based approach illustrated here in the Level Four analysis. Individual-based modeling in ecology is rapidly gaining popularity (DeAngelis and Mooij 2005), especially for situations where the variability in size or age or other traits is important and when the issues demand a spatially explicit treatment of habitat (Tyler and Rose 1994). Following individuals allows for easy representation of differences in reproduction, growth, and mortality, either from genetic differences or from unique experiences, to be included in the model. How to model behavioral movement of organisms (as opposed to advection and diffusion) can be approached in straightforward manner in the individual-based approach by assigning rules and distances moved to individuals (i.e., analogous to Lagrandian particles). The alternative of moving biomass from cell to neighboring cells (Eulerian approach), when based on behavior rather than physics, is less intuitive and can be difficult to parameterize to get realistic spatial distributions. A major disadvantage of the individual-based approach is that data and information are needed on fine scales, which are often unavailable. For example, in the red snapper example here, we moved individual fish every hour; yet, we do not accurately know what cues fish are using to move on such fine temporal and spatial scales. We simulate hourly dynamics because we think local interactions and fine-scale movement are important, and thus representing them will lead to more accurate aggregate (seasonal and annual) predictions of red snapper biomass and spatial distributions. However, representing fine-scale behavior makes validation of the model become more difficult because we need to corroborate both the fine-scale movement (for which there is little data) and the broader-scale predictions. The individual-based modeling approach is excellent for exploring the mechanisms underlying key questions in a research mode. Most individual-based models cannot yet be validated to a sufficient level of confidence to allow easy use in the fisheries management arena. As advances in data collection methods continue (e.g., radio-tracking), more rigorous validation of fine-scale individual-based models will become the norm and they will become much more visible in fisheries management decision-making.

Developing the individual-based model, even only for demonstration purposes here, highlighted several, potentially critical, data gaps. How to represent the benefits and costs of being near artificial structures during foraging during the night time hours and during the day light hours remains uncertain, yet is critical for quantifying the effects of removing artificial structures. We simply imposed 20% respiration and mortality penalties for not being in an artificial cell during day light hours; there are many possible ways proximity to artificial structures can affect the movement, growth, and mortality of red snapper. We also assumed natural and fishing mortality rates were constant across the spatial grid. Mortality from other fish predators and fishing is likely concentrated near artificial structures, and responds to changes in the number and locations of artificial structures. Representing more sophisticated and more realistic benefits and costs of artificial structures to red snapper, and simulating natural and fishing mortalities dynamically in response to fish distributions, can be incorporated into the model as information becomes available. The model can also easily accommodate more species than the three simulated here, and parameter values can be specified by age or size.

The individual-based modeling approach will continue to be developed, refined, and tested using existing data and data from ongoing studies. There are extensive data now available on short and long-term movement patterns from tagging studies and acoustics (Patterson and Cowan 2003; Peabody and Wilson 2006; Westmeyer et al. in press; McDonough and Cowan in preparation). The challenge will be in how to realistically represent the mortality risks in space and time and the benefits and costs of being positioned near or on artificial structures. Further attempts to refine the model to include dynamic mortality and the benefits and costs of proximity to artificial structure should help clarify what information is missing and critical, and thus what data needs to be collected to improve the realism of the model for use in evaluating removals of artificial structures.

6.0 THE ROLE OF PETROLEUM PLATFORMS AND CONSTRUCTED REEFS IN NON-INDIGENOUS SPECIES INTRODUCTIONS AND RANGE EXPANSION

This Chapter was authored by D. Sheehy, Aquabio, Inc. in a report to Versar, Inc. dated 12 September 2007

In preceding sections of this report, the primary topic of discussion has been how GOM platforms and structures may influence fish populations. However, an additional issue relating to the ecological consequences of artificial structures in an ecosystem was identified in the course of our literature search and review. This was the fact that artificial structures can play a role in the establishment and range expansion of non-indigenous species. Non-indigenous species (NIS) have the potential to create ecological problems as well as adverse economic impacts. Biological invasions resulting in the establishment of species beyond their normal geographic range are altering coastal ecosystems worldwide, and their adverse impacts are increasing. Anthropogenic habitat alteration such as installation of platforms can be a contributing factor in the establishment and expansion of such species. Although ship ballast water appears to be the largest single vector for marine introduction, fouling communities on ships, offshore petroleum platforms, and certain reefs constructed from platforms or inactive vessels are identified as contributors. There is growing concern over the reported increase in such introductions world-wide (Ruiz et al., 1997), including the marine waters of the Northern Gulf of Mexico.

Platforms provide hard substrate and vertical profile throughout the water column where none previously existed. Such habitat alterations are likely to continue as petroleum exploration and production move farther offshore into deeper waters, and existing obsolete or non-productive platforms in shallower waters closer to shore are decommissioned and removed for scrapping or reused to construct reefs.

Significant fisheries benefits are attributed to the addition of platform habitat in the Northern GOM, as described elsewhere in this report. Additional benefits may accrue if decommissioned platforms are appropriately used to construct reefs (Sheehy and Vik 1982; Driessen 1985). However, depending on how these decommissioned platforms are handled when removed or redeployed as reefs, further transfers or range expansions of NIS may also occur. Both the positive benefits and negative potential impacts of platform disposal or reuse should be considered in the strategic planning process.

This section briefly reviews the potential contributions of petroleum platforms and constructed reefs as source or sink habitats for NIS in the GOM and how the NIS issue may affect the removal and reuse of petroleum platforms. Current concerns about NIS, conditions in the GOM that may contribute to the further introductions, and NIS species already found in the GOM are described. Species native to the GOM that might be transferred to other region by mobile platforms are also noted. Potential approaches for evaluating the risks related to the NIS problem, reducing NIS impacts, and improving the benefits associated with platform decommissioning are briefly introduced in the report section dealing with research needs.

6.1 BACKGROUND

NIS impacts may include changes in ecological diversity, injury to native species, and economic losses. Some species introductions, which have occurred either through translocation or habitat alteration, have come to be viewed as beneficial. In most cases, however, species intentionally introduced, accidentally transferred with hard substrate habitat and ballast water, or occupying newly created habitat or disturbed areas have proven to be nuisances. Efforts to understand the origins, extent, and vectors for NIS introductions have been established in the GOM. As part of this effort, several NIS initiatives have been developed to address this issue and track the subset that may become harmful invasive species (EPA, 2000; GMFC, 2007; Smithsonian Environmental Research Center, 2007; USGS, 2007, ACOE 2005). Partnerships among these groups along with active participation of Gulf States academic institutions and research sponsored by the MMS are contributing to improving both the quantity and quality of information on NIS.

A variety of terms, a number of which are synonymous, are used in the literature to describe species that are not normally native to a region. These include *non-indigenous, non-native*, *introduced*, *invasive, alien*, and *exotic*. For this section, we use the term *non-indigenous species* (NIS) to indicate a species that is not indigenous. This is a neutral term that does not imply whether or not the species is a threat to the ecology or economy of an area. The dichotomy described by indigenous versus non-indigenous does not account for the uncertainty associated with many species. The term "cryptogenic" (i.e., of unknown origin: Carlson, 1996) applies to many species for which the status is unclear.

