Literature Review and Synthesis of Land-Based Sources of Pollution Affecting Essential Fish Habitats in Southeast Florida

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Executive Summary

A variety of technical reports and publications are available that characterize the effects of Land Based Sources of Pollution (LBSP) on marine and estuarine habitats in southeast Florida. Resource managers in southeast Florida need a synthesis of this information in order to further understanding of the connections between LBSP and marine and estuarine habitats and to develop informed management decisions to abate LBSP threats. However, the available information in this body of work can be highly technical, difficult to obtain, and multi-disciplinary. To address this problem, over 144 publication and technical reports were reviewed and synthesized.

A review of the available literature on the adverse effects of LSPB on coral reefs and associated habitats showed that coral reefs in tropical and subtropical latitudes are experiencing these threats. This report identifies and describes the primary pollutant threats in Florida and mechanisms for introduction into estuarine and marine ecosystems. Additionally, a review of available literature on marine and estuarine habitats in southeast Florida showed that sustainable coral reef ecosystems require functional back reef habitats (e.g. seagrass, mangrove, soft bottom, coastal inlets and nearshore hardbottom) to provide nursery, shelter, and foraging opportunities for reef fish and the other organisms in coral reef and associated habitats. Ecosystem management brings an integrated perspective to natural resource management. It takes a big-picture approach, replacing short term, single species management with multi-species, long-term and large-scale approaches. This report provides a description of the habitats designated as Essential Fish Habitats and identifies the main LBSP threats to each habitat type.

As a result of this review a number of conclusions and recommendations were developed. Six of the leading recommendations include:

- Reduce nutrient loading from all anthropogenic sources and pathways, including surface water management systems, coastal inlets, submarine groundwater discharge, and ocean outfall discharge, to improve conditions for nearshore and offshore habitats, including the coral reef ecosystem in southeast Florida.

- Provide an ecosystem-based fisheries habitat perspective to current water quality improvement planning and management activities in southeast Florida to reduce LBSP impacts to estuarine and marine fisheries habitats. The ecosystem based fisheries management approach considers the physical, chemical and biological components and connections between species and between habitats.

- Support implementation of numeric nutrient water quality criteria for nitrogen and phosphorus that are in the process of being developed by the state of Florida

- Support construction of additional water storage reservoirs, stormwater treatment areas and appropriate technologies to reduce nutrient levels before release of water to southeast Florida estuaries and to modulate salinity changes in those estuaries.

- Modify beach nourishment activities to minimize sedimentation and turbidity impacts to nearshore hardbottom, including worm reef, and offshore reef habitats.

- Update the literature review and synthesis of LBSP impacts on EFH to include new information regarding water management activities, pollution reduction efforts, and results of recent research.

Table of Contents

Acknowledgements 1

Acronyms and Abbreviations 7

1 Introduction 8

  1.1 Florida's Coral Reef Tract 9

  1.2 Coral Reef Management in Southeast Florida 10

  1.3 Land Based Sources of Pollution Focus Team and Technical Advisory Committee 11

  1.4 Stressors and Pollutants 11

  1.5 Back Reef Habitats 12

2 Land Based Pollutants 12

  2.1 Nutrients 12

  2.2 Turbidity 14

  2.3 Salinity 14

  2.4 Sedimentation 15

  2.5 Heavy Metals 16

  2.6 Hydrocarbons and other organics 16

  2.7 Biocides 16

  2.8 Pathogens 17

  2.9 Pharmaceutical and Personal Care Products 18

3 Land-based Sources 19

  3.1 Water Management Systems 21

  3.2 Coastal Inlets 21

  3.3 Submarine Groundwater Discharge 23

  3.4 Ocean Outfall Discharge 23

4 Fisheries Habitats 26

  4.1 Mangrove Habitats 27

  4.2 Seagrass Habitats 27

  4.3 Oyster Reef and Shell Habitats 28

  4.4 Soft-Bottom Habitats 29

4.5 Nearshore Hardbottom and Worm Reef Habitats 30
4.6 Coral, Coral Reefs and Offshore Hardbottom Habitats 31
5 Land Based Sources of Pollution Threats to Fisheries Habitats 32
5.1 LBSP Threats in Mangrove Habitats 32
5.2 LBSP Threats to Seagrass Habitats 33
5.3 LBSP Threats to Oyster Habitats 34
5.4 LBSP Threats to Soft-bottom Habitats 35
5.5 LBSP Threats to Nearshore Hardbottom and Worm Reef Habitats 35
5.6 LBSP Threats to Coral and Coral Reef and Offshore Hardbottom Habitats 36
6 Conclusions and Recommendations 39
6.1 Conclusions 39
6.2 Recommendations 41
7 References 42

Acronyms and Abbreviations

AOML – Atlantic Oceanographic and Meteorological Laboratory
BCDERD – Broward County Development and Environmental Regulation Division
BNP – Biscayne National Park
CAMA – Coastal and Aquatic Managed Areas
CRCP – Coral Reef Conservation Program
DDT – dichlorodiphenyltrichloroethane
DEP – Florida Department of Environmental Protection
EFH– Essential Fish Habitat
EPA – Environmental Protection Agency
FKNMS – Florida Keys National Marine Sanctuary
LAS – Local Action Strategy
LBSP – Land-based Sources of Pollution
NOAA – National Oceanic and Atmospheric Administration
NTU– Nephalometric Units
Pg/l– picograms/liter
ppt– parts per thousand
Psu– Photosynthetic Units
RECOVER – Restoration Coordination and Verification
SAFMC – South Atlantic Fishery Management Council
SEFCRI – Southeast Florida Coral Reef Initiative
SFWMD – South Florida Water Management District
SGD – Submarine Groundwater Discharge
STORET– Storage and Retrieval database for Florida water quality data
TBT – Tri-butyl tin
USCRTF – United States Coral Reef Task Force

1 Introduction

The effects of land based sources of pollution (LBSP) on coral reefs have received extensive research focus, in tropical and subtropical regions around the world (Fabricius 2005) and in Florida (Trnka et al. 2006). In tropical and subtropical ecosystems in the Atlantic-Caribbean, coral reefs, mangroves, unvegetated bottom, and seagrass are all physically, chemically and biologically connected (Beets et al. 2003, Eggleston et al. 2004, Jones et al. 2010). The effects of LBSP on marine and estuarine habitat connectivity arepoorly understood. The purpose of this report is to present the findings of current literature regarding LBSP effects on these habitats in southeast Florida.

Recreation and tourism are two of Florida’s most important industries, which generated an estimated $62 billion in sales in 2005. Much of Florida’s recreation and tourism is associated with reef-related activities such as fishing, diving, boating, and industries supporting these activities. Results from two studies of economic activity associated with natural and artificial reefs in Florida indicated that reef-related recreation and tourism supported more than 36,000 jobs and that a total of $2.3 billion in sales and $1.1 billion in income were generated annually from reef-related expenditures (Johns et al. 2001, Johns et al. 2004). These findings clearly demonstrate that conservation and sustainable use of coral reef and fisheries resources are very important to Florida’s economy.

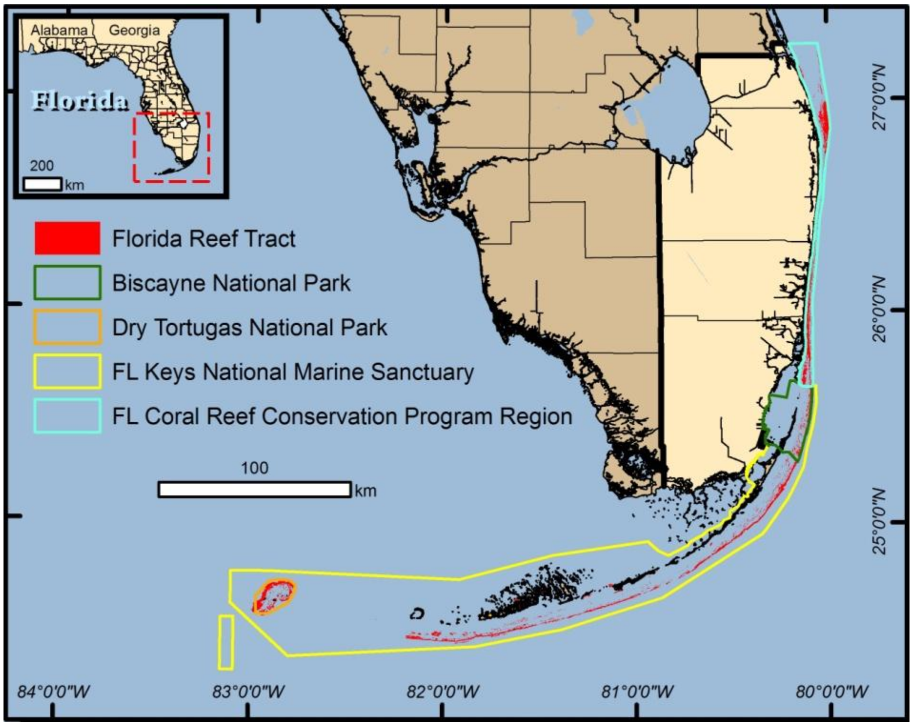

Figure 1. The Florida coral reef tract from west of the Dry Tortugas to northern Martin County, Florida.

Figure provided by DEP-CAMA-CRCP

1.1 Florida’s Coral Reef Tract

The Florida coral reef tract occurs along the coast of Florida beginning west of the Dry Tortugas, running east and north along the Atlantic side of the Florida Keys and the southeast Florida coastline to the St. Lucie Inlet (Martin County) (Figure 1). The northern extension of the Florida coral reef tract runs parallel to the Atlantic coastline of southeast Florida (Banks et al. 2007, Walker et al. 2008, Gilliam 2010). This northern third of the Florida reef tract spans approximately 170 km, from the northern border of Biscayne National Park (BNP) in Miami-Dade County to the St Lucie Inlet (Figure 1). The reefs and hardbottom habitats in the northern third of the Florida reef tract support diverse biological communities (Gilliam 2010), which provide habitat to important fisheries (Ferro et al. 2005, SAFMC 2009). Marine and estuarine fisheries habitats observed in southeast Florida consist of a varying mosaic of contiguous coral reefs, marine and estuarine soft substrate habitats (e.g. tidal sand flats and mud flats), seagrass, oyster reefs, mangroves, offshore hardbottom and nearshore hardbottom, including worm reef.

For the purposes of this report, *southeast Florida* refers to Miami-Dade, Broward, Palm Beach, and Martin counties and the *southeast Florida coral reef tract* (Banks et al. 2007) refers to coral reef habitats offshore of these four counties (Figure 2). The southeast Florida reef tract occurs approximately 3 to 4 km from shore (Banks et al. 2007, Gilliam 2010) and includes offshore hardbottom and coral reef-associated biological assemblages that occur on linear Holocene mid-shelf and shelf margin bank reefs formed from elkhorn coral (*Acropora palmata*). These bank reefs extend from Miami-Dade County to Palm Beach County (Banks et al. 2007, Walker et al. 2008, Gilliam 2010). Limestone ridges composed of Anastasia formation form terraces colonized by reef organisms such as sponges, octocorals, macroalgae and stony corals characterize the reefs from Palm Beach County to Martin County (Banks et al. 2007, Gilliam 2010). These reef formations are separated by large expanses of soft substrate habitats consisting primarily of marine sandy bottom (Banks et al. 2007, Walker et al. 2008). Nearshore hardbottom habitats off southeast Florida range from flat expanses of exposed rock with little relief to patch reef-like vertical mounds in depths from 0 to 4m (CSA International, Inc. 2009). The benthic assemblages of nearshore hardbottom habitat include octocoral, macroalgae, sponge and stony corals of varying proportions (Gilliam 2010). Worm reefs (*Phragmatopoma lapidosa*) are observed in shallow depths (0 to 4 m) along the southeast Florida coast (Lindeman and Snyder 1999, Walker et al. 2008, CSA International, Inc. 2009).

