Nearshore and Midshelf Reefs

FNAI Global Rank:	**G1/G2/G3**	
FNAI State Rank:	**S1/S2/S3**	
Federally Listed Species in S. FL:		**8**
State Listed Species in S. FL:		**15**

Marine habitats usually fall under the stewardship of the National Marine Fisheries Service (NMFS). However, the Fish and Wildlife Service (FWS) is involved in marine habitat conservation through transfer fund agreements with the U. S. Army Corps of Engineers (COE). The COE civil works program includes beach nourishment and renourishment projects which affect the nearshore marine environment and the FWS, as an advisory agency, provides the COE with comments regarding the environmental aspects of those projects. Accordingly, this account represents a contribution toward existing recovery plans under NMFS' authority and, therefore, is limited to a brief discussion on reef ecology and management within the scope of FWS authority.

Synonymy

The term "nearshore reefs" is meant here to include all solid physical substrate below the mean high water line (MHW) and seaward of Atlantic Ocean or Gulf of Mexico shoreline which may be vulnerable to fill deposition and turbidity (loss of light penetration through the water column) associated with beach nourishment. The zone has been defined by the State of Florida Department of Environmental Regulation (DEP) as the area landward of the 4 m (13.1 ft) depth contour. This definition would exclude solid subtidal substrate within bays and estuaries. "Rock outcrops" or "rock substrate" could be considered synonymous; however, artificial reefs constructed of other materials could also be located within this zone. Midshelf reefs include those reefs between the 4 m (13.1 ft) isobath and the practical limits of dredging operations or about the 20 m (65.6 ft) depth isobath. The general term "hard bottom" has also been applied to these deeper reef areas. This term includes the solid substrate and epifauna which occupies the substrate.

The epifaunal assemblages associated with such substrate are varied and, accordingly, have been given many names. The term nearshore reefs is not used in the Florida Natural Areas Inventory (FNAI) system of classification, but for the purposes of this plan, include: consolidated substrate, octocoral bed, sponge bed, worm reef, algal bed and composite substrate. Coral reefs, as defined by FNAI, have limited relevance to this discussion in that, they are generally too far offshore to be buried by beach fill, located where they are vulnerable only to the dredging operations associated with beach nourishment, and then, only in Miami-Dade County. Coral reefs should be distinguished from hard bottom which supports some reef-building corals. These hard bottom communities may extend as far north as Palm Beach County on Florida's east coast. Less relevant to this discussion but worth mentioning are the *Oculina* (ivory tree coral) reefs which occur in depths greater than 30.5 m (100 ft) from St. Lucie County to Jacksonville, and the intertidal vermetid reefs off of the Ten Thousand Islands which are remnant structures formed by the reef-building gastropod, *Petaloconchus* sp. In most areas neither reef-building (hermatypic) corals, octocorals, sponges, reef-building worms, nor algae dominate. Accordingly, the more general terms given in the preceding paragraph will be used most frequently in this discussion.

Distribution and Description

Geologically, the rock formations upon which reef communities develop are known as the Anastasia formation which form the backbone of the Atlantic coastal ridge (Stauble and McNeill 1985). This limestone formation is the result of several Pleistocene accretion events and is named for Anastasia Island were it was first described (Puri and Vernon 1964). Portions of the formation are exposed beneath the sea surface resulting in an extensive reef system.

Florida's reefs are not dominated by a single phylogenetic group, making specific classification difficult. Of the various types of reef, the coral reef, which is dominated by hermatypic corals, has the most structural complexity. These formations form the most popular image associated with the term "reef." Coral reefs are best developed in the U.S., primarily within the Florida Reef Tract (primarily in Monroe County). Most of the Florida Keys' coral reefs are well known due to the clarity of the water and the popularity of SCUBA diving. The ecology of coral reefs is described in some detail by Jaap (1984). The coral reefs in the Florida Keys are a trust resource of the National Oceanic and Atmospheric Administration (NOAA) and are protected as part of the Florida Keys National Marine Sanctuary. A special set of management plans has been developed for this resource (NOAA 1996).

Farther north, through Miami-Dade and Broward (Figure 1) counties on the east coast and Collier County on the west coast, water clarity and temperature declines as do reef-building corals. Although the range of hermatypic corals may extend as far north as Stuart on the east coast, the solid substrate is increasingly populated by soft corals (gorgonians). North of Stuart, the warm waters of the Gulf Stream are farther offshore, soft corals are fewer and hard bottom communities are more prevalent. Hard bottom communities are populated by sponges, small (ahermatypic) hard corals, tunicates, bryozoans, algae, and sabellariid worms. Such communities are typical of Florida's West coast from Collier County north; however, few studies have

