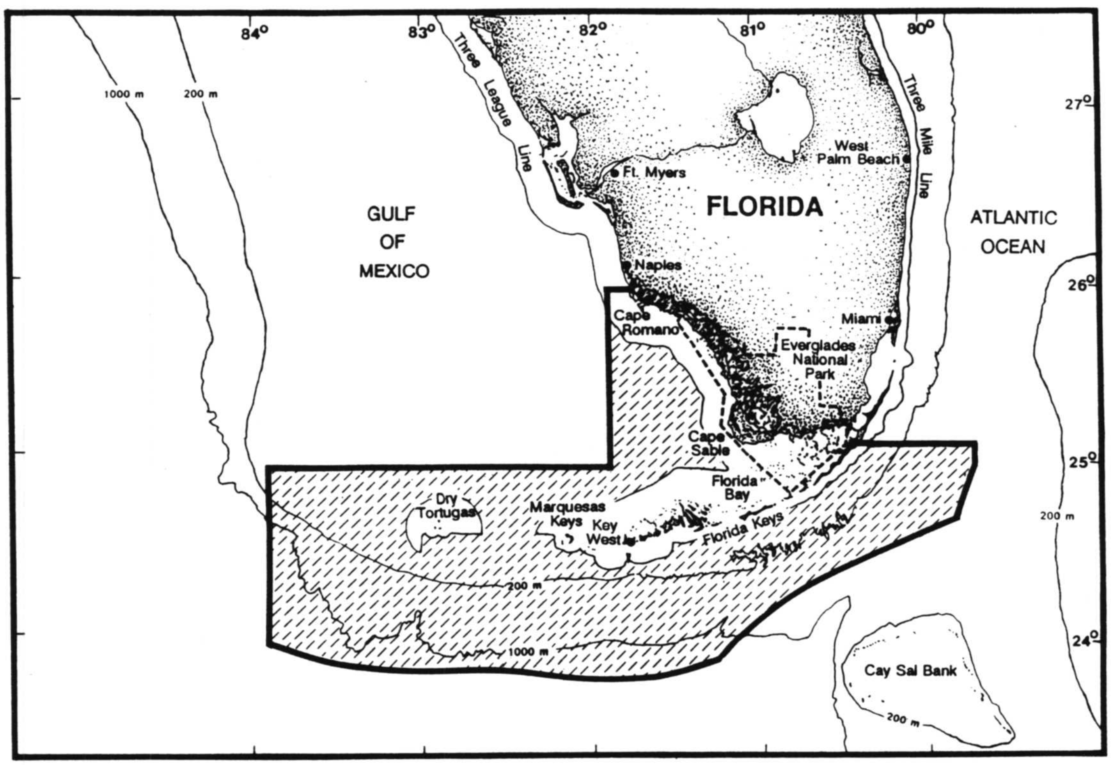
OCS Study
MMS 95-0029

Synthesis of Available Biological, Geological, Chemical, Socioeconomic, and Cultural Resource Information for the South Florida Area

Supplemental Report: A Comparison of Seagrass Beds in Panama and South Florida



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Supplemental Report: A Comparison of Seagrass Beds in Panama and South Florida

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Dr. Joseph C. Zieman (University of Virginia) and Dr. Marshall reviewed an earlier draft of the Supplemental Report and provided helpful, constructive comments. Report conclusions, as well as any remaining errors or technical inaccuracies, are the responsibility of Continental Shelf Associates, Inc.

INTRODUCTION

Numerous environmental and socioeconomic studies have been conducted in South Florida by government agencies, university researchers, private organizations, and individuals. In 1988, the Minerals Management Service (MMS) awarded a contract to Continental Shelf Associates, Inc. to synthesize the available information and evaluate potential effects of offshore oil and gas exploration and development. The goal was to help policy makers reach informed decisions about future lease offerings and environmental restrictions on offshore oil and gas operations. In May 1990, a Final Report entitled "Synthesis of Available Biological, Geological, Chemical, Socioeconomic, and Cultural Resource Information for the South Florida Area" (Phillips and Larson 1990) was completed. A Master Bibliography and an Executive Summary were subsequently produced. The study area is shown in **Figure 1.**

Oil spill effects on South Florida seagrass, coral reef, and mangrove communities were a key topic in the Final Report. Because there have been no major oil spill studies in South Florida, results from similar environments elsewhere were reviewed. One of the most frequently cited examples was the 1986 Bahía Las Minas spill in Panama, which was the largest ever recorded in coastal habitats of the tropical Americas (Jackson et al. 1989). The spill occurred on the Atlantic coast near the field laboratory of the Smithsonian Tropical Research Institute (STRI). Post-spill studies by STRI scientists began immediately, with funding by the MMS. A synthesis report was issued in 1993 (Keller and Jackson 1993).

The MMS was interested in the Bahía Las Minas spill because study findings might help to predict oil spill impacts in South Florida. The coastal environments and many of the species affected in Panama are similar to those found in South Florida. Jackson et al. (1989), reporting preliminary observations of the Panama spill, noted that "our observations are relevant to assessment of potential biological effects of pollution in several areas where extraction or refining of oil is ongoing or planned," including South Florida. However, no one has systematically compared conditions in Panama and South Florida to determine whether and to what extent study results are transferable. That critical question is the topic of this Supplemental Report. This comparison focuses on seagrass communities.

BACKGROUND: THE BAHÍA LAS MINAS SPILL

In April 1986, 9.6 to 16.0 million liters (60,000 to 100,000 barrels) of medium-weight crude oil spilled from a refinery storage tank into Panamanian coastal waters (Keller and Jackson 1993). The spill occurred in a complex region of seagrass beds, coral reefs, and mangrove forests near the Caribbean entrance to the Panama Canal (**Figure 2**). For six days after the spill, onshore winds caused the oil to remain within the small embayment (Bahía Cativá) adjacent to the refinery. Then, shifting winds and runoff from rains caused a large quantity of oil to float to sea past a boom across the mouth of the embayment (Keller and

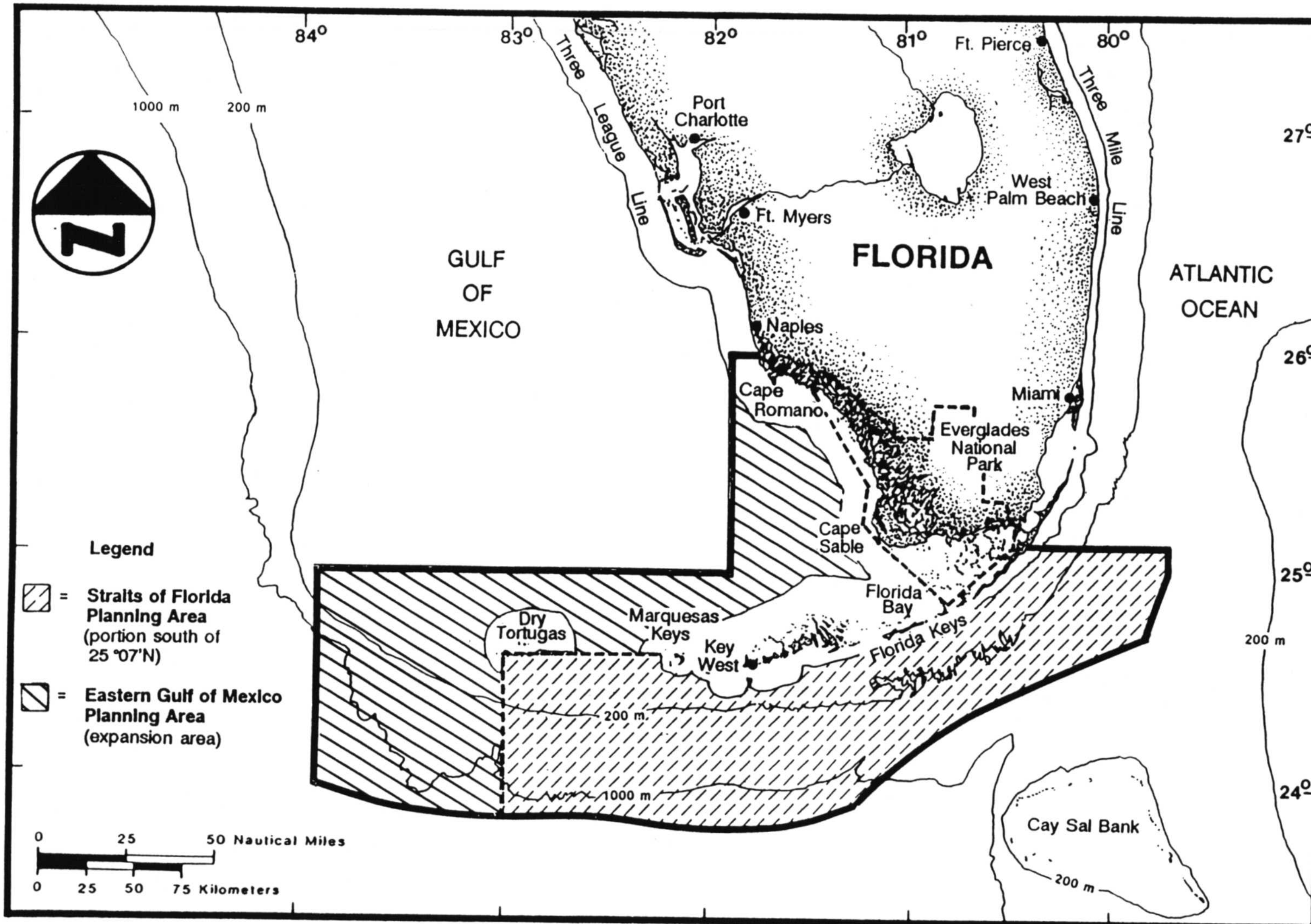

Figure 1. Study area.

