Presented at the 1981 Seminar on the Petroleum Industry and
the Nigerian Environment, 9-12 November 1981, Warri, Nigeria

13. SENSITIVITY OF COASTAL ENVIRONMENTS TO OIL SPILLS

Dr. ERICH R. GUNDLACH, MILES O. HAYES and CHARLES D. GETTER,
Research Planning Institute, Inc., 925 Gervais Street, Columbia,
South Carolina, U. S. A., 29201

ABSTRACT

Cost-effective, prespill contingency planning revolves around three primary components namely, the selection of the spill-sensitive areas, the likelihood of oil impact, and the analysis of costs to protect those sites. Spill-sensitive areas are characterized with the Environmental Sensitivity Index (ESI) which ranks shoreline types in terms of spill sensitivity; designates ecologically important sites and also includes the socioeconomic and spills response information. The likelihood of spills affecting certain areas can be determined by computer analysis. Economic consideration is the basis of all contingency planning. By the careful selection of the investigated coastline in terms of spill sensitivity and probable impact, and analysing costs versus equipment capability to protect those areas, fincancial resources may be most effectively utilized.

INTRODUCTION

The key to effective oil spill contingency planning for marine waters encompasses three primary aspects: (a) location and selection of the most oil-sensitive areas, (b) the likelihood of oil impact on most sensitive environments, and (c) an analysis of spill equipment effectiveness and costs associated with protecting those areas. Within this format, manpower and equipment can be most effectively prepared to protect valuable resources, depending on the willingness to bear the associated costs. These prerequisites for spill damage prevention are particularly appropriate at this conference, as Nigeria contains an extensive array of offshore oil platforms as well as expanding oil port facilities. The purpose of this paper is to discuss briefly each of these key aspects and indicate their scientific basis and particular relevance to prespill planning.

