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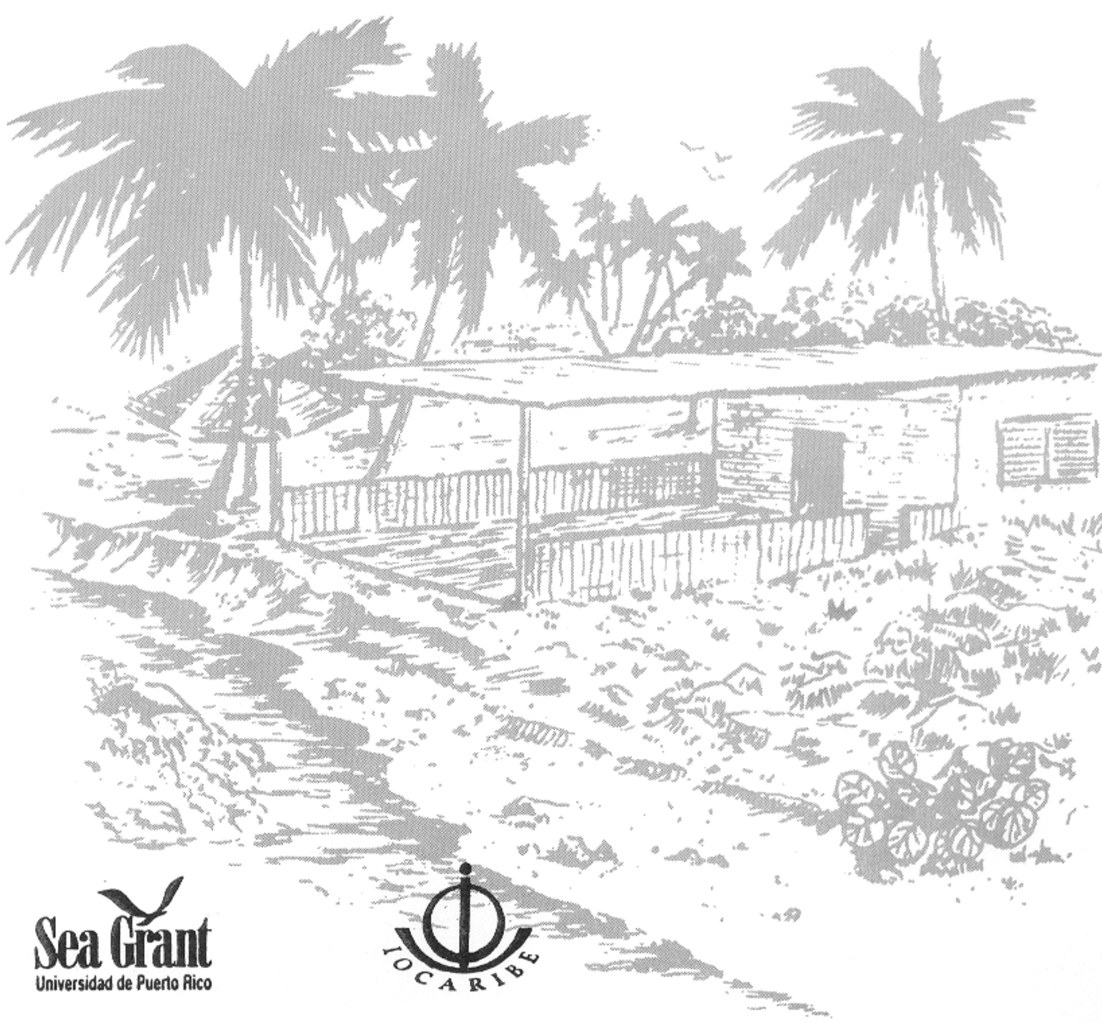
Workshop papers



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COMPARATIVE MANAGEMENT OF BEACH SYSTEMS OF FLORIDA AND THE ANTILLES: APPLICATIONS USING ECOLOGICAL ASSESSMENT AND DECISION SUPPORT PROCEDURES

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Abstract

A primary contrast in beach system management between Florida and the Antilles involves the differential utilization of sediments. Although sediments are mined in both regions, the sites and destinations differ substantially. In Florida, sediments are dredged from submerged deposits and dumped on beaches and subtidal habitats, while in the Antilles they are primarily mined from beaches and used as construction material. Within both regions, there are needs to optimize multiple policy issues raised by these approaches. Recent methodological developments within the fields of environmental assessment and decision-support may aid evaluations of these and related issues. Using comparative ecological risk assessment and analytic hierarchy procedures, preliminary frameworks to identify optimal policy combinations were developed for: 1) beach nourishment alternatives in Florida, and 2) construction material alternatives in the Antilles. Preliminary results from both examples are presented, with emphasis on the assessment of environmental effects of differing nourishment alternatives upon coastal fish populations of southeast Florida. The frameworks produced logical and explicit characterizations of highly complex problems, but don't yet represent definitive results. Both frameworks were designed to foster future revisions by local experts for further application within both regions. A variety of other assessment and decision-support options exist which may also be applied to the policy issues examined. Whatever specific approaches are used, formal considerations of cumulative effects are necessary. Upon systematic application, group-based environmental assessment and decision-support tools can substantially aid the evaluation of diverse coastal management issues throughout the Caribbean region.

Introduction

Coastal managers face similar information and policy needs in Florida and the Lesser and Greater Antilles. However, specific ecological and socio-economic attributes of these systems can vary widely between regions. Comparative identification of areas of both overlap and divergence can help to sharpen approaches to the management of both regional systems, and potentially, generate transfers of previously isolated technical or administrative experiences which benefit both systems.

Many fundamental needs in both regions revolve around two issues. First, there is a common need for baseline environmental information, collated in a systematic structure, which identifies key voids and allows assessment of the effects of anthropogenic modifications. This derives partially from the importance of environmental impact assessments (EIA's) in both Florida and the Caribbean islands. Having a variety of specific names (e.g., environmental impact statements, biological characterizations, etc.), these reports are often the primary technical and administrative evaluation of the biological effects of large-scale coastal modifications. Such reports are useful but can emphasize limited existing information at the

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expense of evaluating the significance of what isn't yet known. Resulting conclusions can be oriented towards why the project will have acceptable impacts instead of detailed consideration of: 1) what still isn't known, and 2) the actual lethal and sublethal effects on the varied populations impacted. In addition, there is a frequent lack of consideration for cumulative impacts (Spaling and Smit, 1993, Dixon and Montz, 1995), despite a large literature demonstrating the profound effects that multiple projects within a region can have (Odum, 1982; Cocklin et al. 1992; Rothschild et al. 1994; Vestal and Reiser, 1995). Such cumulative effects can develop even when the effects of one project alone (the scale of the typical EIA) are subtle, and therefore administratively acceptable. The probability of some of the nearshore habitats or organisms of southeast Florida or the Antilles being subject to "death by a thousand cuts" scenarios which have affected other natural systems (preceding references) subjected to frequent, "relatively benign" disturbances is infrequently developed as an issue in EIA's.

Second, there is a common need for systematic decision support techniques which offer logically consistent methods to detail and cumulatively evaluate policy decisions. Management of coastal systems involves complicated syntheses of geology, engineering, biology, law, economics, and politics. Administrative decision-making involves the extraction of conclusions from these complex scientific and political arenas despite often competing agendas. Not surprisingly, real-world coastal management decisions are sometimes made in relatively oblique manners, characterized by the absence of formally structured analytical procedures. In the absence of explicitly structured logic paths for decision-making, the appearance of subjectivity is increased, and opportunities for constructive, retrospective analyses are reduced. Explicit use of logical decision-support methods reflects a commitment to open and objective policy-formulation.

Recently, useful methods to deal with both of these issues have been independently developed. First, after substantial developmental work, a revised framework for assessing the environmental effects of human activities (comparative ecological risk assessment, CERA) was formalized by the EPA in 1992. This approach involves simultaneous evaluations of both stressors, effects, and their potential co-occurrence using flexible protocols which help insure comprehensive evaluations of effects (EPA, 1992; Harwell et al., 1995). The applications of CERA principles to EIA's could result in more comprehensive technical products which also carry more administrative weight. Second, decision support procedures, originally developed for industrial and political applications are now frequently applied in natural resource management (Keyes and Palmer, 1993; Schmoldt et al., 1994). These systems aid decision-making among multiple policy alternatives by categorizing system complexity based on group-based weighting of factors at multiple levels of significance. Both of these approaches can be applied in iterative manners and by use of group-based protocols.

Synthetic applications of CERA-based ecological assessments and flexible decision support procedures may substantially enhance the scientific and public policy objectives of coastal management in both Florida and the Caribbean islands. The objectives of the present study were to investigate this possibility within the limited space available by preliminary construction of: 1) a comparative summary of fundamental attributes of beach systems in both regions, 2) a framework for environmental assessment of the effects of differing beach management alternatives in southeast Florida which incorporates applicable decision-support procedures, and 3) an outline of potential ecological assessment and decision support frameworks for beach management alternatives in the Antilles. These ecological assessment and decision-support frameworks can serve as templates for future comprehensive examinations of beach management issues on a region-specific basis.