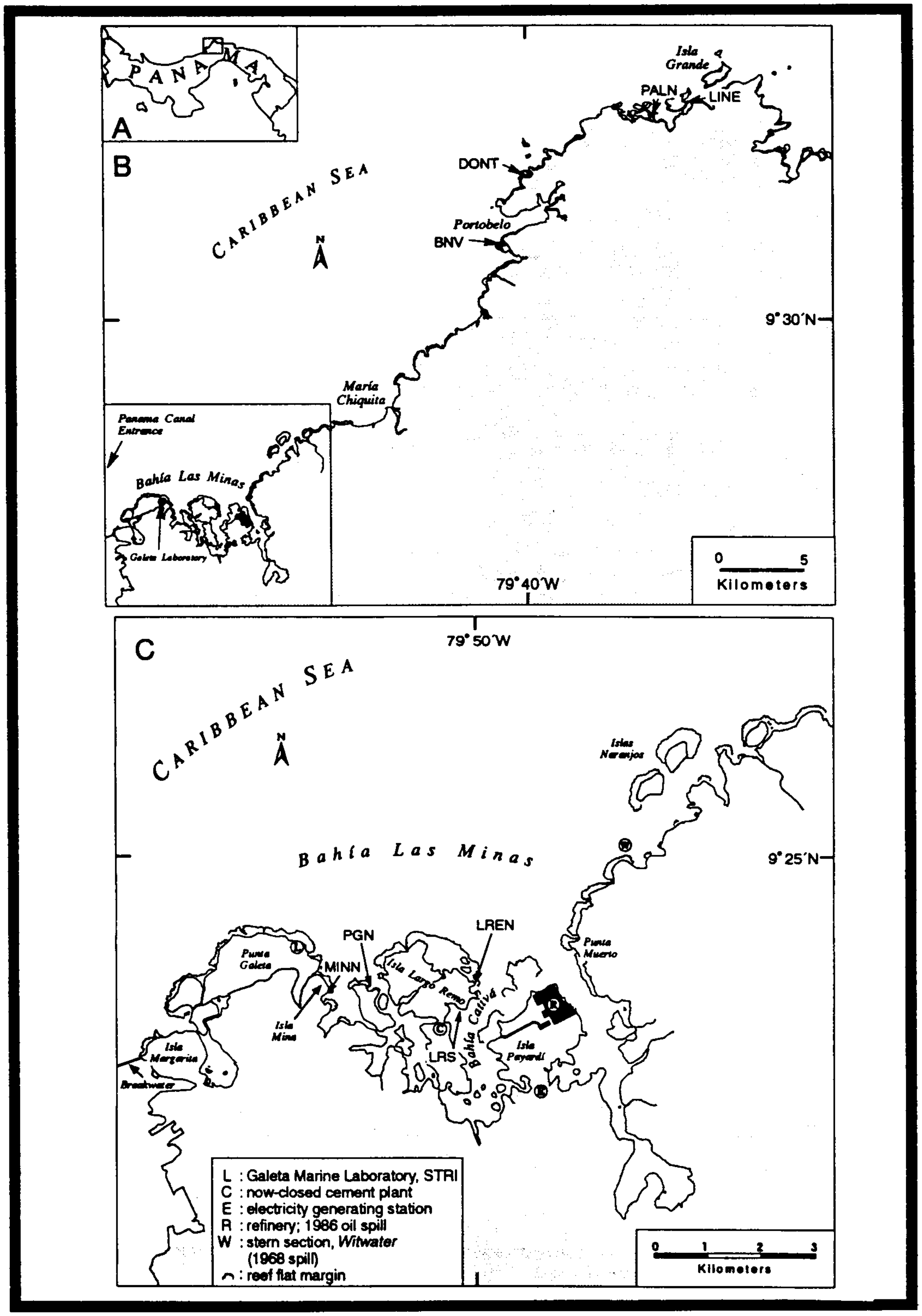

Figure 2. Seagrass study sites in the region of Panama affected by the April 1986 oil spill (From: Marshall et al. 1993). **A.** General location in Panama. **B.** Location of unoiled sites (BNV, DONT, PALN, and LINE). The boxed area indicates the site of the 1986 spill. **C.** Location of the refinery (R) and oiled sites in Bahía Las Minas (MINN, PGN, LREN, and LRS).

Jackson 1993). Subsequently, the oil spread along the coast, reaching mangroves, small estuaries, and sand beaches within 10 km of the refinery.

The spill site was near the Galeta Marine Laboratory of the STRI, and some of the oiled environments had been studied previously by STRI scientists. The MMS and the STRI quickly entered into a cooperative agreement to investigate the immediate and long-term effects of this spill. A synthesis report was issued in 1993 (Keller and Jackson 1993). The following discussion of STRI seagrass studies is based on the synthesis report (Keller and Jackson 1993), especially the chapter on subtidal seagrass communities (Marshall et al. 1993).

Subtidal Seagrass Study

The Panamanian seagrass beds oiled by the 1986 spill occur within a 11 km straight line distance extending from Isla Margarita to the west to las Islas Naranjos on the eastern edge of Bahía Las Minas (**Figure 2**). The actual shoreline distance affected by the spill, due to the geographical complexity created by a labyrinthine system of small islands, river mouths, and numerous embayments, is about 82 km (Jackson et al. 1989). The seagrass beds were 1 to 2 ha in size and were located in shallow lagoons (<1 m depth) between small fringing reefs and mangrove-covered shorelines.

Seagrass bed studies completed before the spill include epifaunal (Heck 1977, 1979; Weinstein and Heck 1979) and infaunal surveys (Jackson 1973; Vasquez-Montoya 1979, 1983). However, the pre-spill data were not appropriate as a quantitative baseline for evaluating effects (Marshall et al. 1993). Therefore, effects on seagrasses were evaluated by comparing oiled and unoiled sites after the spill. Four oiled and four unoiled sites (**Figure 2**) were sampled quarterly from September 1986 until July 1989. All oiled sites were within 6 km of the refinery. The unoiled sites were located a considerable distance from the refinery (20 to 40 km), but were believed to be similar to the oiled beds in physical and biological characteristics (Marshall et al. 1993).

Water depth profiles were produced initially for each site along transects from the shore to the seaward edge of each bed. The investigators also measured the position of the seaward edge of seagrass beds after July 1988 (when they first noticed that some oiled beds appeared to be receding). Background data collected for each site included salinity, sediment silt/clay percentage and organic content, and presence/absence of visible oil. On each sampling date, core samples of seagrass, macroalgae, and benthic infauna were collected, and surface sediment scrapes were obtained for grain size and hydrocarbons. Mobile epifauna were also collected at each site, using pushnet samplers. Infauna and epifauna were identified to major taxonomic groups (except for polychaetes, which were identified to family, and caridean shrimp, which were identified to species). Size frequency and reproductive characteristics were measured on the two most abundant species of caridean shrimp.

Marshall et al. (1993) reported findings of the subtidal seagrass study. Their major points are summarized below:

- Oil was deposited on and persisted in seagrass bed sediments. Concentrations as high as 4,020 ppm were detected in surface sediments five months after the spill. Two years later, analyses showed that oil had penetrated thick mats of seagrass roots and rhizomes to a depth of at least 20 cm (Burns 1993).

- Seagrasses died at the shoreward margins of some oiled seagrass beds. At one site visited two years after the spill, seagrass had died within a 5-m wide band along the shoreward margin. It is unknown whether similar losses occurred at other sites prior to this observation. Subsequently, changes in seagrass bed margins were measured at all sites for about one year, and the margins of oiled beds generally receded (20 to 90 cm), whereas unoiled beds generally did not.

- The spill apparently had a transitory effect on the predominant seagrass, *Thalassia* (other than at the bed margins, as noted above). Total, subsurface, and blade biomass of *Thalassia* was lower initially at oiled sites. However, this difference disappeared within a few months, and subsequently, seagrass biomass at both oiled and unoiled sites generally decreased through the last sampling period, approximately three years after the spill. *Syringodium*, the second-ranked seagrass, was more sensitive than *Thalassia* to oiling; *Syringodium* biomass remained lower at oiled sites even during the second and third years after the spill.

- Living calcareous algae were virtually absent at oiled sites initially, but this difference did not persist. The abundance of fleshy algae did not seem to be affected by oiling.

- Total densities of infauna (excluding polychaetes) and sedentary epifauna were initially lower in oiled beds than in unoiled beds. During the three years after the spill, abundance generally increased at oiled sites and decreased at unoiled sites (the latter for unknown reasons), eventually converging to similar levels. Amphipods, cumaceans, isopods, ophiuroids, sipunculids, and tanaids appeared to be strongly affected, whereas gastropods, bivalves, and brachyuran crabs apparently were not.

- Among epifauna, groups with direct development were more strongly affected than were partial brooders or those with pelagic larvae. This might have been due to effects of oiling on reproduction of brooding species within the bed. In contrast, species with pelagic larvae could have repopulated through recruitment from distant seagrass beds.

- Epifaunal echinoderms were strongly affected by the spill; large sea urchins and holothurians were still more abundant at unoiled sites six years after the spill. Because these organisms are easily counted in the field, the investigators suggested that they may be useful as "indicators" of the effects of oil spills in seagrass beds.

Other Study Components

In addition to the subtidal seagrass study, several other components of the STRI project provide relevant information to evaluate the applicability of the Panama spill data to South Florida:

- Hydrocarbon data show that oil persisted in mangrove forest sediments for more than five years (Burns 1993). Although much of the spilled oil weathered rapidly, oil buried at one mangrove site was preserved relatively intact in anoxic sediments for five years. Oil in mangrove sediments constitutes a source of chronic, potentially toxic leakage onto adjacent habitats, including seagrass beds.

- One of the most dramatic effects of the spill was the destruction of an intertidal seagrass bed/reef flat habitat at one site (Steger and Caldwell 1993). Before the spill, there was an intertidal seagrass bed with scattered pieces of coral rubble, bordered by a mangrove stand. After the seagrass was killed by oil and decayed, the coral rubble and sediment formerly bound together by roots and rhizomes began to erode. The area is now dominated by large pieces of coral rubble resting on a fine, sand/silt substratum, bordered by a mud flat. There is little chance that this habitat will ever recover.

- About 64 ha, or 7% of the mangrove habitat in the area, was deforested, mostly in a 50-m wide coastal strip (Duke and Pinzón 1993). A much larger area was affected to some extent by oiling. Mature trees surviving the initial oiling suffered persistent canopy deterioration. In oiled canopy gaps, seedling recruitment and growth were extremely variable, with significant growth suppression in areas of residual oil. These effects persisted at least 5 to 6 years after the spill. Loss of mangrove forest resulted in erosion and increased sedimentation on adjacent seagrass beds and coral reefs.

- There was a striking reduction in cover, abundance, and diversity of live corals (especially the elkhorn coral *Acropora palmata*) immediately after the spill (Guzmán et al. 1993). On oiled reefs, coral injuries were more frequent and coral growth rates were lower than on unoiled reefs. Low coral recruitment rates on oiled reefs indicated there was little prospect for rapid recovery.