The term *invasive species* is used herein to mean the arrival, establishment, and diffusion of a non-native species that has the potential for harm. Executive Order 13112 (Federal Register, 1999) defines invasive species as "an alien species whose introduction does or is likely to cause economic or environmental harm to human health." In this report, we would simply clarify that this definition includes the likelihood for ecological harm. A noninvasive species is an NIS that remains localized within its new environment and does not result in environmental harm.

The process by which NIS become successful invaders is generally broken down into three component phases (*sensu* Carlton, 2004):

1. Transport - uptake from the donor biota and transport along a disbursal pathway or vector.
2. Introduction – release or inoculation and initial survival on the donor biota in the new environment
3. Establishment – survival of donor biota to form a reproducing population

In natural marine communities, NIS are transported to a new region through two processes: natural range expansions, and deliberate or accidental introductions (Carlton, 1987). Range expansions consist of dispersal of a species into a region where the species did not formerly exist. Range expansions can occur naturally, but may be influenced by habitat alterations or other anthropogenic factors that improve the probability for survival. Introductions consist of transportation and initial survival of a NIS by human activity into a region where the species did not formerly exist.

To be successful, an invader species must pass through all three phases. Here, we are interested in cases where offshore petroleum platforms or other types of constructed reefs (e.g. ships) may be directly involved in the transport, introduction, or establishment of NIS in the Northern GOM as well as changes in environmental conditions that may contribute to successful establishment of invasive species.

Recent inventories of estuarine and marine NIS/invasive species in the GOM region (Ray, 2005a) include 74 animal species, most of which are estuarine. Although fishes are the most abundant category on the list, at least 10 of these species were deliberate introductions and most others are freshwater or estuarine. A number of others are accidental releases from aquaculture activities or aquaria. Many of the other listed species are mollusks, crustaceans, and polychaete worms, although apparent prevalence may reflect their ease of detection and identification rather than their actual degree of representation. Out of the 74 species, only two species of mussels (*Perna perna* and *Perna viridis*) and two species of crabs (*Petrolisthes armatus* and *Eriocheir sinensis*) are currently characterized as invasive (Ray, 2005a). NIS or invasive listings vary between databases and are subject to change as information becomes available.

6.2 FACTORS INFLUENCING NIS IN THE GULF OF MEXICO

A number of factors influence the potential for NIS introductions and their possible adverse consequences. Although the GOM appears to have fewer established NIS than either the Pacific or Atlantic coasts, this may be due to this area being one of the least studied in the U.S. in terms of marine bioinvasions (Carlton, 2001). In actuality, the GOM region may be particularly vulnerable to aquatic species introductions due to:

- Large numbers of commercial vessels from a wide range of regions coming through numerous large-scale GOM ports.
- Active, year round, cross state recreational boating, fishing, and other aquatic recreational activities.
- Extensive and expanding offshore habitat alteration in the form of petroleum platforms and constructed reefs.
- Subtropical climate and abundant habitat that make the region hospitable to NIS (USEPA, 2000).
- Changing GOM environmental conditions that may contribute to increased NIS introduction or establishment.

- Potential changes in the locations and types of petroleum platforms as exploration and production move farther offshore and involve more mobile and semi-submersible platforms that also have ballast water.

Vessel transit is the primary source of marine and estuarine NIS transport due to releases from ballast water and hull fouling communities. Factors that contribute to enhancing this vector include increased vessel traffic, changes of in-port berthing to more marine regions, higher frequency of port visits, the limited period of effectiveness of antifouling paints, the phasing out of tributylin (TBT) antifouling paint, and greater speed of modern vessels (Minchin and Gollasch, 2003).

There are a number of reports in the literature documenting the association between biological invasions and anthropogenically disturbed habitat (Byers, 2002). Both the placement and removal of petroleum platforms alter local habitats and may create new opportunities for NIS introduction. These altered habitats change fish distribution and local abundance as well as provide hard substrate conditions where none previously existed. The increasing use and reuse of mobile offshore drilling units (MODUs), which can carry entire communities to a new area when relocated (Keeney, 2002), may further increase the introduction and spread of NIS in the GOM.

The introduction and establishment of NIS may be enhanced through an interaction between several of these factors. For example, the introduction of propagules from ship ballast water or hulls may coincide with the provision of new habitat in the form of platforms or constructed reefs. Habitat availability may also be a factor when the source of propagules is natural, for example eddies associated with the Loop Current. Similarly, synergistic effects may occur due to changes in the level or geographic extent of eutrophic conditions, the frequency or duration hypoxic or anoxic conditions, frequency of severe storms, warming water temperatures, or overfishing. Such changes in environmental conditions often alter the outcomes of normal competitive interactions among species that may put previously well-adapted indigenous species at a competitive disadvantage with non-indigenous species. For example, excess nutrients have been shown to favor those species with comparatively higher growth rates, thereby suppressing the growth of other co-existing species. Similarly, NIS species that are tolerant of low oxygen conditions will also have a competitive advantage (Byers, 2002).

6.3 NON-INDIGENOUS SPECIES ASSOCIATED WITH PETROLEUM PLATFORMS AND CONSTRUCTED REEFS IN THE GULF OF MEXICO

Human-made structures such as petroleum platforms and constructed reefs can provide suitable habitats for non-indigenous marine species and can function as corridors for their range expansion (Bulleri and Airoldi, 2005). The platform-related vectors for such introductions include the provision of new substrate, the movement of hard substrate with attached fouling community, and the release of ballast water (for MODUs). It has been suggested for some time that offshore petroleum platforms facilitate species range expansions and/or the introduction of NIS into new geographic areas.

Gallaway and Lewbel (1981) suggested that the network of petroleum platforms in the GOM might provide 'stepping stones' of vertical relief and hard substrate across a soft seafloor environment. Large-scale water mass movements determine the transport of planktonic organisms and may provide a linkage between sources elsewhere in the GOM and the platform sinks. If NIS become established on a platform, the platform can then become a source for further transfer. NOAA's Flower Garden Banks National Marine Sanctuary is concerned that species introduced by platforms may affect the Sanctuary's reef (Keeney, 2002).

The ecology of the living communities that occupy or use the reef habitat in the northern GOM has been described, but efforts to monitor the presence of NIS in the northern GOM are fairly recent and still limited (GMFC, 2007). Although most reported marine NIS are mollusks and crustaceans, many other groups ranging from microorganisms to fish are also represented. As with endangered species, obvious and larger species often receive high visibility, but growing concerns focus on microorganisms causing diseases in other commercially important species and harmful algae responsible for adverse ecological impacts and human health effects for those consuming marine seafood.

Some marine NIS associated with platforms or constructed reefs in the GOM are described below. Six NIS marine species are commonly listed as present in the GOM on multiple databases (Table 6-1). Nine other marine NIS species identified on at least two lists/ databases of GOM NIS species are identified in Table 6-2. Most of the marine NIS have not yet been characterized as invasive, but some such as the source dinoflagellate for ciguatera, viruses responsible for shellfish diseases, the brown and green mussels, and an ascidian may be considered invasive (The Global Invasive Species Database [GISD], 2007) in the GOM.