Methods

Ecological Assessment Frameworks

For both regions, recently developed protocols based on a broad 3-stage process for CERA development (EPA, 1992; Harwell et al., 1995), provided a useful framework for evaluating the project objectives. Primary subcomponents within each of these three stages are summarized in Figure 1. The CERA process simultaneously evaluates information on both the specific stressors introduced by an anthropogenic event and the biological effects upon the organisms and life stages in question. Subsequently, detailed information on stressors and effects is integrated based on spatial and temporal patterns of co-occurrence using quantitative and qualitative techniques specific to the problem. Due to the inherent complexity of characterizing stressors, effects, and their co-occurrence, full-scale ecological risk assessments are large projects, typically requiring a team of experts. The mechanics of executing a full CERA are detailed in the above references.

The present study provides selected sections from preliminary ecological assessment frameworks based on issues of importance to the environmental management of beach systems within two regions of the Caribbean. For Florida, the environmental effects of ten beach nourishment alternatives upon marine fish populations were evaluated based on details from a larger study (Lindeman, in prep[1]). Most components within this assessment are not included here due to space limitations. However, the information presented here was adequate for the construction of multi-criteria hierarchies for preliminary decision-support analyses.

For the Antilles, the environmental effects of seven alternative sources of sand for construction material (aggregate) were structured in a preliminary assessment framework. Unlike the renourishment alternatives assessed for Florida, many of the construction aggregate alternatives in the Antillean framework did not involve marine ecological effects. Therefore the Antillean framework focused upon a broader range of potential ecological effects than just those associated with marine fishes. Preliminary information was derived from a variety of unpublished sources, as well as Green and Cambers (1991). This is a *preliminary* framework for large-scale CERA-based assessments which may focus on one or many of these alternatives. Iterative revisions are encouraged.

Decision Support Frameworks

To aid decision-making among the alternative policy choices and complex technical attributes of beach systems, analytical hierarchy procedures (AHP) were used to categorize system complexities and evaluate key factors and nested subcomponents (Saaty, 1986; Golden et al., 1989). AHP analyses contain several fundamental attributes. A hierarchic structure is developed which consists of a primary goal containing nested criteria of increasing specificity. Top-down these levels include criteria, subcriteria (possibly occupying several levels), and alternatives at the terminal level. Nodes within each level may contain up to 9 nodes in the subsequent level. Criteria and subcriteria are assigned differing weights relative to other factors at each respective level. Instead of assigning numbers to simultaneously rank one alternative versus all others, pairwise comparisons are executed for all criteria, and nested subcriteria, developed within the hierarchy. These relative comparisons represent ratio scales,

[1] - Lindeman, K. C. In prep. Development and cross-shelf habitat use of grunts and snappers (Percoidei): effects of differing shoreline management policies. Ph.D. Dissertation, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami.

not only averaged ranks, and can accommodate both qualitative and quantitative information. This allows evaluations of multiple factors separately, and ultimately, appropriate combination into a single ratio scale value for each alternative (Saaty, 1986; 1996).

AHP analyses were included within the integration subcomponent of the risk characterization stage of the Florida assessment as a multi-objective solution procedure (*sensu* Keyes and Palmer, 1993) using Windows-based software (*Expert Choice*™). This software allows resource managers to structure and execute hundreds of quantitative and qualitative assessments simultaneously to evaluate alternatives and rapidly calculate summary values (Schmoldt et al., 1994). Such hierarchic structures are flexible and can be modified to incorporate dynamic circumstances or opinions of differing experts. Comparative analyses were guided by data matrices produced from the analysis and risk characterization phases of the preliminary Florida CERA which integrated primary factors reflecting environmental impact with all of the policy alternatives. Sensitivity analyses (performance-type) were employed to evaluate the effects of differing weighting schemes upon model outcomes.

These analytic processes are iterative. The model structures, data matrices, and their decision outcomes will evolve with increasing insight into the complex biological and technological attributes of beach system management within each of the regions examined. In addition, AHP methods have been used in combination with other approaches, including linear programming and multi-objective programming (Schmoldt, et al, 1994). Other decision-support approaches are available (Keyes and Palmer, 1993; Peterson et al., 1994), and may independently prove more applicable to the present issues. However, given the prior successful applications of AHP methods, their ease of use, and the lack of any decision-support methods within the arena of beach system environmental management, the use of AHP methods in preliminary applications appears to be warranted.

Geographic Frameworks

Several differing beach systems are represented among the 35 Florida counties with marine shorelines. The present study focused on the subtropical Atlantic beaches of the southeast and east-central shore of the Florida mainland (in particular, Dade through Martin counties). Antilles refers here to the Caribbean island arc system extending from Cuba through Trinidad. The majority of information was derived from islands of the eastern Caribbean, although beach management issues in Puerto Rico were also considered. These islands possess diverse geomorphologies (ranging from low islands with carbonate beaches to high islands with igneous beaches) which greatly influence specific attributes of ecological assessment procedures.

Results

Comparisons of physical and management attributes of beach systems of Florida and the Antilles are summarized in Table 1. Of primary significance to the present study is the fundamentally different way in which sediments are treated as management tools. In Florida, sediments are typically mined from offshore and pumped onto erosional beaches for nourishment, a process occurring uncommonly in the Antilles at the present time. In the Antilles, sediments are mined directly from the beach and transported inland for use as the fundamental component of the aggregate used to produce bricks, concrete and plaster, a process not occurring in Florida (Table 1). In each region, these fundamental strategies have raised many environmental and policy questions and are at the center of substantial management discussions regarding environmental effects, enforcement of protective measures, mitigation, and potential alternatives. Progress on the environmental components of these

Figure 1. Overview of the three stages of a comparative ecological risk assessment and primary components within each stage (based on Harwell et al., 1995, Figs. 2.4-2.6; and EPA, 1992). The framework is designed to be flexible; specific assessments may show some differences in structuring.

PROBLEM FORMULATION

Stress Characterization
- Types
- Properties
- Distributions

Effects Characterization
- Types
- Properties
- Distributions

↓

Ecosystem Susceptibility
and Stress Co-occurrence

↓

Endpoint and Indicator Selection

↓

Conceptual Model

⇓

ANALYSIS

Stress Characterization → Distribution Patterns → Exposure Analysis → Exposure Profile

Effects Characterization → Effects Data Evaluation → Ecological Response Analysis → Stressor-Response Analysis

Distribution Patterns ↔ Ecosystem Characterization ↔ Effects Data Evaluation

⇓

RISK CHARACTERIZATION

Risk Integration

Integration ↔ Uncertainty

↓

Risk Description
- Ecological Significance
- Risk Summary

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issues is constrained by the lack of systematic CERA frameworks for ecological assessments. Progress on the policy components is hindered by the lack of systematic decision-support methods for policy formulation.

Preliminary Assessment Framework: Environmental Effects of Florida Beach Management Alternatives

Examples from several sections of a preliminary assessment addressing the effects of differing beach management alternatives upon coastal fishes are provided below. As space limitations preclude inclusion of all sections (see Lindeman, in prep. for additional details), emphasis was placed on characterizations of potential stressors and effects associated with each management alternative. It is not possible to characterize all ecological aspects of stressor effects upon all resident and transient fauna subjected to beach management activities. Therefore, CERA methods typically identify representative taxa for particularly detailed evaluation. In the present example, early life stages of economically and ecologically valuable fishes were chosen as the representative taxa. Considerable evidence suggests that survivorship of early life stages is a key determinant of ultimate adult population sizes (Sale, 1991; Richards and Lindeman, 1987; Doherty and Williams, 1988). Therefore, early demersal life stages were emphasized in evaluations of potential effects.

Stressor Characterizations

Ten individual management alternatives designed to retain or renourish erosional beaches (collectively termed nourishment in the present study) of Florida were considered in the following summaries. The ten alternatives were placed within two categories, sedimentary deposition and structural (Table 2). Three fundamental categories of stressors were identified: turbidity, sedimentation (burial), and direct mechanical impacts. The specific stressors are largely dependent on the engineering characteristics of each alternative. These characteristics are summarized below.

Sedimentary Deposition Alternatives: Dredge & Fill

Large-scale beach dredge projects in southeast Florida are based on the excavation of sediments from midshelf areas (1-6 km offshore) and the dumping of the fill on shorelines where it is bulldozed into a broad beach. When first done on a highly eroded shore, they are termed "restorations". Most involve the excavation and dumping of up to 1,500,000 yd^3 of sediments per project. In practice, follow-up dredge projects, termed "renourishments", are usually incorporated into the original engineering design at 5-10 year intervals. Whether a restoration or renourishment, excavation typically occurs at one or more large, mid-shelf "borrow sites" which geotechnical surveys have identified as possessing beach-compatible sediments. These evaluations consider various sediment characteristics. The ratio of fines (silts and clays) to larger sediments is of particular environmental importance.