STUDY APPROACH

The comparison of seagrass beds in South Florida and Panama is not intended to be exhaustive. Rather, it focuses on those aspects that are most critical in predicting the effects of oil spills on seagrasses. The response of seagrass beds to oiling depends on a variety of environmental factors (Zieman et al. 1984; Marshall et al. 1990). For this report, the factors are divided into three groups:

- Spill Circumstances. The effects of an oil spill depend in part on unpredictable factors such as spill location, volume, duration, rate of release, and chemical composition, as well as the effectiveness of spill containment and cleanup measures. Effects also depend on unpredictable environmental variables such as weather, sea state, and tidal stage at the time of a spill.

- Seagrass Distribution and Environmental Setting. Factors that determine the severity of spill effects include the geographic distribution, areal extent, and water depth of seagrass beds; bed location, including proximity to mangrove shorelines; tidal range and wave energy regime; and history of environmental problems (Zieman et al. 1984; Jackson et al. 1989; Marshall et al. 1990).

- Species Composition of seagrass bed communities, including both seagrasses and associated flora and fauna. Species composition is important because species differ in their sensitivity to oiling (Gilfillan 1990).

This report focuses on the last two topics, which are discussed in separate chapters. Spill circumstances are not part of the comparison because they cannot be predicted in advance. The exact circumstances of the Bahía Las Minas spill could not be repeated in the South Florida study area because no oil refineries are present, nor are they likely to be permitted in the coastal zone (Phillips 1990). However, there is a large volume of tanker traffic passing through the Straits of Florida, which could produce a spill of comparable or greater volume.

SEAGRASS DISTRIBUTION AND ENVIRONMENTAL SETTING

GEOGRAPHIC DISTRIBUTION AND AREAL EXTENT

South Florida possesses one of the largest seagrass resources in the world; total coverage of seagrass beds in South Florida is estimated to be about 5,500 km^2 (Zieman 1982; Iverson and Bittaker 1986; Zieman and Zieman 1989). The South Florida seagrass beds range in size from thousands of hectares to small patches in mangrove-lined bays and lagoons. The seagrasses occur in four main areas: (1) throughout Florida Bay[1], which provides a shallow, protected environment for extensive seagrass development; (2) Hawk Channel between the Florida Keys and the Florida Reef Tract; (3) the lower Keys from Big Pine Key to Key West; and (4) the Marquesas-Dry Tortugas area. Greater water clarity on the Atlantic side of the Florida Keys allows extensive seagrass bed development in Hawk Channel, despite the higher wave energy. To the north of the Florida Keys on the Atlantic coast, increasing wave exposure limits seagrass beds to small pockets in protected inlets and lagoons (Zieman 1982). Turbidity and reduced salinity due to Everglades drainage limit seagrass bed distribution along the Gulf Coast north of Florida Bay (Zieman and Zieman 1989), although sparse *Halophila* beds occur offshore on the Southwest Florida shelf (Continental Shelf Associates, Inc. 1989).

In contrast, the steep terrain of the nearshore shelf in Panama prevents the development of extensive offshore seagrass beds. Additionally, the narrow continental shelf of Panama's Caribbean coast renders this area a higher energy coastline than most of South Florida. Seagrass beds are generally located in protected waters, such as in island-fringed lagoons or estuaries, or behind reefs or barrier islands (Zieman 1982, 1990). Consequently, Panamanian seagrass beds occur mainly behind well developed reefs and barrier islands where these structures absorb wave energy and allow seagrass development. Panamanian seagrass beds occur in small, discontinuous patches often separated by wide areas of coral reef or sandy channel (Heck 1979; M. Marshall, pers. observ.).

None of the Panamanian seagrass beds studied were larger than 2 ha in size, because there are no larger beds along this coast. These beds are not comparable to the much larger seagrass meadows typical of Florida Bay and the Florida Keys. South Florida seagrass beds can extend for many kilometers without being interrupted by other habitats such as mud banks, oyster bars, coral reefs, or tidal channels.

This comparison shows that South Florida seagrass beds are extensive, whereas the Panamanian beds are small and discontinuous. The difference is

[1]Florida Bay as discussed here corresponds to the boundaries of Everglades National Park south of Cape Sable.

important from at least two respects. First, despite the size of the Panama spill and the length of coastline affected, a relatively small area of seagrass beds was contaminated. A much larger area of South Florida seagrass beds could be oiled by a single spill. Second, the pattern of recovery from an oil spill might be different in South Florida, because some animals could migrate to unaffected areas and extensive source beds for new recruits would exist. Small, isolated seagrass beds may be subject to severe setbacks or total elimination, as contrasted with seagrass beds that are part of a larger, continuous system (Zieman et al. 1984). However, incorporation of oil in seagrass bed sediments (as happened in Panama) could inhibit recovery even if new recruits were available.

WATER DEPTH

Seagrass vertical distribution is limited by exposure and desiccation in shallow water and by the availability of photosynthetically active radiation at greater depths. In South Florida, seagrasses grow at depths ranging from the intertidal to >40 m (Zieman 1982; Continental Shelf Associates, Inc. 1989). However, the development of rich, productive seagrass beds is generally limited to water depths of $\leq$10 to 12 m (Zieman 1982, 1990). In Florida Bay, which is characterized by a "honeycomb" pattern of anastomosing mudbanks (shoals) and basins, maximum seagrass density occurs at depths of 1 to 3 m. Extensive seagrass beds also occur in water depths of 1 to 3 m around islands in the lower Keys. In the clearer waters of Hawk Channel behind the Florida Reef Tract, dense beds occur at depths of 6 to 8 m (Zieman 1990).

All of the Panamanian seagrass beds studied by Marshall et al. (1993) are in shallow water (<1 m; mean depth ranged from 11 to 64 cm) and are situated between mangrove shorelines and fringing coral reefs. The steep terrain of the nearshore shelf in Panama prevents the development of extensive offshore seagrass beds in deeper water. Seagrasses also occur on intertidal reef flats in Panama (Jackson et al. 1989; Steger and Caldwell 1993).

With respect to depth distribution of seagrasses, the Panamanian sites studied by Marshall et al. (1993) seem most similar to shallow, subtidal seagrass beds in Florida Bay and adjacent to islands in the lower Florida Keys (M. Marshall, pers. observ.; M. J. Thompson, pers. observ.; J. Zieman, 1992, pers. comm., Univ. of Virginia).

According to Marshall et al. (1990), intertidal and shallow subtidal seagrass beds are the most susceptible to oiling. The most severe effects on seagrasses in the Panama spill study occurred on intertidal reef flats (Jackson et al. 1989; Steger and Caldwell 1993). Heavily oiled intertidal beds were killed and may never recover (Steger and Caldwell 1993), whereas subtidal seagrass beds survived everywhere, with mortality at the margins and more subtle effects within the beds (Marshall et al. 1993).

Data from subtidal Panamanian seagrass beds (Marshall et al. 1993) could greatly underestimate the severity of oil spill effects on Florida Bay seagrasses. Many seagrasses on Florida Bay mudbanks are exposed at very low tides and could be highly vulnerable to oiling, similar to the intertidal reef flat beds in Panama studied by Steger and Caldwell (1993). The mudbanks are concentrated in the western part of Florida Bay, and the shallowest portions of these beds support a seagrass standing crop that is twice the bay-wide average (Zieman 1990).

On the other hand, data from the shallow subtidal Panamanian beds may overestimate oil spill impacts on Hawk Channel seagrasses. Because of their greater water depth, the Hawk Channel beds might escape oil exposure. However, under certain conditions (e.g., storms, wave action), oil can become mixed into emulsions with seawater and combine with sediment particles and sink to the bottom, resulting in oiling of deeper beds (Marshall et al. 1990).

PROXIMITY TO MANGROVE SHORELINES

All of the Panamanian seagrass beds studied occur in shallow lagoons between fringing coral reefs and mangrove shorelines. The distance between seagrass beds and mangrove shoreline ranged from a few meters to a few tens of meters (Marshall et al. 1993). This is significant because mangrove sediments tend to absorb spilled oil, which may then be released gradually over a period of years. Hydrocarbon data show that oil persisted in mangrove forest sediments for more than five years after the spill (Burns 1993). Although much of the spilled oil weathered rapidly, oil buried at one mangrove site was preserved relatively intact in anoxic sediments for five years. Oil slicks, presumably from mangrove sediments, were seen in Bahía Las Minas throughout the duration of the seagrass project. This oil constitutes a source of chronic, potentially toxic leakage onto adjacent seagrass beds.

From the standpoint of mangrove shorelines, the Panamanian seagrass beds are more similar to those of Florida Bay and the lower Keys rather than those of Hawk Channel. Extensive mangrove forests occur on the mainland coast of Florida Bay, and mangroves also occur on islands throughout the bay and on the shoreline of the Florida Keys. Some seagrass beds in Florida Bay and the lower Keys are near mangrove shoreline, whereas the Hawk Channel beds are not. Both the seagrass beds and the mangrove forests of South Florida are much larger and more extensive than those of Panama (Snedaker 1990; Zieman 1990). Although most individual seagrass beds would not be as close to mangrove shorelines as those in Panama, a similar effect could be observed if a major spill reached Florida Bay or the lower Keys. Oil reaching the mangrove shorelines would be absorbed and would probably leak out slowly over many years, as happened in Panama.

WAVE ENERGY REGIME

The importance of wave exposure in limiting seagrass bed development has been cited above. Wave energy is also important from other respects in determining the effects of an oil spill. For example, wave action can help to break up oil slicks, and it can enhance the effectiveness of dispersants[2]. Two other important aspects are discussed below.

Wave action can enhance sedimentation of oil by creating oil-in-water emulsions that settle with sediment particles. In August 1986, several months after the Bahía Las Minas spill, an emulsion of oil suspended in seawater was seen over the fringing reefs at the seaward edges of two seagrass study sites (Marshall et al. 1993). The emulsion presumably was created by turbulence resulting from waves crashing onto the reef crest. Droplets from this emulsion may have combined with suspended sediment particles to produce a heavier-than-water combination of oil and sediment. Oil sunken by this mechanism may have accounted for some part of that detected in seagrass bed sediments. Because the Panama seagrass beds are on a high energy coast, compared to the usually calm waters of the vast expanses of Florida Bay, this proposed mechanism may not be as important over the South Florida seagrass beds. However, winter storms in South Florida are energetic and could produce a similar effect in Florida Bay.

Wave regime can also influence the resilience of seagrass communities following a disturbance. It has been noted above that the Panamanian seagrass beds occur along a higher energy coast than South Florida. Perhaps for this reason, Panamanian seagrass beds seem more susceptible to wave induced erosion (blowouts) than do the large seagrass beds off Florida (Heck 1979). Such blowouts occur when normal, dry season wave action breaches the integrity of the root system within a seagrass bed and produces an open, sandy area. Once opened, the seaward edges of such blowouts usually continues to erode toward the sea, while the shoreward edge tends to repopulate with seagrass (Patriquin 1975). The results of this phenomenon render the seagrass habitats off Panama more dynamic in terms of species succession and regeneration than their counterparts off South Florida.