A wood-boring mollusk (*Lydrodus medilobatus*) and two isopods *(Spheoma terebrans* and *S. walkeri*) are also listed as invasive, but damage is primarily limited to shore sites and estuarine areas. Other non-indigenous species have been occasionally found in the GOM and others, yet undocumented or cryptogenic, certainly exist.

6.3.1 Harmful algae - *Ciguatera*

Although not yet listed as a NIS, the source dinoflagellates for ciguatera, *Gambierdiscus toxicus* (Figure 6-1), have recently been found growing on algae on oil platforms in the Northwest GOM. All six platforms examined off Port Aransas had *G. toxicus*. These benthic dinoflagellates produce polyether toxins that cause ciguatera fish poisoning in humans. Although a clear linkage between petroleum platforms and ciguatera has not yet been demonstrated, these findings suggest that the provision of hard substrate in areas commonly devoid of this habitat may have unintended consequences for human health (Villareal, 2006).

Table 6-1. Commonly Identified Marine Non-Indigenous Species in the Northern Gulf of Mexico				
Species Name	**Common Name**	**Means of Introduction**	**Habitat**	**Impacts**
Tubastrea coccinea	Orange cup coral	Natural currents, fouling	Hard substrate, platforms, coral reefs	Competition with benthic invertebrates, may contribute to removal of native corals
Perna perna	Brown Mussel	Ballast water, fouling	Hard substrate, platforms; Texas	Fouling navigation buoys, intake pipes: competition with indigenous species, Thermal tolerance may limit expansion
Perna viridis	Green Mussel	Ballast water, fouling	Generally estuarine, but found on artificial reefs, spreading south and northwest from Tampa	Clog intake pipes, foul manmade structures, oyster reef injury, disease transfer, Wider thermal tolerance, may expand to the rest of the GOM
Phyllorhiza punctata	Australian Spotted Jellyfish	Natural currents (loop current eddies), or fouling	Pelagic medusae, hard substrate scyphistoma stage	Comm. fisheries (shrimp nets), predation on eggs and larvae of economically important species, food competition with larval fish
Didemnum perlucidum	White Crust Tunicate (ascidian)	Ballast water, fouling	Hard substrate, platforms	Overgrows and smoothers epibiots
Hypsoblennius invemar	Tessellated Blenny	Ballast water, fouling on ships or oil rigs from South America.	Hard substrate. Occupies empty barnacle tests, platforms	Possible competition with native species
Sources include: Gulf States Marine Fisheries Commission: U.S. Geological Survey, Global Invasive Species Database; ACOE (Ray)				

Table 6-2.Additional species listed* as marine non-indigenous species in the northern Gulf of Mexico

Species Name	**Common Name**	**Means of Introduction**	**Habitat**	**Impacts**
Hydroides elegans	Calcarious tubeworm (Polychaete)	Fouling ship hulls	Tube dwelling on hard substrate	Fouls natural and artificial structures. Provides additional habitat and competes Can grow in high density is tolerant of contaminated waters
Diadumene lineata	Orange striped sea anemone	Fouling on ship hulls	Hard substrate	Unstudied but presumed minimal Possible predators on larvae of commercially important taxa
Balanus amphitrite	Striped barnacle	Fouling on ship hulls	Hard substrate	Fouling on buoys, pilings etc. Unstudied
Balanus reticulatus	Acorn barnacle	Vessel hulls	Mid-upper intertidal Hard substrate	Little data about pre-invasion, perhaps displacement
Balanus trigonus	Acorn barnacle	Vessel hulls	Mid-upper intertidal Hard substrate	Little data about pre-invasion
Centropages typicus	Copepod	Ballast water		Established in Texas
Ligia exotica	Wharf roach	Carried by ships	Rocks and pilings often above water line	Potential competition with native species
Sphaeroma terebrans	Warty Pillbug (Isopod)	Wooden hull ships	Bored into wood, mainly mangroves	Damages mangrove prop roots
Sphaeroma walkeri	Warty Pillbug	Fouling on ship hulls	Associated with reef-building tube worms	May alter the abundance of native species and provide food for benthic predators

* listed in both Ray 2005a and Ruiz et al., 2000. Lost of Florida invasive species

Warming water temperatures and expanding migration patterns of some fish may contribute to the potential for increased *G. toxicus* presence.

Figure 6-1. *Gambierdiscus toxicus*, Ciguatera Dinoflagellate. Photo by Maria Faust

The normal soft muddy sand bottom of the GOM is considered poor habitat for the ciguatera source dinoflagellates but the elevated hard substrate provided by platforms supports corals and other components of the tropical benthos that do provide appropriate substrate. The toxins enter the food web when fish forage on macro algae or other biota that host the epiphytic dinoflagellates. Platforms create a unique habitat in the upper euphotic zone actively used by fishers that provides a connection between fish consumers and potentially toxic fish (Villareal et al., 2006). The active fisheries in combination with the lack of an effective and practical test for ciguatera may result in increases in the occurrence of human poisoning. Only a small number of ciguatera poisoning cases have been reported from fish taken in the Northern GOM in the last 25 years, but recently several additional suspected cases have been reported in Texas. The Center for Disease Control is participating in a voluntary survey to help track future cases.

6.3.2 Invertebrates

Petroleum platforms with extensive hard substrate throughout the water column provide large amounts of surface area exposed to water circulation, thus creating excellent habitat for epibenthic community development. Space on which to live is often the most important limiting resource in marine hard substratum communities. Since platforms are often located in areas that lack hard bottom habitat, they provide novel substrate for colonization. The extensive epibenthic community that develops on the platform superstructure includes an abundance of mobile forms living within the microhabitat created by the encrusting community. The plankton filtering capacity of biofouled platforms effectively concentrates planktonic food resources. Both the sessile and motile species occupying platform habitat support local food webs and contribute to the fish forage base provided by the platforms. NIS introductions that degrade this forage base may reduce the fisheries benefits of the platforms.

Parts of the platform fouling community are not permanent, and the episodic loss and re-exposure provides multiple opportunities for NIS introductions. The platform fouling community is partly removed episodically when the biomass increases drag allowing currents and waves to slough off pieces that create additional hard bottom shell mound substrate at the base of the platforms. The distribution, abundance, and population of motile macro-invertebrates differ among shell mounds and soft bottom. Although the shell mounds persist even after the platforms are removed, many species are more abundant and larger under existing platforms than on mounds without platforms (Bomkamp et al., 2004).

NIS invertebrates have been reported on petroleum platforms in the GOM (Sammarco et al., 2004), California (Page, et al., 2006), and in Brazil. In the GOM, this includes the expansion of coral communities, the introduction of two species of mussel, and the white crust tunicate.