Two fundamental types of dredges are employed. Most projects in south Florida have used cutterhead suction dredges. These dredges use 5-8' diameter terminal heads (baskets) equipped with rotating cutting blades, customizable for size and serration, for actual excavation of the benthos. Large hydraulic machinery pump the excavated material from the back of the basket into a series of pipes leading to shore. The bow of the dredge, holding the cutterhead basket, associated hardware, and discharge pipe, is swung in an arc using a vertical support ("spud") mounted from the stern as a fulcrum. Large craters (borrow-pits) result. Typically, the transport pipes are tethered on the surface leading away from the dredge platform for a short distance and then descend to the bottom for the remainder of the distance to the shore. At emergent or intertidal sites, the fill is blown out of a discharge pipe in a slurry, then redistributed using bulldozers and other gear. Recently, hopper dredges have been employed

Table 1. Comparative aspects of beach systems and their management in Florida and the Antilles. Broad region-scale characterizations only; local-scale variations can occur.

Beach Systems of Florida and the Antilles

Differences

Physical and Biotic Characteristics	Florida	Antilles
Beach sediment budgets:	Highly erosional[1]	Less erosional
Sediment sources and types	$CaCO_3$ and quartz	$CaCO_3$ or igneous
Sediment transport regimes	Longshore/CS[2]	CS/Longshore
Shelf type	Continental	Insular
Management Characteristics		
Administrative infrastructures	Large	Small
Economics of local beach users	Well-developed	Developing

Florida Beach Management:

Mechanically add sediment to beach via offshore and inshore mining

Result: sediments redistributed across shelf by large-scale dredging and resuspension

Antillean Beach Management:

Mechanically remove sediment from beach via beachface and backdune mining

Result: sediments completely removed from system

Similarities

Physical and Biotic Characteristics

- Climate: Tropical/subtropical (wet/dry seasons, hurricanes)
- Biodiversity: High
- Complex beach dynamics: Continuous abiotic/biotic monitoring needed

Management Characteristics

- Tourism-based economies
- Construction setbacks legislated, but often waived
- Environmental assessments often lack cumulative perspective
- Agencies often lack systematic framework for policy decision-making
- Shoreline armoring common

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1 - Accelerated by artificial inlets which remove sediments from the inshore system.

2 - CS = Cross-shelf

Table 2. Summary of selected components of stressor and effect characterizations in preliminary environmental assessment of Florida beach nourishment alternatives.

Nourishment Alternatives:

Sedimentary Deposition Technology		Structural Technology	
DR	Dredge and Fill: Renourishment	**SW**	Seawalls & Revetments
DB	Dredge and Fill: Nearshore Berms	**GJ**	Groins & Jetties
DI	Dredge and Fill: Inlet Maintenance	**BR**	Breakwaters: Submerged & Emergent
QT	Quarry Sediments by Trucking	**BD**	Beachface Dewatering
AB	Aragonite Sediments by Barging		
ST	Inlet Sand Transfer Plants		

Primary Stressor Categories:

• Sedimentation • Turbidity • Mechanical

Spatial Scale of Stressor Distribution:

• Nearshore • Intermediate • Midshelf

Indicator Taxa & Ecological Endpoints:

• Ecologically/Economically Valuable Fishes (early life stage focus)

• Diversity • Habitat Amt. • Nursery Value

Examples of Lethal & Sublethal Effects:

Intensity of Effects		Duration of Effects: Short-term	Duration of Effects: Long-term
	Lethal	• Burial of species fleeing to crevices [1] • Respiratory trauma [2] (erosion of gill filaments)	Loss of settlement habitat [1, 3] resulting in: • Increased predation • Increased starvation
	Sub-lethal	• Respiratory stress [2] • Separation from conspecific schools [2]	• Reduction in growth * • Residence in new, suboptimal habitat *

Stressor inducing the effect:

[1] - Sedimentation (burial)

[2] - Turbidity

[3] - Mechanical impacts

* - Potentially, combinations of all

more frequently. Unlike relatively stationary, deep-digging cutterhead dredges, hopper dredges maneuver over predetermined dredge paths trailing a suction head. Deep craters typically do not result from this method. Sediments are stored in the open hull (hopper) of the vessel and can be taken near the dump site for offloading by various methods, sometimes including hydraulic pumping. Overflow of fill slurry from the hopper can introduce sediments to the water column in much greater amounts than cutterhead systems, post-excavation. Many variations on these basic approaches have been developed.

Other Sedimentary Deposition Alternatives

In addition to large-scale offshore dredging and onshore fill dumping, five other technologies involving the deposition of sediment on beaches can be identified. As the offshore sand sources available for large-scale dredging are almost gone in Dade and limited in Broward County, the need to evaluate other sources of sand is increasing. The most common of these, dredging for inlet maintenance, was not addressed in the preceding section on offshore dredging and inshore filling as inlet maintenance involves inshore dredging of navigation channels.

• Dredge & Fill - Inlet Maintenance

A summary of the structural characteristics of southeast Florida inlets is provided in Table 4-4. Approximately nine of eleven inlets of southeast Florida are periodically dredged to reduce shoaling. Prior to 1970, fill was occasionally dumped into offshore waters. Now, it is almost always pumped to the south side of the inlet's south jetty where slurry is discharged and redistributed with bulldozers on the upper beachface. These projects involve smaller dredges and smaller fill volumes (typically between 25,000-150,000 yd^3) than beach nourishments. These maintenance projects occur at intervals ranging from one to five years at most inlets within the study area. Frequencies and fill volumes vary based on cross-sectional widths, depths, accretion rates, and boating/shipping demands. Detailed breakdowns of the amounts excavated from each inlet are summarized in Table 4-4. Approximately 15,800,000 cubic yards of sediments have been dredged for inlet maintenance in the four county area.

• Dredge & Fill - Nearshore Berms

A new alternative for south Florida, nearshore berm construction, is now under evaluation (ACOE, 1996). This technology is an engineering variation of large-scale offshore dredge and fill, wherein the fill is dumped in nearshore waters instead of onshore. Inlet maintenance projects can also be a source of fill. Such shallow-water berms (3-5 m depths) can theoretically function in two manners. Stable berms attenuate incoming wave energy. Active berms act as feeders for beach sand to migrate inshore and downstream. All nearshore berms currently under evaluation for southeast Florida would be designed as active berms (ACOE, 1996). The assumption is that all nearshore berm sediments will move onshore due to placement within the "depth of closure". Nearshore berms are currently under consideration in combination with large-scale dredge renourishments and restorations at ~20 sites within Palm Beach, Broward, and Dade counties.

• Quarry Trucking

Trucking of sand from inland quarries has been done in the past on some smaller projects. Beach-compatible carbonate sands from quarries are identified, purchased and trucked to the beach site where dump trucks drive onto the beach and unload the sand for bulldozing. Large-scale trucking of inland quarry sands to deposit on south Florida beaches has not commonly sometimes sculpted. Often, piles of boulders (rip-rap) are placed at the base of seawalls. These boulders attenuate both wave energy impacts and scour at the sediment-seawall interface. Once a primary method of beach management in south Florida, these and other shoreline armoring methods fell into disfavor in the 1970's and 1980's due to inconsistent performance, downstream impacts, and the advent of large-scale dredge renourishment. Recently, Florida state agencies have relaxed the conditions to receive permits for seawall construction.

- Groins & Jetties:

These structures are perpendicular, and connected, to the beachface. Jetties are placed individually, or in pairs, at the mouths of inlets and channels to reduce shoaling. Groins are typically placed away from inlets, often in series (groin-fields), to trap sand in front of specific target areas. Jetties are usually larger than groins and are constructed of large boulders (armor stone) placed on top of smaller rock (core stone). Many materials are utilized to construct groins. These include boulders, sheet metal, concrete modules, and wood. In southeast Florida, both of these structural types accrete sand on the north side and erode sand on the south side. Resulting scalloped shoreline configurations are evidence of the starvation of sediment flow further downstream. The massive Miami Beach restoration of 1975-1982 buried many groins, some of which had been in place since the 1930's (Weigel, 1992). As with seawalls, another form of coastal armoring, Florida state agencies have recently relaxed the permitting conditions for groin construction in some cases.

- Breakwaters - Submerged & Emergent:

Although parallel to shore, these structures are not shore-attached. They are placed at distances of 15-150 m offshore in one or more parallel arrays and are designed to reduce wave energy, and therefore, erosion of the leeward beach. In south and central Florida, they have been constructed from concrete modules or boulders. Several submerged breakwaters composed of prefabricated concrete modules have been installed for beach management purposes in the last decade in southeast Florida. Studies of a 4000 ft breakwater system off Palm Beach Island concluded that the engineering attributes were negative (enhanced erosion due to increased lee-side currents, Dean and Chen, 1996) and the environmental attributes were positive (90 species of fishes occurred on the reef, primarily juveniles, Lindeman, 1996). Instead of positioning breakwaters as a continuous structure, semi-continuous breaks may decrease lee-side longshore currents. A series of ~5 emergent rubble-mound breakwaters (lengths of 180-200') are currently under design for Singer Island, in northern Palm Beach County.

- Barrier Island Dewatering:

Based on soil drainage technology long used in civil engineering, dewatering techniques involve pumping water out from underneath the beachface to tighten surficial sediments and enhance accretion potential. Lowering of the seaward components of the barrier island water table is achieved by installation of a drainage system connected to a pumphouse on the lee side of the dune line. During construction, trenches are dug into the beachface and drainage lines are arrayed under the surface of the beach to collect water which can be pumped to collecting ponds or canals on the lee side of the dune. The pumps can be run at predetermined intervals. Another new technology for beach management, only one system has been installed in the study area. This project was constructed on southern Hutchinson Island in Martin County in 1988. It appears that no new projects are being planned in the study area currently.