[2]About one week after the Bahía Las Minas spill, an aircraft sprayed approximately 21,000 liters of the dispersant Corexit 9527 onto oil slicks. According to Keller and Jackson (1993), "the application of dispersant so many days after the spill and the calm sea conditions during the spraying appeared to render chemical dispersion ineffective."

HISTORY OF ENVIRONMENTAL PROBLEMS

Both the Panamanian and South Florida coasts have been affected by human disturbance over a period of many years. These disturbances may have altered the sensitivity and resilience of seagrass beds to oiling. As noted by Jackson et al. (1989), the response of organisms to an oil spill depends in part on the environmental conditions (including chronic disturbance and pollution) under which they exist.

Much of Bahía Las Minas has been subjected to human disturbance, including decades of excavation, dredging and filling for construction of the Panama Canal and the city of Colón; construction of a refinery, a cement plant, and an electrical generating station; drainage and spraying of mangroves for mosquito control; extensive deforestation, resulting in deposition of eroded terrigenous sediments in coastal environments; a previous major oil spill in 1968 (the wreck of the tanker *Witwater*); and numerous minor spills from vessels and port facilities (Jackson et al. 1989; Keller and Jackson 1993). Effects of the 1968 *Witwater* spill on mangrove forests were still noticeable 20 years later (Duke and Pinzón 1993). The cumulative effects of these disturbances (if any) on seagrass communities are unknown. However, the eventual convergence of seagrass bed faunal populations at oiled and unoiled seagrass sites in the years after the 1986 spill suggests that pre-spill status was similar throughout the area (Marshall et al. 1993).

Coastal and nearshore environments of South Florida have also faced numerous anthropogenic problems that have led to decreased seagrass acreage. Historically, much seagrass habitat in South Florida has been lost to dredging and filling for residential and commercial development (Zieman 1982). According to Zieman (1990), the main cause for continued seagrass losses in South Florida is increased turbidity, attributable either to sedimentation (e.g., from construction activities) or eutrophication (e.g., from inadequate sewage treatment in the Florida Keys). Other problems include physical damage (scarring) by small boats and chronic pollutant releases from vessels of all types.

Severe water quality and ecological problems have developed in Florida Bay in recent years. Problems include a massive seagrass die-off, phytoplankton blooms, sponge die-offs, mangrove die-backs, and population reductions in economically significant species such as pink shrimp, sponges, lobster, and various recreational gamefish. Although the causes and mechanisms are not fully understood (Boesch et al. 1993), changes in freshwater inflow from the Everglades are believed to be a major influence (McIvor et al. 1994).

The history of environmental degradation may affect the response of seagrass communities to oiling. In some situations, chronic exposure to pollutants and other environmental stresses produces altered communities that are resistant to disturbance. However, it is not clear what role, if any, the previous environmental stresses played in determining the effects of the Panama spill.

SPECIES COMPOSITION

FLORA

Seagrasses

The species composition of seagrass communities depends on the seagrasses present and their respective densities. *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), and *Halodule wrightii* (shoal grass) dominate and define the South Florida seagrass beds (Zieman 1982, 1990). *Thalassia* is the largest, most abundant, and productive of the South Florida seagrasses. It dominates much of the interior of Florida Bay and the bottom of Hawk Channel. *Syringodium* is the numerically dominant seagrass on the western edge of Florida Bay and in deeper water and channels with consistent high-velocity conditions. *Halodule* is found in shallow water on bank tops and adjacent to mangrove islands. In addition to these three major species, *Ruppia maritima*, a euryhaline angiosperm, is locally abundant in the upper, low-salinity portions of Florida Bay, and in the most hypersaline portions of the bay. Three species of *Halophila* (*H. decipiens*, *H. engelmannii*, and *H. johnsonii*) are found primarily around the fringes of Florida Bay and on the Southwest Florida continental shelf. Although *Halophila* beds can cover large areas (particularly in deep water), their biomass and numerical abundance are low (Continental Shelf Associates, Inc. 1989).

The same dominant species (except *Ruppia*) characterize Panamanian seagrass beds. The dominant seagrasses in the subtidal Panamanian beds are *Thalassia testudinum* and *Syringodium filiforme* (Marshall et al. 1993). *Halodule* is found on intertidal areas at the edges of some of the lagoonal seagrass beds studied (Marshall, pers. observ.). *Halophila decipiens* (and probably other *Halophila* species) are found along the deeper edges of seagrass beds. *Thalassia* also occurs on intertidal reef flats in the study area (Steger and Caldwell 1993).

Algae

Associated with South Florida seagrass communities is a diverse group of macroalgae and microalgae (Zieman et al. 1989). Seagrass beds possess a characteristic assemblage of algal species which can be grouped into three categories:

- Those that grow in soft sediments and have either a holdfast or creeping rhizoids, such as *Halimeda*, *Penicillus*, *Rhipocephalus*, *Udotea*, and *Caulerpa*.

- Those that grow on hard substrates, such as *Dictyota*, *Padina*, and *Sargassum*.

- Those that form detached lumps or clumps of free floating drift algae, such as *Gracilaria*, *Laurencia*, *Digenea*, and *Acanthophora*. These all begin life on hard substrate, but some fragment and grow as drift algae.

The microalgal community in South Florida seagrass beds is represented almost entirely by epiphytic species growing on seagrass blades. Humm (1964) compiled an annotated list of 113 species of algae that were epiphytic on South Florida seagrasses. On the west coast of Florida, Rhodophyta (red algae) accounted for 45% of the epiphytic species seen. Phaeophytes (brown algae) accounted for 12% of the epiphytic species, and Chlorophytes and Cyanophytes (green and blue-green algae) each represented 21% of the species seen (Ballantine and Humm 1975).

Macroalgal genera reported from Panamanian seagrass beds include the substrate-attached *Halimeda*, *Penicillus*, and *Udotea* and *Dictyota*, and the filamentous green alga *Cladophora*. In general, brown algae are sparse in Panamanian seagrass beds compared with other tropical areas, and red algae are highly seasonal in terms of presence and abundance (Heck 1977). There are virtually no data on the epiphytic community of Panamanian seagrasses.

FAUNA

There have been numerous faunal studies of South Florida seagrass beds (Zieman 1982). Most of the studies have focused on Florida Bay and Biscayne Bay; little research has been conducted in shallow seagrass beds surrounding the lower Florida Keys (J. Zieman, 1992 pers. comm., Univ. of Virginia). (As noted in the previous chapter, the shallow seagrass beds around the lower Florida Keys appear most similar in depth range to the Panamanian beds studied). In the faunal comparisons below, it is important to recognize faunal variations within the South Florida area. The fauna of western Florida Bay is largely southern temperate with origins in the Gulf of Mexico, whereas the fauna of the Atlantic side of the Keys, or even the bayside lower Keys, is more Caribbean in origin. In addition, Florida Bay is a mixing zone that does not have one typical fauna (J. Zieman, 1992 pers. comm.).

Faunal characteristics of Panamanian seagrass beds are known from studies conducted in the spill area before 1986 and from post-spill surveys of unoiled beds. All of the pre- and post-spill studies were conducted from the STRI Galeta Marine Laboratory, which is located near the Atlantic entrance to the Panama Canal and 2.5 km from the spill site (**Figure 2**). The laboratory opened in 1970, and it has been the site of many ecological studies on numerous topics. These studies have proven to be an invaluable source of information on pre-spill conditions for reef flat habitats. A simple listing of organisms from the combined studies of the Galeta Point reef flat habitat includes over 775 species (Cubit and Williams 1983).

Seagrass bed studies completed before the spill include epifaunal (Heck 1977, 1979; Weinstein and Heck 1979) and infaunal surveys (Jackson 1973; Vasquez-Montoya 1979, 1983). In pre-spill studies, epifauna were sampled with an otter trawl and infauna were sampled with coring devices. Post-spill studies used pushnet collections for epifauna and core samples for infauna (Marshall et al. 1993). Various methods of monitoring plant species composition and biomass were used in each of these major studies. A similar range of techniques has been used to survey plant and animal assemblages in South Florida seagrass beds.

The following comparisons focus on three main groups for which data are sufficient to allow meaningful comparisons: (1) decapods and stomatopods; (2) molluscs; and (3) fishes. Species lists for these three groups are presented in the **Appendix**. **Table 1** summarizes comparisons at the species and genera levels.

Decapods and Stomatopods

Studies of decapod assemblages from seagrass beds are perhaps the best basis for faunal comparisons between South Florida and Panama. Heck (1977) used an otter trawl, equipped with a 6.3-mm liner, to collect decapod and stomatopod crustaceans from seagrass beds within and adjacent to Bahía Las Minas. Marshall et al. (1993) collected crustaceans with a pushnet (1.0-mm mesh) from several of the same seagrass beds within Bahía Las Minas and in additional unoiled seagrass beds that were not included in Heck's study. These two collection methods resulted in similar species lists but different relative abundances. Many of the small decapods, including the numerically dominant caridean shrimp species were undercollected by Heck's otter trawl, whereas a few large, quick-moving decapods may have avoided Marshall's pushnet. The combination of methods, however, should have provided a complete description of the seagrass bed crustacean fauna. The species listed in **Table A.1** are based on revisions by Coen and Heck (1983), who reviewed Heck's (1977) collection for accuracy. Fewer species are listed in the later paper because specimens were lost during the trip from Panama to Tallahassee (K. Heck, pers. comm.).

Decapods and stomatopods were collected with throw traps from Florida Bay's shallow, mudbank top seagrass beds (Holmquist et al. 1989). Caridean shrimp proved to be the numerical dominants in this seagrass bed study. Other earlier research on seagrass beds in Florida Bay used a variety of collecting techniques and were conducted in areas that included seagrass beds and mud bottoms. No similar studies have been carried out in the shallow seagrass beds adjacent to the lower Florida Keys or the Atlantic side of the upper Florida Keys.

The decapod and stomatopod faunas of South Florida and Panama share numerous species and genera **(Table A.1)**. Only about 19% of the species occur in both areas, but 58% of the species belong to genera that occur in both areas **(Table 1)**. Additionally, the two locations share several of the numerically dominant species and genera (mostly caridean and penaeid shrimp) **(Table 2)**.