6.3.2.1 Corals on Petroleum Platforms

Coral range expansions are anticipated as a consequence of climate change, and petroleum platforms and constructed reefs may provide substrate that contributes to these expansions. Offshore petroleum platforms have already provided opportunities for expansion of coral communities within the Northern GOM (Sammarco et al., 2004). Platforms have also been described as potential stepping-stones for the expansion of coral communities (Achison, 2001). Coral introductions or range expansions related to petroleum platforms have also been reported from Brazil (de Paula and Creed, 2004, 2005). Coral introductions can create problems. The snowflake coral, *Carijoa riisei*, was introduced to Hawaii probably through hull fouling. It has spread throughout the Hawaiian Islands resulting in significant negative impacts by overgrowing black coral, a native deepwater coral.

Sammarco et al. (2004) found 11 coral species on 13 petroleum platforms encompassing an ellipse around the Flower Garden Banks (FGB). Coral abundance and diversity increased with platform age, but the abundance of corals was not related to distance from the FGB. Coral abundance exhibited a non-uniform depth distribution and total abundance peaked at 20-28 m depth. Sammarco et. al. (2004) suggested that platforms with corals have additional intrinsic value as a result of the coral populations and this factor should be considered in decisions involving platform removal. The fact that platforms in offshore environments are capable of maintaining coral growth in areas where none previously existed (due to the availability of hard substrate without sedimentation stress) suggests at least the potential role these corals might play in the broader ecology of coral community dynamics in the GOM.

6.3.2.2 Orange Cup Coral (*Tubastrea coccinea*)

The orange cup coral (*Tubastrea coccinea*; Figure 6-2) is considered a NIS or invasive (Fenner, 2001) in the GOM. It was originally introduce from the Pacific into the Caribbean in 1943, spread throughout the Caribbean in the 1950s, and was introduced to the GOM by the 1960s. The first known sighting of *T. coccinea* on platforms in the Gulf occurred in 1991, and it was later documented on several other platforms in the Gulf of Mexico (Fenner, 2001; Fenner and Banks, 2004). It may have been transported as part of the fouling community on petroleum platforms, and prefers to colonize artificial structures (Fenner and Banks, 2004). It was present in abundance on petroleum platforms (Sammarco et al., 2004) and has been reported on the East Flower Garden Banks (EFGB) and Geyer Bank located 52 km east south-east of the EFGB (Fenner and Banks 2004). It was also reported on a gas platform within the Flower Garden Banks National Marine Sanctuary.

Figure 6-2. *Tubastrea coccinea*, Orange Cup Coral

Tubastrea coccinea prefers shaded vertical surfaces abundantly provided by platforms. The orange cup coral is an endangered species listed on the Convention on International Trade in Endangered Species websites and database (GISD, 2007). It does compete with other benthic invertebrates for substratum space (Vermeji, 2006) and may put native species at risk and contribute to the removal of native corals (Creed, 2006). Platforms may have facilitated the spread of *T. coccinea*, but its high capacity for effective dispersal suggest that platforms are not solely responsible or that their absence would have prevented its introduction in the GOM (Sammarco, et al., 2004). *T. coccinea* does not exhibit strong substrate type preference and readily recruits to all substrates. This opportunistic behavior together with its high fecundity (Creed, and De Paula, 2007) suggests *T. coccinea* can successfully disburse and invade new areas, therefore potentially posing a threat to natural reef systems"

6.3.2.3 Brown Mussel (*Perna perna*)

Invasive mussels, *Perna perna* (Figure 6-3) were first detected off south Texas in 1990 (Hicks and Tunnell, 1993). Within four years, the species further colonized a range of human-made structures including petroleum platforms 6-27 km offshore from Port Aransas at depths ranging from the intertidal zone to 9 m. (Hicks and Tunnel, 1995) and extended as far as southern Vera Cruz, Mexico, a distance of over 1300km. Data indicates a primarily southward disbursal patterns from the initial inoculation point.

Figure 6-3. *Perna perna*, Brown Mussel

More recent studies indicated that growth rate, biomass, productivity, and reproductive effort in Texan populations were similar to those of other *P. perna* populations, suggesting that Northern GOM can support this species (Hicks and Tunnell, 2001). Recruitment varies yearly and some cohorts may not reproduce. Spawning periods extend from March to October at temperatures >18-20 degrees C. Mitochondrial DNA sequence analyses have indicated that the nonindigenous GOM *P. perna* population exhibited a clear genetic affinity with populations from Venezuela (Holland , 2004)

In the Northern GOM, *P. perna* colonizes jetties, navigational buoys, petroleum platforms, wrecks, and other artificial substrate as well as rocky shores. They have a broad salinity tolerance, but narrow incipient thermal limits that may account for their subtidal range in the GOM. Densities of up to 27,000/m^2 have been reported for south Texas jetties (small individuals; mean 16mm plus or minus 0.3 SE). *P. perna* can sink navigational buoys and affect shipping safety (Hicks and Tunnel, 1995). Mussel colonization is becoming a nuisance for water-cooling systems for power plants and can alter the physical structure of a habitat. Although cultivated in some areas, there have been documented severe outbreaks of paralytic shellfish poisoning in Venezuela (GISD, 2007).

6.3.2.4 Green Mussel (*Perna viridis*)

The green or green-lipped mussel (*Perna viridis*; Figure 6-4) has also been introduced in the GOM (Benson et al., 2002) probably through ship ballast water or hull fouling (Chapman, et al., 2003). It is a large mussel, 80-100 mm in length and can form dense populations up to 35,000/m^2 (NIMPIS, 2002). *P. viridis* has a broad salinity and temperature tolerance. *P. viridis* has been found on constructed reefs in Tampa Bay and 16 km off Pinellas County, FL[2]. It is apparently moving both south and northwest from the origin point in Tampa Bay and now ranges from Pensacola, Florida to Brunswick, Georgia, where it was found on a constructed reef 40 km off shore.

Figure 6-4. *Perna viridis*, Green Mussel. Photo USGS, Buck Albert

P. viridis is primarily found in estuarine habitats where it can cause significant damage to oyster reefs and cause fouling problems. *P. viridus* clogs water pipes restricting flow and accumulates on hulls, buoys, and other man-made structures. They may also clog crab traps and clam culture bags, making commercial harvest more difficult. There are still conflicting views on the long-term potential impact on native oyster species (GISD, 2007) but *P. viridis* can outcompete many other fouling species, causing changes in the community structure. It is harvested commercially elsewhere, but is not recommended for consumption when found in areas such as Tampa Bay due to its potential for toxins, parasites, and other health risks (GISD, 2007).

6.3.2.5 White crust tunicate (Didemnum perlucidum)

The introduction of ascidians in tropical and temperate waters is now commonplace. Colonial ascidians are rapidly expanding along the east and west coasts of the US and are also present in the GOM (Bullard et al., 2007; Lambert, 2002). At this point, it is not clear whether or not *D. perlucidum* is a NIS or is simply rapidly expanding in abundance. It is mentioned here

[2] Unpublished data Aquabio, Inc. 2004. Taxonomy confirmed by Mote Marine Lab. These specimens were found in a 0.25m^2 sample

despite questions about its origin and taxonomy (Kott, 2004) because it appears to have significant potential for rapid colonization of artificial substrates and petroleum platforms in the GOM. It is also commonly found on artificial substrates in Brazil (Da Rocha and Monniot, 1995).