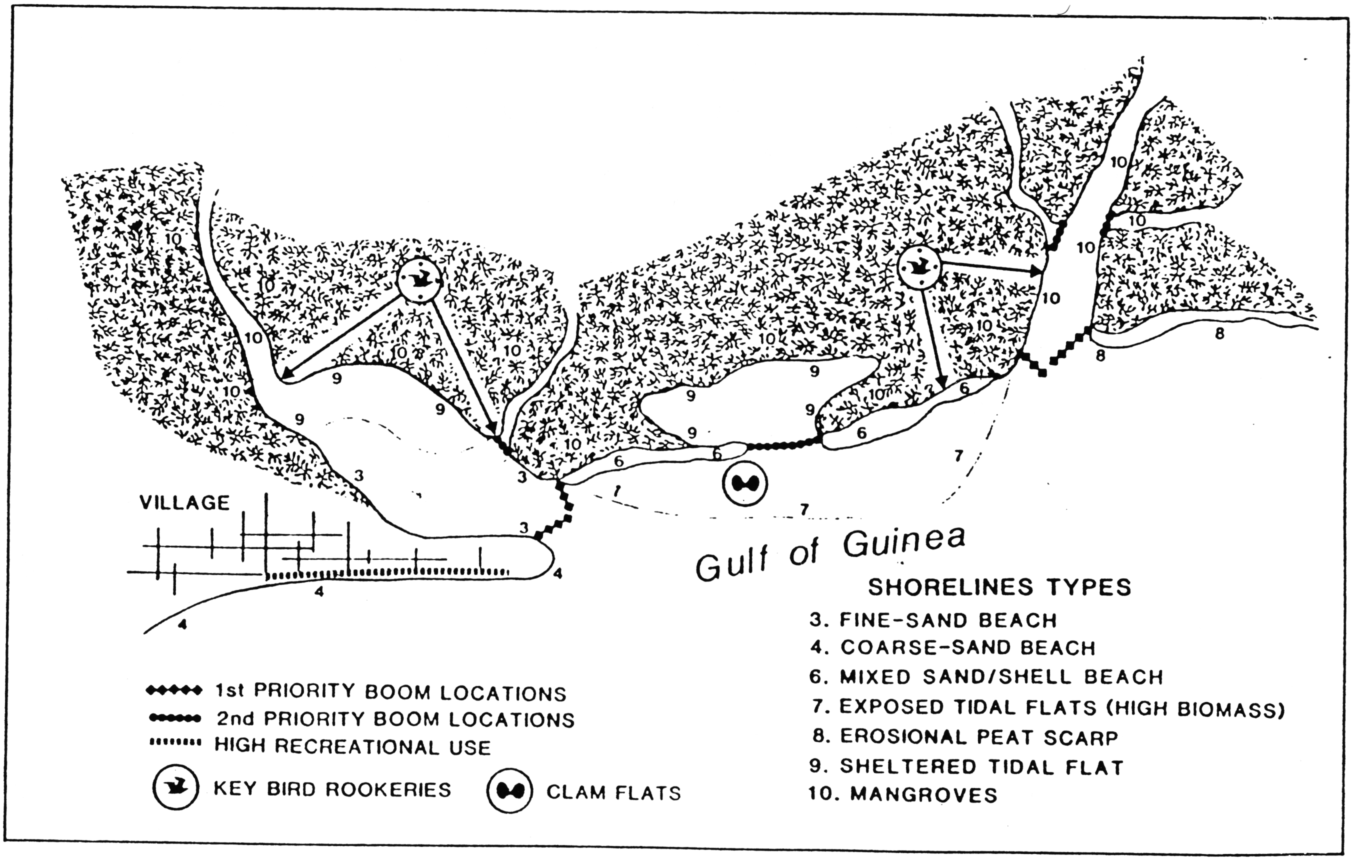

Fig. 1: Example of the application of the Environmental Sensitivity Index to a hypothethical, mangrove-dominated shoreline, indicating ranked shoreline types, biologocally important areas, and priority boom locations. Maps are usually prepared in color to aid rapid understanding of the presented information.

SELECTION OF OIL SENSITIVE AREAS

Under the support of the U.S. government and the state of Alaska, a unique system of classifying nearshore environments in terms of oil sensitivity has been developed[1], [2]. This system, called the Environmental Sensitivity Index (ESI), includes geomorphic, biological and socioeconomic criteria. Table 1 contains references pertinent to the development and support of the ESI. Geomorphic criteria pertain to the observed interaction and persistence of oil on the specific shoreline type. Biological criteria encompass the potential long-term effects to sessile as well as migratory organisms. Areas of socioeconomic importance include major recreational beaches, parks, marinas etc. As described in the following sections, this information, with the addition of primary spill response methods (placement sites for booms and skimmers, etc.), is presented on small-scale maps (usually 1:24,000) and using colors and symbols. An example, prepared in black and white for a hypothetical shoreline, is presented in Figure 1.

The methods of collecting the necessary baseline data primarily include low-level aerial overflights (preferably by helicopter) as well as ground surveys. The detail and spacing of the ground survey depend on the extent of data already collected.

This approach to prespill planning has been used in several areas of the United States (Figure 2) and New

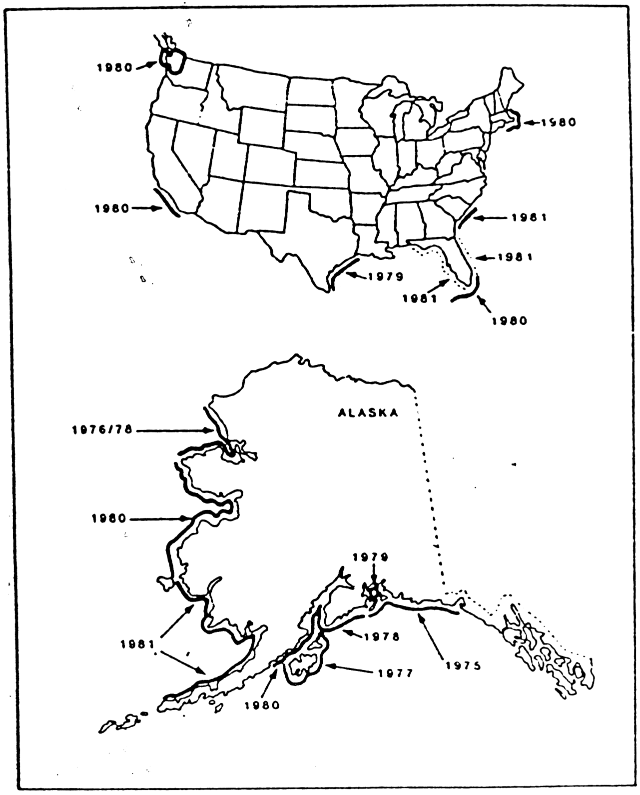

Fig. 2: Coastal areas of the United States to which the oil spill Environmental Sensitivity Index has been applied. Plans are currently underway to continue mapping in Germany and France. New Zaland has already completed a similar project.