Table 1. Summary of faunal comparisons between seagrass beds of South Florida and Panama. The table summarizes data from Appendix Tables A.1 (decapods and stomatopods), A.2 (molluscs), and A.3 (fishes).

Group	Species					Genera					Congeneric Species	
	South Florida	Panama	Total	Shared		South Florida	Panama	Total	Shared			
				No.	Percent				No.	Percent	No.	Percent
Decapods and stomatopods	53	66	100	19	19	38	47	61	24	39	58	58
Molluscs (total)	166	192	311	47	15	102	125	172	55	32	172	55
Gastropods	94	136	204	26	13	53	91	109	35	32	114	56
Bivalves	72	56	107	21	20	49	34	63	20	32	58	54
Fishes	168	106	224	50	22	116	69	142	43	30	111	50

Table 2. Numerically abundant caridean and penaeid shrimp from seagrass beds of South Florida (Florida Bay--Holmquist et al. 1989) and Panama (Bahía Las Minas area--M. Marshall unpubl. data). Numbers indicate rank in each area; for unranked species, 'p' indicates presence, and '--' indicates absence.

Species	Rank	
	South Florida	Panama
Thor floridanus	1	--
Periclimenes americanus	2	4
Hippolyte pleuracanthus	3	--*
Periclimenes longicaudatus	4	10
Alpheus heterochaelis	5	p‡
Penaeus duorarum	6	5
Alpheus normanni	7	p‡
Latreutes fucorum	8	2
Tozeuma carolinense	9	8
Leander paulensis	10	--
Hippolyte zostericola	--*	1
Thor manningi	--	3
Alpheidae	p‡	6‡
Latreutes parvulus	13	7
Sicyonia laevigata	--	9

* See Gore et al. (1981) for a discussion of the *H. pleuracanthus/zostericola* complex.

‡ Alpheids from Panama collections have not been identified to species at the time of this publication and are reported as Alpheidae, whereas the alpheids reported by Holmquist et al. (1989) from Florida Bay were identified to species. *Alpheus heterochaelis* and *A. normanni* are listed as "present" because they were collected during initial alpheid surveys in Panama (M. Marshall, pers. observ.).

Molluscs

Table A.2 lists mollusc species from seagrass beds of South Florida and Panama. The major sources of information on molluscs in Florida Bay (Turney and Perkins 1972) and Panama (Radwin 1969) were studies of living and recently dead molluscs in sediments from the two areas. Turney and Perkins (1972) described subenvironments within Florida Bay based on molluscan distribution patterns. Radwin (1969) studied recent, non-fossil molluscs collected from dredge spoil as it was pumped from the shoreward edge of a coral reef in order to create the foundation of the refinery (the source of the oil spill) in Bahía Las Minas. Turney and Perkins' species list included living molluscs, whereas Radwin's study did not separate living from dead specimens.

Other molluscan species lists from both South Florida and Panama are from general infaunal surveys (**Table A.2**). The empty shells of dead molluscs, which are often the best evidence of the existence of uncommon and rare species in an area, were ignored in these other studies. Empty mollusc shells were kept as part of the STRI seagrass project, but they have not been sorted (M. Marshall, pers. observ.).

The species lists suggest that similar molluscan faunas inhabit seagrass beds of South Florida and Panama. Although only 15% of the species are common to both areas, 55% of the species belong to genera that occur in both areas (**Table 1**). Percentages for gastropods and bivalves are similar. If Radwin's (1969) study had been restricted to seagrass bed fauna, the list of species reported from Panama would have been shorter, but the degree of overlap at the generic and specific levels may have been higher.

Fishes

Species lists for fishes in seagrass beds of South Florida and Panama are presented in **Table A.3**. Springer and McErlean (1962) sampled seagrass beds at Matecumbe Key (Florida Keys) using a seine net. Weinstein and Heck (1979) sampled fish by otter trawl in seagrass beds along the Caribbean coast of Panama, and also in the Cape Romano area of Southwest Florida. Sogard et al. (1989) used throw traps and gill nets to collect fish from seagrass beds on mudbank tops within each of the subenvironments of Florida Bay.

Despite the methodological differences, there are numerous shared and congeneric fish species (**Table 1**). Although only 22% of the species occur in both areas, 50% of the species belong to genera that occur in both areas. However, the Panamanian collections include more coral reef-associated species than those from South Florida (especially Florida Bay and Southwest Florida). For example, several species of Acanthuridae, Chaetodontidae, Haemulidae, Labridae, Lutjanidae, Scaridae, and Serranidae occurred either exclusively in Panama or in Panama and the Florida Keys (Springer and McErlean 1962), but not in Florida Bay (Sogard et al. 1989) or Southwest Florida (Weinstein and

Heck 1979) (**Table A.3**). Similarities between the Panama and Hawk Channel-Florida Keys seagrass ichthyofaunas are even more obvious if the species list generated for Panama is compared with lists generated by sampling coral reefs and adjacent habitats along the Florida reef tract (e.g., Starck 1968; Bohnsack et al. 1987). This comparison shows that most (90%) of the species collected in Panama also occur in South Florida. Also, only five of the 106 species collected in Panama by Weinstein and Heck (1979) are known through taxonomic and zoogeographic studies not to occur in South Florida waters. These are *Haemulon bonariense* (Courtenay 1961), *Amphichthys hildebrandi* (Collette 1966), *Rypticus brachyrhinus* (Courtenay 1967), *Serranus flaviventris* (Robins and Starck 1961), and *Diapterus rhombeus* (Deckert and Greenfield 1987). Of these, all genera except *Amphichthys* occur in South Florida (Robins and Ray 1986).

Table 3 compares the most abundant fish species in seagrass beds of Southwest Florida (Cape Romano area) and Panama, as determined by Weinstein and Heck (1979) using identical methods. The dominant species in the two areas are quite different, with reef-associated elements of the tropical fauna (e.g., *Sparisoma radians*) being much less common in Southwest Florida. Weinstein and Heck (1979) concluded that the Southwest Florida fish fauna is most closely allied with the Carolinean fauna occurring in the Apalachee Bay region of Northwest Florida.

Based on these comparisons, Panamanian fish communities are likely to resemble more closely those of seagrass beds in Hawk Channel and the lower Keys, rather than Florida Bay. Like the Panamanian beds, the Florida Keys seagrass beds exist in oceanic waters and are close to coral reefs (bank reefs or patch reefs). Gilmore (1987), in an analysis of zoogeography of western Atlantic seagrass fish communities, showed that the waters of Southeast Florida and the Florida Keys are inhabited by a tropical fauna, whereas waters of Florida Bay and Southwest Florida are inhabited by a warm temperature fauna. This disjunct distribution is thought to be primarily due to low winter temperatures on the west Florida shelf.

Other Fauna

Various other invertebrates were collected during the course of the STRI seagrass project (Marshall et al. 1993). Polychaetes, the numerically dominant infaunal taxon in Panamanian seagrass beds, have not been completely described (K. Fauchald, pers. comm. 1991). Much descriptive work would be required before a cross-regional (South Florida to Panama) comparison would be useful at the specific level. Despite the earlier works of Vasquez-Montoya (1979) and Fauchald (1977), much of this fauna remains poorly known.

Table 3. Numerically abundant fish species from seagrass beds of South Florida (Cape Romano area) and Panama (Bahía Las Minas area). Collections were made with an otter trawl in both areas (Weinstein and Heck 1979). Numbers indicate rank in each area; '--' indicates absence.

Species	Rank	
	South Florida	Panama
Bairdiella chrysoura	1	--
Lagodon rhomboides	2	--
Eucinostomus gula	3	9
Haemulon plumieri	4	13
Orthopristis chrysoptera	5	--
Lutjanus synagris	6	3
Syngnathus scovelli	7	--
Chilomycterus schoepfi	8	--
Opsanus beta	9	--
Eucinostomus argenteus	10	2
Sparisoma radians	--	1
Ocyurus chrysurus	--	4
Sphoeroides spengleri	28	5
Monacanthus ciliatus	18	6
Monacanthus setifer	48	7
Pseudupeneus maculatus	--	8
Chaetodon capistratus	--	10

Echinoderms were extremely rare in Bahía Las Minas seagrass beds from September 1986 through August 1989 (end of the seagrass subproject) (Marshall et al. 1993). They were seasonally abundant in unoiled seagrass beds outside of the immediate vicinity of Bahía Las Minas. Heck (1977) listed six species from his otter trawl samples, whereas Vasquez-Montoya (1979) identified eight species of echinoderms from within and closely adjacent to Bahía Las Minas. This small data base is not sufficient for comparisons with South Florida data.

Data from other groups also are too limited for meaningful comparisons. A small set of isopods, from pushnet and core samples, was identified by M. Schotte (National Museum of Natural History, Washington, DC). Amphipods were abundant in unoiled areas in pushnet and core samples, but they have not been identified.

CONCLUSIONS

The purpose of this report was to determine whether and to what extent findings from the STRI oil spill study in Panama (Keller and Jackson 1993) can be used to predict oil spill impacts upon South Florida seagrass beds. In the Introduction, three main factors were cited as affecting the response of seagrass beds to oiling:

- Spill circumstances, including spill location, volume, duration, rate of release, and chemical composition, effectiveness of spill containment and cleanup measures, and unpredictable environmental variables such as weather, sea state, and tidal stage at the time of a spill.

- Seagrass distribution and environmental setting, including geographic distribution, areal extent, and water depth of seagrass beds; proximity to mangrove shorelines; wave energy regime; and history of environmental problems.

- Species composition of seagrass bed communities, including both seagrasses and associated flora and fauna.

This report focused on the latter two factors, because spill circumstances cannot be predicted in advance. Conclusions regarding the two factors are discussed individually below.

SEAGRASS DISTRIBUTION AND ENVIRONMENTAL SETTING

Of the environmental factors discussed here, water depth appears to be critical in determining effects of oiling on seagrass beds. Intertidal and shallow subtidal seagrass beds are the most susceptible to oiling (Zieman et al. 1984; Marshall et al. 1990). The most severe effects on seagrasses in Panama occurred on intertidal reef flats. Some heavily oiled intertidal beds were killed and may never recover (Steger and Caldwell 1993), whereas subtidal seagrass beds survived everywhere, with mortality at the margins and more subtle effects within the beds (Marshall et al. 1993).