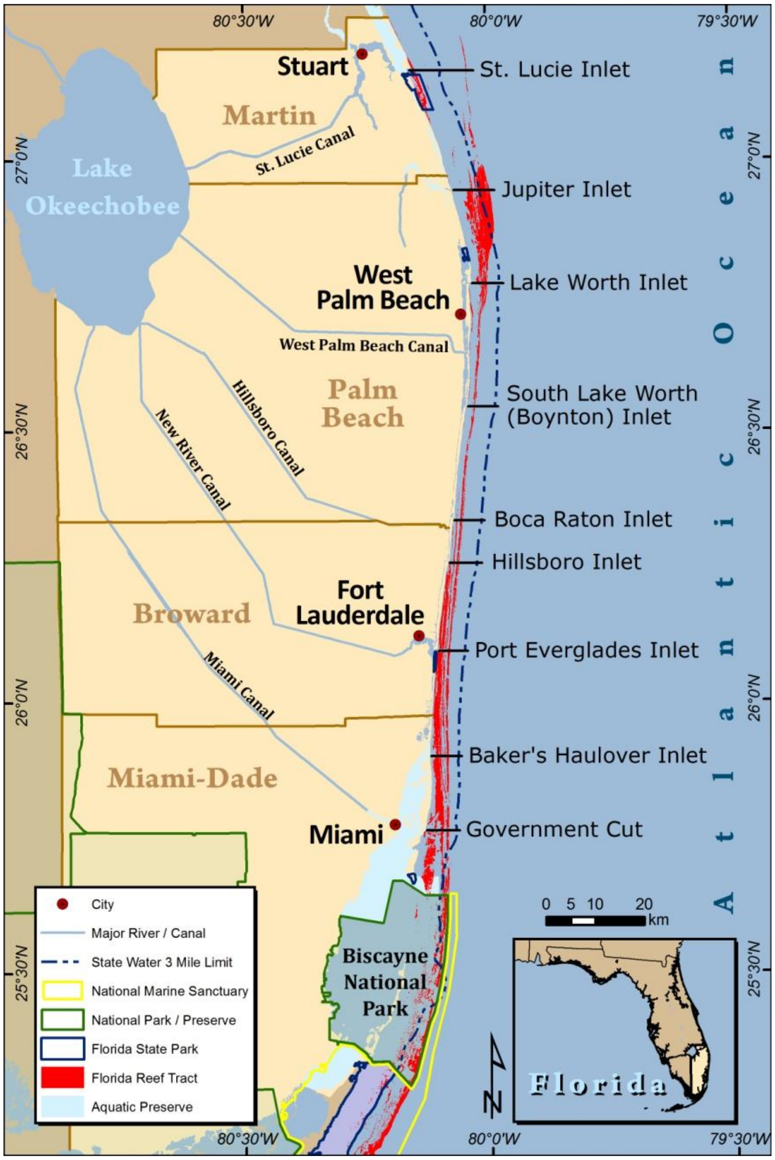

Figure 2. Southeast Florida Reef Tract and Coastal Inlets

Figure provided by DEP-CAMA-CRCP

1.2 Coral Reef Management in Southeast Florida

Under the auspices of the U.S. Coral Reef Task Force (USCRTF), the Florida Local Action Strategy (LAS) was developed to address the need for conservation of coral reefs off southeast Florida (DEP 2004). The Florida Keys National Marine Sanctuary, Key West National Wildlife Refuge, Dry Tortugas National Park, Tortugas Ecological Reserve, and Biscayne National Park had all been previously designated, resulting in coordinated management of the southern two thirds of the Florida reef tract. Early in the LAS process, the lack of information and management along the northern third of the Florida reef tract were identified by the planning team as critical needs for the conservation of these coral reefs (DEP 2004). In response to these needs, the Southeast Florida Coral Reef Initiative (SEFCRI) focused on the northern third of the Florida coral reef tract and includes four focus areas that were developed to address specific threats or issues relating to the conservation and management of coral reef habitat in Florida (Figure 2) (DEP 2004). The SEFCRI region consists of the northern third of the Florida coral reef tract extending approximately 110 miles (170 km) from the northern boundary of Biscayne National Park to St. Lucie Inlet (Figure 2) (DEP 2004, Collier et al. 2008). The SEFCRI focus areas include Fishing, Diving and other Uses, Maritime Industries and Coastal Construction Impacts, Awareness and Appreciation, and Land Based Sources of Pollution (LBSP) (DEP 2004).

1.3 Land Based Sources of Pollution Focus Team and Technical Advisory Committee

The LBSP focus team of the SEFCRI addresses one of the four threat areas identified in the Florida LAS (DEP 2004). The LBSP Focus Team realized the need for specialized expertise regarding LBSP, coral biology and coral reef research early in the LAS process. The LBSP Technical Advisory Committee (LBSP-TAC) was formed to provide managers with scientific and specialized management expertise. Previous LBSP work in southeast Florida has focused on water pollution threats only to corals and coral reefs. Projects undertaken by the LBSP focus team include assimilation of existing published and gray literature regarding the effects of LBSP on corals and coral reef habitats (Trnka et al. 2006), cellular diagnostics to link LBSP to coral reef degradation (Fauth et al. 2006), review of programs that generate LBSP in southeast Florida (Caraco et al. 2009) and an overview of programs that reduce LBSP threats to coral reefs in southeast Florida (Caraco and Drescher 2011).

1.4 Stressors and Pollutants

A number of stressors affect coral reefs and other fisheries habitats in southeast Florida. A stressor is any kind of input, process or activity that adversely affects the functioning of an ecosystem over time (Trnka et al. 2006). Stressors can be naturally occurring, e.g. hurricanes, or can be related to human activities (Moss et al. 2005). A pollutant is a stressor with anthropogenic origins (Trnka et al. 2006). Pollutants may include man-made substances or can be constituents already present in nature that are elevated by human actions (e.g., nutrients, hydrocarbons, metals and sediments) (Trnka et al. 2006). Pollutant levels become unacceptable when they result in detrimental changes to an organism or the biological community (Kruczynski 2002). The degradation of habitat and loss of ecosystem functions, such as primary production, trophic linkages and habitat complexity can result from synergistic (Trnka et al. 2006) and cumulative effects (Duval et al. 2004) of natural and human stressors on a system.

1.5 Back Reef Habitats

Coral reef ecosystems consist of a mosaic of interconnected habitats including the reef tract and back reef habitats, which are defined in Adams et al. (2006) as being landward of the reef crest, along the beach and shoreline, within a lagoon or bay and within estuarine tidal creeks and wetlands. While the term *back reef* usually applies to barrier reef lagoonal ecosystems in the tropics (Adams et al. 2006), the interconnected habitat usage by marine and estuarine organisms observed in tropical back reef ecosystems is also observed in subtropical Florida marine and estuarine ecosystems (Eggleston et al. 2004, Jones et al. 2010). Fish, crustaceans and other marine organisms use these interconnected habitats within southeast Florida estuaries and off the coast as nursery habitat (SAFMC 2009, Lindeman and Snyder 1999, Eggleston et al. 2004, Jones et al. 2010) in the manner described in Adams et al. (2006) as back reef habitats. While Walker et al. (2008) apply the classic perspective (reef crest, lagoon, shoreline system) of the term in stating that there is no back reef component to the southeast Florida reef tract, the use of the term *back reef* in this document is in the context of describing the ecological functions provided by the interconnected marine and estuarine fisheries habitats landward of the eastern edge of the southeast Florida reef tract to the inland extent of tidal influence in southeast Florida estuaries.

Southeast Florida estuaries consist of fisheries habitats including mangrove, seagrass, oyster habitats and tidal mud or sand flats, as well as open water channels between these habitats. LBSP associated with human activities are reducing the levels of ecological services (e.g., nursery, Adams et al. 2006; cover, Caddy 2008; and feeding opportunities, Jones et al. 2010) provided by the back reef habitats of southeast Florida (PBC 2008, DEP 2000, SFWMD 2009a, SFWMD 2009b). Three major water resource influences have been identified as affecting the ecological health of southeast Florida's estuaries: (1) excessive nutrient loading from urban runoff, fertilizers, agricultural operations, and septic systems (SFWMD 2009a, SFWMD 2009b, DEP 2012a); (2) freshwater discharges from the water management or flood control systems resulting in undesirable low and highly variable salinity conditions in some southeast Florida estuaries (PBC 2008, SFWMD 2009a, SFWMD 2012); and (3) undesirable low flows to some estuaries resulting in high salinity conditions (SFWMD 2009a, SFWMD 2009b, DEP 2012a).

2 Land Based Pollutants

Pollutants from human activities on land identified as having the potential to affect fisheries habitats in southeast Florida include: nutrients, turbidity, sedimentation, heavy metals, salinity, pharmaceuticals and personal care products, hydrocarbons and other organics, biocides (pesticides, herbicides and fungicides), and pathogens (Trnka et al. 2006, Caraco et al. 2009).

2.1 Nutrients

Nutrients are considered a pollutant when elevated concentrations have a negative effect on marine and estuarine biological systems (Trnka et al. 2006). Increases in dissolved inorganic nutrients have been shown to reduce coral calcification rates, reduce fertilization success and possibly promote the growth of macroalgae that compete for space with corals (Fabricus 2005). The abundance of clionid sponges, a competitor and predator of corals, increases with elevated nutrient concentrations (Rose and Risk 1985, Summarco 1996, Holmes 2000, Holmes et al. 2000, Rutzler 2002). Declines in coral cover have been associated with increased density of clionid sponges along the coral reef tract in the Florida Keys (Ward-Paige et al. 2005).

Adding scarce nutrients such as nitrogen (N) or phosphorus (P) to surface waters usually boosts the primary productivity of these ecosystems and increases production of algae that forms the base of the aquatic food web (Howarth et al. 2000a, Howarth et al. 2000b). This nutrient-induced increase in production of organic matter is called eutrophication, which is linked to a number of problems in aquatic ecosystems (Howarth et al. 2000a, Howarth et al. 2000b). As the mass of algae in the water grows, the water may become more turbid (Howarth et al. 2000a, Howarth et al. 2000b). As the algae die and decompose, periods of oxygen depletion (hypoxia and anoxia) occur more frequently (Howarth et al. 2000a, Howarth et al. 2000b). Living algae can also contribute to oxygen depletion due to their consumption of oxygen at night (Howarth et al. 2000b). These changes in nutrients, light, and oxygen favor some species over others and cause shifts in the structure of phytoplankton, zooplankton, and benthic communities (Howarth et al. 2000a, Howarth et al. 2000b).

The following excerpt from a report entitled *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution* (Howarth et al. 2000a) describes a number of general observations of the effects of nutrient pollution on estuarine and marine fisheries habitats:

- Nutrient over-enrichment of coastal ecosystems generally triggers ecological changes that decrease the biological diversity of bays and estuaries.
- While moderate N enrichment of some coastal waters may increase fish production, over-enrichment generally degrades the marine food web that supports commercially valuable fish.
- The marked increase in nutrient pollution of coastal waters has been accompanied by an increase in harmful algal blooms, and in at least some cases, pollution has triggered these blooms.
- High nutrient levels and the changes they cause in water quality and the makeup of the algal community are detrimental to the health of coral reefs and the diversity of animal life supported by seagrass and kelp communities.
- Research during the past decade confirms that N is the chief culprit in eutrophication and other impacts of nutrient over-enrichment in temperate coastal waters, while phosphorus (P) is most problematic in eutrophication of freshwater lakes.
- Human conversion of atmospheric N into biologically useable forms, principally synthetic inorganic fertilizers, now matches the natural rate of biological N fixation from all the land surfaces of the earth.

- Both agriculture and the burning of fossil fuels contribute significantly to nonpoint flows of N to coastal waters, either as direct runoff or airborne pollutants.

Evidence is mounting that excessive levels of nutrients are being introduced into southeast Florida watersheds via runoff (Caccia and Boyer 2005, PBC 2008, SFWMD 2009a, SFWMD 2009b, SFWMD 2012), sewage discharge (Futch et al. 2011), and other anthropogenic activities (Howarth et al. 2000a, Caccia and Boyer 2005). Research has shown that concentrations of nutrients tend to decrease with distance from shore (Fabricius 2005, Trnka et al. 2006). Nutrient budgets for southeast Florida coastal waters have not yet been completed, however there are strong indications that input of nutrients from diurnal tidal flushing through inlets (Bloetscher et al. 2010, Carsey et al. 2011) and possibly through submarine groundwater discharge (Bloetscher et al. 2010) are major factors influencing nutrient impacts on coral reef and back reef fisheries habitats in southeast Florida (Trnka et al. 2006, Futch et al. 2011). Currently, the state of Florida does not have numeric nutrient water quality criteria; however, numeric nutrient criteria are in the process of being developed (DEP 2012b).

2.2 Turbidity

Turbidity varies naturally in time and space because it is related to physical forces acting on the seabed, as well as terrestrial runoff (Trnka et al. 2006). Turbidity is largely comprised of dissolved organic matter including light-absorbing colored dissolved organic matter and sediment load with adhered organic components such as bacteria. Increased turbidity reduces water clarity, which subsequently reduces light availability for seagrass (Fonseca et al. 1992, SAFMC 2009, SFWMD 2009b) and coral zooxanthellae photosynthesis (SAFMC 2009, Erftemeijer et al. 2012). Turbidity can reduce the recruitment, survival and settlement of coral larvae (Erftemeijer et al. 2012). Elevated turbidity was shown to result in increased respiration and mucous production in two coral species found in southeast Florida (Telesnicki and Goldberg 1995). The Florida water quality criterion for turbidity is 29 Nephalometric Units (NTUs) above background for Class III waters (Chapter 62-302 F.A.C.). Turbidity at levels below the State criterion of 29 NTUs above background for Class III waters have been shown to have sub-lethal effects on *Dichocoenia stokesii* and *Meandrina meandrites*, both of which are indigenous to southeast Florida (Telesnicki and Goldberg 1995). Telesnicki and Goldberg (1995) found that turbidity levels of approximately 50% of the Florida Class III standard were shown to affect the respiration rates and mucous production of these two species, which indicates that the Florida turbidity criterion does not protect corals from adverse impacts due to turbidity. Waters designated in Ch. 62-302 F.A.C. as Outstanding Florida Waters or Class II waters have a turbidity criterion of zero NTUs above background.