Sedimentary Deposition (cont.)	*Nearshore*	*Intermediate*	*Mid-Shelf*
Dredge/Fill - Inlet Maintenance:	X		
Quarry Sediments by Trucking:	X	?	
Aragonite Sediments by Barging:	X		
Inlet Sand Transfer Plants:	X		
Structural			
Seawalls & Revetments:	?		
Groins & Jetties:	X	X	
Breakwaters - Submerged/Emergent:	X	X	
Beachface Dewatering:	X		

Analyses of Stressors and Effects

The mechanical conditions under which many beach engineering operations occur can preclude direct assessment. For example, visual assessment of direct dumping of dredge fill on hardbottom reefs is not possible - often for weeks post-project due to elevated turbidities at, and adjacent to, the project site. This situation also applies to direct assessment of the interface of the dredge cutterhead and substrate during excavation of fill offshore. In addition, most monitoring studies are based on unreplicated field surveys, have not undergone third-party review and are not published in research journals. Overall, the available environmental literature on the majority of the ten possible alternatives, especially those not involving offshore dredging and nearshore filling, is small. In such cases, plausible statements regarding potentially negative (or positive) effects are possible - but on a limited basis - basic environmental information on many of these alternatives is still unavailable. Due to space limitations, analyses of stressors and effects for the nine alternatives outside of offshore dredging are not provided. Details of these characterizations are available in Lindeman (in prep). Effect characterizations for large-scale dredging were included here as an example of how such characterizations can be accomplished and because of the potential future occurrence of such projects in the Antilles.

Sedimentary Deposition: Offshore Dredge & Inshore Fill

Sedimentation & Turbidity Effects

Midshelf (excavation) areas

The primary references available on dredging effects upon fishes in midshelf areas of southeast Florida is from 1970 and 1971 projects at Pompano and Hallandale, respectively. Qualitative surveys of fishes and invertebrates of reef lines near mid-shelf borrow pits were conducted during, and subsequent to, dredging (Courtenay et al., 1974; Courtenay et al., 1980). In the first study, dredging effects on site-associated spp. on reefs near borrow sites were not observed. Invertebrate impacts from both sedimentation and mechanical abrasions were observed at sites on the second reef line at Hallandale. Effects upon reefs near the 3 Pompano borrow pits were not observed. The latter study was conducted in the Hallandale area only during 1978-79 via follow-up surveys of areas near 1971 dredge sites. The primary ichthyofaunal conclusion was that the dusky jawfish, *Opistognathus whitehursti*, was eliminated locally by incursion of borrow-derived sediments upon the first reef line. As various factors (e.g., natural variations in larval recruitment or local survivorship) may have intervened in the seven year interval, this conclusion is best considered a hypothesis. As approximately 35 offshore dredge projects for beachfill have been executed in the four county study area

Effect Characterizations

The diverse biological systems and the varied engineering alternatives examined herein guarantee a high number of potential effects, both direct and indirect. These effects can operate at scales ranging from the organism through the ecosystem. In addition to characterizing effects and consequences at organismal through community scales, discriminating natural background variation from stressor-induced effects is also important.

Types of Effects

Stressors associated with sedimentation, turbidity, and mechanical impacts can effect co-occurring fishes on scales of individual physiology through local population structure. A detailed listing of potential stressor effects upon marine organism physiology and behavior is provided in Eisler (1979). The diversity of potential effects at the individual level is high. For example, seven differing sensory system variables and at least five other variables associated with motor activity and water-column positioning can be affected by dredge burials of resident fish habitats (Lindeman, in prep.). Effects can be direct or indirect and operate over the short-term, long-term, or both. Indirect effects at the individual level can translate into population-level effects cumulatively. Many effects will show some species specificity, and within species, substantial ontogenetic variation. Typically, the earliest life history stages are the most susceptible. Consideration of effects upon fishes at these scales, and their effects upon higher organizational scales, are absent from the literature on beach dredging impacts in Florida. As the majority of fishes using nearshore areas of southeast Florida are early life stages (Lindeman, in prep.) and life stages of many families using mid-shelf areas are typically older, the greatest direct and indirect impacts may occur at nearshore dump sites.

Interactions between subtle, long-term effects may also occur, adding to the complexity in evaluating overall risk. Examination of cumulative effects of both direct and indirect stressors is complex and often unattempted, yet of potentially profound importance to the full understanding of anthropogenic effects (Cocklin et al., 1992; Vestal and Reiser, 1995). To provide an analytical structure for individual and collective examination of these issues, it is useful to discriminate among lethal and sublethal effects which in turn, can produce differing effects based on the time-scale evaluated. Table 2 structures some of these effects using examples which may occur in association with beach dredge and fill activities. As shown, identical organ systems can undergo sublethal or lethal effects (e.g., respiratory stress vs. respiratory trauma). These variations, in turn, lead to differing effects at greater exposure durations. Additional examples can be developed for each combination of stressor intensity and duration. Variations of this framework were used in alternative-specific overviews of stressors and effects (Lindeman, in prep.).

Cross-Shelf Spatial Distributions of Effects

In terms of the spatial distributions of potential stressors and effects, the ten beach engineering alternatives summarized above have a variety of differing distributional characteristics. A productive way to initially stratify coarse distributions of coastal stressors is by use of a cross-shelf perspective. Three overlapping cross-shelf strata are applicable here: nearshore (0-3 m depth), intermediate (3-5 m), and midshelf (5-15 m). The potential for significant stressor occurrence within each of these strata (indicated by an X), from inshore to offshore, was estimated as follows:

Sedimentary Deposition	*Nearshore*	*Intermediate*	*Mid-Shelf*
Dredge/Fill - Restor./Renourish:	X	X	X
Dredge/Fill - Nearshore Berms:	?	X	X

between 1970 and 1996 (ACOE, 1996; Lindeman, in prep.), it is remarkable that no replicated, peer-reviewed journal publications on the effects upon fishes exist.

Due to the excavation and pumping of 100,000's of cubic yards of sediments during offshore dredging, turbidity clouds are created which extend downstream and cross-shelf for kilometers, and throughout the vertical water column. Turbidity may be most concentrated at the excavation site of cutterhead dredges or at the site of slurry overflow at hopper dredge barges. Heavier sediments settle out, stressing corals and other sessile invertebrates. Typically, gorgonians and sponges tolerate sedimentation stress better than scleractinian corals (Goldberg, 1988). Wilber and Stern (1992) estimated recovery times for borrow site infauna of at least 4-5 years at one project.

Ultimately, dredge-suspended sediments are distributed throughout cross-shelf areas between the excavation and dumping sites and downstream from prevailing flow-fields. Semi-continuous resuspension events of dredge fill sediments by wind and waves can realistically occur over years. This could potentially result in long-term elevation of turbidities in some areas. At least 100 cross-shelf dredging projects may occur between 1969 and 2050, involving the excavation and dumping of at least 100,000,000 yd^3 within a 4 mile by 120 mile corridor between Dade and Martin counties alone (ACOE, 1996; Lindeman, in prep.). Therefore, repetitive, large-scale dredging may result in chronically elevated turbidities on both local and regional scales. Evidence of chronic wind and wave-induced sediment resuspension which lowers mean water clarity can be seen along the entire length of Jupiter Island, Florida, the site of 8 large renourishments in 22 years (Lindeman, in prep.; D. Snyder and K. Lindeman, pers. obs.). Population responses of various organisms to reductions in water quality from chronic turbidity may operate at time scales of decades, masking effects which may be cumulatively substantial. This scenario is at least as plausible as the common assumption that negative effects of large-scale dredging are short-term, if at all.

Intermediate Areas (Pipeline Path)

Leaks from the seams between pipes transporting dredge fill along the benthos could result in effects on nearby fishes and invertebrates. These effects are probably quite limited. During dredging operations, sediments are suspended from excavation areas and dispersed to intermediate cross-shelf areas. Potential effects in the short term, and chronic resuspension in the long-term, discussed in the above section on fish effects at mid-shelf areas, also apply here.

Onshore/Nearshore Areas (Dump Site)

There are no published studies which address the dumping of large volumes of dredge fill upon fishes of nearshore habitats of Florida; either hardbottom or softbottom. As several dozen acres of nearshore reefs are estimated to be buried or impacted by past beach dredging operations (Lindeman, in prep.) and approx. 61 additional acres of direct reef impacts are estimated in the 50 year ACOE plan (1996) for Dade through Palm Beach counties alone, the absence of published research is problematic. Factors related to both sedimentation (effects upon settlement) and turbidity (effects in suspension) can have both direct and indirect effects upon fishes. In addition to large scale anthropogenic pulsing, such factors require evaluation relative to natural background levels.