In South Florida, seagrasses are ubiquitous, but the largest and most productive seagrass beds occur in shallow waters (<1 to 3 m) of Florida Bay and in deeper waters (6 to 8 m) of Hawk Channel between the Florida Keys and the Florida Reef Tract. The small Panamanian beds, which occur in shallow lagoons (<1 m depth) between fringing coral reefs and mangrove shoreline, seem most similar to shallow seagrass beds adjacent to islands in the lower Florida Keys. They are also similar in depth range to shallow, subtidal seagrass beds on mudbanks and around islands in Florida Bay.

Because all of the Panamanian seagrass beds studied by Marshall et al. (1993) were subtidal, the data could greatly underestimate the severity of oil spill effects on Florida Bay seagrasses. Large expanses of seagrass on Florida Bay mudbanks are exposed at very low tides and could be highly vulnerable to oiling at certain times, similar to the intertidal reef flat beds in Panama studied by Steger and Caldwell (1993). The mudbanks are concentrated in the western part of Florida Bay, and the shallowest portions of these beds support a seagrass standing crop that is twice the bay-wide average (Zieman 1990).

On the other hand, data from the shallow subtidal Panamanian beds may overestimate oil spill impacts on Hawk Channel seagrasses. Because of their greater water depth, the Hawk Channel beds might escape oil exposure unless passing slicks were sprayed with dispersant to protect "more sensitive" inshore habitats. However, under certain conditions (e.g., storms, wave action), oil can become mixed into emulsions with seawater and combine with sediment particles and sink to the bottom, resulting in oiling of deeper beds (Marshall et al. 1990).

Proximity to mangrove shorelines is also an important consideration. All of the Panamanian seagrass beds were near mangrove shorelines, resulting in chronic exposure over several years as oil leaked out of contaminated sediments. Loss of mangroves increased erosion and sedimentation, which also may have affected adjacent seagrass beds. Florida Bay is lined by extensive mangrove forests which, if oiled, could become a chronic source of oil and sediment deposition on Florida Bay seagrass beds. The largest shallow bank beds in Florida Bay are well to the south of the mainland mangrove fringe, but mangroves also occur throughout the bay on small islands. In contrast, Hawk Channel seagrass beds are not surrounded on any side by an oil-absorptive mangrove shoreline.

A key difference between Panama and South Florida is the areal extent of seagrass beds. South Florida seagrass beds are extensive, whereas the Panamanian beds are small and discontinuous. The difference is important from at least two respects. First, despite the size of the Panama spill and the length of coastline affected, a relatively small area of seagrass beds was contaminated. A much larger area of seagrass beds could be oiled by a single spill reaching Florida Bay or the lower Keys. Second, the pattern of recovery from an oil spill might be different in South Florida, because some animals could migrate to unaffected areas and extensive source beds for new recruits would exist. Small, isolated seagrass beds may be subject to severe setbacks or total elimination, as contrasted with seagrass beds that are part of a larger, continuous system (Zieman et al. 1984). However, incorporation of oil in seagrass bed sediments (as happened in Panama) could inhibit recovery even if new recruits were available.

SPECIES COMPOSITION

In general, the species composition of seagrass communities in South Florida and Panama is similar. The dominant seagrass species are the same, and although many of the epifaunal and infaunal species are different, most species belong to genera that occur in both areas. Given the similarities at the generic level, there is no basis to assume that these sensitivities differ greatly between the two areas.

However, a distinction must be made between seagrass faunal communities of Florida Bay and those of the Florida Keys. As noted in particular for fishes, Florida Bay seagrass fauna have warm temperate affinities, whereas those associated with the Florida Keys have more tropical Caribbean affinities and are therefore more similar to Panamanian seagrass communities.

Thus, seagrass beds in the lower Keys are most similar to the Panamanian beds with respect to water depth, seagrass species, and fauna. In contrast, although Florida Bay seagrass beds resemble Panamanian beds with respect to water depth and seagrass species, they possess a different (more temperate) seagrass fauna.

SUMMARY

Data from the STRI study (Keller and Jackson 1993) could be useful in helping to predict effects of an oil spill on South Florida seagrass beds. However, environmental and biological differences between the two areas must be taken into consideration.

The seagrass portion of the STRI study (Marshall et al. 1993) focused on shallow, subtidal seagrass beds in lagoons between fringing reefs and mangrove shorelines. These beds are similar to seagrass beds adjacent to islands in the lower Keys with respect to water depth, seagrass species, and associated fauna. They are also similar in depth range to extensive, shallow, subtidal seagrass beds on mudbanks and around islands in Florida Bay, although Florida Bay possesses a more temperate seagrass fauna. The Panamanian beds are in much shallower water (<1 m depth) than the extensive seagrass beds (6 to 8 m depth) that occur in Hawk Channel between the Florida Keys and the Florida Reef Tract.

Data from the seagrass study (Marshall et al. 1993) are probably a good indication of potential spill effects in shallow, subtidal seagrass beds, such as those adjacent to islands in the lower Florida Keys. They are also relevant to shallow, subtidal beds in Florida Bay which are similar in water depth and proximity to mangrove shorelines. However, the data could greatly underestimate the severity of oil spill impacts to seagrasses on Florida Bay mudbanks, many of which are exposed during very low tides. A better indicator of potential effects on these mudbank seagrasses is provided by the observations of Steger and Caldwell (1993), who documented the apparently irreversible destruction of an intertidal seagrass bed at one reef flat site.

Because of water depth differences, data from the seagrass study (Marshall et al. 1993) are less useful for predicting impacts to seagrass beds in deeper waters of Hawk Channel. The Hawk Channel beds might escape oil exposure, although oil could be deposited under certain circumstances (e.g., if dispersants were used, or if wave action formed oil-in-water emulsions). Also, unlike the Panamanian seagrass beds, the Hawk Channel beds also are not surrounded on any side by an oil-absorptive mangrove shoreline.

The areal extent of seagrass beds is much greater in South Florida than in Panama. It is difficult to predict how this difference in scale might affect patterns of damage and recovery. Obviously, a much larger area of South Florida seagrass beds (and adjacent mangroves) could be oiled by a single spill of similar size. Patterns of recovery might be different in South Florida because some animals could migrate to unaffected areas and extensive source beds for new recruits would exist. However, chronic oil release from contaminated mangrove sediments and incorporation of oil into seagrass bed sediments (as happened in Panama) could inhibit recovery even if new recruits were available.

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APPENDIX

SPECIES LISTS

Table A.1. Comparison of decapod and stomatopod crustacean species lists for South Florida (Florida Bay) and Panama (Bahía Las Minas area). Source codes: for Florida, (1) Holmquist et al. (1989); for Panama, (2) Heck (1977) as modified in Coen and Heck (1983), and (3) Marshall (unpublished data).

Species	South Florida	Panama
DECAPODA		
Penaeidae		
Metapenaeopsis martinella		2,3
Penaeus duorarum notialis	1	2,3
Trachypenaeus similis		3
Sicyoniidae		
Sicyonia laevigata		2,3
Stenopodidae		
Stenopus hispidus		2
Palaemonidae		
Leander tenuicornis	1	2,3
L. paulensis	1	
Palaemon floridanus	1	2
P. northropi		3
Periclimenes americanus	1	2,3
P. iridescens	1	
P. longicaudatus	1	3
Gnathophyllidae		
Gnathophylloides mineri		2,3
Gnathophyllum americanum		3
Processidae		
Ambidexter symmetricus	1	2,3
Processa fimbriata		2,3
P. bermudensis	1	
Alpheidae		
Alpheus armillatus	1	2
A. floridanus		2,3
A. formosus		2
A. normanni	1	2
A. heterochaelis	1	
Synalpheus fritzmulleri		2,3
S. goodei		2
S. pandionensis		2
S. townsendi		2,3
Ogyrididae		
Ogyrides alphaerostris	1	
Hippolytidae		
Hippolyte zostericola		2,3
H. pleuracanthus	1	
Latreutes parvulus	1	3
L. fucorum	1	2,3
Thor manningi		2,3
T. dobkini	1	
T. floridanus	1	
Tozeuma carolinense	1	2,3
Trachycaris restrictus		2,3
Scyllaridae		
Scyllarus sp.		2
Palinuridae		
Palinurus argus	1	2,3
Diogenidae		
Calcinus tibicen		2
Clibanarius antillensis		2,3
Dardanus venosus		2
Paguristes limonensis		2
P. anomalus	1	
P. tortugae	1	
Paguridae		
Pagurus bonairensis		2
P. brevidactylus		2
P. mclaughlinae	1	

Table A.1. (continued).

Species	South Florida	Panama
Porcellanidae		
Megalobrachium mortenseni		2
Petrolishtes armatus	1	2
P. galathinus		2
Dromiidae		
Dromidia antillensis		2
Calappidae		
Calappa angusta		2
C. ocellata		2
Calappa sp.	1	
Hepatus pudibundus		2,3
Majidae		
Chorinus heros		2
Libinia dubia	1	
Metaporhapsis calcarata	1	
Macrocoeloma diplacanthum		2,3
Microphrys bicornutus	1	2
Mithrax forceps	1	2
M. ruber		2
Pelia mutica	1	
Pitho aculeata		2,3
P. lherminieri		2
P. quadridentata		2
P. sexdentata		2
P. anisodon	1	
Podochela gracilipes		2
P. riisei	1	2,3
P. sidneyi		2
Stenorhynchus seticornis		2
Parthenopidae		
Heterocrypta granulata		2
Goneplacidae		
Cyrtoplax spinidentata		2
Eucratopsis crassimanus	1	
Portunidae		
Callinectes ornatus	1	
C. sapidus	1	
C. danae		2,3
Cronius ruber		2,3
C. timidulus		2
Portunus depressifrons	1	
P. gibbesii	1	
P. ordwayi	1	2
P. sayi	1	
P. sebae	1	
P. spinimanus	1	
Xanthidae		
Menippe mercenaria	1	
Dyspanopeus texanus	1	
Eurypanopeus depressus	1	
Micropanope sp.	1	
Neopanope packardii	1	
Panopeus occidentalis	1	2
P. simpsoni	1	
Pilumnus dasypodus		2
Rithropanopeus harrisii	1	
Pinnotheridae		
Pinnixia sayana	1	
Ocypodidae		
Uca sp.	1	
STOMATOPODA		
Squillidae		
Meiosquilla quadridens	1	
Gonodactylidae		
Gonodactylus lacunatus		2
Pseudosquillidae		
Pseudosquilla ciliata	1	2

Table A.2. Comparison of mollusc species lists for South Florida (mainly Florida Bay) and Panama (Bahía Las Minas area). Numerous other Panamanian species, not included in this list because of unknown habitat associations, were recorded (Radwin 1969) from the dredged material used as a foundation for the Bahía Las Minas oil refinery (the source of the 1986 spill). Source codes: for Florida, (1) Tabb and Manning (1961), (2) Tabb et al. (1962), (3) Hudson et al. (1970), (4) Turney and Perkins (1972), and (5) McClanahan (unpublished data); for Panama, (6) Radwin (1969), (7) Jackson (1973), (8) Heck (1977), (9) Vasquez-Montoya (1979), (10) Cubit and Williams (1983), and (11) Marshall and Batista (unpublished data).