2.3 Salinity

Changes in salinity have been cited as a cause of sub-lethal and lethal effects on corals (Trnka et al. 2006), oysters (PBC 2008, SFWMD 2012) and seagrass (SFWMD 2009a, SFWMD 2012) in southeast Florida. Salinity fluctuations have been cited as a factor in the loss of oyster and seagrass habitats in the SEFCRI region including St. Lucie River (SFWMD 2009a, SFWMD 2012), Lake Worth Lagoon (PBC 2008, SFWMD 2009b) and Biscayne Bay watersheds (Caccia and Boyer 2005). There is also growing concern regarding the detrimental role salinity fluctuations play in the survivorship of already stressed coral reef organisms or other benthic fauna existing in marginal environments (Trnka et al. 2006). The ability of benthic organisms including oysters, seagrass and corals in marginal habitats to survive both short- and long-term salinity fluctuations is a growing area of research essential for their persistence in such environments (Trnka et al. 2006, PBC 2008). For example, sub-optimal salinity patterns can persist in coastal lagoons like Biscayne Bay for several days due to canal discharges or storm events (Manzello and Lirman 2003, Caccia and Boyer 2005).

Porter et al. (1999) studied the combined effects of temperature and salinity in Florida Bay and found exposure to elevated temperatures and salinities after 36 hours caused coral mortality. Similar experiments in the Pacific focused on short (hours) exposure times (Moberg et al. 1997). Photosynthesis to respiration ratios were significantly lowered in the hard corals *Porites lutea* and *Pocillopora damicornis* when exposed to sudden salinity drops (hours) from ambient. Photosynthetic activity, in particular, dropped from 30 photosynthetic units (psu is the ratio of light-harvesting pigments to reaction-center chlorophyll) to 20 and 10 psu, with *P. lutea* being slightly less affected (Moberg et al. 1997). Coles and Jokiel (1978) found that low salinity reduces the ability of a coral to survive during short-term exposure to elevated temperatures.

2.4 Sedimentation

Sedimentation can cause mortality of filter feeding animals such as corals (Rogers 1990, Erftemeijer et al. 2012), sponges (SAFMC 2009) and oysters (PBC 2008) by inhibiting feeding (Rogers 1990), and by physically smothering or burial of sessile organisms (Rogers 1990, SAFMC 2009, Trnka et al. 2006, Erftemeijer et al. 2012). Sedimentation can decrease growth rates of oysters (PBC 2008) and corals (Dodge et al. 1974, Rogers 1990) through shading or abrasion. Sub-lethal effects of sedimentation on corals include increased respiration and mucus production, as well as decreases in photosynthesis, reproduction, and larval survival rates (Telesniki and Goldberg 1995, Trnka et al. 2006, Erftemeijer et al. 2012). Sedimentation can also adversely affect seagrass and other soft bottom estuarine habitats by direct burial and contribute to turbidity that decreases light penetration and reduces photosynthetic production in coastal waters (SAFMC 2009, PBC 2008). Human activities such as beach nourishment have been shown to increase sedimentation on coral (Jordan et al. 2010) and nearshore hardbottom habitats (Lindeman and Snyder 1999, CSA International, Inc. 2009) in southeast Florida. Section 5.6 provides additional details regarding beach nourishment associated sedimentation threats to nearshore hardbottom habitats.

2.5 Heavy Metals

Heavy metals are known to have lethal and sub-lethal effects on marine fauna such as corals (Peters et al. 1997), mollusks (Spicer and Weber 2004), and crustaceans (Spicer and Weber 2004, Barbieri et al. 2005). Elevated metal concentrations have been shown to have a negative impact on coral fecundity, reproduction and recruitment (Peters et al. 1997, Negri and Heyward 2001, Reichelt-Brushett and Harrison 2005, Reichelt-Brushett and Michalek 2005, Victor and Richmond 2005). Copper, lead, zinc, cadmium and nickel adversely affected fertilization success on scleractinian coral, with copper being the most toxic (Reichelt-Brushett and Harrison 2005, Reichelt-Brushett and Michalek 2005). Heavy metals can become toxic if the bioavailable metal concentrations exceed threshold values, which vary for different organisms (SAFMC 2009). Many heavy metals have detrimental effects on coral and oyster fertilization and larval settlement success (SAFMC 2009). Water quality criteria for heavy metals are listed in Chapter 62-302, Florida Administrative Code (F.A.C.).

2.6 Hydrocarbons and other organics

Organic pollution occurs when hydrocarbons are released into the environment via sewage effluent, stormwater runoff or oil spills (Peters et al. 1997, Trnka et al. 2006). Much of the research on organic pollutants has focused on the effects of oil spills and oil spills combined with dispersants on coral reefs (Peters et al. 1981, Dodge and Gilbert 1984, Dodge et al. 1985). Research suggests that small scale chronic oil spills may be more toxic than single, large scale spills and that dispersants in combination with oil caused greater tissue death and bleaching events in coral than the oil, alone (Peters et al. 1997). Short term exposure to a chemically dispersed oil resulted in changes in coral calcification rates and prominent signs of stress for a short period of time (Dodge et al. 1985). Stony coral colonies (*Manicina areolata)* that were exposed to fuel oil treatments for a period of three months showed signs of hydrocarbon contamination even after being transferred to clean seawater for two weeks (Peters et al. 1981). Exposure of corals to hydrocarbons caused tissue atrophy, degeneration, and reduced fecundity (Peters et al. 1981). Petroleum products released by oil spills remaining near the surface of the water may not contact the reef or other sub-tidal habitats; however, these compounds may still affect developing larvae that float near the water surface (Peters et al. 1997, SAFMC 1998). Intertidal oyster habitats are particularly vulnerable to hydrocarbon pollution (Street et al. 2005). Florida water quality criteria for hydrocarbons and organic compounds are included in Chapter 62-302 F.A.C.

2.7 Biocides

Biocides including pesticides, herbicides, and fungicides are widely used and can be introduced into marine environments through terrestrial runoff (Peters et al. 1997, Fabricius 2005, Trnka et al. 2006, Markey et al. 2007) and marine antifouling paints (Fabricius 2005, Trnka et al. 2006, Futch et al. 2011). These chemicals and their degradation compounds can be highly toxic to corals, crustaceans, and other benthic fauna at very low concentrations (Peters et al. 1997, SAFMC 1998, Trnka et al. 2006, SAFMC 2009). Increasing levels of pesticides, particularly lindane, DDT, and chlordane are found in nearly 100 percent of corals in the Great Barrier Reef (Peters et al. 1997, Trnka et al. 2006) and reefs off the Florida Keys (Markey et al. 2007). In general, data on pollutants and biological responses is much more complete for temperate marine and freshwater systems (Peters et al. 1997). The fate and transport of biocides in tropical or sub-tropical marine systems has not been determined (Peters et al. 1997).

One of the ways that herbicides and pesticides can adversely affect corals is by interfering with photosynthesis (Raberg et al. 2003, Jones and Kerswel 2003, and Harrington et al. 2005, Markey et al. 2007). In addition to affecting coral photosynthesis, biocides may also result in reduced fertilization success (Peters et al. 1997, Trnka et al. 2006, Markey et al. 2007). Agricultural or urban residential runoff can introduce sedimentation in combination with biocides to estuarine fisheries habitats (Harrington et al. 2005). The effects of sedimentation on crustose coralline algae are significantly enhanced in combination with increased concentrations of diuron (Harrington et al. 2005). Evidence of fifteen pesticides, including atrazine, chlorpyrifos ethyl, and diazinon has been found at inflows throughout the southeast Florida region (Weaver and Payne 2004).

Tri-butyl tin (TBT) was commonly found in antifouling paints before being banned in 1990 (Connelly et al. 2001). Some researchers have stated that TBT is the most toxic substance ever introduced into the environment (Goldberg 1986; Maguire 1987, Trnka et al. 2006). Organic booster biocides have since been introduced as an alternative to TBT (Konstantinou and Albanis 2004, SAFMC 1998). These include copper-based antifouling agents like Irgarol 1051 and diuron (Konstantinou and Albanis 2004, Trnka et al. 2006). Several studies have indicated that these compounds are also toxic to coral (Dahl and Blank 1996, Owen et al. 2002, Jones and Kerswel 2003, Jones et al. 2003). The chronic effects of these compounds are unknown and difficult to determine (Konstantinou and Albanis 2004).

There is little data on the long term environmental effects on coral and other marine organisms, despite the widespread usage of chemical biocides (Haynes et al. 2000, Raberg et al. 2003). Research on multiple stressors of marine organisms and their interactions with biocides are limited (Raberg et al. 2003). Future research should focus on synergistic effects of biocides with other pollutants (e.g. sedimentation, turbidity and nutrient pollution) and natural stressors, as well as effects of biocides on reproduction and larval settlement of benthic fauna (Raberg et al. 2003).

2.8 Pathogens

Research on pathogens in tropical and subtropical systems has focused primarily on corals (Sutherland et al. 2004, Fabricius 2005, Sutherland et al. 2011). Notable work has also been done on oyster pathogens, such as Dermo and MSX in temperate regions, (VIMS 2012a, VIMS 2012b), however little information is available regarding oyster pathogens in southeast Florida.

A total of 18 coral diseases were described in Sutherland et al. (2004). Four were reported globally while the other 14 were only documented in the Caribbean area. There is limited knowledge regarding how infection and disease transmission occurs in corals (Sutherland et al. 2004); however, Sutherland et al. (2011) found infection of elkhorn coral with white pox occurred when the *Serratia marcescens* bacterial pathogen was introduced to the corals via sediment deposited on the coral colonies. While declines in corals have led to the identification of some diseases, impacts of these diseases on coral reef communities are poorly understood (Richardson 1998). Future research will indicate whether plague-like signs in coral species represent a single disease condition by a single pathogen, or if plague-like diseases represent different diseases caused by a variety of pathogens (Sutherland et al. 2004, Sutherland et al. 2011). The occurrence of pathogenic human enteric viruses in marine waters is not well characterized; however, some work has recently been conducted in southeast Florida (example studies include Futch et al. 2011, Sutherland et al. 2011, Carsey et al. 2011). The contamination of marine waters with viruses should be considered an important issue for human health, as well as an environmental issue (Griffin et al. 2003).

2.9 Pharmaceutical and Personal Care Products

Personal care products, (e.g., lotions, fragrances, and insect repellent), medications, and hormones often end up in estuarine and marine environments (Atkinson et al. 2003, Singh et al. 2009). Research on the effects of pharmaceutical products on coral reef communities and other marine organisms is in its infancy (Isidori et al. 2005, Singh et al. 2009, Futch et al. 2011). A recent study has shown cholesterol, caffeine, DEET, and a number of hormones are commonly detected in the waters off southeast Florida (Singh et al. 2009). In another study, concentrations of steroidal estrogens were measured at 20 sites in the coastal waters of the United States, including sites off the Florida coast (Atkinson et al. 2003). Estrogen concentrations of approximately 2000 picograms/liter (pg/l) were recorded near the Florida coast (Atkinson et al. 2003). Estrogen concentrations at twelve of the sites were above 300 pg/l; the concentration at which corals begin to take up estrogen from the water column (Atkinson et al. 2003). Some research has shown that estrogen may be biologically active in corals, which appears to cause tissue thickening, reduced skeletal growth, and reduced fecundity (Tarrant et al. 2004). From work completed in the Pacific, exposure to estradiol caused a 29% reduction in the number of egg-sperm bundles released by *Montipora capitata* colonies compared to control groups (Tarrant et al. 2004). *Porites compressa* had 13-24% slower growth rates and corals treated with estrone had thicker tissues than controls (Tarrant et al. 2004). The effects of these pharmaceutical products on other marine and estuarine organisms have not been studied. Florida water quality criteria do not currently include pharmaceutical or personal care product compounds.

3 Land-based Sources

There are multiple routes for human generated substances to find their way to marine and estuarine habitats in southeast Florida (Figure 3) (Caccia and Boyer 2005, Trnka et al. 2006, SFWMD 2009b). The four methods of wastewater effluent disposal in Florida include: ocean outfalls, surface discharges, deep well injection, and reuse (Bloetscher and Gokgoz 2001). Agricultural nutrients (Caccia and Boyer 2005, Fabricius 2005), leaking septic tanks (Caccia and Boyer 2005) and storm water moves through water management systems to southeast Florida estuaries (SFWMD 2009b) and to the coastal ocean via inlets or groundwater discharge (Trnka et al. 2006, Singh et al. 2009, Bloetscher et al. 2010). The discharge of untreated (Caccia and Boyer 2005) and treated wastewater (DEP 2010), the discharge of stormwater from urban development (Caccia and Boyer 2005, BCEPD 2007) and agriculture (SFWMD 2009a), and the increase of populations in these watersheds (Caccia and Boyer 2005, Trnka et al. 2006), have contributed to the degradation of the water quality and fisheries habitats of the southeast Florida ecosystem (DEP 2006, SFWMD 2009b). These discharges carry excess nutrients, suspended and dissolved organic matter, and other pollutants to the estuaries (Caccia and Boyer 2005, BCEPD 2007, SFWMD 2009b, Carsey et al. 2011), which in turn affect the water quality, flora, and fauna in the estuaries and adjacent coastal waters (Boyer et al. 2008, SFWMD 2009b, Carsey et al. 2011).