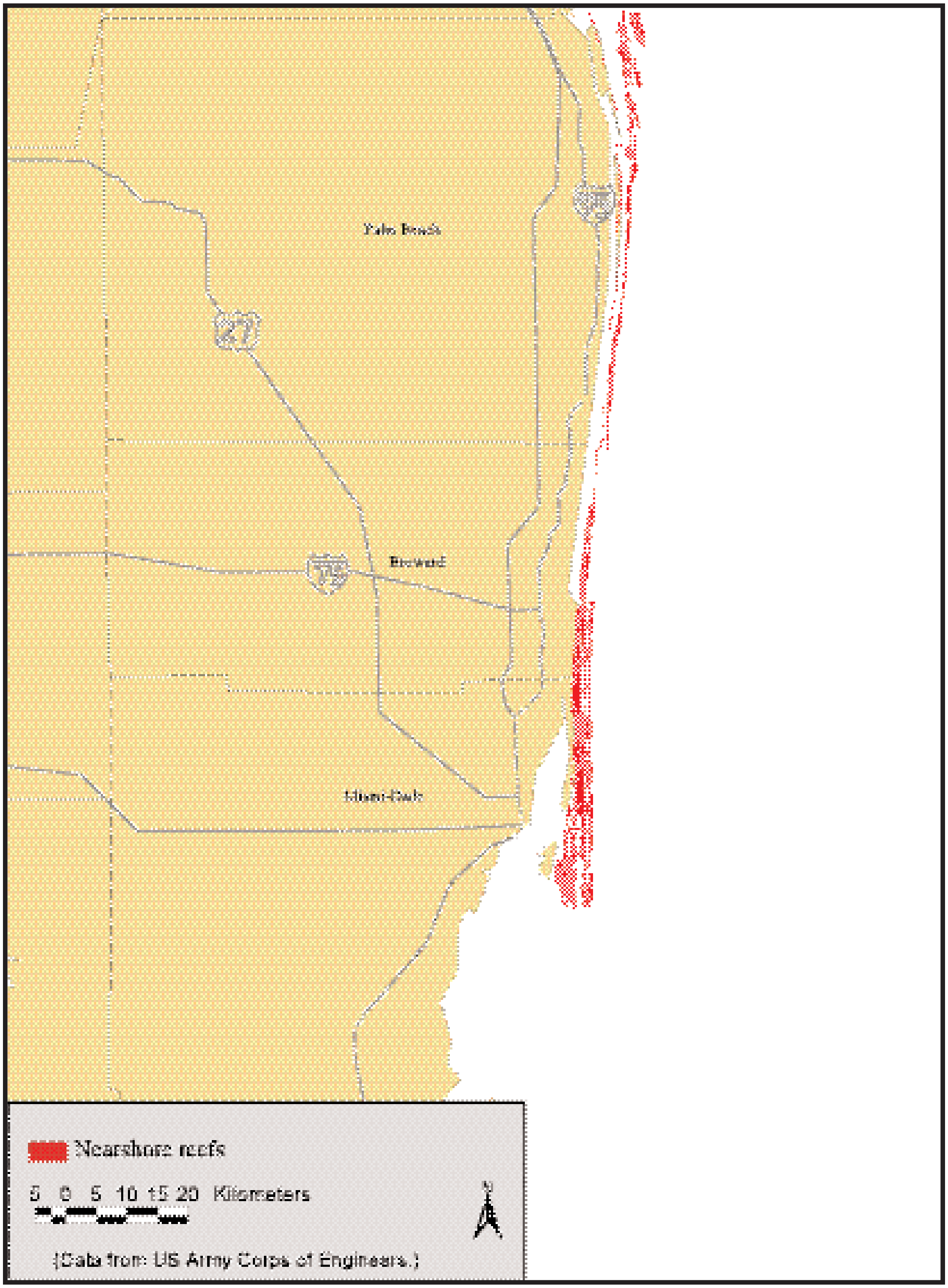

Figure 1. Nearshore reefs in Miami-Dade, Broward and Palm Beach counties, Florida (data from the U.S. Army Corps of Engineers).

been completed on sabellariid worms reefs on Florida's west coast. Consequently, most of the reef ecology referenced in this recovery plan has been obtained from research performed on the east coast.

Sabellariid worms can dominate the reef community and form a unique reef type known as "worm reef." These reefs are most often formed in high-energy surf zones between Martin and Brevard counties (Kirtley and Tanner 1968), thus may provide shoreline protection by reducing wave energy on the beach. Such reefs are composed of loosely cemented sand particles which are held together by a mucus secreted by the worms when building their casing. Sabellariid worm colonies provide habitat for over 325 species of invertebrates (Nelson 1989). Nelson and Demetraides (1992) found that, seasonally, abundances of isopod and amphipod species can be as high as 50,000 and 22,000 individuals per square meter, respectively. Algal species can also dominate some reef areas. Offshore of central Florida at Vero Beach, 109 algal species were identified by Juett *et al.* (1976).