Administrative environmental reviews of fish impacts typically assume that fishes will simply swim away from dredge dumping, or will only be temporarily displaced. However, many of the species of nearshore reefs are represented primarily by life stages which are site-attached at the time of habitat elimination. These include newly settled stages of grunts, snappers, and high hats, and all life stages of damselfishes, clinids and gobies. These and other species which characterize ichthyofaunal compositions of natural and artificial nearshore reefs of southeast Florida (Lindeman, in prep.; Lindeman, 1996), can't simply swim away in many cases. Such life stages are not adapted for extended flight behaviors and subsequent vagrancy (e.g., grunts are morphologically and ecologically adapted to utilize structural habitats for daytime shelter, Lindeman, 1986). Fundamental questions of physiological thresholds, flight behaviors, ontogenetic variation in effects, reduction of growth, increases in predation, and synergistic effects upon local adult population sizes are unaddressed over both short- and long-term time scales. For both juvenile and adult fauna adapted for site-attachment at the time of large-scale burial, assumptions of temporary displacement may be leaps of faith, as much as tenable hypotheses. Logistic difficulties in detailing direct or indirect mortalities of individual fishes in water made anthropogenically opaque for months don't strengthen the null hypothesis of no, or limited fish mortality from such burials. More realistic hypotheses would focus on coarse estimations of mortality based on mobility-based groupings of fish taxa (Lindeman, in prep). In addition to the limited data on direct mortality, indirect effects are entirely unknown.

<u>Mechanical Habitat Effects</u>

These effects are based on physical modification of habitat structure (direct fill burial is treated under sedimentation). Although directly affecting many invertebrates, these effects are primarily indirect for fishes. No studies of such effects exist for fishes in Florida. Such research will require linkage of habitat losses/modifications to organismal or population scale effects.

Midshelf (Excavation) Areas

Cutterhead dredges mechanically disrupt the bottom and physically remove bottom sediments and on-site fauna, digging as deep as 35'. Trailing suction heads of hopper dredges remove surficial sediments and infauna, but with reduced volume and depth compared to cutterheads. Despite putative buffer zones between dredges and reefs, cutterhead dredges and associated construction equipment (e.g., discharge pipelines, mooring chains) can mechanically damage hardbottom areas as in projects at Sunny Isles (Blair et al., 1990) and Boca Raton (Barry, et al, 1990). Athough, more care is taken during planning and excavation periods, small buffer zones (150-400') are often used, and better positioning systems (GIS) exist, the sheer number of new projects, the on-site realities of marine construction activities, and the reduced availability of sand suggests that direct mechanical effects are not a past issue and require continued examination.

Intermediate Cross-Shelf Areas (Pipeline Path)

36" to 24" diameter pipelines are typically used to transport hydraulically pumped, newly excavated fill across-shelf to the dump site. There are many precedents for these pipelines to be laid directly across hardbottom or to be moved in storms. In either case, damage to hardbottom structures can occur.

Onshore/Nearshore Areas (Dump Site)

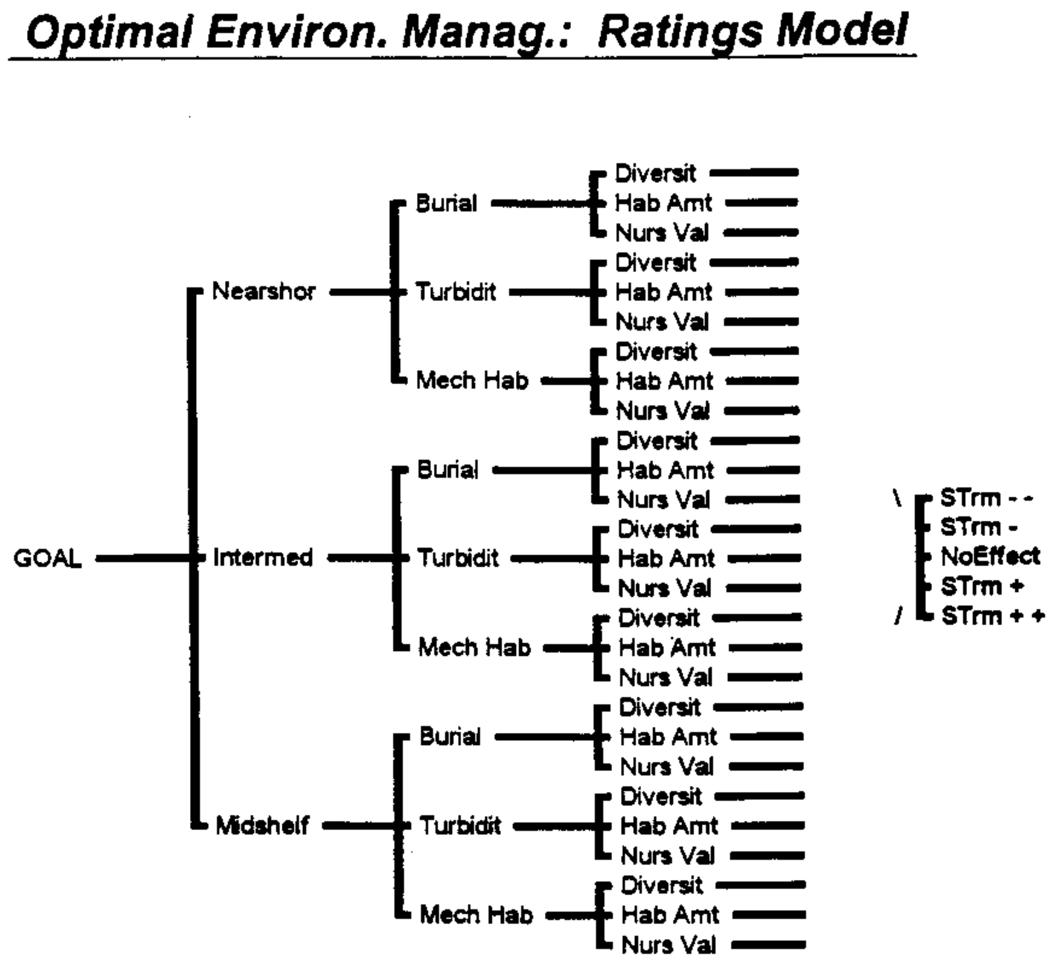
Direct burial and subsequent abrasion effects are evaluated under the Sedimentation and Turbidity Effects section above.

Integration and Characterization of Management Alternatives

<u>Analytic Hierarchy Components and Assessment</u>

The analytic framework was based on a hierarchy consisting of a primary goal containing nested criteria of increasing specificity. The operational project goal was defined as: *optimal environmental management of southeast Florida beach systems*. After preliminary analyses of several hierarchic structures, a ratings model was ultimately chosen as the primary analytical model (Figure 2). Ratings models separate the alternatives (ten total in this case) from the model structure and compare them against sets of standards which occupy the terminal model

Figure 2. Analytic hierarchy based on ratings model comparisons within three criteria, with a set of five environmental standards terminally nested within each criteria path (ranging from very negative = Strm --, to very positive = Strm ++). The ten engineering alternatives (Table 2) are situated outside the formal hierarchy but are still ranked according to the standards.



nodes. In this case, the standards represented a scale of estimated environmental effects upon fishes. For all criteria above the terminal node, weights were calculated by pairwise comparisons. With the current project goal, the ratings approach fostered more logical consistency and confidence in the assignment of ranks according to standards based on existing knowledge. Also, the integration of ecological endpoints and indicators was enhanced in the ratings model, as they fit logically as the penultimate node between the effects-defined criteria and the standards. Therefore, the structure of the ratings model proceeded from *cross-shelf spatial scales* (3 nodes), to *effect types* (3 nodes), to *ecological endpoints* (3 nodes), and terminated at a range of *standards* (left to right in Figure 2).

The standards consisted of 5 estimates of short term environmental effects: highly negative (Strm --), negative (Strm -), no effect (NoEffect), positive (Strm +), highly positive (Strm ++). Comparisons among alternatives involved assignment of one of these five effect estimators for each alternative within each criteria path. As there were three criteria with three nested nodes above the standards, 27 total criteria paths (defined by nested combinations of cross-shelf distributions, impact types, and ecological indicators) by 10 alternatives produced a total of 270 individual effect estimations in the full analysis. At higher levels of the model (cross-shelf spatial scales through ecological endpoints) priorities were based on pairwise comparisons of the relative importance of differing nodes within each criterion level. Nearshore and midshelf areas were considered the most important nodes within the cross-shelf spatial scale criterion, while intermediate areas were considered less important. Therefore, at this level, the former two nodes were given weights of .4 and the latter, a weight of .2. All factors within the effect type and ecological endpoint levels were weighted equally.