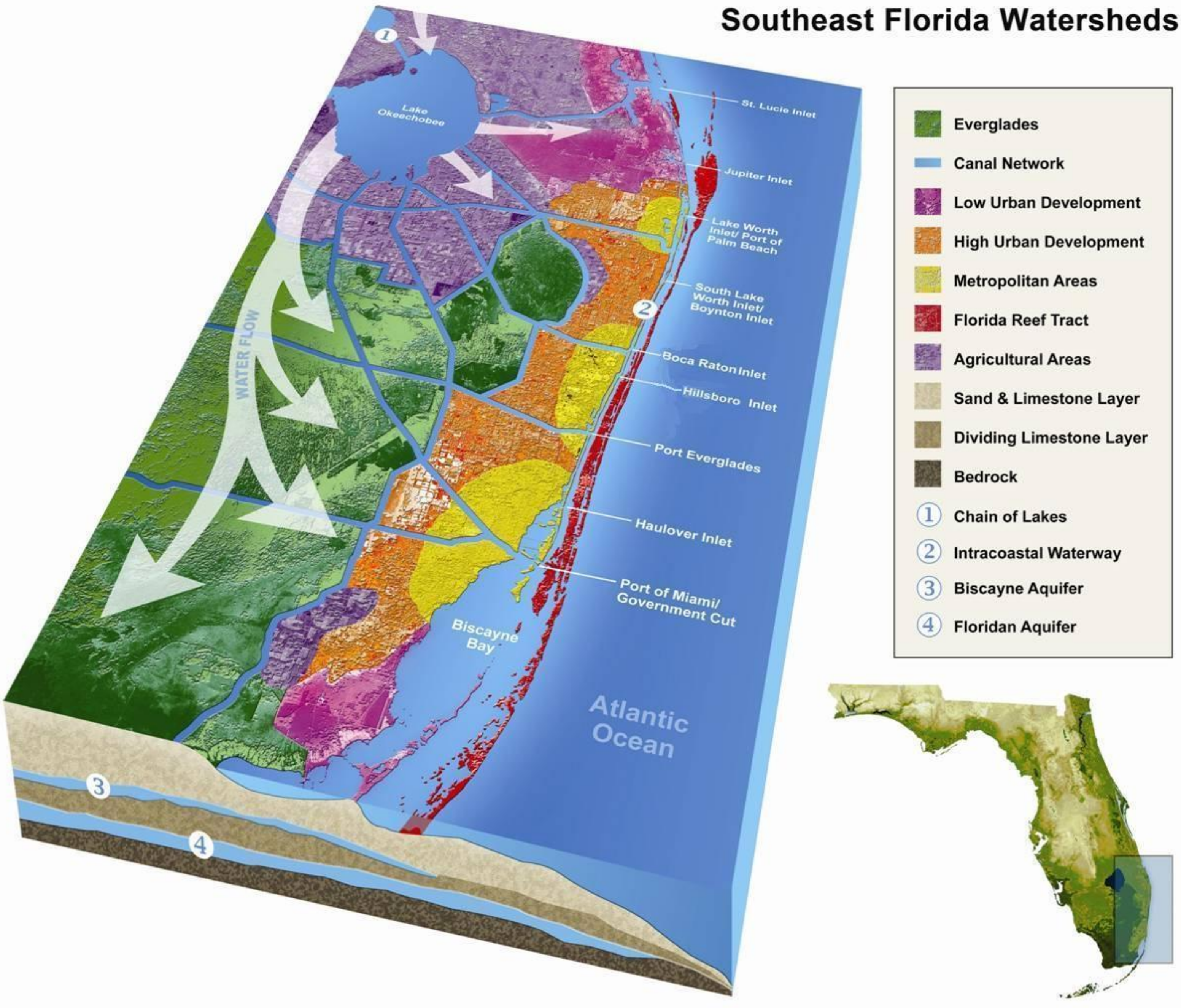

Figure 3. Water flows and LBSP pathways in southeast Florida. Figure provided by DEP-CAMA-CRCP

3.1 Water Management Systems

Agricultural drainage canals and urban flood control systems transport pollutants, stormwater runoff, and discharges to southeast Florida estuarine waters (Caccia and Boyer 2005, SFWMD 2009a, Carsey et al. 2011). Agricultural practices (e.g. fertilizers and biocides); leaking septic systems; residential, commercial, and industrial stormwater all contribute nutrients, pathogens (bacteria and viruses), heavy metals, biocides, hydrocarbons, and other organics to surface waters in southeast Florida (Caccia and Boyer 2005, SFWMD 2009a, SFWMD 2009b). Rapid salinity changes, turbidity (SFWMD 2009a, SFWMD 2009b), sedimentation and siltation (PBC 2008) also occur with the discharge from water management canals to southeast Florida estuaries (Caccia and Boyer 2005). The combination of stressors may contribute to synergistic effects (Duval et al. 2004) that magnify adverse impacts to fisheries habitats like oysters (PBC 2005), seagrass (SFWMD 2009a), and mangroves (Odum et al. 1982) in southeast Florida.

3.2 Coastal Inlets

Inlets located within the southeast Florida region include: St. Lucie, Jupiter, Lake Worth, Boynton, Boca Raton, Hillsboro, Port Everglades, Bakers Haulover and Port of Miami/Government Cut (Figure 2). Inlets are an important component to water dynamics in southeast Florida; however, detailed information on the hydrodynamic regimes and the composition of the waters moving through the inlets is lacking (Bloetscher et al. 2010).

In 2007, scientists at the NOAA, Atlantic Oceanic and Meteorological Laboratory (AOML) and other partners investigated sources of pollution to coastal waters of southeast Florida at selected locations. Previous investigations had indicated that waters exiting Lake Worth Lagoon at Boynton Inlet were likely to be a significant source of LBSP to the coastal ocean (Figure 4), so this inlet was included in the study (Carsey et al. 2011). As expected, results demonstrated that the outgoing tides contained significant amounts of nutrient pollution (Carsey et al. 2011). Nutrient concentrations were highly variable and related to tidal stage and recent rainfall events (Carsey et al. 2011). Slower tidal flows had higher concentrations of nutrients (Carsey et al. 2011). Tidal nutrient fluxes observed in this study were compared with reported daily nutrient flux totals from treated-wastewater plant ocean outfall discharge locations near the Boynton Inlet. The highest inlet nutrient fluxes were on the same order of magnitude with nutrient fluxes observed at the ocean outfalls, but inlet nutrient fluxes were much lower during the non-peak tidal stages (Carsey et al. 2011). In addition to nutrients, a variety of microbial contaminants, including live enterococci, human enterococci, human *Bacteroides*, other bacterial pathogens, adenovirus, norovirus and enterovirus were detected in outgoing tides from Boynton Inlet (Carsey et al. 2011). This detailed examination of one of the nine coastal inlets in southeast Florida provides a glimpse of the magnitude of the LBSP challenges facing this region.

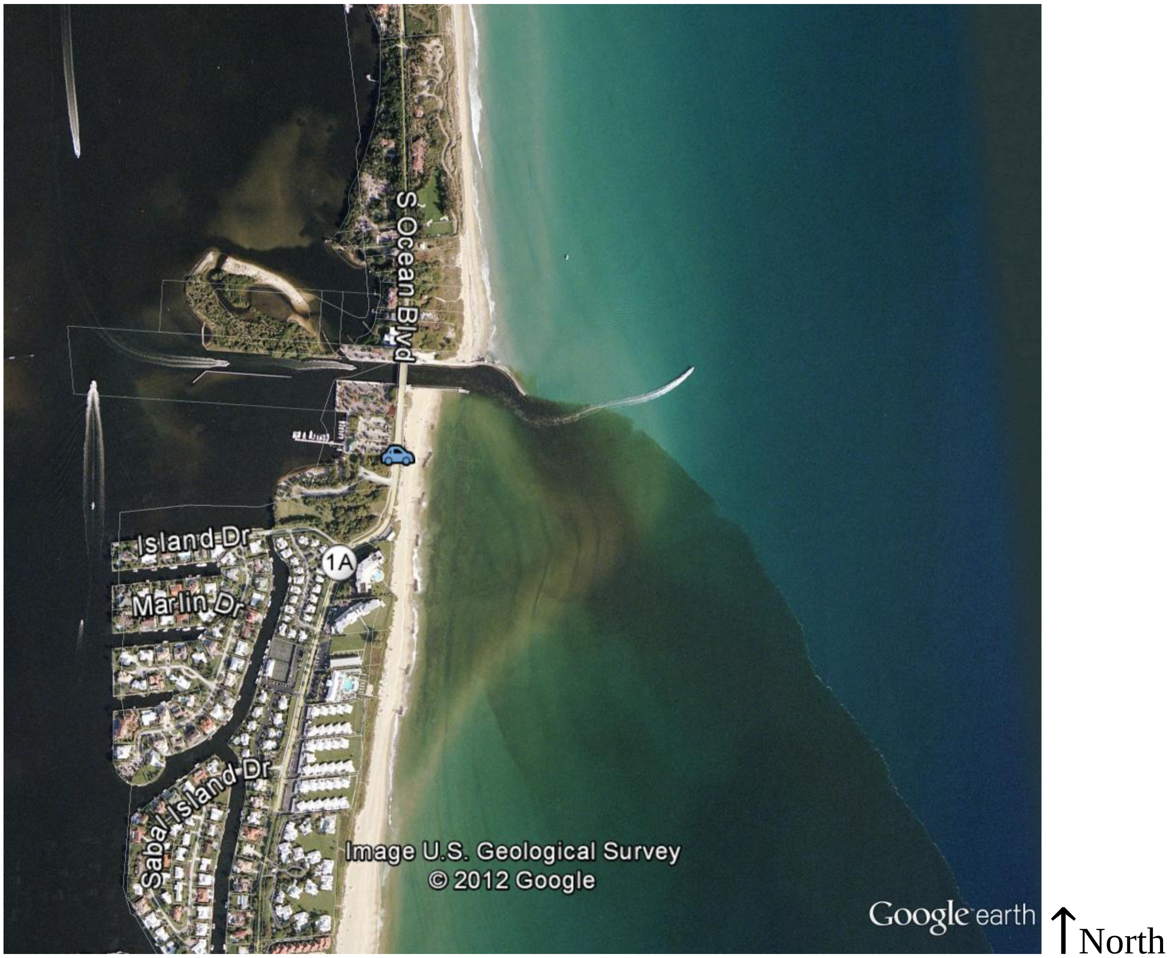

Figure 4. Water ebbing from Boynton Inlet, Palm Beach County, Florida.
Note the plume is dispersing to the south.

The Broward County Development and Environmental Regulation Division (BCDERD) has compiled data on the chemical, biological, and physical characteristics of surface waters flowing to two of the inlets in southeast Florida since 1972: Port Everglades and the Hillsboro Inlet (BCDERD 2001). A network of monitoring stations contains sites located within primary freshwater canals, remnant major rivers, and the Intracoastal Waterway that connect to these two inlets (BCDERD 2001). The initial impetus for establishing this surface water quality monitoring network was to monitor the effects of discharging effluent from wastewater treatment plants into Broward County waterways (BCDERD 2001). Direct discharge of effluent into surface waters stopped in 1988 so emphasis shifted to identifying ambient water quality conditions (BCDERD 2001). Sites are sampled on a quarterly basis for nutrients, bacteria, chlorophyll a, total organic carbon, dissolved oxygen, pH, temperature, and specific conductivity (BCDERD 2001). This report includes comparisons of measured pollutant concentrations to state water quality standards and assessments of water quality in sampled waterways (BCDERD

2001). Data from these sites are also entered into the state STORET and national databases. STORET is an acronym for STORage and RETrieval database, which is the database currently used by DEP to capture, store, and report chemical, physical, and biological water quality data. A detailed report on surface water quality in Broward County from 1972 through 1997 can be found in *Broward County, Florida Historical Atlas: 1972-1997 Technical Report TR:01-03*. The atlas is now being updated by the BCDERD to include data collected since 1997.

3.3 Submarine Groundwater Discharge

There is very little data available on the quantity and composition of groundwater entering the coastal ocean through submarine groundwater discharge (SGD) off southeast Florida (Trnka et al. 2006, Bloetscher et al. 2010). New technologies and models are needed in order to estimate pollutant fluxes and differentiate between factors that influence submarine groundwater discharge so this source of pollutants to coral reef and back reef communities can be quantified (Trnka et al. 2006, Bloetscher et al. 2010, Futch et al. 2011).