Species Diversity and Ecology

Biodiversity of visible organisms is much higher on nearshore reefs than on sandy bottom. Epifaunal organisms flourish on the stationary foothold provided by the rock and are virtually absent in areas where shifting sands preclude settlement. Algae also flourish on this reef substrate. At the bottom of the food chain, algae provides a primary food source for a variety of organisms including: invertebrates, fishes, and even the endangered green sea turtle (*Chelonia mydas*). Fish are also more abundant on nearshore reefs. Approximately 192 species are known to inhabit the nearshore reefs of South Florida (Lindeman 1997). Vare (1991) recorded only seven species from observations over sand bottom in Palm Beach County. Lindeman (1997) counted 30 times more individuals per transect on nearshore reefs than per transect over adjacent sandy bottom.

Sessile Invertebrates

Reef fauna may be divided into sessile and motile components. The sessile component consists of primary producers and consumers or heterotrophs such as suspension and filter-feeding organisms. The exposed rock provides stable substrate for this epifauna which, through photosynthesis and filter and suspension feeding, provides basic organic material on which much of the reef's food web is based. Carbon fixed far offsite is concentrated on the reefs by filter-feeding organisms such as sponges and barnacles. These animals trap nutrient-rich phytoplankton as it is swept past the reef by wave- and wind-generated currents. Sessile cnidaria such as anemones and stinging hydroids capture zooplankton and other larger organisms which drift to them. The attached invertebrates contribute to the basic structure of the reef providing more holes and crevices and additional protection from predation for small motile invertebrates and fishes. Some filter-feeding polychaetes live in the sand among and around the rock outcrops of the reef. These are fed upon by reef dwelling fish such as the spotfin moharra (*Eusinostomus argenteus*) which with protrusile mouthparts is adapted to extract the worms from the sand. These are, in turn, consumed by the common snook (*Centropomus undecimalis*) and other reef predators.

Mobile Macroinvertebrates

The most comprehensive list (325 species) of macroinvertebrates found on the nearshore reefs, compiled south of Sebastian Inlet, Indian River County by Nelson (1988, 1989), has been described by its author as incomplete. Nelson points to the scientific value which must exist in the unknown species which reside on nearshore reefs. This potential has been discussed by other researchers as well. Some gastropod species, for example, are rare and endemic to small nearshore reaches of the Florida coastline (Petuch 1988). These species could be in danger of extinction by shell collecting or by beach nourishment if small localized populations were to be buried by beach fill. There may be as many as 40 such species, most of which are trust resources of the NMFS. Their occurrence in U.S. waters renders them eligible for candidacy by the FWS and/or NMFS (E. Petuch, Florida Atlantic University, personal communication 1998).

Gastropod species which occur in the rocky intertidal zone are especially vulnerable to population decimation by shell collectors and beach nourishment. The existing populations of intertidal species could be habitat-limited. This habitat is rare on the east coast and the beachrock outcrops along Palm Beach and Martin counties, which are unique in Florida, represent the only extensive, naturally occurring rock cliffs found along the southeastern United States (Petuch 1988). *Cerithium lindae* occurs on beachrock shorelines from Fort Pierce (St. Lucie County) to Blowing Rocks near Jupiter (Palm Beach County) (Petuch 1987). *Nerita lindae*, a cryptic species, and *Modulus papei* have a similar, limited distribution. Two periwinkle species from this habitat have, as yet, to be named in the scientific literature.

Herbivorous invertebrates pass nutrients and energy to higher trophic levels. Herbivory in crustaceans is well documented (see Odum 1969 for one example). Isopods, shrimp, crabs, *etc*., consume sessile and epiphytic algae, then are themselves consumed by higher predators such as the sheepshead (*Archosargus probatocephalus*). Gastropods also are known to graze on algae passing nutrients and energy produced on the reef up the food web. Gastropod predators may include other invertebrates such as the Florida lobster (*Panulirus argus*) which is highly valued as food by humans.

Two invertebrate reef species are of particular importance for their commercial and recreational fisheries value. The Florida lobster makes up the most popular fishery of the nearshore reefs of southeast Florida. After spending its early postlarval life stages in estuarine habitats, the young lobsters move to nearshore reefs where they may spend a good part of their adult lives. Many of these adults move further offshore seasonally (Lyons *et al.* 1981). On Florida's west coast, the stone crab (*Menippe mercenaria*) is similarly important. Bert (1985, 1992) found that stone crabs are significantly more abundant along limestone outcroppings where crabs excavate holes beneath the rocks.

Fishes

Fish are attracted to the basic reef structure for shelter, foraging, and reproduction. The numerous crevices, holes, and undercut ledges provide refuge from larger predatory fish. It also provides a barrier to currents and substrate for attachment of demersile adhesive eggs. Lindeman (1997) states that approximately 16 fish species may utilize nearshore reefs as spawning habitat. Aside from this, the sessile organisms and associated symbionts provide a large diverse food base on which some fish species feed directly; others benefit from this indirectly by feeding on invertebrates such as small crabs and shrimp which are nurtured by sessile plant material and epiphytic algae. The role of fishes and other motile species in the ecology of coral reef systems has been discussed in detail by Sale (1991).