Species	South Florida	Panama
GASTROPODA		
Fissurellidae		
Emarginula pumila		6
Hemitoma octoradiata		6
Diodora caynensis	1,3	6,11
D. meta	1	
D. listeri		6
D. dysoni	2	
Diodora sp.		
Lucapina suffusa		6
Fissurella fascicularis		6
F. nodosa		6
Acmaeidae		
Acmaea pustulata		11
Trochidae		
Calliostoma jujubinum tampaense	1,2,3,4	
C. euglyptum		6
C. javanicum		6
Cittarium pica		6
Tegula fasciata	1,2,3,4,5	6
Solariorbis schumoi		6
S. corylus		6
S. hondurasensis		6
S. infracarinata		6
S. shimeri		6
Anticlimax schumoi		6
Turbinidae		
Turbo castaneus	1,2,3,4	6
T. canaliculatus	5	
T. filosus		6
Astraea phoebia	3,5,5	6
A. tecta americana	3,4,5	6
A. caelata		6
A. longispina	4	
Liotia tricarinata		6
Neritidae		
Smaragadia viridis	4	6,11
Neritina virginea		6,11
Architectonicidae		
Architectonica nobilis		6
Heliacus perrieri		6
Littorinidae		
Littorina angulifera	1	
Littorina sp.		6
Vermetidae		
Vermicularia sp.	1	
Vermetus varians		6
Aletes mcgintyi		6
A. nebulosus		6
A. floridanus		6
Stephopoma myrakeenae		6
Spiroglyphus annulatus		6
Thylacoides sp.		6

Table A.2. (continued).

Species	South Florida	Panama
Modulidae		
Modulus modulus	1,2,3,4,5	6,8
M. carchedonius		6
Potamididae		
Cerithidea costata	1	
C. scalariformis	1	
Cerithidae		
Batillaria minima	1,3	
Cerithium floridanum	1,2,5	
C. muscarum	1,3,4,5	
C. eburneum	1,2,4,5	8,9,11
C. algicola	2	6
C. litteratum	4,5	6,11
C. moenense		6
C. variabile	4	6,9,11
Bittium varium	1,4	6
Alabina cerithioides		6
Litiopa melanostoma		6
Epitoniidae		
Epitonium sp.	1	
E. foliaceicostum		6
Opalia crenata		6
Depressiscala nautilae		6
Calyptraeidae		
Calyptraea centralis	1,2	6
Crucibulum auriculum		6
Crepidula maculosa		6
C. convexa	1,3	6
C. aculeata	1	
C. plana	1,2,3	6
Crepidula sp.	4	
Strombidae		
Strombus alatus	1	
S. gigas	5	
S. pugilis		6
S. ranius	5	6,11
Eratoidae		
Erato maugeriae	1,2	6
Trivia candidula	1,2	
T. pediculus		6
T. quadripunctata		6
Trivia sp.	4	
Cypraeidae		
Cypraea cervus	5	
Naticidae		
Polinices duplicatus	1,2	
P. lacteus		6,11
P. hepaticus		11
Naticea canrena	1	6
N. livida	2	
Tectonaticea pusilla		6
Sinum maculatum		6
Glypheithema floridana		6
Turbinellidae		
Vasum muricatum		11
Cassiidae		
Phalium granulatum	1	
Ficidae		
Ficus communis	1	
Muricidae		
Murex recurvirostris rubidus	1,2	8
M. ponum	1,2	
M. florifer	1,2	
M. cellulosus	1,2,3	
M. brevifrons	4	
M. rubidus		6
M. woodringi		6
Chicoreus florifer		6

Table A.2. (continued).

Species	South Florida	Panama
Muricidae (continued)		
Muricopsis ostrearum	1,3	
M. oxytatus		6
M. philippina		6
Risomurex schrammi		6
R. muricoides		6
Muricidae (continued)		
Morula (Drupa) nodulosa	5	6
M. didyma		6
Thais deltoidea		6
Urosalpinx tampaensis	1	
Eupleura sulcidentata	1,3	
E. caudata	2	
Columbellidae		
Columbella mercatoria	1,2,4,5	6
C. rusticoides	1,2,3,4	
Anachis avara	1,2,4	
A. obesa	1,2	6
A. translirata	1,2	
A. petri		6
Astyris lunata		6
Conella ovuloides		6
Cosmioconcha nitens		6
Nitidella nitida		6
Steironepion monilifera		6
Zafrona pulchella		6
Mitrella lunata	4	
Buccinidae		
Engina turbinella		6
Bailya intricata		6
Caducifer adelus		6
Cantharus tinctus	1,5	
C. auritulus		6
Pisania pusio		6
Melongenidae		
Melongena corona	1,3,4	
M. melongena		6
Busycon contrarium	1,2,3	
B. spiratum	1,2,3	
Nassariidae		
Nassarius vibex	1,3,4	9
N. ambiguus	2,4	
N. ciniscuius		6
Fasciolariidae		
Fasciolaria tulipa	1,2,3,4,5	6,8,9,11
F. hunteria	1,2,3	
Fusilatrius cayohuesonicus		6
Pleuroploca gigantea	1,2,4,5	
Latirus infundibulum		6
L. carinifera		6
Leucozonia nassa		6
Olividae		
Oliva caribaeenis		6
Olivella nivea		6
O. chiriquiensis		6
O. sp.	1	
O. minuta	3	
Minioliva myrmecoon		6
Marginellidae	4	
Marginella denticulata	5	
M. guttata	5	
M. (Prunum) apicina	1,3,5	
P. carneum		6
Volvarina avena		6
Gibberula bocasensis		6
G. ovuliformis		6

Table A.2. (continued).

Species	South Florida	Panama
Conidae		
Conus spurius spurius		6
C. regius		6
C. daucus		6
C. granulatus		6
C. largillierti		6
C. pygmaea		6
C. mus		6
C. mindanus		6
C. floridanus	1	
C. stearnsi	1,2,3	
C. jaspideus	1,2	6
Terebridae		
Terebra dislocata	1,2	
T. taurinum		6
T. spei		6
Turridae		
Polystira albida		6
Drillia albinodata		6
D. albomaculata		6
Syntomodrillia lissotropis		6
Crassispira auberti		6
C. harfordiana		6
C. chazaliei		6
C. ebenina	1,2	
C. ostrearum	1,2	
*C. albomaculata**	2	
Cerodrillia thea	1,3	
C. perryae	2	
Nannodiella oxytata		6
Brachycythara biconica		6
Ithycythara psila		6
Mangelia filosa		6
M. stellata§	4	
Mangelia sp.	4	
Thelecythara floridana		6
Acmaturris sp.		6
Daphnella lymnaeiformis		6
Bullidae		
Bulla occidentalis		6
B. striata	1,3	
Atydae		
Atys guildingi		6
A. riisiana		6
A. caribaea	1	
Haminoea elegans	1	
H. succinea	1	
H. antillarum	1,3	9
Aplysidae		
Bursatella leachi plei	1	
Pleurobranchidae		
Pleurobranchus atlanticus	1,2	
Ellobiidae		
Melampus coffeus	1	
Ischnochitonidae		
Chaetopleura apiculata	1,2	
Ischnochiton papillosus	3	
PELECYPODA		
Arca zebra		6
A. imbricata		6
Arcopsis adamsi	1,2,3,4	6,9,11
Anadara chemnitzi		6
A. notabilis	1	6,11
Barbatia cancellaria		6
B. candida		6
Noetia ponderosa	1	

Table A.2. (continued).

Species	South Florida	Panama
Glycymeridae		
Glycymeris pectinata	1,2,3,4	6
Mytilidae		
Brachiodontes exustus	1,3,4	7
B. recurvus	1	
Amygdalum papyria	1	
Musculus lateralis	1,2,3	
Modiolus americanus‡	4	6
Lithophaga antillarum		6
Botula fusca		6
Pteriidae		
Pteria colymbus	1	
Pinnidae		
Pinna carnea	1	
Atrina rigida	1,2,3,4	
A. serrata	1,2	
Pectinidae		
Pecten ziczac	1,2	
Aequipecten muscosus	1,2	
A. irradians	1,3	
Pecten gibbus	1	
Limidae		
Lima pellucida	1,3,4	
Anomiidae		
Anomia simplex	1	
Pteriidae		
Pinctada radiata	3,4	
Ostreidae		
Ostrea equestris	1	
Crassostrea virginica	1	
Carditidae		
Cardita floridana	1,2,3,4	
Venericardia tridentata	1	9
Lucinidae		
Lucina pensylvanica		6
L. nassula		6
L. pectinatus		6
L. muricatus		6
L. amiantus	1,2	
L. multilineata	4	
Phacoides pectinatus	1	7
P. nassula	1,4	
Codakia orbiculata	1,2,3,4	6,9
C. orbicularis	4	6,9,11
C. pectinella		6
Ungulinidae		
Diplodonta punctata		11
Cardiidae		
Trachycardium isocardia		6
T. muricatum	1,2,4	6
T. egmontianum	1,2	
Laevicardium laevigatum	4	6
L. mortoni	1,3,4	6
L. multilineata		6
Trigonocardia antillarum		6
Americardia media		6
Papyridea soleniformis		6
Veneridae		
Chione cancellata	1,2,3,4	6,9,11
C. paphia		6
Anomalocardia cunimeris	1,3,4	
Pitar simpsoni	1	
P. fulminata	4	
Transenella cubaiana	3	
T. stimpsoni	3	
Transenella sp.	4	
Macrocallista nimbosa	1	
M. maculata	1	6

Table A.2. (continued).