Studies in other areas have presented evidence that direct groundwater flow to the ocean can be a significant source of nutrients (Futch et al. 2011). Researchers in the Florida Keys found that nutrient concentrations were one to two orders of magnitude higher in groundwater than in coastal waters near the Florida Keys (Paytan et al. 2006). The nutrient contribution from SGD was highly variable between samples due to the many factors that influence SGD, but there was a general concentration gradient for nutrients with concentrations being highest near the shoreline (Paytan et al. 2006). The authors noted that the reef tract off the Florida Keys is several kilometers offshore and therefore it is not clear whether the groundwater is being transported all the way to the reef (Paytan et al. 2006). The coral reef tract off southeast Florida is much closer to shore than the coral reef tract in the Florida Keys.

Submarine groundwater discharge may also be a source of pathogens, bacteria and other chemicals (Corbett et al. 2001, Paytan et al. 2006, Futch et al. 2011). Since SGD eventually ends up in the coastal ocean, any pollutant that is picked up along the way may contribute to poor water quality and algal blooms (Corbett et al. 2001, Futch et al. 2011). The sources of pollutants to the groundwater, mechanisms that affect SGD, and the impacts of these inputs on coral reefs and other fisheries habitats need to be evaluated (Paytan et al. 2006, Bloetscher et al. 2010, Futch et al. 2011).

3.4 Ocean Outfall Discharge

One of the most discussed sources of pollutants to coastal waters of southeast Florida has been ocean wastewater outfalls. The impacts of wastewater effluent to coral reefs in southeast Florida has been also been extensively debated. Ocean outfall discharges are a source of nutrients and other pollutants to the coastal ocean (Carsey et al. 2010). Until recently, there were six wastewater effluent outfalls in use off southeast Florida, which required secondary treatment of effluent that removed at least 85% of biodegradable organics and suspended solids (DEP 2010). Secondary treatment does not remove dissolved nutrients, pharmaceuticals, heavy metals or personal care products (Bloetscher and Gokgoz 2001). Advanced treatment has not historically been required and would reduce dissolved nutrient, pharmaceutical and personal care product concentrations (Polar 2007).

The initial dilution of ocean outfall effluent discharges is important for determining environmental impacts of the effluent discharge (Proni et al. 1994, Wanninkohf et al. 2004). The development of realistic initial dilution design criteria and standards for waste water management are essential for environmental protection and for evaluating the economic aspects of water quality improvements and waste water management (Proni et al. 1994). The physical oceanography of coastal waters must be thoroughly understood, in order to track the movement and evaluate the effects of effluent water (Proni et al. 1994, Wanninkohf et al. 2004). The Florida Current and nearshore countercurrents are the dominant factors affecting the mixing and dispersal of effluent plumes in southeast Florida (Proni et al. 1994, Wanninkohf et al. 2004). Water quality parameters sampled in treatment plants in southeast Florida indicate that routinely monitored constituents (e.g. biodegradable organics and total suspended solids) are at allowable levels (Bloetscher and Gokgoz 2001, Futch et al. 2011); however, the fates of pesticides, pharmaceutical and personal care products, solvents (organics), and cleaners in the outfall effluent are less well studied (Bloetscher and Gokgoz 2001). Further research and better analytical techniques are necessary to understand their impacts and detect concentrations that may exist in south Florida wastewater treatment plants (Bloetscher et al. 2010).

Factors that decrease the risks of pollutant loading from ocean outfalls not only include the rapid dispersal and dilution of plumes by the Florida Current (Bloetscher et al. 2010, Futch et al. 2011), but also the distance of the outfalls from land and reefs; i.e. the lowest risk outfalls are farthest from land and reefs (Miami-Dade Central outfall), whereas the highest risk outfalls are closest to land and reefs (Boca Raton and Boynton Beach/Del Ray Beach outfalls) (Trnka et al. 2006). Diffusers are fittings on outfall pipes that promote mixing of discharges with ambient water. The use of multi-port diffusers appears to aid in dispersal of the effluent compared to single-port diffusers, discharging the effluent at a faster speed appears to also increase the rate of dispersal and dilution (Proni et al. 1994). Vertical mixing of the ocean outfall discharged waters with surrounding waters occurs within 13 km of the outfall (Wanninkohf et al. 2005). Other researchers have indicated that vertical mixing may occur much closer to the discharge location than was shown in the study by Wanninkohf et al. (2005) due to sensitivity of the equipment used in that work (Pers. Comm. Jack Stamates, NOAA AOML via email October 25, 2012).

A study of water quality parameters at six ocean outfall discharge locations in southeast Florida was conducted in 2006, as part of the NOAA-AOML, Florida Area Coastal Environment

(FACE) program (Carsey et al. 2010). This study found that surface samples showed the highest nutrient concentrations versus samples taken at other depths; surface samples taken nearest the boil showed the highest nutrient concentrations in comparison to other samples collected in the vicinity of the outfall (Carsey et al. 2010). In general, the lowest concentrations of nutrient pollutants were observed in the deepest near-bottom samples, and near-bottom nutrient concentrations at the outfall were similar to those in the surrounding areas (Carsey et al. 2010). The outfall plumes were found to be dynamic, irregular, and mainly at the surface, due to density differences between the fresh discharge waters and saline marine waters (Carsey et al. 2010). The plumes generally remained in the upper 10 m of the water column while undergoing mixing with ambient waters (Carsey et al. 2010). Results from the survey cruise also indicate that the ocean outfall discharges dilute to ambient levels of salinity within 300 m of the outfall boil (Carsey et al. 2010).

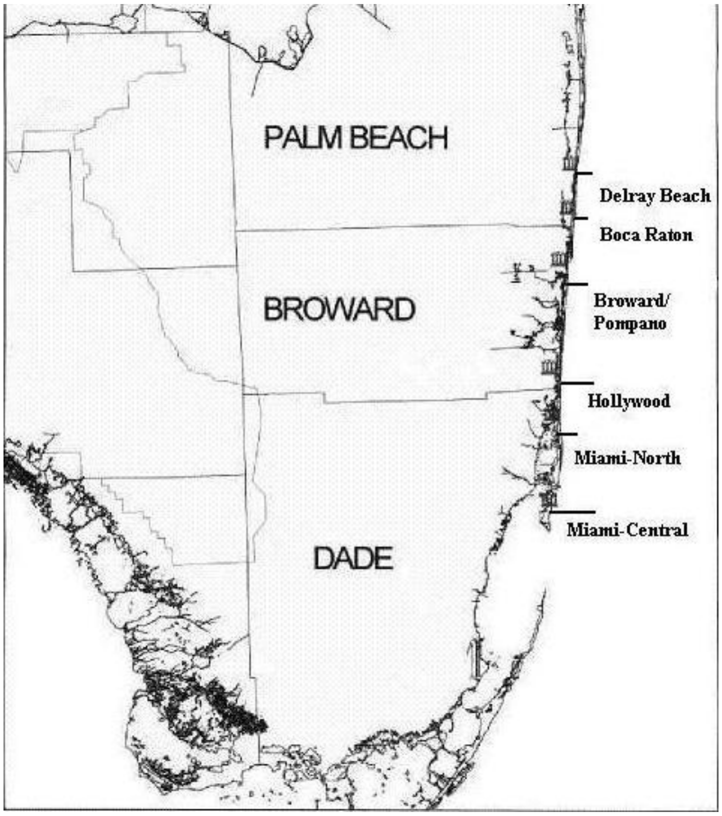

Figure 5. Ocean Outfall Discharge Locations in Southeast Florida.
Distance of outfall pipes from shore is exaggerated and not to scale. Figure was taken from Christie (1997) with revisions. Figure provided by DEP-CAMA-CRCP

The Florida Legislature passed the Ocean Outfall Act in 2008 requiring advanced treatment of ocean outfall discharge, greater water reuse and eventual closing of ocean outfalls by 2018 in Florida (DEP 2010). The Ocean Outfall Act was amended in 2012, extending the closure date of ocean outfalls to December 31, 2025 (refer to subsection 403.086(9)(d), Florida Statutes). Advanced treatment would reduce dissolved nutrient concentrations and address other pollutants that secondary treatment does not. Since passage of this law, wastewater disposal in southern Palm Beach County has primarily used deep well injection (DEP 2010). Flows to the Delray/Boynton outfall have been reduced to very low levels and only occur during the wet season, when water levels exceed the capacity of the deep well injection system (DEP 2010). Progress on closing the other outfalls has been slower.

4 Fisheries Habitats

Back reef systems found in southeast Florida generally include the reef tract (landward of the reef crest), offshore and nearshore hardbottom, marine and estuarine soft bottom, barrier island shorelines, as well as shallow bays and large embayments that include multiple categories of fisheries habitats (e.g. Indian River Lagoon, Lake Worth Lagoon, Biscayne Bay) (Macauley et al. 2002, Adams et al. 2006). Each back-reef system supports unique and dynamic plant and animal communities that can potentially be impacted by anthropogenic materials transported from inland activities (Macauley et al. 2002, Adams et al. 2006). In addition, anthropogenic impacts may be cumulative in nature and are often synergistic; therefore the effects of individual stressors are often difficult to differentiate and reductions of a particular stressor may not result in immediate improvement of environmental conditions (Duval et al. 2004).

Ecological services related to fisheries provided by back reef systems such as mangrove, seagrass and oyster habitats include primary production to support higher trophic levels (SAFMC 2009), larval settlement areas (Eggleston et al. 2004, Kendall et al. 2004, Jones et al. 2010), nursery habitat for post-larvae of juvenile fish and crustaceans (Duval et al. 2004, Adams et al. 2006, Jones et al. 2010), and “cover” such as refuge from predation and foraging opportunities (Caddy 2008). Additional biological and physical services include the nutrient uptake and sediment stabilization of mangrove and seagrass (Odum et al. 1982, Dawes et al. 1995, SAFMC 2009), water filtration and three dimensional effects of oyster reefs, bars and rocks on the hydrodymanic regime (waves and currents), and shoreline stabilization provided by mangrove root systems (Odum et al. 1982, Dawes et al. 1995, Kendall et al. 2004).

Seagrass, mangrove, oyster, soft bottom, hardbottom and coral reefs are important components of the coastal ecosystem in southeast Florida and are designated as EFH by the South Atlantic Fishery Management Council (SAFMC 2009). Loss of one of these habitats would affect the components of other communities, as they are dependent on one another. Mangrove forests and seagrass beds represent highly productive habitats, on which numerous species, such as spiny lobster and commercial finfish, depend for development, recruitment, and feeding (SAFMC 2009). These habitats are also crucial to reducing nutrient flows in the coastal environment and without seagrass beds and mangroves to assist in trapping sediments, coastal waters would deposit particulates on corals and other sessile fauna (SAFMC 2009).

4.1 Mangrove Habitats

Mangrove forests consist of a combination of one to four species of mangrove including red (*Rhizophora mangle*), black (*Avicennia germinans*) and white mangroves (*Laguncularia racemosa*) and buttonwood (*Conocarpus erectus*) (Odum et al. 1982). These species occupy wide ranges in the coastal zone from regularly flooded tidal regimes to higher elevations that may receive tidal waters only several times per year or during storm events (Odum et al. 1982). The growth of mangroves appears to be limited to estuarine systems and more inland areas that are subject to saline intrusions in southeast Florida (Odum et al. 1982). Mangrove forests and riparian fringe occur along sheltered coastlines with exposure to the open water of lagoons and bays (Odum et al. 1982). The tree canopy foliage forms a vertical wall and these forests are usually dominated by red mangroves (Odum et al. 1982). The characteristics of the red mangrove habitat are related to the patterns of tidal inundation through which organic materials and propagules are exported during ebb tides (Odum et al. 1982). This is a very important habitat type for fishery organisms because of the presence of abundant food and refuge the mangrove prop roots provide (Eggleston et al. 2004). Riverine mangrove forests occur in areas that have estuarine water exchange and are a very productive habitat type. This high productivity is attributed to the reduced salinity and the fact that freshwater runoff from land provides mineral nutrients required for growth. The high production of mangroves provides rich organic material to the adjoining low-salinity system, and is an important habitat for fishery organisms (Ley 1992). Mangrove habitats provide essential fish habitat to federally managed species in the Snapper-Grouper Complex, Peneaid Shrimp, and Spiny Lobster fishery management units (SAFMC 2009).

4.2 Seagrass Habitats

Seagrass species form recognizable biological and physical assemblages known as seagrass meadows. These meadows are usually defined by a visible boundary delineating unvegetated and vegetated substrate and vary in size from small, isolated patches of plants less than a meter in diameter to a continuous distribution of grass tens of square kilometers in area (SAFMC 2009). Seagrass meadows are dynamic spatial and temporal features of the coastal landscape (den Hartog 1971, SAFMC 2009). Seagrass occurs on unconsolidated sediments in a wide range of physical settings and different stages of meadow development leading to a variety of cover patterns, ranging from patchy to continuous. Depending on the species and the environmental conditions, a meadow may attain full development in a few months (e.g. *Halophila* spp.) (SAFMC 2009). For example, on the east and southeast coast of Florida between Sebastian Inlet in the Indian River Lagoon and North Biscayne Bay, *Halophila decipiens* forms annual meadows in water generally deeper than 1.5 to 2.0 m (Dawes et al. 1995). This species is also observed in the coastal ocean in depths exceeding 24 m off Palm Beach County.