Table 1 — **Principal Oil Spills and References Which Serve As a Basis for the Environmental Sensitivity Index**

Oil spills	Date	Type and amount	References
WW II Tanker, United States East Coast	Jan.-June 1942	Various; 533,740 tons	4
TORREY CANYON, Scilly Isles, U.K.	March, 1967	Arabian Gulf Crude: 117,000 tons total; 18,000 tons onshore	5, 6
Santa Barbara blowout	Jan. 1969	California crude; 11,290 to 112,900 tons total: 4,509 tons onshore	7, 8
ARROW, Chedabucto Bay, Nova Scotia	Feb. 1970	Bunker C; 18,220 tons total	9, 10
METULA, Strait of Magellan, Chile	Aug. 1974	Saudi Arabian Crude; 53,000 tons total; 40,000 tons onshore	11, 12, 13
URQUIOLA La Coruna, Spain	Arabian Gulf Crude; 110,000 tons total; May, 1978	25,000—30,000 tons onshore	1, 14
AMOCO CADIZ, Brittany, France	March, 1978	Arabian Gulf crude; 223,000 tons total	15, 16
HOWARD STAR, Tampa Bay,	Oct., 1978	Crude and distillate approx. 140 tons	17
PECK SLIP, Puerto Rico	Dec. 1978	No. 6 oil; 1,500 tons	18, 19
IXTOC I, Gulf of Mexico	June, 1979—April 1980	Crude oil; several hundred thousand tons	20, 21, 22
BURMAH AGATE, Texas	Nov. 1979	Crude and refined product	23, 24

Zealand[3], and is in progress or planning in France and Germany. It has been field tested during several U.S. government-sponsored spill drills and under actual spill conditions during the IXTOC I impact on the South Texas coast[21,22].

Shoreline Types

The shoreline of a designated study-area is categorized based on sediment type, geomorphology and biota. After field work and study of related literature, each shoreline type is ranked on a scale of 1 to 10 in terms of potential sensitivity to oil spills. Shorelines having the value 10 would show the most long-term damage from oil if impacted, while those designated as 1 or 2 would show the least. The specific characterization applied to the study area varies from region to region (e.g., a Nigerian index would be much different from one used in Alaska). A tentative index for the Nigerian coastline is presented below. Shorelines are listed in terms of increasing oil spill sensitivity.

1. Observations during the URQUIOLA and AMOCO CADIZ oil spills showed that oil was generally kept 5 to 10 m offshore by waves reflecting off steep rocky cliffs. Damage was minimal, and oil that did strike the cliffs was removed rapidly by wave activity. In Nigeria, the most similar type shoreline to the steep rocky cliffs of Europe would be exposed seawalls or revetments. Biomass is usually low on exposed shores of this type. Where organisms are present, they are usually fairly resistant to oil and show relatively rapid recovery. Cleanup is usually unnecessary and could be dangerous.

2. *Eroding Wave-Cut Platforms*

   Deposited oil is removed relatively rapidly from this environment because of its wave-swept condition. This was observed to take less than a few weeks at the METULA site. Cleanup is usually unnecessary except for socioeconomic reasons.

3. *Flat, Fine-Grained Sand Beaches*

   Compact, fine-grained sand beaches inhibit oil penetration, and as they generally accrete very slowly between storms, the depth of oil burial is minimal. Cleanup is simplified by the presence of a hard substrate. Amphipod populations are likely to be destroyed; although, as was observed at the AMOCO CADIZ spill, recovery may occur after a few months.

4. *Steeper, Medium-to Coarse-Grained Sand Beaches*

   As observed at the URQUIOLA spill site, oil burial and penetration may be great on depositional medium- to coarse- grained sand beaches. Cleanup tends to grind oil into the beach because of the loose packing of the sediment. After a major spill, oil from the beach face is eliminated by natural wave activity, usually within a few months.

5. *Exposed Tidal Flats (Low-Biomass)*

   As observed at the METULA and URQUIOLA spill sites, oil does not readily adhere to, or penetrate into, the compact surface of these sand or mud flats, but is pushed by waves to the upper fringing zone. Cleanup should concentrate on oil removal from the upper intertidal, with specific precautions against soft substrates.

6. *Mixed Sand and Shell Beaches*

   Penetration in this type of beach can be rapid and deep (35 cm along South Texas after IXTOC I oil deposition). Oil may persist for six months or longer. Biomass is commonly very low. Cleanup is very difficult, although the French military at the AMOCO CADIZ site effectively used bulldozers and high pressure spraying without removing any sediment.