Species	South Florida	Panama
Veneridae (continued)		
Dosinia elegans	1	
D. discus		6
Callocardia albida		6
Antigona listeri		6
Gouldia cerina		6
Tellinidae		
Tellina listeri		6
T. angulosa		6
T. martinicensis		6
T. versicolor	1,2	9
T. promera	1	
T. tampaensis	1,3	
T. similis	1,3,4	
T. lineata	1,3	
T. alternata	1	7,11
T. punicea	1	6
T. texana	4	
T. mera	4	
Tellidora cristata	1,2	
Scissula exilis		6
Macoma mitchili	1	
M. constricta	1	9
M. tenta		6
Arcopagia fausta		6
Semelidae		
Semele proficua	1,2	6
S. purpurascens		6
Abra aequalis	1	
A. lioica		6
Cumingia tellinoides	4	
Sanguinolariidae		
Tagelus plebius	1	
T. divisus	1	11
Mactridae		
Spisula solidissima	1	
Labiosa plicatella	1	
Mactra fragilis	1,2,4	
Corbiculiidae		
Polymesoda caroliniana	1	
Pseudocyrena maritima	4	
Corbulidae		
Corbula contracta	1,2	
C. barrattiana	1,2	
C. swiftiana	2	6
C. dietziana		6
C. cubaniana		6
C. caribaea		6
Notocorbula operculata		6
Pholadidae		
Cyrtopleura costata	1	
Lyonsiidae		
Lyonsia hyalina	1,3,4	
Cuspidariidae		
Cardiomya costellata	4	

* listed in (2) as *Monilispira albinodonta*.
‡ listed in (4) as *Volsella americana*.
§ listed in (4) as *Stellatoma stellata*.

Table A.3. Comparison of fish species lists for South Florida and Panama. Collection methods used in each study are discussed in the text. Source codes: for South Florida, (1) Springer and McErlean (1962)--Matecumbe Key; (2) Weinstein and Heck (1979)--Cape Romano area; and (3) Sogard et al. (1989)--Florida Bay; for Panama, (2) Weinstein and Heck (1979)--Bahía Las Minas area.

Species	South Florida	Panama
Rhincodontidae		
Ginglymostoma cirratum		2
Carcharhinidae		
Carcharhinus limbatus	3	
Negaprion brevirostris	3	
Sphyrnidae		
Sphyrna tiburo	3	
Pristidae		
Pristis pectinata	3	
Rhinobatidae		
Rhinobatos lentiginosus	3	
Torpedinidae		
Narcine brasiliensis	2	
Dasyatidae		
Dasyatis sabina	2	
Urolophidae		
Urolophus jamaicensis		2
Elopidae		
Elops saurus	1,3	
Albulidae		
Albula vulpes	3	
Muraenidae		
Gymnothorax vicinus		2
Ophichthidae		
Ahlia egmontis	3	
Myrophis punctatus	3	
Clupeidae		
Harengula jaguana	1,3	
Jenkinsia lamprotaenia	1,3	
Opisthonema oglinum	1,3	
Sardinella aurita	1	
S. brasiliensis	3	
Sardinella sp.		2
Engraulidae		
Anchoa cubana	1	
A. mitchilli	1,3	
A. lyolepis		2
A. hepsetus	3	2
Anchoviella perfasciata	1	
Synodontidae		
Synodus foetens	1,2,3	2
S. poeyi		2
S. intermedius		2
Ariidae		
Arius felis	2,3	
Bagre marinus	1,3	
Batrachoididae		
Opsanus beta	1,2,3	
Amphichthys hildebrandi		2
Porichthys plectrodon	3	
Gobiesocidae		
Acyrtops beryllinus	1	
Gobiesox strumosus	1	
Antennariidae		
Histrio histrio	1,3	2
Antennarius scaber		2
Ogcocephalidae		
Ogcocephalus radiatus	2	
Bythitidae		
Ogilbia cayorum	3	

Table A.3. (continued).

Species	South Florida	Panama
Carapidae		
Carapus bermudensis	1	2
Exocoetidae		
Chiodorus atherinoides	3	
Hemiramphus brasiliensis	1,3	
Hyporhamphus unifasciatus	3	
Belonidae		
Strongylura marina	3	
S. notata	1,3	
S. timucu	1,3	
Tylosurus crocodilus	3	
Cyprinodontidae		
Adinia xenica	3	
Cyprinodon variegatus	3	
Floridichthys carpio	1,3	
Fundulus sp.	3	
Lucania parva	1,3	
Poeciliidae		
Poecilia latipinna	3	
Atherinidae		
Atherinomorus stipes	1,3	
Hypoatherina harringtonensis	1,3	
Menidia peninsulae	3	
Menidia sp.		2
Aulostomidae		
Aulostomus maculatus		2
Fistulariidae		
Fistularia tabacaria		2
Holocentridae		
Holocentrus rufus		2
Syngnathidae		
Anarchopterus criniger	3	
Cosmocampus albirostris	1,3	
C. brachycephalus	1	
Hippocampus erectus	2	
H. reidi	2	2
H. zosterae	1,2,3	
Syngnathus dunckeri	1	
S. floridae	1,2,3	2
S. louisianae	1,2,3	
S. scovelli	1,2,3	
Micrognathus crinigerus	2	
Centropomidae		
Centropomus pectinatus	3	
Serranidae		
Diplectrum bivittatum	3	2
D. formosum	2	
Epinephelus striatus		2
E. morio	2	2
E. itajara		2
Alphestes afer		2
Rypticus brachyrhinus		2
R. saponaceus		2
Myctoperca bonaci	1	2
M. microlepis	2	
Serranus flaviventris		2
S. subligarius	2	
Serraniculus pumilio	2	
Apogonidae		
Astrapogon alutus		2
Phaeoptyx pigmentaria		2
Pomatomidae		
Pomatomus saltatrix	3	
Rachycentridae		
Rachycentron canadum	3	
Echeneidae		
Echeneis naucrates	1	

Table A.3. (continued).

Species	South Florida	Panama
Carangidae		
Trachinotus carolinus	3	
T. falcatus	3	
Caranx crysos	3	
C. hippos	1,3	
C. bartholomaei		2
C. latus	3	2
Chloroscombrus chrysurus		2
Oligoplites saurus	3	
Selene vomer	3	
Lutjanidae		
Lutjanus synagris	2,3	2
L. griseus	1,2,3	2
L. analis	1	2
L. apodus	1	2
L. jocu		2
Ocyurus chrysurus	1	2
Lobotidae		
Lobotes surinamensis	1	
Gerreidae		
Eucinostomus argenteus	1,2	2
E. gula	1,2,3	2
E. lefroyi	1	2
E. harengulus	3	
Eucinostomus spp.	3	
Diapterus rhombeus		2
Gerres cinereus	3	2
Haemulidae		
Haemulon parra	1,3	2
H. plumieri	1,2,3	2
H. sciurus	1,3	2
H. aurolineatum	1,2,3	2
H. bonariense		2
H. flavolineatum	1	2
H. chrysargyreum	3	
Haemulon sp.	3	
Anisotremus virginicus	2	
Orthopristis chrysoptera	1,2,3	
Sparidae		
Archosargus probatocephalus	3	
A. rhomboidalis	3	2
Lagodon rhomboides	1,2,3	
Calamus arctifrons	1	
C. penna		2
Sciaenidae		
Bairdiella batebana	2	
B. chrysoura	2,3	
B. sanctaeluciae		2
Cynoscion nebulosus	2,3	
C. arenarius	3	
Leiostomus xanthurus	3	
Menticirrhus saxatilis	1	
Pogonias cromis	3	
Sciaenops ocellatus	3	
Odontoscion dentex		2
Mullidae		
Pseudupeneus maculatus	1	2
Ephippidae		
Chaetodipterus faber	1,2,3	2
Chaetodontidae		
Chaetodon capistratus		2
C. striatus		2
C. ocellatus		2
Pomacanthidae		
Pomacanthus paru		2

Table A.3. (continued).

Species	South Florida	Panama
Pomacentridae		
Pomacentrus leucostictus	1	
P. planifrons		2
Labridae		
Doratonatus megalepis	1	2
Halichoeres bivittatus	1	2
H. poeyi		2
Hemipteronotus martinicensis	1	
Scaridae		
Sparisoma radians	1	2
S. chrysopterum	1	2
S. rubripinne	1	2
S. viride	1	
Sparisoma sp.	3	
Cryptotomus roseus		2
Nicholsina usta	1,2	2
Scarus croicensis	1	2
S. guacamaia	1	
Mugilidae		
Mugil cephalus	3	
M. curema	1,3	
M. gyrans	3	
M. trichodon	1	
Sphyraenidae		
Sphyraena barracuda	1,3	2
S. guachancho		2
S. picudilla		2
Polynemidae		
Polydactylus virginicus		2
Clinidae		
Chaenopsis ocellata	3	
Paraclinus fasciatus	3	2
P. marmoratus	1,3	
Labrisomus nuchipinnus		2
Malacoctenus aurolineatus		2
M. macropus	1	
Blenniidae		
Chasmodes saburrae	3	
Hypsoblennius ionthas	2	
Callionymidae		
Diplogrammus pauciradiatus	1,3	
Gobiidae		
Barbulifer ceuthoecus	1,3	
Gobionellus hastatus		2
G. saepepallens	3	2
G. stigmaturus	1	
Gobiosoma robustum	1,2,3	
Microgobius gulosus	3	
Coryphopterus glaucofraenum		2
Bathygobius curacao		2
Acanthuridae		
Acanthurus chirurgus	1	2
A. bahianus	1	2
Dactylopteridae		
Dactylopterus volitans		2
Stromateidae		
Nomeus gronovii	3	
Scorpaenidae		
Scorpaena bergi		2
S. brasiliensis	1	
S. grandicornis	1	2
S. isthmensis		2
S. plumieri	1	2
Triglidae		
Prionotus salmonicolor	1	
P. scitulus	2	
P. tribulus	1	

Table A.3. (continued).

Species	South Florida	Panama
Bothidae		
Ancyclopsetta quadrocellata	2	
Citharichthys macrops	1	
C. spilopterus		2
Bothus ocellatus	1	2
B. maculiferus		2
Syacium micrurum		2
Paralichthys albigutta	2,3	
Etropus crossotus	2	
Soleidae		
Achirus lineatus	1,3	
Trinectes inscriptus	1	
T. maculatus	3	
Cynoglossidae		
Symphurus plagiusa	1,3	2
Balistidae		
Balistes capriscus	1	
Monacanthus ciliatus	1,2,3	2
M. hispidus	1,2,3	
M. setifer	2	2
M. tuckeri		2
Aleuterus schoepfi		2
Ostraciidae		
Lactophrys quadricornis	1,2,3	2
L. triqueter		2
L. trigonus	1,2	2
Tetraodontidae		
Sphoeroides nephelus	1,2,3	2
S. testudineus		2
S. spengleri	1,2,3	2
Canthigaster rostrata		2
Diodontidae		
Chilomycterus schoepfi	1,2,3	
C. antennatus		2
Diodon holocanthus	1	2

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.