The dynamic spatial and temporal features of seagrass meadows are important aspects of fishery habitats. Small seagrass patches or beds and entire meadows can move, the rate of which may vary on a scale of hours to decades (SAFMC 2009). Seagrass habitats must be recognized as including not only continuously vegetated beds but also patchy environments with the unvegetated areas between patches as part of the habitat (SAFMC 2009). Data show that patchy habitats provide many ecological functions similar to continuous meadows (Murphey and Fonseca 1995, Fonseca 1996). It should be recognized that the absence of seagrass in a particular location does not necessarily mean that the location is not viable seagrass habitat.

High rates of primary production and particle deposition make seagrass habitats important in the cycling of nutrients as both sources and sinks (SAFMC 2009). During periods of growth, the high rate of leaf turnover and epiphyte growth provides nutrients and energy for herbivores and a mechanism for nutrient export and retention (SAFMC 2009). Retention of nutrients within seagrass meadows occurs by particle deposition and burial, as well as the formation of organic matter in the sediments by the roots and rhizomes (SAFMC 2009). Seagrass are sensitive to the availability and abundance of nutrients in their environment and often retain nutrient signatures representing environmental conditions they have experienced (Fourqurean et al. 1992). Seagrass habitats provide essential fish habitat to federally managed species in the Snapper-Grouper Complex, Coastal Migratory Pelagic, Peneaid Shrimp, and Spiny Lobster fishery management units (SAFMC 2009).

4.3 Oyster Reef and Shell Habitats

The eastern oyster, *Crassostrea virginica*, forms oyster reef habitats which can be defined as the natural intertidal and subtidal structures that are composed of oyster shell, live oysters, and other organisms that are discrete, contiguous and clearly distinguishable from scattered oysters in marshes and mudflats (SAFMC 2009). Both intertidal and subtidal populations of oysters are found in the tidal creeks and estuaries of southeast Florida (PBC 2008, SFWMD 2009a, SFWMD 2012). Habitat and environmental conditions are usually the limiting factors controlling oyster abundance (PBC 2008, SAFMC 2009). Optimal salinity and temperature ranges for oysters are 12 ppt to 25 ppt and 10°C to 26°C, respectively (SAFMC 2009). Oysters can tolerate extremes in salinity (5 ppt and 30 ppt), temperature (0°C and 32°C), turbidity and dissolved oxygen (SAFMC 2009). However, favorable salinity and temperature regimes are important criteria for successful reproduction and spawning (Bahr and Lanier 1981, SFWMD 2012). Spat settlement and survival are best on clean, firm surfaces, such as oyster shell exposed to good water circulation (SAFMC 2009). Oyster reefs depend on water currents to provide food and oxygen, remove wastes and sediments, and disperse larvae (Bahr and Lanier 1981).

Intertidal oysters have often been described as a “keystone” species in an estuary and provide significant surface area as habitat (Bahr and Lanier 1981, PBC 2008). The intertidal oyster community has been identified as critical to a healthy estuarine ecosystem in south Florida (PBC 2008, SFWMD 2009a). Direct and indirect ecosystem services (e.g. filtering capacity, benthic-pelagic coupling, nutrient dynamics, sediment stabilization, provision of habitat) derived from the oyster have been largely ignored or underestimated (SAFMC 2009). Oysters can remove, via filter feeding, large amounts of particulate material from the water column and release large quantities of inorganic and organic nutrients into tidal creek waters (Dame et al. 1989, PBC 2008). The role of the oyster reef as structure contributes to the ecological value of these features, as important fisheries habitat (PBC 2008, Peterson et al. 2003). The three-dimensional oyster reef provides more area for attachment of oysters and other sessile organisms and creates more habitat niches than occur on the surrounding flat or soft-bottom habitat. Clams, mussels, anemones, polychaete worms, amphipods, sponges, and many species of crabs are part of the oyster reef community. These structures modify the hydrodynamic regime of the surrounding area by changing the patterns of waves and currents. By reducing wave energy, oyster structures improve conditions for other adjacent habitats, such as seagrass beds and mangrove forests (SAFMC 2009). Oysters provide other ecological services such as recycling nutrients and organic matter, and they are prey for many finfish.

Oyster habitats form an important part of a healthy estuarine ecosystem, but their ecological function and significance remain under-appreciated and under-studied in south Florida (SAFMC 2009, PBC 2008). Individual oysters filter 4 to 34 liters of water per hour, removing phytoplankton, particulate organic carbon, sediments, pollutants, and microorganisms from the water column (SAFMC 2009). The filter feeding by oysters results in greater light penetration immediately downstream, promoting the growth of seagrass and other estuarine plants. The ability of oysters to form large biogenic reefs qualifies it as a keystone species for estuarine ecosystems (SAFMC 2009).

Fishes known to use oyster habitats include drums, jacks, snook, sheepshead, spotted seatrout, flounders and many other families (Peterson et al. 2003). Oyster reefs in high salinity waters are also an important habitat for managed species such as groupers and snappers (Peterson et al. 2003). In addition to fishes, many other animals, such as crustaceans, echinoderms, mollusks, mammals, and birds come to oyster habitats for food or shelter (SAFMC 2009). Oyster reef and shell habitats provide essential fish habitat to federally managed species in the Snapper-Grouper Complex, and Peneaid Shrimp fishery management units (SAFMC 2009).

4.4 Soft-Bottom Habitats

Soft-bottom habitat is defined by the South Atlantic Fishery Management Council as unconsolidated, unvegetated sediment that occurs in freshwater, estuarine, and marine systems (SAFMC 2009). Environmental characteristics, such as sediment grain size and distribution, salinity, dissolved oxygen, and flow conditions will affect the condition of the soft bottom habitat and the types of organisms that use it. Although soft-bottom habitats lack visible structural habitat, sediments support an abundance of microscopic plants and burrowing animals below the surface. Soft-bottom habitat can be characterized by geomorphology (the shape and size of the system), sediment type, water depth, hydrography (riverine, intertidal, or subtidal), and salinity regime. The physical and chemical properties of soft-bottom habitats affect the benthic organisms that inhabit them and the value of these areas as fish habitat (SAFMC 2009). Soft-bottom habitats play a very important role in the ecology of estuarine ecosystems as a storage reservoir of chemicals and microbes (SAFMC 2009). Intense biogeochemical processing and recycling of nutrients in soft bottom habitats can establish a filter to trap and reprocess natural and human-induced nutrient loading and toxic substances (SAFMC 2009). Stratification of the water column can lead to depletion of dissolved oxygen in bottom water (Malone et al. 1988, PBC 2008). Water column stratification affects the mixing and oxygen exchange between water and the sediments (SAFMC 2009) and oxygen depleted bottom water with overlying layers of oxygenated waters (SFWMD 2009a).

Intertidal shorelines, flats, tidal deltas, and sand bars modify wave energy, reduce shoreline erosion and also provide important fisheries habitat (Adams et al. 2006, SAFMC 2009). Tidal flats and mud flats within bays, lagoons and riverine systems provide important foraging habitats for many species of finfish and shellfish in Florida (SFWMD 2009a). Soft bottom habitats are important for fishes such as herrings, drums, flounder, snook and barracuda, and crustaceans such as shrimp, crabs and lobster in southeast Florida (SAFMC 2009). Soft bottom (unconsolidated sediment) habitats provide essential fish habitat to federally managed species in the Coastal Migratory Pelagic, Peneaid Shrimp, and Spiny Lobster fishery management units (SAFMC 2009).

4.5 Nearshore Hardbottom and Worm Reef Habitats

Nearshore hardbottom habitats, along with worm reefs, are the primary natural reef structures closest to the southeast Florida shoreline (Lindeman and Snyder 1999, CSA International, Inc. 2009, Walker et al. 2008). Nearshore hardbottom habitats are derived from large ridges of coquina mollusks, sand, and shell marl (SAFMC 2009), while worm reefs are the result of the tube worm, *Phragmatopoma lapidosa*, forming structures with their tube building (Zale and Merrifield 1989, Lindeman and Snyder 1999). The majority of nearshore hardbottom reefs in southeast Florida are within 200 m of the shore (SAFMC 1998, Walker et al. 2008). Nearshore hardbottom habitats on the mainland of Florida have a patchy distribution among large expanses of soft-bottom consisting of coarse sediments (SAFMC 2009). Hard corals are rare in nearshore hardbottom off southeast Florida, due to high turbidity and wave energy; however, hard corals that are encountered on nearshore hardbottom include *Siderastrea radians*, *Oculina diffusa* and *Oculina varicosa* (SAFMC 1998).

Nearshore hardbottom and worm reef provide important nursery habitat and cover for predominantly juvenile fishes (Lindeman and Snyder 1999, Caddy 2008). A total of 86 taxa of fish were observed in these habitats, with grunts, wrasses, and parrot fish being the top three families in abundance (Lindeman and Snyder 1999). Ferro et al. (2005) observed 144 species of fishes on the “inshore reef tract” between 1998 and 2002 off Broward County Florida. This "inshore reef tract" was described as ranging from 1.8 m to 9.1 m in depth (Ferro et al. 2005), which corresponds to nearshore hardbottom habitats described in Walker et al. (2008). These definitions of nearshore hardbottom differ from that found in the SAFMC (2009) document describing EFH. While the SAFMC (2009) describes nearshore hardbottom as occurring in the depth range of 0 to 4 m, the Ferro et al. (2005) study overlaps this depth range (1.8-9.1m) and includes nearshore hard bottom with the "inshore reef tract". The Ferro et al. (2005) study provides one of the few data sets with species composition and relative abundance for these habitats within the SEFCRI region. Nearshore hard bottom and worm reef habitats provide essential fish habitat to federally managed species in the Snapper-Grouper Complex, Coastal Migratory Pelagic, Coral, and Spiny Lobster fishery management units (SAFMC 2009).

4.6 Coral, Coral Reefs and Offshore Hardbottom Habitats

Coral communities in different geographical regions of Florida support different benthic assemblages (Banks et al. 2007). Coral communities in southeast Florida have been described by Goldberg (1973a), Moyer et al. (2003), Gilliam et al. (2007a and b), and Banks et al. (2007), and mapped using GIS and remote sensing techniques by Walker et al. (2008). Several lines of offshore hardbottom reefs, derived from Pleistocene and Holocene reefs, begin in depths usually exceeding 8 m, and in bands that roughly parallel the shore (Goldberg 1973, Lighty 1977, Banks et al. 2007, Walker et al. 2008, Futch et al. 2011). Coral communities constitute a group of communities characterized by a thin veneer of live corals and other biota overlying assorted types of hard substrate. They are usually of low relief and on the continental shelf (Bright et al. 1981); many coral communities are associated with relict reefs, where the coral veneer is supported by dead corals (Banks et al. 2007). This group of coral habitats encompasses a large portion of the SEFCRI region containing stony corals (Walker et al. 2008). Most coral communities in southeast Florida have a diverse assemblage of stony corals, but lack the clear ecological zonation and density of frame builders typical of other coral reef communities throughout the Caribbean (Banks et al. 2007). Diverse biotic zonation patterns vary between many of these communities because of their geologic structure and geographic location. For example the shallow water (<5m) coral communities located nearshore differ from the coral communities in deep water (>20m) in stony coral species, size distribution, and density (Gilliam et al. 2007a, Gilliam et al. 2007b). Coral communities are common on rocky ledges (Walker et al. 2008), overlying relict reefs and on a variety of sediment types (Banks et al. 2007).

Fish assemblages using these habitats in southeast Florida include a diverse group of demersal fishes, such as grunts, wrasses, parrot fish, gobies, blennies, jawfish, butterfly fish, angel fish, and damsel fish (Ferro et al. 2005), as well as fishes in the snapper/grouper complex (SAFMC 2009) and pelagic fish such as jacks, mackerels, cobia (Ferro et al. 2005), and dolphin (SAFMC 2009, Ault and Franklin 2011). A total of 211 species in 52 families of fish were observed in point-count visual censuses conducted on reefs off Broward County, Florida between 1998 and 2002 (Ferro et al. 2005). Coral, coral reef and offshore hardbottom habitats provide essential fish habitat to federally managed species in the Coral, Snapper-Grouper Complex, Coastal Migratory Pelagic, and Spiny Lobster fishery management units (SAFMC 2009).

5 Land Based Sources of Pollution Threats to Fisheries Habitats

Marine and estuarine habitats support unique and dynamic plant and animal communities that can potentially be impacted by LBSP transported from inland activities (Adams et al. 2006, Macauley et al. 2002). Pre-drainage estuarine systems in southeast Florida received freshwater inflow primarily from direct rainfall and basin runoff that resulted in low nutrient inputs to estuarine systems (PBC 2008). These natural patterns of freshwater inflow sustained an ecologically appropriate range of salinity conditions with fewer of the extreme shifts in salinity that are currently being experienced (PBC 2008, SFWMD 2009a).