Although the list may be incomplete due to collecting difficulties, Gilmore *et al.* (1981) recorded 107 fish species utilizing the nearshore reefs of east-central Florida. Using new data and additional lists, Lindeman (1997) documented the occurrence of 192 species of fishes on nearshore hardbottom reefs of east Florida, an increase of 85 species. Smith (1976) gives a complete discussion on the distribution of nearshore and offshore reef fishes on Florida's west coast. To date, published information on abundances, other quantitative components and trophic interactions of the reef fish community is sparse. In the only quantitative study of nearshore hardbottom fishes, Lindeman (1997) and Lindeman and Snyder (in prep.), recorded sailor's choice (*Haemulon parrai*), silver porgy (*Diplodis argenteus*) and cocoa damselfish (*Pomacentrus variabilis*) as the most abundant species at two Jupiter (Palm Beach County) sites. In terms of mean numbers of species or mean numbers of individuals per transect, statistically significant differences did not exist between sites. Vose and Nelson (1994) discusses the food habits of gray tiggerfish (*Balistes capriscus*) residing on offshore artificial reefs compared to those on nearby natural reefs off Vero Beach, Florida. Other species were also discussed in his dissertation (Vose 1990).

Relatively abundant food fish species occur on nearshore and midshelf reefs. These include the sheepshead (*Achosargus prpbatocephalus),* the porkfish (*Anisotremus virginicus*), black margate (*Anisotremus surinamensis*), mutton snapper (*Lutjanus analis*), gray snapper (*Lutjanus griseus*), black sea bass (*Centropristis striata*), flounder (*Paralichthys dentatus*), and gray triggerfish (*Balistes capriscus*). Juveniles of commercial importance include the gag grouper (*Micteroperca microlepis*), red grouper (*Epinephelus morio*), and black grouper (*Epinephelus bonaci*). Another abundant predator on the reefs is the sport and food fish, the common snook. Many other species are collected for aquariums. These include angelfish (Pomacanthidae), butterflyfish (Chaetodontidae), wrasses (Labridae), damselfish (Pomacentridae) and doctorfish (Acanthuridae). The smaller tropical fish are important ecologically as prey for grouper, snook and other piscivores. Other important prey would include the silver porgy (*Diplodus argenteus*) and at least two species of mojarra (*Eucimostomus* sp.). All species present on the reef are of scientific importance and of some value to recreational divers.

Some fishes are dependant upon the reef during much of their life span. One such species is the striped croaker (*Bairdiella sanctaeluciae*) whose only known breeding population on the North American continent resides on the nearshore reefs of Brevard, Indian River, and St. Lucie counties (Gilmore 1992). Other species settle out from their planktonic stage and spend their early life stages on the nearshore reefs. One of the most important functions of nearshore rock outcrops may be in providing nursery habitat for juvenile fishes. Survival of these early life stages plays a critical demographic role in determining adult population sizes (Richards and Lindeman 1987). Lindeman and Snyder (in prep.) found that more than 80 percent of the individuals on Jupiter area (Palm Beach County) nearshore reefs were early life stages.

Other species require the nearshore reef as a staging area from juvenile estuarine habitat to deep offshore reef habitat. Young snook are known to utilize the marshes and seagrasses of the Indian River (Gilmore *et al.*, 1983) before moving to deeper habitat as adults. Gag grouper (Ross and Moser 1995), red grouper (Moe 1969) and gray snapper and likely many of their congeners (Stark and Schroeder 1970) exhibit similar patterns in early life. Young grouper and snapper may remain on the nearshore reefs for several years and then continue to move offshore with continued growth to deeper reefs. In so doing, they are recruited into offshore commercial and recreational fisheries.

Wildlife Species of Concern

Federally listed species that depend upon or utilize the reef community include: West Indian manatee (*Trichechus manatus*), piping plover (*Charadrius melodus*), roseate tern (*Sterna dougallii dougallii*), loggerhead sea turtle (*Caretta caretta*), leatherback sea turtle (*Dermochelys coriacea*), Kemp's ridley sea turtle (*Lepidochelys kempii*), hawksbill sea turtle (*Eretmochelys imbricata*), and green sea turtle (*Chelonia mydas*). Biological accounts and recovery tasks for these species are included in "The Species" section of this recovery plan.

Sea Turtles

The NMFS and the FWS have prepared recovery plans for the **green, loggerhead, leatherback, hawksbill** (NMFS and FWS 1991a, 1991b, 1992, and 1993, respectively), and **Kemp's ridley sea turtle** (FWS and NMFS 1992). Sea turtles are commonly sighted by SCUBA divers on the nearshore and midshelf reefs of Florida. It is becoming increasingly evident that this habitat is important to a variety of sea turtle species. Ehrhart *et al.* (1996) have studied sea turtles at the nearshore reefs off Sebastian in east-central Florida. For the years 1989 to 1995 they reported a mean capture rate of 6.28 green sea turtles per gill net km-hr. Loggerhead sea turtles appear to be less abundant on nearshore reefs as the mean catch rate of this species was 0.23 turtles per km-hr during the same period. Wershoven and Wershoven (1988) reported that in Broward County turtles were sighted in 106 out of 188 dives. Captured green sea turtles ranged in size from 27.4 to 67 cm (10.8 to 26.4 in) carapace length while captured hawksbill ranged from 34 to 60 cm (13.4 to 23.6 in). The peak capture rate per unit effort (hours of diving) occurred in June. Stomach content analysis of dead sea turtles recovered from the same area revealed that the benthic algae *Bryothamnion seaforthii* is an important food source for these young turtles. Similarly, Meylan (1988) found that the hawksbill sea turtles she sampled appeared to feed almost exclusively on reef sponges.