Lambert (2002) reports that *D. perlucidum* (Figure 6-5) has completely overgrown a number of oil rigs sunk as artificial reefs off Texas. It has covered hundreds of square meters and smothering the sponges and bivalves that grew on the platforms. It apparently covered 100% of the platform superstructure that had previously been out of the water. Other species in this genus (*Didemnum sp. A*) also have the ability to cause significant ecological damage, smothering natural communities, reducing structural complexity, and likely killing infaunal organisms that provide food for fish (Bullard et. al., 2007). To date there is no indication that *D. perlucidum* has expanded to nearby natural reef habitats, but any degradation of natural reef structure may provide a competitive advantage and monitoring is recommended (Lambert, 2002).

Figure 6-5. *Didemnum perlucidum*, White Crust Tunicate. Photo Rosana M. Rocha

6.3.2.6 Australian Spotted Jellyfish (Phyllorhiza punctata)

Although not yet directly associated with platform or reef habitat, the Australian spotted jellyfish (Phyllorhiza punctata; Figure 6-6) are already considered invasive in the GOM. The bipartite life history of the scyphozoa stage complicates the understanding of these episodic invasions. The invasive jellyfish or medusa stage, which generates the noticeable impacts, is the sexually reproductive stage of the jellyfish; full establishment of a population requires the benthic scyphistoma (polypoid) stage (Johnson et al., 2005) that could take advantage of hard substrate including platforms or constructed reefs. Depending upon environmental conditions, scyphistoma can live longer than 12 months and benthic stages could be cryptic (Haddad and Junior, 2006).

Figure 6-6. *Phyllorhiza punctata*, Australian Whitespotted jellyfish. Photo Univ. of California Museum of Paleontology, Berkley

The initial GOM invasion noted in 2000 may have been the result of natural transport via Loop Current eddies (Johnson et al., 2005). A second invasion event occurred in 2007. Other introductions to the GOM from the Caribbean Sea may have been via ship transport either as fouling benthic scyphistoma or as ephyrae in ballast water. The spread of P. punctata in the Pacific and between the Pacific and Caribbean has been attributed to hull fouling transport of polyps (Larsen and Arneson, 1990; Perry, 2005).

These large jellyfish (average bell width is 35 cm) have been found in swarms of up to 500,000 in a 150-km^2 area (Ray, 2000a). P. punctata is responsible predation impacts on the eggs and larva of important fish and shellfish (Graham et al., 2003) and also competes with them for planktonic food. During the invasion in 2000, both fish eggs and dominant copepods were being cleared at a rate of nearly 100% per day. Graham et al. (2003) suggested that P. punctata might have an indirect effect on zooplankton production through changes in chemical or physical properties of water. This is manifested by surface foam streaks down-wind of a super-swarm and may be due to high dissolved organic matter loading by the swarm. Mucus released into the water by high concentrations of jellyfish increased the viscosity of the water and may elevate toxins as mucus-bound nematocysts are discharged (Graham et al., 2003)

To date, the greatest economic impacts have been the result of clogging shrimp nets that caused damage for this important commercial fishery. Economic losses range in the millions of dollars (GISD, 2007). These jellyfish can also plug boat cooling water intakes and other fishing gear, and have caused fisheries closures in productive areas (Perry, 2005). Global warming has been suggested as a factor in the increase of jellyfish range expansions worldwide and coastal artificial structures may provide a favorable environment for their polyps (Masuda et al., 2007).

6.3.3 Fish

6.3.3.1 Platforms as propagule sources or sink habitat for NIS Fish

Most non-indigenous marine fish introductions are probably the result of ballast water transport and release (Wonham et. al., 2000) rather than hull fouling. Larger fish are less likely to be transported with platforms or obsolete vessels used as reef materials, except in ballast water. Platforms or reefs may, however, provide habitat that can directly or indirectly support NIS introductions or range expansions. Range expansions may also be due to the availability of the epibenthic microhabitat by small cryptic species. Movement of in-water structures may be more likely a factor in the introduction of small cryptic species such as blennies and gobies that are broadly reported on platforms. These species are often closely associated with the fouling community on platforms. Indirect effects include increasing the availability of food resources and providing spawning or ovodeposition sites that alter local distributions of larger species and potentially contribute to range expansions.

The network of platforms may also serve as a vector for range expansions for larger non-cryptic fish. The introduction and establishment of sergeant majors (*Abudefduf saxatilis*) at the FGBNMS and recent (1997) appearance of yellowtail snapper, *Ocyurus chrysurus* (Pattengill 1998) suggests that these range expansions resulted from movement along the platforms in the eastern side of the Gulf, where they were reported by recreational fishers. A series of platforms may create a corridor by shortening the distance between desired habitats and thus allow progressive movement over time. Where fish introductions occur by removal of natural barriers, such as entry into the Mediterranean through the Suez Canal, fish species moving past former barriers occupy constructed reefs (Spanier, 2000 and personal communication 2007).

6.3.3.2 Tessellated Blenny (*Hypsoblennius invemar*)

The tessellated blenny (*Hypsoblennius invemar*; Figure 6-7) is generally considered introduced to the GOM through shipping or transport of oilrigs from South America (either on barnacles attached to hulls or in ballast). It was first documented on oil platforms off Cameron, LA and Galveston TX in 1979 and not present at Galveston before 1979 (Dennis and Bright, 1988).

Figure 6-7. *Hypsoblennius invemar,* Tessellated Blenny. Photo T. Rauch

H. invemar lives in empty barnacle tests and is often found in abundance where the hydroid *Cnidoscyphus marginatus* is abundant (Smith-Vaniz, 1980). Studies suggest that attached invertebrates in the fouling community on the platforms provide a predation refuge, allowing indigenous and NIS blenny species to exist in otherwise unsuitable habitat, specifically the open shallow waters of the northern GOM (Topoloski and Szedlmayer 2004). Petroleum platforms have been associated with blenny (Gerhardinger et al., 2006), goby (Francis et. al., 2003), or damselfish (Foster and Nikon, 1979) introductions elsewhere. Bleniidae, Gobiidae, and Pleuronectidae dominated the list of ballast-mediated introductions and blennies and gobies were the families most frequently established (Wonham et al., 2000).

6.4 NATIVE SPECIES THAT MAY BE TRANSFERRED TO OTHER REGIONS BY GULF OF MEXICO PETROLEUM PLATFORMS

Two species resident in the fouling communities on mobile petroleum platforms or drilling ships in the Northern GOM have been identified as potential NIS candidates if platforms are moved out of the region. These native GOM species may become NIS if introduced outside their normal range and are briefly noted (GISD, 2007).

6.4.1 Atlantic barnacle (*Chthamalus proteus*)

Chthamalus proteus is a barnacle native to the Caribbean and Western Atlantic. It was introduced into the Pacific in the 1970s, reported in Hawaii in 1995, and is now one of the most abundant organisms in the upper intertidal harbors and bays throughout the Hawaiian Islands. It is a serious fouling organism that can alter natural substrates through dense colonization, potentially leading to habitat conversion and alteration of native species settlement patterns. Transport is either via hull fouling or ballast water.