Excessive freshwater discharges from drainage canals adversely impact estuarine biological communities throughout southeast Florida (PBC 2008, SFWMD 2009a, SFWMD 2009b, SFWMD 2012). Water management and canal dredging have had major impacts on fisheries habitats within these estuaries (Caccia and Boyer 2005, PBC 2008). Natural habitats (e.g., mangrove, seagrass, oyster, and soft-bottom communities), drainage patterns, and land uses within southeast Florida watersheds have been significantly altered over time (SFWMD 2009a, SFWMD 2009b). In addition to water management and canal dredging, coastal development and agricultural activities have also affected the quality, quantity, timing, and distribution of water flows to estuarine habitats (PBC 2008, SFWMD 2009a, SFWMD 2009b). Wet season flows have increased due to additional and more rapid runoff from cleared land and impervious areas; and dry season flows have decreased due to lack of natural water storage and increased water supply demand for agricultural and urban development (SFWMD 2009a, SFWMD 2009b, SFWMD 2012). Three major watershed influences affecting fisheries habitats in southeast Florida estuaries include: (1) excessive nutrient loading mainly from urban runoff, use of fertilizers, agricultural operations, insufficient wastewater treatment and leaking septic systems (SFWMD 2009a); (2) excessive freshwater discharges from water management activities (PBC 2008, SFWMD 2009a SFWMD 2009a) and (3) undesirable low flows to southeast Florida estuaries resulting in high salinity conditions in the estuary (SFWMD 2009a).

5.1 LBSP Threats in Mangrove Habitats

A wide variety LBSP threats to mangrove habitats have been documented in southeast Florida. Coastal erosion, which results in sedimentation and siltation (Odum et al. 1982), oil spills (Odum et al. 1982), and nutrient pollution (Sutula et al. 2001, Lovelock et al. 2006) have all been identified as LBSP threats affecting mangroves in southeast Florida. In addition, changes in water management can also adversely affect mangroves (SFWMD 2009a). The complex root systems of mangroves baffle currents and play a major role in sediment deposition, shoreline stabilization, and nutrient cycling in estuaries. These communities contribute to peat formation and are critical to combating sea level rise and the stabilization of floodplain alluvial deposition. Odum et al. (1982) observed that the aerial prop root system of red mangroves is one of the plant's most vulnerable components because of their susceptibility to clogging, prolonged flooding, and boring damage from invertebrates. They note that any process that coats the aerial prop roots with fine sediments or covers them with water for long periods has the potential of being a destructive agent (Odum et al. 1982). Considerable damage to mangrove resources in southeast Florida has occurred due to oil coating of the prop roots (Odum et al. 1982).

Researchers have found that mangroves are sensitive to nutrient pollution (Odum et al. 1982, Sutula et al. 2001, Lovelock et al. 2006). Increased nutrient concentrations result in physiological changes that affect the mangroves' ability to maintain a favorable water balance with minimum salt uptake (Lovelock et al. 2006). Odum et al. (1982) found mangroves to be nutrient limited and susceptible to pollution threats including oil spills, fine particulate deposition, phosphorus, and inundation by water for prolonged periods. Sutula et al. (2001) documented that mangrove forests are phosphorus limited, unlike many other coastal habitats, which tend to be nitrogen limited. Lovelock et al. (2006) found that mangroves were vulnerable to nutrient pollution from both nitrogen and phosphorus, but that phosphorus had a greater physiological effect on mangroves.

5.2 LBSP Threats to Seagrass Habitats

In southeast Florida, seagrass habitats experience many anthropogenic impacts such as sedimentation and turbidity from stormwater runoff, herbicide and hydrocarbon exposure and nutrient enrichment (PBC 2008, SAFMC 2009, SFWMD 2009a, SFWMD 2009b, SFWMD 2012). Especially problematic are excessive epiphytic loads and smothering by transient macroalgae, both of which are often associated with nutrient enrichment (Howrth et al. 2000b, PBC 2008, SFWMD 2009a, SAFMC 1998). Excessive nutrient discharges and suspended sediments can also disrupt seagrass systems by causing water column algal blooms that diminish the amount of light available for seagrass (Dennison et al. 1993, Howarth et al. 2000a). Nutrient enrichment will often have detrimental effects that cascade up and down the food webs of seagrass habitats for example, low dissolved oxygen concentrations from algal blooms, and toxic concentrations of hydrogen sulfide from decaying algae diminish the ability of seagrass to filter water and stabilize sediments, thus altering the water column environment for filter feeders and primary producers (SAFMC 2009).

Water quality and, in particular, water clarity is now considered the most critical factor in the maintenance of healthy seagrass habitats (PBC 2008, SAFMC 2009, SFWMD 2009a, SFWMD 2009b). Seagrass generally requires light levels reaching the leaves of 15 to 25 percent of the surface incident light (Kenworthy and Fonseca 1996). Many factors act to reduce water column transparency, with excess suspended solids and nutrients being considered to be among the most important and most controllable through watershed management practices (Howarth et al. 2000a, Howarth et al. 2000b). Seagrass are also susceptible to wide fluctuations in salinity and species-specific tolerances have been documented for the seven seagrass species occurring in Florida. For example, the federally-threatened species, Johnson's seagrass (*Halophila johnsonii*), whose range is restricted to southeast Florida, showed complete mortality at 10 psu for 10 days (Kahn and Durako 2008).

Subtidal seagrass meadows have suffered little damage from oil spills; however, intertidal beds are at risk from oil spill-related impacts (Durako et al. 1993, Kenworthy et al. 1993). Oil spill related impacts on the seagrass-associated fauna can range from smothering to lowered stress tolerance, reduced market values, and incorporation of carcinogenic and mutagenic substances into the food chain (SAFMC 2009). The loss of seagrass leads to several undesirable and difficult to reverse outcomes (SAFMC 2009). Seagrass losses can lead to reduced sediment binding and water motion baffling capability of the habitat, allowing sediments to be re-suspended and transported more easily (Fonseca 1996). Increased shoreline erosion and increased water column turbidity can result from loss of seagrass (SAFMC 2009).

5.3 LBSP Threats to Oyster Habitats

LBSP threats to oyster habitats include sedimentation and salinity fluctuations (Caccia and Boyer 2005, PBC 2008, SFWMD 2009a, SFWMD 2009b, SAFMC 2009). Oyster populations in south Florida appear to be limited by the availability of suitable substrate (PBC 2008). Sedimentation and the accumulation of muck on available substrate makes the substrate unsuitable for oyster larval settlement, recruitment and growth of larval oysters (PBC 2008). In addition, accumulation of muck with high organic content may also impact the dissolved oxygen content to the extent that larval settlement and growth of previously settled oysters are affected (PBC 2008).

Excessive freshwater discharges from drainage canals adversely impact estuarine biological communities (PBC 2008, SFWMD 2009a, SFWMD 2009b, SFWMD 2012). Pre-drainage estuarine systems received freshwater inflow primarily from direct rainfall and basin runoff that resulted in low nutrient inputs to estuarine systems in southeast Florida (PBC 2008). These natural patterns of freshwater inflow sustained an ecologically appropriate range of salinity conditions (PBC 2008). Water management and dredging practices have had major impacts on the presence of oysters within these estuaries (Caccia and Boyer 2005, PBC 2008, SFWMD 2012). While Comprehensive Everglades Restoration Projects implemented in the C-51 Basin will have an impact on freshwater discharges and consequently sedimentation and salinity, the magnitude of increased oyster colonization resulting from these projects is very difficult to predict (PBC 2008). Exposure of oysters to biocides, hydrocarbons, and heavy metals has been investigated in Florida. Results indicate that while these threats may have sub-lethal effects, they are not determining factors in oyster abundance or distribution in southeast Florida (Lewis et al. 2004, Volety 2008).

5.4 LBSP Threats to Soft-bottom Habitats

Sedimentation (PBC 2008), turbidity (SFWMD 2009a), deposition of organic material (SFWMD 2009a), salinity fluctuations, (SFWMD 2009a, SFWMD 2009b), nutrient loading (Howarth et al. 2000a SFWMD 2009a), and associated low dissolved oxygen threaten estuarine soft bottom fisheries habitats in the southeast Florida (SFWMD 2009a). Excessive nutrient discharges can disrupt estuarine systems by causing water column algal blooms that diminish the amount of light and dissolved oxygen available for benthic resources (Howarth et al. 2000a, Howarth et al. 2000b, Dennison et al. 1993, PBC 2008, Street et al. 2005). As a result of excessive nutrient loading and freshwater discharges, southeast Florida estuaries often exhibit the typical signs of eutrophication, including algal blooms (Howarth et al. 2000a, Howarth et al. 2000b, PBC 2008, SFWMD 2009a, SFWMD 2009b). Decomposition of the algal biomass results in additional oxygen demand that can lead to hypoxic conditions (Howarth et al. 200b). Other environmental problems resulting from LBSP include increased suspended sediments in the water column, lesions on fish, and reduced species diversity and abundance of benthic infauna (PBC 2008, SFWMD 2009a, SFWMD 2012). Muck deposits (fine sediment coupled with high organic loading) increase estuarine biological oxygen demand and decrease benthic diversity while re-suspension of fine sediments contributes to poor water clarity and hypoxia.

5.5 LBSP Threats to Nearshore Hardbottom and Worm Reef Habitats

Land based sources of pollution affecting nearshore hardbottom and worm reef habitats include sedimentation (Lindeman and Snyder 1999, CSA International, Inc. 2009), nutrients , turbidity, heavy metals, pharmaceuticals, biocides, and pathogens (Fabricius 2005, Fauth et al. 2006, Carsey et al. 2010). The proximity of nearshore hardbottom and worm reef to potential sources of nutrients, heavy metals, pharmaceuticals and biocides such as inlets, ocean outfalls and submarine groundwater discharges increases the risk and magnitude of impacts to benthic resources in these habitats (Carsey et al. 2011, Kaczmarsky et al. 2005, Fabricius 2005, Fauth et al. 2006, Reich et al. 2008).

Sedimentation and turbidity may originate from anthropogenic sources such as construction and beach nourishment activities (Zale and Merrifield 1989, Jordan et al. 2010), water management activities, such as regulatory releases in the St. Lucie estuary (SFWMD 2009a, SFWMD 2012), or from natural phenomena such as hurricanes and winter storms re-suspending sediments (Trnka et al. 2006, SAFMC 2009,). Florida water quality standards do not include a criterion for sedimentation; however, in permitting of most coastal construction activities, sedimentation is usually prohibited and best management practices are usually required to prevent sedimentation impacts to coastal resources. Beach nourishment is an exception to the usual prohibition of sedimentation. By its nature, i.e. deposition of sediments along the coastal shoreline, beach nourishment increases sediments within the dynamic sand sharing system of southeast Florida’s beaches and results in sedimentation of adjacent marine habitats. Beach nourishment continues to be the primary anthropogenic impact to nearshore hardbottom and worm reef habitats in southeast Florida (CSA International, Inc. 2009).

Nearshore hardbottom and worm reef ecosystems in southeast Florida are dynamic habitats that often occur within or near the sand-sharing system of the beaches in this region (Zale and Merrifield 1989, Walker et al. 2008). Proximity to these moving sands results in varying levels of exposure and covering of the reefs by a veneer of sand (Zale and Merrifield 1989, Lindeman and Snyder 1999). Human activities such as beach nourishment or sand transfer pumping can change the dynamics of the covering and uncovering of nearshore hardbottom and worm reefs (Zale and Merrifield 1989, CSA International, Inc. 2009). Little research has been conducted on the effects of heavy metals, biocides or pharmaceuticals on worm reefs (Zale and Merrifield 1989). Some lethal and sub-lethal responses by tube worms to hydrocarbons, cadmium and the reference toxicant dodecyl sodium sulfate have been reported (Mulhern 1976, Kavanaugh 1979, Zale and Merrifield 1989). The concentrations of these pollutants in the nearshore waters of southeast Florida are not known.

5.6 LBSP Threats to Coral, Coral Reef and Offshore Hardbottom Habitats

Land-based sources of pollution threats to coral reefs and offshore hardbottom include nutrient pollution (Pastorok and Bilyard 1985, Fabricius 2005, Kaczmarsky et al. 2005, Carsey et al. 2010), pharmaceutical and personal care products (Singh et al. 2009), pathogens (Sutherland et al. 2011), sedimentation and turbidity (Rogers 1990, Telesnicki and Goldberg 1995), and biocides (Raberg et al. 2003, Markey et al. 2007). Increases in dissolved inorganic nutrients have been shown to reduce coral calcification rates, reduce fertilization success, and possibly promote the growth of macroalgae that compete for space with corals (Fabricus 2005). Research activities led by Lapointe (1997, 2005a, 2005b) have concluded that increased nitrogen and/or phosphorous concentrations can cause an increase in macroalgal production resulting in an increase in harmful algal blooms on southeast Florida reefs.