Model Results

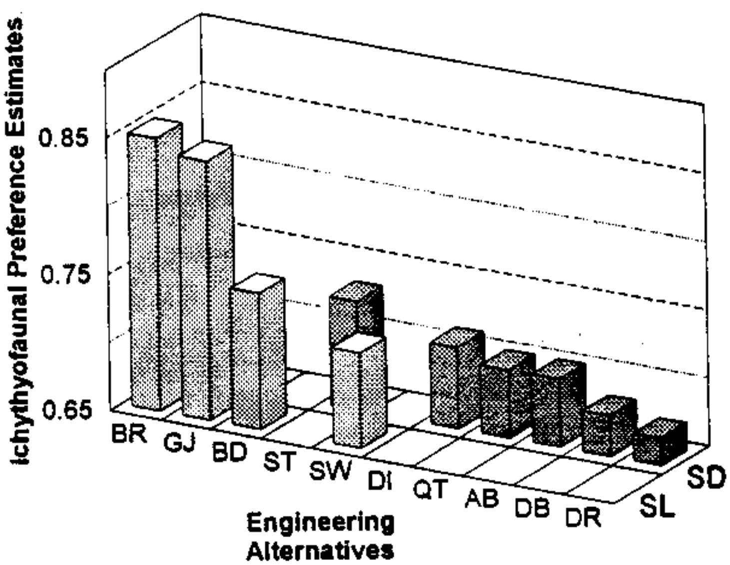
Comparisons of estimated environmental effects of ten engineering alternatives were performed using the ratings structure described above. This preliminary analysis included alternatives within the two differing categories of Sedimentary Deposition Technology (SD) and Structural Technology (SL), discussed above. The results are given in Figure 3. Due to the lack of detailed consideration of effects elsewhere, and their direct societal importance, effects upon fishes only were evaluated at this stage. Future applications of such analyses to other organisms, and the full breadth of other higher level factors (e.g., engineering, economics) are discussed in Lindeman (in prep).

The three most favorable alternatives in this preliminary analysis were breakwaters, groin fields/jetties, and beach dewatering systems (Fig. 3). The former two alternatives ranked high due to a variety of positive ichthyofaunal attributes. The latter alternative, and those ranked fourth and fifth, were characterized by basically neutral ichthyofaunal effects. The remaining alternatives reflected increasingly higher intensities of negative ichthyofaunal effects (Lindeman, in prep.). The highest rated SD technology was sand transfer plants. The lowest rated SD technologies were offshore dredge/inshore fill operations (restorations or renourishments) and nearshore berms (Fig. 3).

Sensitivity analyses proved useful in examining criterion-specific weighting effects upon total ranks (Saaty and Vargas, 1994). As almost all SD technologies ranked more negative for environmental effects than SL technologies and are often considered more routinely in planning processes, SD results are emphasized here (Fig. 4A). What-if analyses on SD technology alternatives are given in Figure 4B (weights skewed to mid-shelf areas). These results ranked sand transfer plants highest in terms of environmental preference no matter how weights of cross-shelf areas were varied, although the spread between alternatives was reduced by increased weighting of the midshelf spatial scale (Fig. 4B). This consistency of high ranks for

Figure 3. Summary of analytical hierarchy analysis of estimated ichthyofaunal effects of ten engineering alternatives for beach management in Florida.

Engineering Alternatives	Engineer. Categories	SD Totals	SL Totals
BR	SD		0.85
GJ	SL		0.84
BD			0.75
ST		0.73	
SW			0.72
DI		0.71	
QT		0.7	
AB		0.7	
DB		0.68	
DR		0.67	



Sedimentary Deposition Technologies (SD)

DR: Dredge - Renour./Restor.
DB: Dredge - Nearshore Berms
DI: Dredge - Inlet Maintenance
QT: Quarry Trucking of Sand
AB: Aragonite Barging
ST: Sand Transfer Plant

Structural Technologies (SL)

SW: Sea Walls/Revetments
GJ: Groin Fields/Jetties
BR: Breakwaters
BD: Beach Dewatering

occurred in recent years. Costs and logistics have been considered prohibitive. Due to the complete consumption of remaining offshore sand deposits for dredging in Dade County (predicted to occur within several years, ACOE, 1996), there may be an increased interest in acquiring sand from inland sources. The demand, and the reduced marine environmental concerns may make this alternative more acceptable in coming years.

- Aragonite Barging

The barging of aragonite sediments to southeast Florida from the Bahamas has recently received considerable attention. Aragonite would be purchased from existing mining operations, primarily on the Grand Bahamas shelf, and then barged to eroded areas of south Florida for deposition in shoreline areas. Aragonite is not endemic to the east Florida shoreline and may lithify more rapidly than native sediments (H. Wanless, pers. comm.). Impacts of large-scale mining operations in the Bahamas have not been extensively examined. Only one small project (25,000 yds^3) at Fisher Island, Dade County, has been constructed in Southeast Florida. Despite hopes that the vast aragonite deposits of the Bahamas would solve south Florida's sand deficit problems, the current policy of the Bahamian government towards aragonite export for Florida beaches is negative. This policy appears to be set for the short-term, however, changes in leadership or perspective could reverse this position. In this event, frequent and large scale depositions of aragonite on Florida's beaches are possible.

- Sand Transfer Plants

Inlet bypassing using sand transfer plants (STP's) is also receiving substantial management attention. STP's are fixed sediment pumping stations situated in shallow water on the accretionary sides of inlet jetties (the north sides in southeast Florida). They use submerged pipes under the inlet to pump naturally accreted sediments from the north sides of the northern jetties to the south sides of the southern jetties where the sand is deposited from a discharge pipe. These systems are geologically favorable as they keep sediments in the natural longshore transport system by bypassing the inlet channels which otherwise act as sediment sinks. Current technology permits a fully operational STP in south Florida to bypass 100,000-200,000 yds^3 annually. Only two STP's, at Lake Worth Inlet and S. Lake Worth Inlet, exist in the study area. Both are decades old and have been functioning poorly or not at all in recent years. There has been considerable interest at the state and local level to rehabilitate these existing facilities. In response, the new federal planning document (ACOE, 1996) recommends cost-shared funding to refurbish and operate both plants at full bypassing capacity. No other STPs are currently under development in this region.

<u>Structural Alternatives</u>

The first two alternatives in this category, collectively termed shoreline armoring, have been employed for beach management world-wide for decades. The latter two have only recently received serious consideration as beach management alternatives in southeast Florida.

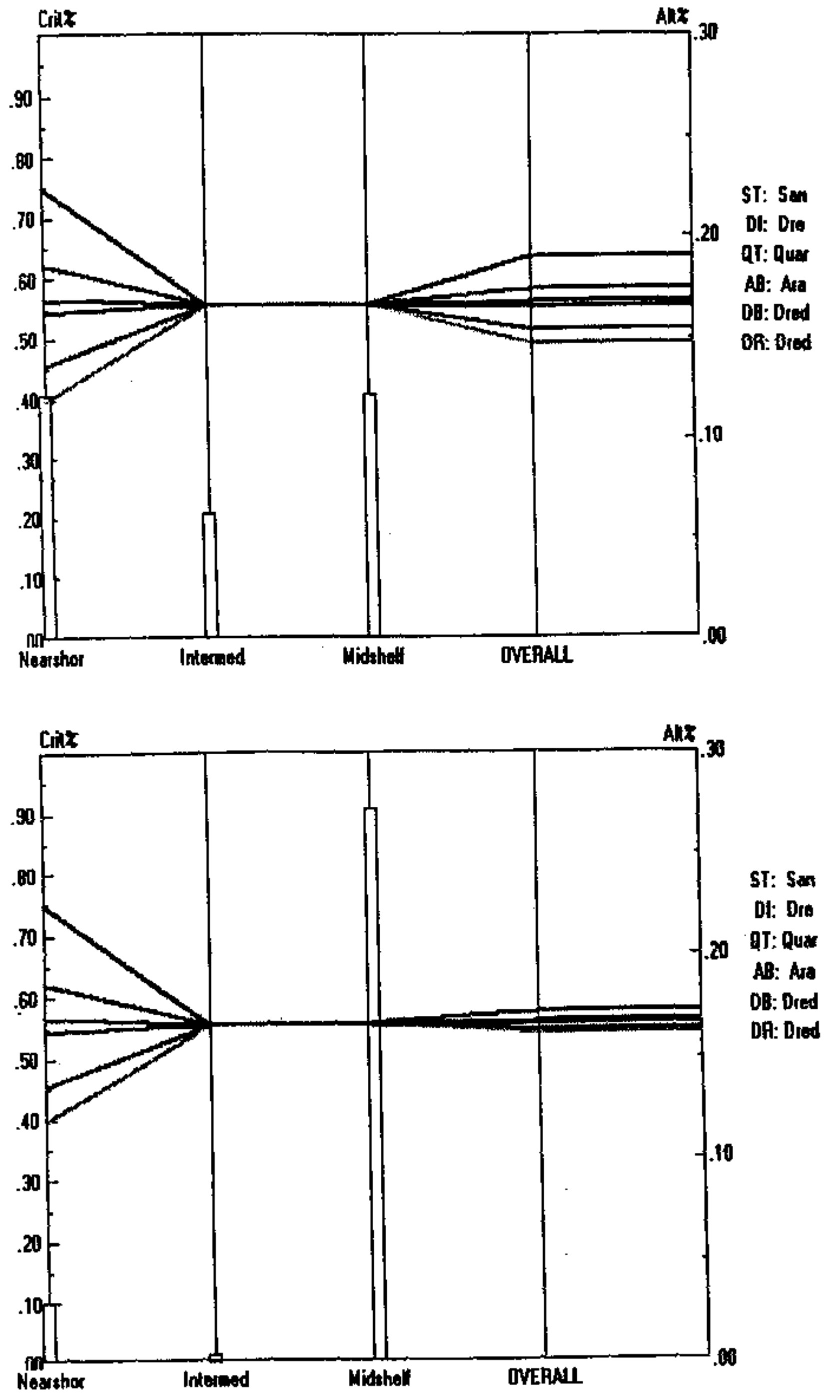
- Seawalls & Revetments:

These are structures which are parallel, and connected, to the beachface. Seawalls (bulkheads) are typically vertical, whereas revetments are typically oblique. They are usually designed to support the foundation of developed property and to deflect wave actions. Through time they can develop toe scour and other foundation weaknesses. Erosion rates can be increased immediately in front of these structures due to enhanced wave backwash and other characteristics. Although typically flat, the oceanward faces of seawalls and revetments are

Figure 4. Sensitivity analyses of AHP results among six types of sedimentary deposition alternatives. A) Nearshore and midshelf spatial scales equally weighted. B) What-if results with weighting of cross-shelf strata skewed to midshelf. Weights of criteria are represented by the height of the vertical bars against the left axis. Relative preferences of differing alternatives are represented by horizontal lines. The overall value for each alternative is on the right axis.