Although the **common snook** prefers intermediate estuarine-mangrove conditions (Bohlke and Chaplin 1970), it is frequently seen by SCUBA divers utilizing the reef ecosystem. The distribution of the snook has been recorded from South Carolina to southeastern Brazil, including the Central American coast and Gulf of Mexico. The carnivorous snook feeds primarily on fishes and crustaceans, and can tolerate either wholly fresh or salt water. The young commonly inhabit back bays, shorelines, and shallow coastal streams. The species can be identified by its olive green coloration, and dull silvery sides with a black lateral line. In addition to its importance as a predatory species, the snook is highly prized by humans for sport and food. The State of Florida has classified the snook as a species of special concern.

The **Key silverside** (*Menidia conchorum*) is known from Long Key to Key West in Monroe County. Although the species is essentially a marine fish, it is tolerant of a wide range of salinities. Aquatic vegetation such as *Thalassia, Diplanthera,* and *Acetabularia* are often, but not always present. The diet of the Key silverside consists of animal microorganisms, with copepods, mysids, isopods, amphipods, and insects the most important. The Key silverside is currently listed by the State of Florida as a threatened species.

Status and Trends

Until recently, the extent of nearshore reefs in South Florida was virtually unknown. The Florida DEP (1997) coordinated an effort to consolidate the known information and to map solid substrate on the northeast and east central coast of Florida. This effort has resulted in the first reef atlas for that area.

The sea floor out to the 18.3 m- (60 ft) depth contour has recently been mapped in Miami-Dade, Broward, and Palm Beach counties with side scan sonar by the COE (1996); thus, in these counties the extent of reefs is well known (See Figure 1). Other mapped nearshore areas include Venice Beach in Sarasota County; Hutchinson Island in Martin County; Sand Key in Pinellas County and Vero Beach in Indian River County. In some instances, however, the surveys are out-dated due to the dynamics of sand movement in the nearshore area, or were done prior to construction of a beach project. The deposition of fill on the shoreline adjacent to these areas has undoubtedly changed bottom bathymetry considerably. Nevertheless, with deeper reef areas taken into account, we estimate that less than one percent of areas statewide which may contain hard bottom communities have been mapped.

Few areas have been monitored to the extent that trends in habitat change are apparent. To our knowledge, only the nearshore reefs of Palm Beach County have been photographed regularly and, from these data, some nearshore reef areas have been shown to increase within the last decade. Acreage is known to change over the course of time, but in most areas of South Florida, it is unknown whether the trend is toward increasing or decreasing net acreage.

With the absence of historical data, the health of the reef system is uncertain. Lindeman (1997) estimates that in southeast Florida alone, approximately 48 million cubic yards of offshore sediment has been deposited in the nearshore area in the last 36 years. Unknown acreage of nearshore reef habitat has been buried by this practice and many more acres may have been degraded by chronic long-term turbidity and sedimentation. At least 80 million cubic yards is proposed to be deposited on the beaches of southeast Florida in the next 50 years based on renourishment intervals (COE 1996, Lindeman 1997). Some coral reef and offshore hard bottom acreage in the vicinity of the borrow areas has been damaged by direct contact with the dredge in Miami-Dade and Broward counties (Dade County 1988, 1990; Britt & Associates 1979). Additional reef damage occurred at Boca Raton when a steel tow cable was dragged across the substrate (R. Spadoni, Coastal Planning and Engineering, personal communication 1997).

Use of high-quality material for beach nourishment is critical to constructing an environmentally sound project (Goldberg 1988). Natural beaches generally contain much less than 5 percent silt and clay; however, given the quality of borrow material in South Florida, the 5 percent threshold may be a good target criteria (P. Davis, Palm Beach County Department of Environmental Resources Management, personal communication 1998). Finding a borrow area that has material of a similar composition can be difficult. Surface layers of offshore borrow material may be low in silt because of the winnowing effects of currents and wave action on the sea floor; deeper layers may contain higher quantities of silt. This is important when considering the effects of light attenuation due to resuspension of dredged materials. Placing silt-containing material on a beach may not only reduce photosynthesis on nearshore reefs but may also expose silt-laden layers of sediment to currents and wave action, inducing an increase in long-term turbidity around the borrow area.

Persistent long-term turbidity caused by beach nourishment projects may have profound biological consequences which are unknown as yet. Increased turbidity reduces light penetration which is critical to corals and algae that already may be stressed from sedimentation and turbid conditions. Under these conditions, chronic turbidity can be expected to stress organisms, reduce growth, and, in extreme conditions, may cause death. Telesnicki and Goldberg (1995) have demonstrated that adverse effects can take place in hard corals even with turbidity levels below the State threshold. Dodge and Vaisnys (1977) and Bak (1978) have also demonstrated adverse effects in corals. Similar effects may occur in related species.