6.4.2 Leathery tunicate (*Styela plicata*)

Styela plicata (sea squirt) is widely distributed temperate to subtropical tunicate that can compete with native encrusters and exclude them from hard substrates. *S. plicata* is a fouler of ships, docks, power plants, and shellfish ponds. It can be introduced to new locations either by hull fouling or ballast water. *S. plicata* is often covered with non-ascidian epibiots that can travel with the tunicate and add NIS to other systems (Fuller, 2007). The larvae can invade occupied space and grow quickly to a large size attached to other organisms. Due to its large size, *S. plicata* then sloughs off taking other marine organisms with it. This removal of existing species destabilizes the community. Sutherland (1978) indicated that the presence of this tunicate also inhibits recruitment and growth of other larval species.

6.5 SUMMARY OF NIS INTRODUCTIONS AND RANGE EXPANSIONS

Both petroleum platforms and constructed reefs provide suitable habitats for NIS and may function as vectors or corridors for their expansion. The vertical profile of platforms differentiates them from the normal range of constructed reefs and enables them to recruit species throughout the water column. Unlike other alterations of the coastal environment, the fact that platforms are not permanently located and are likely to be moved or removed at some point presents additional NIS risk.

As sources of NIS, platforms differ from commercial vessels more commonly associated with NIS transport in that they remain in one place for long periods (without hull maintenance) and, when transferred, move at a slower speed than most vessels. Thus the fouling community on platforms may be more developed and suffer less loss during in-water transit. Platforms are more like inactive MARAD or U. S. Navy vessels that are stored for long periods of time and have well developed fouling communities that have caused NIS problems when transferred outside the region where these communities are indigenous.

The presence of NIS on platforms and linkage between platforms and NIS introductions elsewhere confirm that this problem is not unique to the GOM. However, the number and scale of platforms in the GOM along with a range of collateral stress factors increases risk of future adverse NIS impacts. Six NIS marine species are commonly listed on multiple databases as present in the GOM. Several of these are associated with petroleum platforms and perhaps two of these might be considered invasive at this time. Both the brown mussel and the white crust tunicate (ascidian) currently cause problems. The green mussel, although occasionally found on constructed reefs off Florida, currently has invasive impacts primarily in restricted to estuarine areas. The Australian spotted jellyfish is invasive, but has not yet been linked to petroleum platforms or reefs. Other potential invasive impacts, such as ciguatera, have largely been inferred and these problems require further study. However, due to the magnitude of the habitat alteration resulting from offshore platform relocation and the potential consequences of delays in platform removal or reuse as reefs, further evaluation may be needed to better determine the potential for adverse NIS impacts.

To reduce the potential for unintended invasive species consequences, a cautious approach is justified in decommissioned platform disposal or redeployment as constructed reefs. Before large numbers of platforms are moved or removed, a screening program for identifying and assessing the potential consequences of expanding NIS introductions might help reduce NIS risk and improve fisheries benefits. Risk assessment approaches focused on propagule pressure may help predict likely NIS. Decision analysis methods may assist resource managers to guide the allocation of resources toward the most invasive species. Possible approaches for managing NIS risk are presented in Section 7.0, Research Needs.

7.0 RESEARCH NEEDS

In the Section 5.4, Discussion, Drs. Cowan and Rose discuss the types of data and information that are needed to fully explore and quantify the role that platforms may have in fish production in the GOM. Here, those research needs are again described and expanded upon based on input from the rest of the project Team.

7.1 PLATFORM ECOLOGY AND TROPHODYNAMICS

Additional basic research about how platforms interact with biota in the broadest sense is needed to understand how large-scale removals will affect the ecosystem in the northwest Gulf. The effect of platform structures on energy flow and food webs is of particular interest. This type of work was begun in the 1970s and early 1980s (cf, Gallaway et al. 1981), but important trophic interactions still are not completely understood. A fruitful area of research would be to better quantify the extent to which primary production and passively-concentrated plankton and nutrients are transmitted to higher trophic levels as a result of the presence of platforms. Studies that better describe the diets of fishes that occur at platforms also are needed. Many of our assessments of species associations with platforms (Section 5.5.0) were tenuous because limited data about diets are available, or the data were not collected at platforms specifically. Comparative data about diets of fishes at low-profile natural reefs and other areas that are not affected by platforms also are needed to evaluate the role of platforms in fish production.

7.2 POPULATION VITAL RATES

The information needed to assess the effects of platforms on fish populations conceptually is clear. Production rates are determined by population vital rates (recruitment, growth, and survival); therefore, independent estimates of population vital rates are needed for fish affected by platforms, and for comparable populations that are not associated with platforms. Vital rates are affected by other factors such as prey availability, refuge from predators, and fishing pressure. It is difficult to assess the effect of platforms on some species, even qualitatively, in the absence of additional data because some of these factors positively affect fish populations and some of them negatively affect populations. The assessments of fish association with platforms reported in this manuscript provide a valuable synthesis of the data currently available but, perhaps more importantly, highlight the lack of published data about vital rates for many species. In the absence of this type of data, inference about the effects of platforms will be limited to circumstantial evidence.

We acknowledge that designing studies to quantify vital rates at platforms versus other habitats in the northwestern Gulf will be challenging because few "control" areas exist in the region that are not affected by platforms. Designing appropriate studies will be particularly difficult for large, mobile fish species, many of which are commercially important.

Nevertheless, we hope that identifying this important gap in existing data will spur innovative research to quantify basic population dynamics of important fish species.

7.3 STUDY DESIGNS – BACI

One method of quantifying the effects of platform removals is to experimentally remove specific platforms in a pattern designed to allow for comparisons. During conducting this project, we attempted to use the Southeast Area Mapping and Assessment Program (SEAMAP) trawl data to evaluate the effects of platform removals for this report using a Before/After-Control/Impact analysis model (BACI; cf, Morrison et al. 2001). Using this approach, catch rates and sizes of motile benthic epifauna would be evaluated for years in which a given platform or group of platforms were in place, and then compared to catch rates and sizes of epifauna for the same area after the platforms had been removed, and to nearby control areas that were unchanged to judge temporal trends. This analysis was not successful. Sampling during any given season/year of SEAMAP includes only about 200 stations spread over the entire northern and western Gulf. As a result, there were insufficient samples having the spatial proximity to the platform and control locations to make a meaningful assessment. Despite the fact that SEAMAP data were not appropriate for this type of analysis, we recommend that the BACI approach or similar designs be applied to future studies that are specifically designed to determine the effects of platform removals.

7.4 EVALUATING AND MITIGATING POTENTIAL NIS IMPACTS

NIS concerns associated with petroleum platform removal and reuse as constructed reef materials may delay decommissioned platform removal or constrain future reef construction options. This could affect both the petroleum companies required to remove the decommissioned platforms and the regional fishing industry that uses these structures. Evaluating NIS vectors of concern, prevention options, and approaches for mitigating potential impacts can help planning for platform decommissioning and reuse. Risk analysis methods frequently used to assess chemical and physical hazards, can be effectively applied to help assess NIS impacts, select appropriate mitigation strategies, and enhance benefits from future reef construction.