A.

B.



sand transfer plants was primarily due to no negative effects upon the ecological indicators examined. Once operational, such systems are economically competitive with dredging, create no substantial environmental problems anywhere across the shelf, keep nearshore sediments out of inlets, reduce the need for both inlet and renourishment dredging, and therefore, reduce the concentration of silts and clays in shallow waters. The current ACOE plans to refurbish two plants are endorsed. Due to long-term economic and environmental issues, and shortages of beach compatible sand from offshore dredge areas, planning to construct several additional sand transfer plants on the east coast of Florida is suggested.

The least preferred technologies from AHP analyses of ichthyofaunal effects among SD technologies were offshore dredging and inshore filling (restoration/renourishment) and dredging to create nearshore berms. Although rankings were based on short-term factors, a variety of long-term consequences of repetitive dredging and dumping are possible (discussed above). The negative rankings of these two alternatives was based on potential effects across multiple cross-shelf scales, and therefore, did not improve with varying weighting of cross-shelf areas (Fig. 4).

Uncertainties and Monitoring Needs

Differing weights will be assigned by different experts throughout the criteria nodes of models of this complexity. Iterative development is essential for full maturation of this preliminary framework. Additionally, group-based methods to flesh out diverse opinions and subsequently build consensus models (e.g., Delphi methods discussed in Titus and Narayanan, 1995, Saaty and Vargas, 1994) should be applied not only to fishes, but to the breadth of taxa within nearshore coastal areas. For example, sea turtles will show different ranks in relationship to seawalls than fishes. Ultimately, AHP or other multi-criteria decision tools should be developed to encompass multiple policy criteria, particularly the engineering and economic attributes of potential alternatives. In a comprehensive policy hierarchy, these latter criteria will be weighted higher than environmental factors.

Although originally attempted in the pure pairwise comparison model, an effect duration criterion which included long term effects could not be inserted into the current decision-support structuring. There are still too few cumulative data available on effects. With initiation of long-term monitoring programs, cumulative information could become available and this critical aspect of ecological assessment can be examined in more formal fashions. Of substantial long-term importance are the potential cumulative effects of chronic turbidity via wind- and wave-induced resuspension of dredged sediments. Arrays of nephelometers over regional scales would permit long-term separation of dredge-induced turbidity and resuspension from natural background levels. An aerial imagery database from planes or satellites may substantially aid predictive evaluations of physical and biological effects of these massive dredging projects. Predictive knowledge of local and mesoscale dynamics of sediment behavior, and population responses of organisms, will be delayed until long-term, mesoscale information is acquired.

Preliminary Environmental Assessment and Decision-Support Frameworks: Sand Aggregate Alternatives in the Antilles

Based on a fundamental issue in Antillean beach management, the goal of the present example is to *outline* systematic approaches for identifying the optimal alternative, or combination of alternatives, to provide aggregate for construction purposes. Detailed decision-support analyses and ecological risk assessments, based on revised versions of this framework, will be required for future *identification* of optimal alternatives. A representative range of alternatives available for construction aggregate is given in Table 3. These eight alternatives can be organized into three categories based on ultimate origin of aggregate: terrestrial mining, submerged dredging, and importation. Many small island developing states (SIDS) may not have all of these alternatives, while larger islands (e.g., Puerto Rico) will. The framework constructed here is inclusive of all islands types. Comprehensive analyses for many SIDS may involve fewer alternatives and should usually be island-specific.

Table 3. Representative alternatives available for construction aggregate in the Antilles.

Terrestrial Mining	Submerged Dredging	Importation
Beachface Mining	Offshore Dredging	Importation from off-island
Backdune Mining	Navigational Channel Dredging	
Inland Mining - Quarries	River Dredging	

Selected Assessment Issues - Antillean Framework

Large-scale ecological risk assessments of multiple alternatives for construction aggregate will require simultaneous characterization of primary stressors and biological effects. Stressor characterizations will largely depend on the engineering characteristics of each alternative, while potential effects will be largely based on the habitat and organisms co-occurring with a particular alternative. Diverse sources of aggregate are potentially available on some larger islands, including inland quarries, rivers, beaches and offshore deposits. Assessments which evaluate the full range of alternatives on such islands will require substantial knowledge of terrestrial and fresh water organisms and processes, as well as marine. The importation of aggregate from off-island sources within or outside of the Antilles also raises ecological risk issues. These include the need for quarantines of aggregate from some exporting countries (M. Porter, pers. comm.) or excavation and transport effects at the exporters source area. Several alternatives of particular relevance to coastal marine areas are considered below.

One alternative common to many nations of the region is the mining of beachface areas to directly obtain aggregate for construction. Substantial environmental and public safety problems may result from the cumulative removal of this fundamental ocean-land interface. Recently, considerable efforts have been taken by almost every Antillean nation to eliminate or regulate this practice. Enforcement of such regulations is the true test of governmental commitment to these new policies. Many islands of the region have made admirable progress in this regard. Unfortunately, many islands have few other alternatives readily available and beach mining, regulated or not, remains a key source of aggregate. A CERA approach to an EIA for beachface sandmining activities should include sea turtles if nesting beaches are affected, in addition to any substantial terrestrial effects.

Due to the diminishing role of sand mining as an aggregate source, interest in mining offshore sediments via dredge operations is growing. Although offshore dredging for aggregate has rarely occurred in this region, dredging activities which could induce similar environmental stressors have. Inshore, such activities include the dredging of marinas or port entrances for navigational maintenance purposes (with dredged material used as aggregate or as beachfill). Offshore, such activities include the dredging of fill material for beach nourishment (Table 4). Although published information from the Antilles on direct dredging effects is limited, Bak (1978) demonstrated both lethal and sublethal effects upon several genera of stony corals in Curaçao. Dodge et al. (1974) demonstrated that natural resuspension of sediments decreased coral growth in Jamaica, indirect evidence that anthropogenic increases in turbidity may effect coral reefs negatively. Some of the literature on the environmental effects of offshore dredging of carbonate sediments in subtropical areas of Florida is applicable to Antillean SIDS (e.g., Marszalek, 1981; Nelson, 1985; Blair et al, 1991; Fisher et al., 1992). However, information from many other reports - both monitoring and EIA (typically environmental impact statements mandated by the U. S. National Environmental Policy Act), are not published in peer-review journals, suffer from inadequate survey designs (see Osenberg and Schmitt, 1996, for a recent review of problems with impact studies) or EIA frameworks which do not thoroughly evaluate stressors, effects, or cumulative impacts. All of these factors reinforce the need for detailed, cumulative-oriented EIA's in the Antilles, particularly as offshore dredge projects are an increasingly attractive alternative source of construction aggregate.

Selected Decision Support Issues - Antillean Framework:

In the prior section, primary alternatives for construction aggregate in the Antilles were identified. Subsequently, a preliminary analytic hierarchy representing the primary factors determining the optimal aggregate, using nested levels of criteria and subcriteria, was constructed (Figure 5). Based on preliminary analyses and existing evaluations of construction aggregate sources, particularly sand mining of beaches (Green and Cambers, 1991; Cambers and James, 1994), two primary criteria were identified: economic and environmental. In applied policy formulation, economic issues typically outweigh environmental issues. Therefore, within the two primary criteria, economic issues were given a weight of .75, while environmental issues were given a weight of .25. The economic criterion includes several factors (availability, quality of aggregate) that could arguably be placed in a third criterion, engineering. As stated previously, AHP procedures involving policy decisions are best conducted by group decision-making. Exact placement of criteria in the future should be based on group-consensus.

In the current framework, both the economic and environmental criteria contain four subcriteria each (Fig. 5). The economic subcriteria are cost of aggregate per standard unit, availability in the future, quality for construction purposes, and social desirability. Cost was considered the most important factor within the economic criterion. Environmental subcriteria were based on general stressor/effect categories which could effect either aquatic or terrestrial biota. These subcriteria included: air pollution effects (primarily terrestrial effects), mechanical effects on-site (aquatic or terrestrial), sedimentation effects (aquatic), and turbidity effects (aquatic). Due to their differing relevance among the various alternatives, pairwise ranking of these criteria was difficult. Ultimately, mechanical effects were rated highest (in part due to their relevance at sea or on land), sedimentation and turbidity were ranked intermediate, and air discharges were ranked lowest. Weights which reflect the relative importance of each subcriterion towards achievement of the overall goal are given in Figure 5. Detailed evaluation of alternative-specific biological effects will require the evaluation of representative taxa. The four environmental subcriteria could potentially effect from one to four general faunal types: fishes, invertebrates, reptiles/amphibians, and birds.