Chronic turbidity from resuspension of fine sediments from the beach and near the borrow site may result in sublethal effects (*e.g.* reduced feeding or reproduction) which produce long-term consequences. Increased turbidity from resuspension of sediments may continue for years after dredging has stopped (Levin 1970, Courtenay *et al.* 1975, Dodge and Vaisnys 1977). In one instance, project-induced turbidity was reported to persist as many as 7 years (Courtenay *et al.* 1980). While the State of Florida's Department of Environmental Protection requires that turbidity levels remain below 29 Nephelometric Turbidity Units (NTU's) above background during dredging and filling for beach construction, the effects of this level of turbidity on reef communities is not known, as these effects of turbidity on hard bottom epifaunal assemblages has been poorly studied.

In addition to the effects of turbidity, deposition of suspended sediments may also occur when the sediments which cause turbidity fall out of the water column. Griffin (1974) has recommended that the rate of sediment deposition from dredging operations should not exceed 200 $mg/cm^2/day$ during any 7 day period; otherwise stress to reef building coral could result. One fourth of the coral species tested by Rogers (1983) were damaged when exposed to this deposition rate for 38 days. These sediments may also decrease populations of fish and echinoderms (Brock *et al.*, 1965, 1966), inhibit feeding of shellfish (Brehmer 1965), harm fish eggs (Wickett 1959), reduce photosynthetic production in plants, and trap phytoplanktyon carrying them to the bottom (Bartsch 1960).

Management

The Florida DEP, as co-sponsor in many beach nourishment projects, assesses the environmental effects of those projects. In many cases, the DEP has outlined requirements for habitat mapping, mitigation and monitoring prior to FWS involvement. The COE funds the FWS, in coordination with the NMFS and the GFC, to formulate recommendations on the environmental aspects of beach nourishment projects. The NMFS has recently proposed to designate nearshore reef as Essential Fish Habitat and is in the process of drawing guidelines for that designation.

In the past, beach fill has been deposited without adequate pre-project surveys of the impact area to determine the extent of habitat which may be lost or affected by the project. More recently, surveys of the physical environment have been performed, but complete qualitative biological surveys are not done. No quantitative biological surveys have been performed on project impact areas.

Once the locations of nearshore and midshelf reefs areas are known, and the project is designed to minimize burial and degradation due to turbidity and sedimentation, quantitative biological surveys of the epifauna and motile component of the projected impact area should be conducted to determine the population densities of key species prior to impact. An artificial reef should then be designed to maximize habitat values for those species. Too often, artificial reefs are created without a clearly defined purpose and without sufficient planning. The United States in particular has pursued an unsophisticated and frugal approach to artificial reef planning and construction. Scrap and discarded rubble, because of its low cost, is most commonly used (McGurrin, *et al.*, 1989) despite its inadequacy to provide suitable habitat for targeted species. With careful design and placement, fish population densities on artificial reefs can exceed those of natural reefs (Bohnsack and Sutherland 1985, Randall 1963, Smith *et al.* 1979). Accordingly, the Japanese have invested billions of dollars in developing techniques to create new habitat and increase seafood production (Grove *et al.* 1989, Sonu and Grove 1985). These efforts have been reported by Sheehy (1983), and Brock and Norris (1989) to have resulted in much more efficient reef technology. While costs per area of reef are higher, the increase in reef fish and epibenthic organism abundance per area over traditional U.S. reef technology may more than offset this cost (Sato 1985).

To correct the deficiencies in and fragmentation of the U.S. artificial reef program, the Secretary of Commerce was directed, under the provisions of the

National Fishing Enhancement Act of 1984, to develop and publish a long-term National Artificial Reef Plan to promote and facilitate effective artificial reef use based on the best scientific information available. A working plan was published by the NMFS in 1985 (Stone 1985). The plan as it pertains to Florida is currently undergoing revision by the Atlantic States Marine Fisheries Commission. To conform to the plan the project should have a list of species and user groups intended to benefit from the designed reef.

In recent years, research into artificial reef design effects on community structure have greatly increased our ability to optimize habitat value of designed reefs. Study on the effects of module spacing (Frazier and Lindberg 1994, Lindberg *et al.* 1990), reef size (Bohnsack *et al.* 1994), reef height (Bortone *et al.* 1994), reef shape (Dade County 1995, Kim *et al.* 1994), hole size (Eklund 1996, 1997) and number of chambers (Sheehy 1976) have been accomplished as of this writing.