Szmant et al. (1999) and Szmant (2002), have challenged LaPointe’s findings that changes in macroalgal abundance are the result of nutrient pollution. Szmant’s (2002) research indicates that there are multiple causes of change in coral and algal abundance and cover. Regional algal community changes were caused by changes in grazing patterns, overfishing of herbivores and declines in long-spined urchin populations throughout the Caribbean and that data support nutrient pollution as a cause of coral reef decline on local scales, but not on a regional scale (Szmant 2002).

The southeast Florida reef tract has experienced extensive blooms of macroalgae and cyanobacteria during the past 25 years (Collier et al. 2008). Beginning in 1989, blooms of *Codium isthmocladum* impacted deep (27 to 45 m) reefs off northern Broward County and Palm Beach County (Collier et al. 2008). Monitoring studies showed that these blooms were adapted to low light levels and developed seasonally in the late spring and summer (Lapointe 1997). Water column sampling for dissolved inorganic nutrients and tissue analysis for carbon:nitrogen:phosphorus (C:N:P) ratios further indicated that the *C. isthmocladum* blooms were related to nutrient enrichment (nitrogen and phosphorus) from both natural and anthropogenic land-based sources (Lapointe et al. 2005a, Collier et al. 2008).

The effects of nutrient pollution on corals, coral reefs, and offshore hardbottom have been studied extensively (Pastorok and Bilyard 1985, Costa et al. 2000, Szmant 2002, Fabricius 2005), including along the Florida reef tract (LaPointe 1997, Leichter et al. 2003, Kaczmarsky et al. 2005, LaPointe et al. 2005a, Ward-Paige et al. 2005, Futch et al. 2011). While disagreement on the sources of nutrients to the southeast Florida coral reef tract continues, the literature shows that corals, coral reefs, and offshore hardbottom are adversely affected by nutrient enrichment (LaPointe 1997, Szmant et al. 1999, Szmant 2002, Fabricius 2005, Trnka et al. 2006, Bloetscher et al. 2010).

Bloetscher and colleagues (2010) conducted a literature review and evaluation of coastal ocean discharges and assessed environmental impacts resulting from those discharges in southeast Florida. Literature regarding the baseline state of coral reefs and the effects of stressors in Florida were found to be lacking (Bloetscher et al. 2010). The evaluation was not able to make a causal link between secondary-treated wastewater discharges and biological population shifts in southeast Florida (Bloetscher et al. 2010). The authors found that inlet discharges may be a greater magnitude of anthropogenic source of pollutants to southeast Florida coastal ecosystems than ocean outfall discharge of secondary treated wastewater and that information is lacking regarding the contributions of upwelling and submarine groundwater discharge to nearshore nutrient loading (Bloetscher et al. 2010). The lack of resolution of research results appears to be related to the lack of a pre-discharge baseline assessment of the biological communities making lack of pre-post nutrient loading comparisons, lack of water quality monitoring, the geographic scales of the coral reef ecosystem and nearshore coastal hydrodynamics, as well as the chronic effects of these stressors to the southeast Florida reef system over the last century (Bloetcsher et al. 2010).

Other compounds found in wastewater and stormwater that are likely to affect corals, coral reefs, and hardbottom habitats include pharmaceutical and personal care products. The effects of these compounds on benthic assemblages in Florida have received some recent attention by researchers (Singh et al. 2009). Hormones and steroids such as estrone (Atkinson et al. 2003), cholesterol, caffeine, and DEET were found in the waters of southeast Florida and the Florida Keys (Singh et al. 2009). The magnitude of the effects of these compounds on corals, coral reefs and offshore hardbottoms has not been assessed.

The effects of anthropogenic pathogens on corals have been studied in the tropics around the world and in Florida (Kaczmarsky et al. 2005, Fabricius 2005, Costa et al. 2000, Futch et al. 2011, Sutherland et al. 2011). Sutherland and colleagues (2011) found a causal link between the human pathogen *Serratia marcesens* that is found in human sewage and the coral disease acroporid serratosis (described as "White Pox") in elkhorn corals in the Florida Keys. The effects of anthropogenic pathogens on other coral reef organisms, such as sponges, mollusks and crustaceans remain less well known. Human viruses and fecal bacteria were investigated off Broward County, Florida by Futch et al. (2011). Widespread distribution of human noroviruses (a common source of human gastroenteritis) was observed, despite low levels of fecal bacteria in water, sponge, and coral tissue samples (Futch et al. 2011). Fauth et al. (2006) completed a feasibility study using enzymatic biomarkers to identify stress in *Porites astreoides* around southeast Florida inlets and wastewater outfalls and found that stress responses in corals around the Hollywood wastewater outfall were consistent with sewage exposure.

Sedimentation is known to adversely affect corals (Rogers 1990, Fabricius 2005, Jordan et al. 2010). Rogers' (1990) work in the U.S. Virgin Islands found that sediment particles smother reef organisms, reduce light available for photosynthesis and can adversely affect the structure and function of the coral reef ecosystem by altering physical and biological processes. Sedimentation may also affect coral/algal completion for substrate (Nugues and Roberts 2003). Jordan et al. (2010) found increased sedimentation on southeast Florida reefs and hardbottoms associated with an adjacent beach nourishment project. While reef organisms including corals, sponges, reef-building worms, and crustose coralline algae have varying tolerances for sedimentation stress, all these reef-associated organisms are adversely affected to some degree by increases in sedimentation (Rogers 1990, Jordan et al. 2010).

The turbidity regime in marine systems can have a significant effect on the energetics of corals (Telesnicki and Goldberg 1995, Fabricius 2005, Trnka et al. 2006) and other coral reef organisms (Duval et al. 2004). Adverse effects of turbidity include sub-lethal effects on reef fauna such as increased respiration and mucous production, and lethal effects such as smothering of organisms, depending on the magnitude and duration of the turbidity (Telesnicki and Goldberg 1995, Fabricius 2005). Reduced light penetration into the water column may change benthic species composition from species that need higher light (hermatypic corals) to species adapted to lower light levels (algae and cyanobacteria) (Fabricius 2005). Turbidity affects coral respiration and species-specific responses (i.e., benthic community structure) can be reflective of the synergistic effects across water quality gradients (Anthony and Connolly 2004, Hennige et al. 2010).

Biocides including pesticides, herbicides, and fungicides have been shown to adversely affect corals and other epibenthic organisms, such as barnacles, oysters and hydroids (Raberg et al. 2003, Fabricius 2005, Markey et al. 2007). Southeast Florida coral reefs and offshore hardbottom are subject to stormwater runoff from agricultural, residential, and industrial development where the use of pesticides, herbicides and fungicides is common (Trnka et al. 2006). In addition, the use of antifoulant paint in south Florida contributes biocides specifically designed to disrupt epibenthic organisms (Trnka et al. 2006). While the effects of these compounds have been studied by companies developing their formulations, little work has been conducted to assess the immediate or long-term effects of these compounds in the environment.

6 Conclusions and Recommendations

6.1 Conclusions

Several pollutants adversely affect all of the fisheries habitats found in southeast Florida, such as nutrient pollution, sedimentation, and turbidity. Other pollutants have specific effects on only a few fisheries habitats, such as pathogens specific to corals or oysters. Heavy metal pollution and hydrocarbon pollution affect intertidal oyster and seagrass habitats to a greater degree than sub-tidal habitats. Some pollutants, such as pharmaceutical and personal care products have not been studied well enough to determine the extent of adverse impacts that may result from this pollution. Based on the review of existing literature, the following conclusions are provided:

Region-wide water management

- Changes in salinity are a cause of sub-lethal and lethal effects on corals, oysters, and seagrass. Salinity fluctuations are a factor in the loss of oyster and seagrass habitats in the St. Lucie River, Lake Worth Lagoon, and Biscayne Bay watersheds within southeast Florida. There is growing concern regarding the detrimental role salinity fluctuations play in the survival of coral reef organisms and other benthic fauna existing in marginal environments.
- Emerging water management issues include central Everglades restoration projects, implementation of water management improvements, numeric nutrient water quality criteria, and results of new research on pollution reduction in southeast Florida.
- The synergistic effects of degraded water quality cause changes in fisheries habitats and fish community structure.

Nutrients

- Nutrient enrichment of coastal waters can cause ecological changes that decrease the biological diversity and productivity of estuarine and marine fisheries habitats. Nutrient pollution degrades marine food webs that support commercially and recreationally important fish.
- Increases in nutrient pollution of coastal waters have been accompanied by an increase in harmful algal blooms.

- High nutrient levels are detrimental to the fisheries habitat functions of coral reefs and seagrass habitats.
- Mangroves are vulnerable to nutrient pollution from both nitrogen and phosphorus, but phosphorus has a greater physiological effect on mangroves. Increased phosphorus can upset the water balance and salt excretion functions of mangroves.
- Mangrove forests are phosphorus limited, unlike many other coastal habitats, which tend to be nitrogen limited.

Water Clarity, turbidity and sedimentation

- Increased turbidity reduces water clarity, which results in lower light levels for seagrasses and coral zooxanthellae.
- Sedimentation can kill filter feeding animals such as corals, sponges and oysters by inhibiting feeding, smothering or burying these fauna. Sedimentation can also decrease growth rates of corals, oysters, and other benthic fauna by shading or abrasion.
- Sedimentation can adversely affect seagrass and soft substrate habitats by burial or by increasing turbidity through resuspension of silt by wind and waves.
- Sedimentation associated with beach nourishment activities remains a threat to nearshore hardbottom and worm reef habitats

Hydrocarbons and organics

- Mangroves are susceptible to pollution threats including hydrocarbon/organics, fine particulate deposition and inundation by water for prolonged periods.
- Exposure of corals to hydrocarbons caused tissue atrophy, degeneration, and reduced fecundity.
- Petroleum products released by oil spills that remain near the surface of the water may never contact reefs or other sub-tidal habitats; however, these compounds can still affect larvae that float near the water surface.
- Intertidal oyster and seagrass habitats are particularly vulnerable to hydrocarbon pollution.

Biocides

- Biocides including pesticides, herbicides and fungicides are widely used and can enter estuarine and marine environments through terrestrial runoff and marine antifouling paints. These chemicals and their degradation products can be highly toxic to corals, bivalves, crustaceans, and other benthic fauna at very low concentrations.

Pathogens

- Research on diseases in corals in tropical and subtropical ecosystems has focused primarily on bacterial pathogens. At least 14 coral diseases have been documented in the Caribbean areas. One coral pathogen has been associated with human sewage.
- Significant work has been conducted on oyster pathogens, such as Dermo and MSX, in temperate regions; however, little information is available regarding oyster pathogens in southeast Florida.
- The contamination of marine waters with viruses should be considered an important human health issue, as well as an environmental issue.

Personal Care and Pharmaceuticals

- Personal care products, (e.g., lotions, fragrances, and insect repellent), medications and hormones often end up in estuarine and marine environments. None of the wastewater treatments currently used in Florida removes these pollutants from effluent prior to disposal.

Heavy Metals

- Many heavy metals have adverse effects on coral and oyster fertilization and larval settlement success. Elevated metal concentrations have been shown to have a negative impact on coral reproduction and recruitment.

6.2 Recommendations

Region-wide water management

- Provide an ecosystem-based perspective to current water quality improvement planning and management activities in southeast Florida to reduce LBSP impacts to estuarine and marine fisheries habitats.
- The construction of water storage reservoirs and stormwater treatment areas, are recommended to reduce nutrient levels before release of water to southeast Florida estuaries and modulate salinity changes within those estuaries.
- Support implementation of numeric nutrient water quality criteria for nitrogen and phosphorus that are in the process of being developed by the state of Florida.
- Conduct monitoring of relevant water quality parameters associated with environmental improvement projects (e.g. Everglades and other restoration projects). Facilitate collaboration between agencies with existing monitoring capacity and organizations in need of water quality information for use in management decisions.

Nutrients

- Reduce nutrient loading from all anthropogenic sources and pathways, including surface water management systems, coastal inlets, submarine groundwater discharge, and ocean

outfall discharge, to improve conditions for nearshore and offshore habitats and the coral reef ecosystem in southeast Florida.
- Evaluate input of nutrients and other pollutants from coastal inlets and submarine groundwater discharge as major factors influencing LBSP impacts on fisheries habitats in southeast Florida.
- Complete nutrient budgets for southeast Florida coastal waters and watersheds to understand the scope and magnitude of impacts and water quality improvements to southeast Florida waters.

Water Clarity, Turbidity and Sedimentation
- Modify beach nourishment activities to prevent sedimentation and turbidity impacts to nearshore hardbottom, worm reef and offshore reef habitats.
- Restore marine habitats as a critical resource management tool to reduce LBSP effects by increasing sediment accumulation, sequestration of pollutants, and nutrient uptake by submerged and emergent plants.

Recommendations for additional research
- Facilitate research addressing gaps of knowledge regarding the effects of personal care products and pharmaceuticals on marine and estuarine organisms.
- Facilitate research on the identity and effects of pathogens on keystone species in southeast Florida including oysters, corals, and sponges.
- Improve technologies for monitoring turbidity and sedimentation
- Update the literature review and synthesis of LBSP on EFH in southeast Florida to include new information regarding water management activities, pollution reduction efforts and results of recent research. Updates can be done as addenda to this report.

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