7.4.1 Potential Impacts - NIS Issues Delay Transfer of Federal Inactive Vessels

Growing concerns about the introduction of NIS may alter future reef construction and the disposal of materials that have existing fouling communities such as decommissioned petroleum platforms in the GOM. Similarities exist between petroleum platforms and the Maritime Administration (MARAD) and U.S. Navy inactive fleets since, in both cases, they remain stationary in the water for extended periods, do not regularly have their fouling communities removed, and may be transferred in the water. There have been a number of documented problems with the transfer of inactive ships. Despite efforts to eliminate the existing community, the 1998 transfer of the decommissioned battleship *Missouri* from the State of Washington to Pearl Harbor resulted in the introduction of the Mediterranean mussel (*Mytilus galloprovicialis*). Similar problems have occurred with active Navy dry docks transiting the Pacific. The decommissioned US Navy dry dock *Machinist*, from Subic Bay, Philippines introduced a sponge *Gelliodes fibrosa* and the bivalve mollusk *Chama maceropylla* as well as 3 other non-native species from its hull fouling community to Hawaii's waters.

Recently concerns over potential NIS impacts resulted in a temporary halt to MARAD's ship-scrapping program that was designed to reduce the inventory of its inactive fleet. This program has also made selected non-combatant vessels available for reef construction by states. A similar U.S. Navy ship-to-reef program for combatant vessels was also temporarily halted. Restrictions on inactive vessel movement now preclude the towing of inactive Navy vessels from California to Hawaii. These MARAD and Navy program interruptions were due, in part, to a requirement that hulls of the ships have their fouling community removed before leaving for either the salvage yard or potential reef site. This requirement was implemented in order to reduce the potential for NIS transport. However, even after agreeing to removal of the fouling community, a secondary concern was raised over the potential release of toxic metals from the required hull scraping (*scamping*) while the vessel is in the water. This issue has not yet been fully resolved and may restrict the hull cleaning to the use of drydocks instead of open slips. Similar biosecurity concerns could impact the petroleum industry in the future.

MARAD's current approach[3] to reducing potential NIS impacts is focused on characterizing water bodies and characterizing the risk associated with various transfer scenarios. The effort is directed at defining various levels of NIS risk in order to establish cost-effective strategies for low, medium, and high-risk vessel transfers. New Zealand and Australia perform similar biosecurity risk analyses to assess vessel transfer impacts (Coutts and Taylor, 2004; Hewitt and Campbell, 2007). A similar risk-based decision support approach might be useful in considering alternative platform to reef conversion options.

7.4.2 NIS Vectors – Predicting Introduction Linked to Offshore Platforms

Understanding NIS vectors or pathways is essential to evaluating the risk of introduction and in establishing risk reduction methods. In the case of offshore platforms, the primary vectors for the introduction of NIS include movement of platforms, with existing biofouling communities or ballast water, outside the area where the fouling community developed or potential ballast water propagules were acquired. This movement can occur during the removal of decommissioned platforms for scrapping, redeployment of MODUs, or reuse of decommissioned platforms for reef construction. Since such platform movement occurs only

[3] Carolyn Junemann: USDOT, MARAD "Obsolete Ships and Hull Fouling Issues" slide presentation at the International Conference on Aquatic Invasive Species, Key Biscayne, May 2006.

occasionally, ballast water exchange is infrequent and probably less of a problem than with commercial vessels, which more routinely exchange water. However, movement of entire fouling communities pose a greater NIS threat, especially if the movement is outside the general area and occurs with in-water transit.

For MODUs, NIS inoculation may also come from ballast water that provides propagules dependent on hard substrate for survival. Studies on the introduction of toxic dinoflagellates in Australasia during the past 100 years suggest that they most probably were introduced via ballast water from bulk-cargo shipping from Japan and/or Southeast Asia. This relationship between inoculation and habitat requirements suggests that ballast water exchange locations and prevailing circulation are factors that may interact with habitat provided by petroleum platforms and constructed reefs to determine the potential for NIS introduction.

Understanding the NIS vectors involves more than just the initial inoculation and should address subsequent potential transport within the GOM. Individual platforms or reef sites may provide habitat for NIS; the network of platforms may also provide some unique characteristics for transfer of NIS among platforms or reefs based on location, circulation, and the period of viability for propagules. Although removal or relocation decisions are often made on a platform-by-platform basis, they should be made in the context of the system or network composed of platforms, constructed and natural reefs, other sources of introduction (ballast water exchange points), and movements of water masses. Failure to consider the connectivity between platforms or reefs may lead to unintended NIS consequences.

7.4.3 Preventing or Controlling Non-indigenous or Invasive Species Establishment

Preventing or reducing the potential for future NIS problems is a far more cost-effective risk reduction approach than dealing with adverse impacts. Prevention would entail interdicting the vector to reduce potential transport or introduction of NIS. For petroleum platforms, a combination of 1) monitoring prior to any removal or redeployment, 2) treating or removing species of concern, 3) choosing appropriate removal and transport methods, and 4) selecting suitable sites for future reef construction may help reduce the probability of negative NIS consequences. A screening process designed to assess the invasion potential of species resident on a decommissioned platform prior to introducing it into a new system is recommended. Predicting the invasiveness of a species is one of the most challenging tasks for bioinvasion ecologists ((Johnson et al., 2005). However, recent studies suggest that reducing propagule pressure (the number of individuals released and frequency of releases) may reduce the probability of establishment (Kolar and Lodge, 2001).

Control of marine NIS risk once they have become introduced in a new area is much more difficult and often has a very short window for rapid response for eradication. Success depends upon the species involved, and required treatment may result in short-term collateral injuries to indigenous species. Monitoring for early NIS detection is critical to any possible risk reduction strategy. If necessary, cost-effective control of NIS should target the weak link in the life cycle of the NIS. This is the phase where demographic reduction most effectively reduces population densities or slows the spread (Buhl et al., 2004). Characterizing the supply of propagules and their distribution is critical to understanding invasion risk and developing useful management strategies (Vertling et al., 2005). Once NIS are established, however, maintenance control often becomes cost prohibitive and the impact may become irreversible.

7.4.4 Planning for Removal of Decommissioned Platforms – NIS Risk Assessment

Information about NIS may help inform future risk management decisions regarding platform removal and reuse. Although some data related to NIS introductions is available, significant data gaps exist. To effectively incorporate NIS issues into the planning process, additional data may be required. An integrated base GIS system with the location of platforms, other hard bottom habitat, known locations of NIS, known ballast water exchange areas, water circulation patterns, and the geographic extent of other stress factors such eutrophic, hypoxic and/or anoxic conditions, and sedimentation rates would be a useful starting point. This type of biophysical modeling system[4] might help assess NIS risk by identifying the potential sources of introduction, likely vectors to existing platforms or reefs, and sites for reef construction using obsolete platforms that would reduce the potential for additional NIS transfers.