As knowledge about the effects of design modifications on reef communities increases, it may become possible to design reefs to benefit key species or age classes. The evidence that natural nearshore reefs, not offshore reefs, provide nursery and juvenile staging habitat for many reef fish species (Lindeman 1997) suggests that constructing artificial reefs closer to shore may supplement natural nearshore reefs by providing additional nursery and juvenile staging habitat for many reef fish species. Ecklund (1996) has confirmed the intuitive sense that small hole sizes benefit small fishes. These findings lead to the conclusion that nearshore artificial reefs with numerous small scale features would increase benefits for juvenile fishes. Further refinements in our knowledge of the effects of such design features is inevitable and sorely needed.

As an example of how a user group can be targeted, it is clear in many cases that snorkelers are the largest user group which will incur losses by a beach fill project. In addition to recreating habitat to support fish, invertebrates, and algal species, artificial reefs mitigate for beach fill projects by also providing habitat for the snorkler. This requires certain design features. The structures must provide a scenic, safe, accessible and productive replacement for the nearshore reefs lost and degraded by the project. Accordingly, in addition to designing the reef to benefit species which are important by virtue of their scarcity or ecological role, some artificial reefs could be designed to benefit species which are popular among snorkelers.

Populations of reef dwelling species can be quantified to some extent and the artificial reef mitigation ratios can be adjusted accordingly. In light of the evidence that population densities on well-designed artificial reefs can exceed those of natural reefs, it is possible that with enough care in design and deployment, mitigation acreage could be less than the acreage of natural nearshore reef burial.

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Restoration of Nearshore and Midshelf Reefs

Restoration Objective: To prevent further losses of nearshore and midshelf reef habitat values (primary and secondary production, refuge habitat, nursery habitat, biodiversity, educational).

Restoration Criteria

The primary threat to the health of Florida's nearshore reef system is the deposition of beach fill. Rock outcrops within the beach fill areas are buried, the epifaunal organisms associated with those outcrops are smothered, and the habitat which the reef provides to motile fishes and invertebrates is lost. The zone of direct burial increases in time as the fill material relaxes or is washed seaward by wave action and is transported to adjacent areas by littoral drift. Impacts extend beyond the fill zone when the fill material contains high amounts of silt and clay. Suspended fine material not only reduces light penetration but may settle out of the water, degrading reef areas seaward of this zone. Midshelf reefs can similarly be affected by turbidity and sedimentation when the borrow site contains fine material. Midshelf reefs may also be damaged by direct contact with the dredge and dredge-related equipment.

A measurable criterion for meeting the stated restoration objective would be to prevent any further loss of nearshore reef (natural or artificial) acreage due to beach fill. That is, each acre lost by burial should be replaced by carefully designed and deployed artificial reefs. The above stated criterion is an interim criterion. The restoration objective of maintaining habitat *values* cannot be achieved until those values to threatened and endangered sea turtles, the vertebrate and invertebrate fisheries species mentioned in this report, and all other reef species which are of recreational or scientific importance, are understood. Life history information on the green sea turtle, for example, is incomplete (Ehrhart, *et al.* 1996). The value of South Florida's nearshore reefs to species which may only use nearshore reefs during a particular life stage, and for which basic life history information is lacking, cannot be measured with any confidence. The identification of factors which may limit a population is not possible. Degradation of nearshore reef habitat could have serious implications for populations of species if such habitat already represents a demographic bottleneck in the South Florida Ecosystem's carrying capacity for those species. The ultimate objective for restoration of the nearshore and midshelf reef systems would be to accomplish the basic research required to understand the value of the reefs to the species with which we are concerned, and to replace lost values through informed, responsible artificial reef design and deployment.

Community-level Restoration Actions

1. **Prevent burial and degradation of existing habitat**.

   1.1. **Map the location and extent of vulnerable reef areas using aerial photography, where possible.** Impact reduction can only be achieved once the area within the beach fill template and the sea floor within one thousand feet of the borrow site have been thoroughly mapped. The preferred method for mapping reefs within either zone is aerial photography. Ground-truthing of aerials is also necessary to eliminated false signatures, which are due to drift algae and schools of fish.

1.2. **Map vulnerable reef areas using side scan sonar.** Borrow areas, unless they are located in the shoal of an inlet, are in deeper water and farther offshore than the fill zone. Thus, frequently, side scan sonar rather than aerial photographs, must be used to map nearby bottom features. Like aerial photographs, side scan sonographs must be ground-truthed to create a reliable map of the sea floor.

1.3. **Locate project fill and borrow areas away from reef areas.** Once a project area has been thoroughly mapped, the project fill and borrow areas should be situated to minimize nearshore reef burial and sedimentation or mechanical damage to midshelf reefs.

1.4. **Establish buffer zones.** Establish minimum buffer area of 121.9 m (400 ft) between the dredge area and the reefs to help avoid excessive sedimentation and/or mechanical damage.

2. **Prevent net loss of habitat.**

2.1. **Mitigate for reef burial.** Recommend compensation for beach nourishment and renourishment projects once the applicant has demonstrated that all efforts have been made to avoid and minimize adverse affects to the reefs.

2.3. **Deploy mitigation prior to project construction.** Estimate the minimum acreage of natural reef expected to be buried by the project. At least half that acreage in artificial substrate should be deployed prior to project construction. This measure would provide refuge habitat for motile organisms displaced by the project.