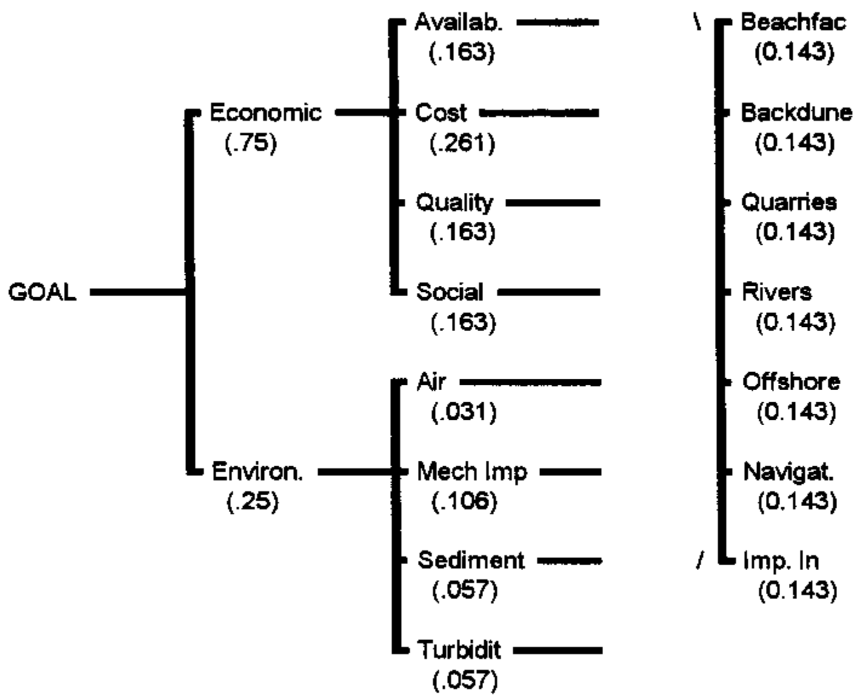
With the identification of alternatives, construction of a full hierarchy, and weighting of component criteria, the actual pairwise assessment of all alternatives within all terminal nodes of the hierarchy is possible. The preliminary hierarchy constructed here contained eight

Table 4. Preliminary summary of marine dredging activities for beachfill at selected Antillean islands. Comprehensive regional data is currently unavailable. Examples of substantial marine dredging/filling for airport runways or other industrial sites are also included.

Country	Primary Beach-fill Sources	Frequency	Specific Project Examples	
			Volume (~ yd^3)	Project Information
Anguilla	Offshore	Uncommon	30,000	Hotel shore, after hurricane Louis, 1995.
Antigua	Inshore	Uncommon	-	Marina-derived fill used for both beach and aggregate.
Barbados	Inshore	Uncommon	-	-
British Virgin Islands	Offshore	Uncommon	10,000	Hotel shore, after hurricane Hugo, 1989.
Grenada	Not done?	-	-	Substantial offshore dredging for airport fill.
Montserrat	Not done?	-	-	-
St. Kitts & Nevis	Offshore	Occasional	12,000; 95,000	Two differing hotel shores recently filled.
Puerto Rico	Inshore	Uncommon	Variable	Channel dredge material used for beachfill.
St. Lucia	Inshore	Occasional	-	Recent dredging for beachfill at 2 sites.
St. Vincent & Grenadines	Not done?	Pending?	-	Substantial offshore dredging for airport fill.
Trinidad & Tobago	Not done?	-	-	Substantial dredging for fill for industrial sites.
Turks & Caicos	Not done?	Pending?	-	Feasibility studies underway.
U. S. Virgin Islands	Inshore, and imported from BVI	Uncommon	-	Also, airport runway extension - mountain sediments used to fill depths up to 90'.

Figure 5. Preliminary hierarchy for Antillean aggregate source example. The seven alternatives are on the far right and insert into the terminal nodes of each terminal subcriterion. The numbers in parentheses are the weights of each factor relative to all other factors within the same level of the hierarchy. See text for further details.

DECISION HIERARCHY FOR ALTERNATIVE SOURCES OF CONSTRUCTION AGGREGATE



terminal nodes and seven alternatives requiring 21 individual inter-alternative comparisons within each terminal node (a total of 168 comparisons overall). Subsequent to the final pairwise comparison process, *Expert Choice* software executes the synthesis step producing final preference values for all alternatives, and sensitivity analyses allowing dissection of the role of individual factors and predictive what-if analyses. Modification of the model to reflect outside expert opinion, insight gained from the initial execution of the entire process, or dynamic circumstances, is a fundamental component of the "end" of each decision-analysis cycle. In the present study, we have not executed the final analytic components described in this paragraph. This step should be taken after group decision exercises are conducted which generate a hierarchy structure, and pairwise comparison process, specific to the criteria and subcriteria of individual islands.

Discussion

Comparisons of Florida and the Antilles

One of the most substantial differences in beach system management between Florida and the Antilles involves the fundamental approach towards sediment management. Although both approaches have recently emphasized mining of sediments, the sites and destinations are radically different. In Florida, sand is dredged from offshore and dumped on beachfaces, while in the Antilles it is mined from beachfaces and used as construction material. Comparatively, relative positives and negatives exist for both approaches. For example, in terms of sediment management, the approach in Florida is "better" than the Antilles - at least the sand isn't permanently removed from the system. On the other hand, in terms of marine ecology, Florida is worse than the Antilles - massive benthic disturbances are semi-continuously introduced into coastal areas with little consideration of long term effects. In both cases, beachfaces are subjected to substantial artificial modification: either by partial or complete removal, or by semi-continuous burial with dredge fill. These differences in sediment management approaches are perhaps due more to regional variation in geology and hydrodynamics than to management philosophies (Table 1). For example, despite limited statutory and administrative infrastructures, control of coastal building construction is based on setback lines in almost all Antillean nations, very similar to the approach used in Florida.

The present study developed examples of how optimal policy alternatives, individually or in combination, could be identified for two regionally-distinct beach management issues. These preliminary frameworks illustrate how relatively new and useful approaches to both environmental assessment and policy-formulation can be employed in region-specific manners. They are not meant to represent definitive results. The structure of the Florida example and the Antillean policy analysis were designed to catalyze regional experts to systematically refine these initial frameworks into revised analytic structures for direct application in both regions. Although both examples employed aspects of CERA techniques for environmental assessment and AHP techniques for policy analysis, differences existed as well. For example, unlike Florida, the Antillean AHP structure included criteria in addition to environmental issues. The inclusion of such criteria could have been switched based on the specific information available and the proximal management needs. The point is that both analytical approaches are flexible within themselves and can be used independently, in combination with each other, or in combination with other environmental assessment or decision support methods. The possibilities for differing integrations are as varied as the breadth of problems and management perspectives. In the wider Caribbean Basin, the potential for innovative and powerful applications of such tools is substantial, yet untouched.

The Need for a Cumulative Perspective

A wide variety of literature (Odum, 1982; Spaling and Smit, 1993; Hilton, 1994) has suggested that current EIA approaches aren't fulfilling their comprehensive purposes. It is commonly known that EIA's are perceived by some development interests and governments as simply "the cost of doing business", despite the best intentions of the preparers. Often in EIA documents, conclusions of no long-term effects are reached after high-quality literature reviews that identify a variety of: 1) *negative impacts* or 2) *information voids*. Such contrasts between analyses and conclusions are distributed among many EIA's associated with beach dredging projects. Perhaps such contradictions can be warranted in the presence of thorough and up-front mitigation, but the points here are simple:

(1) for dozens of biological variables among hundreds of species - we don't yet know if cumulative population-scale effects are benign, particularly with large-scale dredging.

(2) administrative momentum can build from one EIA to the next - reinforcing an optimistic hypothesis with incomplete data as an acceptable conclusion, and eventually, a "fact" - (often with little new impact data between the successive EIA's).

Collectively, these problems, and others (e.g., Spaling and Smit, 1993), undercut the scientific value of environmental impact assessments. When cumulative effects are possible but unevaluated, this should be overtly stated, with some detail paid to worst-case, as well as best-case scenarios. Too often, no or little cumulative consideration is given, or it is obfuscated by euphemistic predictions. Repetitive reviews of limited databases are fostered, and in time, codified as dogma. Ultimately, resources can be diverted from doing the detailed field or lab research needed to fill the key information voids. Recently, a variety of methodological approaches for incorporating cumulative effects into EIA's have been developed (e.g., Cocklin et al., 1992; Vestal and Rieser, 1995; Dixon and Montz, 1995). Given the potential for long term biological consequences in Florida and the Antilles, future EIA's from both regions should include detailed assessment of cumulative effects.

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