7.4.4.1 Decision Risk Analysis

Risk analysis approaches are useful in evaluating the potential NIS risks and in helping to select appropriate removal, reuse, and mitigation approaches. A variety of risk analysis approaches have been used to assess the potential for successful introductions and many are similar to methods used by epidemiologists. Two basic approaches that are useful for an initial screening and management level review are decision trees and multiple attribute decision analysis. These methods have been useful for a range of impact assessments and mitigation or restoration planning projects and can help establish priorities for action or identify scenarios with different levels of risk. They are also used in Homeland Security programs to identify cost-effective monitoring and intervention priorities. More sophisticated predictive models for assessing invasion risk would be required to provide valid input for the decision analysis. For NIS applis, the explicit consideration of uncertainty would help identify key areas for future research.

Decision tree methods describe potential courses of action and assign probabilities and consequences to each branch of the tree to evaluate alternative approaches in terms of expected value (or impact). Once the decision model is constructed, it can also be used to calculate the value of additional information, such as pre-removal monitoring of NIS that would best aid in refining future removal/relocation decisions. It can also be used to explore the return-on-investment in potential mitigation approaches. Decision tree methods were used to assess

[4] With minor modification such a system could also be used to develop a network of constructed reefs built from decommissioned platforms that might contribute to rebuilding some fish stocks. For stoc rebuilding applications, some of these reefs would be located in no take areas.

potential impacts associated with the deliberate introduction of non-native species for fisheries enhancement.

Multiattribute decision analysis methods are commonly used to rank alternatives, set priorities, and create multifactor indices. Site selection, remedial action decisions, and other types of decision incorporating multiple incommensurate factors and uncertainty are well suited for this type of approach. These methods have been used to help select constructed reef sites and materials/designs for many years and are also used for restoration planning (Sheehy et al. 2000). NIS impact factors could readily be added to those typically used in reef site evaluations. Environmental assessments are readily developed from (tiered to) multiattribute analyses.

7.4.4.2 Criteria to Consider in Evaluating Potential Impacts

Many engineering, economic, and environmental considerations influence decisions regarding platform decommissioning and potential reuse. These decisions should also include a consideration of the risk of transferring or potentially recruiting NIS. A risk-based decision process that considers individual decommissioned platforms as well as the location of other hard bottom and that is based on the potential supply of NIS propagules, their transport, and likely successful establishment is recommended. Some NIS factors that may influence disposal or relocation of decommissioned platforms include:

1. Presence and characteristics of existing NIS associated with the platform (monitoring)
2. Proposed removal and or disposal options (methods, costs, mitigation, etc.)
3. Transit process for any movement if reused as material for constructed reefs
4. Location of proposed reefs
5. Proximity to sanctuaries, natural hard bottom, and other platforms constructed reefs (where subsequent transfer of NIS from platforms may be a concern).
6. Other potential environmental stressors such as hypoxic/anoxic events, eutrophic conditions, etc. that may contribute to NIS introduction and establishment.
7. Ballast water exchange sites (to reduce the probability of colonization by propagules from ballast water).
8. Circulation patterns that would influence disbursal of propagules from potential sources to petroleum platform sinks or from platform sources to other sites should also be considered in the selection of reef locations.

For simple removal for disposal ashore, the first three factors are the basic concerns. For platforms to be relocated outside the immediate vicinity of their origin, the last five items (4-8) are also relevant.

The presence of known NIS on a platform will determine the potential source of propagules that may be transferred. The traits of identified NIS species, including their dispersal characteristics and rate of establishment and growth to reproductive age will also determine their porotental for successful invasion (Stohlgren and Schnase 2006). Pre-decommissioning monitoring may be recommended if information is not already available. Campbell et al., 2007 have reviewed survey evaluation methods and techniques for petroleum platform assessment outlined by Carney (2005) provide a starting point for considering assessment approaches.

The proposed method of removal or transfer of mobile platforms, including how any ballast water is treated, as well as any proposed mitigation measures may also determine the potential vectors for NIS transfers. Several decommissioning options exist and have been used in the past for rig and submersible production platform transfer. Cutting off rigs below the bottom mud line and moving them on a barge deck may reduce survival of propagules sources depending on mitigation or surface transit times. In contrast, using floating methods or towing mobile platforms may increase the probability for NIS species surviving transit and serving as a source of propagules for future inoculations.

If platforms are to be reused as reef materials, the location proposed will also influence the potential for introduction of or future recruitment of NIS. In the past, some platforms have been moved considerable distances for reef construction. At least one platform was moved from the GOM to the Atlantic offshore of Miami. In another case, an experimental subsea production platform was blown full of air and towed about 300 miles from Louisiana to a site off Franklin County, Florida in 1980. Other platforms have been transferred after being cut into sections, placed on barges, or towed with external floatation systems. Long-distant transfers are problematic if any fouling community or ballast water remains with the platform. From the perspective of NIS transfer, toppling the platforms in place or within a relatively short distance from the production site will reduce NIS transfer potential.

7.4.4.3 Opportunities for Fisheries Enhancement

An information system set up to monitor NIS and help prevent further expansion could, with additional information, be used to develop an effective system of constructed reefs from decommissioned platforms. The large number of platforms scheduled for removal may provide a unique opportunity for a more systematic approach to platform reuse for reef construction. A case-by-case evaluation approach was recommended for California (Schroeder and Love, 2004) and is relevant in the GOM, but due to the density of platforms in the GOM, the linkage between platforms and other hard bottom habitats must also be considered[5]. Just as the connectivity between platforms and reefs is important to evaluating NIS vector (Hickerson and Schmahl,

[5] The approach involves identifying hubs in the *network*. To disrupt a network (impair a vector), the objective would be to remove hubs; to create a resilient network (MPAs) the objective would be create robust hubs.

2005), this connectivity can also be used to improve the performance of platforms used as constructed reefs by integrating the habitat construction with stock rebuilding efforts and/or marine protected areas.

This type of connected or linked reef concept is now being used in Japan to enhance commercial fish stocks. Japanese research has suggested the benefits of evaluating the currents and water mass movements that transport larvae from existing spawning areas to constructed reefs. Designed and prefabricated constructed reefs are being placed where recruitment is predicted (Sheehy, unpublished). This type of systematic approach, which considers the exchange between relocated platforms and larval sources, may inform strategic planning for reef construction in the GOM to help maximize the fisheries benefits from constructed reefs.

The current approach to planning Marine Protected Areas (MPAs) also suggests that networks of sanctuaries need to be considered with the intent of linking them for exchange. Using constructed reefs in sanctuaries has been considered for some time, but is now being implemented in East Asia. In the Adriatic Sea, the area around the "Paguro," a wrecked platform, has been declared a Marine Protected Area with all fishing prohibited. The benefits of such enhanced refugia have been well documented and might contribute to stock rebuilding efforts in the GOM. Placing some reefs in no take areas will be required if the objective is stock rebuilding, but research on NASA restricted areas indicates that such no take areas can also generate measureable fisheries benefits (Callum et al. 2001).

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