2.4. **Measure impacts using aerial photography.** A new set of aerial photographs or new side scan sonographs of the nearshore should be taken as close to 1 year after the project is completed as possible (when the fill has equilibrated or "relaxed") and a measurement of the reef area buried by the project should be made. This is done through comparison with the aerial photograph taken before construction. The resulting acreage represents the acreage of artificial reef necessary to compensate for natural reef burial.

2.5. **Survey mitigation area.** Survey the area chosen for the mitigation to ensure that there is a solid subsurface beneath the sand so that the newly placed structure does not sink into the bottom to the extent that its value as mitigation is reduced.

2.6. **Use clean sand.** Use of sand with a silt content of 5 percent or less to reduce the resulting turbidity and sedimentation. Configure borrow areas based upon the goal of matching sand characteristics of the fill area as closely as possible.

3. **Monitor the effects of projects on nearshore and midshelf reefs.**

3.1. **Monitor offshore reef impacts.** Recommend that all applicants proposing to dredge for beach projects initiate and perform a thorough off-shore reef monitoring program.

3.2. **Improve monitoring capability.** In addition to buffer zones around the offshore reefs near the borrow area, develop a sensitive monitoring system with a 24 hour response capability. The system should be developed by, or in collaboration with, an expert in the physiological effects of turbidity and sedimentation on South Florida offshore reef epibenthos, particularly the hard corals, octocorals and sponges. The system should provide advanced warning to the project sponsor and their contractors of an incident in which turbidity or sedimentation damage to reef organisms could occur. An array of transmissiometers in the vicinity of the potentially affected resources has been suggested.

3.3. **Limit sedimentation.** Within 1,000 feet of the affected reef/resources, install sediment traps both at the surface and near the bottom. Measurements should be taken during the construction phase. A sedimentation rate of 200 $mg/cm^2/day$, particularly on coral reefs, should not be exceeded.

4. **Restore areas to suitable habitat.** “Restoration” of reef habitat which has been buried by beach fill is probably unfeasible. Nearshore ocean bottom areas which once had reefs which were buried by beach fill can be enhanced by deployment of artificial reefs. Most beach projects have not been constructed with the benefit of before and after aerial photographs to assist in assessing actual acreage of reef burial. To attempt to restore an area which may have sustained such impacts, a list of the locations of past nourishments and renourishments of those areas would have to be made and historical aerials obtained in the hope that any historical reef bottom would be visible in those aerials. Alternatively, deployment of nearshore artificial reefs could be made at appropriate nearshore sites around the southern half of the State to achieve ecosystem-wide enhancement. The reefs should mimic natural reefs in form and function. Restoration of some midshelf habitat values has been accomplished in Miami-Dade County. Artificial reefs were constructed to replace values lost due to the dredge denuding reef during construction of the Sunny Isles project. Palm Beach County has restored some reef habitat values by constructing four mitigation reefs and one enhancement reef in the nearshore area, and approximately 35 enhancement reefs in the midshelf zone.

5. **Conduct Research**.

5.1. **Research needs are varied** and include gathering basic information on the life histories of reef inhabitants, population density studies of both natural and various artificial reef designs, and studies of the short- and long-term turbidity effects of beach construction and the effects of that turbidity on reef ecology. A standard protocol for censusing fishes and invertebrate populations on natural and artificial reefs should be adopted in order to allow comparisons from one reef type to another.

5.2. **Assess the value of reefs to sea turtles, other transient and resident inhabitants.** Additional study of the value of nearshore reefs to sea turtles, fishes and invertebrate species, particularly during sensitive juvenile life stages or during reproduction, is needed. Basic information on the population densities of valued species on natural reefs is also desired to assist in determining the effects of reef loss on their populations.

5.3. **Incorporate monitoring and annual reporting to the COE and resource agencies on the effectiveness of the mitigation as a project feature.** After a project is constructed and artificial reef is deployed, a research opportunity is created. Monitoring should include qualitative measurement of the macroepibenthos per square meter. Comparisons should be made between total biomass, macroepifloral biomass and macroepifaunal biomass at the designed reef and at the natural reefs prior to burial. Fin fish communities at both reef types should be censused and compared in number, species and biomass (estimated). Fish community structure should also be compared at both reef types using multivariate analyses: classification and ordination. Sampling should take place once in each season for 3 years or until it is clear that population densities and community structure has stabilized. Similarity indices between the natural reef data and the artificial reef data should be calculated to determine whether or not the target species are benefiting from the mitigation. The foregoing research should be done with a view toward promoting a better understanding of design effects on reef communities and to facilitate the development of an increasingly effective artificial reef strategy and better informed decision making for future civil works projects.

6. **Inform the public about the value of Florida's reefs.** Each artificial reef area should be placed near a public beach, if possible. A sign or display explaining why the reef was built along with a brief discussion of the ecological value of nearshore substrate and Florida's reefs in general should be included. Pictures of abundant reef inhabitants would enable the public to identify what they observe while snorkeling.