7. *Exposed Tidal Flats (High-Biomass)*

   Although oil does not adhere directly to most of the tidal flat, organisms within the sediment can seriously be affected. At the AMOCO CADIZ spill site, millions of heart urchins and clams that inhabited the lower intertidal and shallow subtidal zone of this environment were killed. Areas with espcially high productivity are noted with special symbols. Cleanup should concentrate on hard-substrate, upper intertidal areas.

8. *Erosional Peat Scarps*

   This category is so designated because it commonly fronts a marsh or mangrove area and, during storms, oil could easily overtop the scarp. In addition, the eroding zone commonly is composed of fine grained organic detritus which can interact with the oil and be carried to offshore bottom areas, thereby spreading the contamination. Cleanup is extremely difficult.

9. *Sheltered Tidal Flats*

   Several sheltered tidal flats at the site of the AMOCO CADIZ oil spill in France remain severely contaminated three years after the spill. Even in places where mechanical cleanup operations succeeded in removing surface oil, the interstitial water remained contaminated. At the Metula spill site in Patagonia, sheltered tidal flats were still heavily oiled 6.5 years after the spill. A high biomass of deposit and filter feeders creates the potential for severe biological damage, as well. Long-term biological changes may include failure of certain species to recolonize oiled substrate.

10. *Sheltered Salt Marshes and Mangroves*

    Salt marshes are one of the most productive portions of the coastal zone. It has been shown that large amounts of oil in the marsh environment can be devastating, as at the METULA and AMOCO CADIZ spill sites. At West Falmouth, Massachusetts, the effects of the 650 ton FLORIDA spill (№ 2 oil) were detectable for at least 7 years after the spill[25]. With lesser quantities, the marsh may be able to recover (e.g., URQUIOLA site), although repeated spill incidents are usually damaging[26]. Marshes that have been lightly oiled are often best left to recover naturally. Thick accumulations, however, must be removed lest placement of sediment and replanting, has been successful on a small scale.[27]

Mangrove environments are especially common along the Nigerian coastline. In cases where both substrate and root systems are oiled, defoliation and tree death may occur rapidly (within three months as observed at the PECK SLIP site in Puerto Rico). Recovery of killed mangroves may take decades if the substrate remains oiled (and due to slow tree growth). Even if the mangrove area is not killed outright, numerous stress responses may be noted. This includes sublethal effects on the tree as well as mangrove-associated organisms, for example Tables 2 and 3.

Biological Information

It is equally necessary to note, on detailed maps, areas of special biological importance, including localities of oil-sensitive, protected, or commercial species and communities. This information is represented on the prepared maps by symbols and colored circles (Figs. 3 and 4). The color of the circle aids rapid identification of the type of organism present: yellow = mammals; green = birds; blue = fishes; and orange = shellfish. The silhouette in the center of the marker refers to the major ecological group. The number refers to a species or species group listed in an accompanying text prepared specifically for the study site. Seasonality data, presented on the outer perimeter of the marker, indicate the seasons of the year that a particular species or group of species (i.e., mixed bird colonies) are most likely present. Consideration is given to such factors as reproduction, migration, and feeding behaviour.

Table 2 — **Observed mangrove and mangrove community stress responses**[29]

	Stress responses	References
1.	Tree mortality	19, 30, 31
2.	Defoliation of canopy	19, 29, 31, 32
3.	Root Mortality	29, 32, 33
4.	Bark fissuring	17, 18
5.	Seedling mortality	34
6.	Epithelial scarring	34
7.	Lenticel expansion	31
8.	Adventitious pneumatophores	35
9.	Leaf deformities/chlorosis	29, 31, 34
10.	Propagule stunting/bending	17, 18
11.	Leaf stunting	29
12.	Reduction in leaf number	17
13.	Number of lenticels	18
	Community	
14.	Epiphytic mortality	29, 31
15.	Tree snail density	29, 30
16.	Tree crab density	29, 30
17.	Changes in infaunal community	36

Table 3 — **Laboratory studies in which mangrove stress responses were noted**[30]

Concentrations (ppm)	Fuel types	Toxic effects	References
100	Diesel	Growth alterations	37
300	No. 2	91.7% mortality; survivors with no new leaves	38
300	Bunker C	23.9% mortality: survivors with fewer new leaves	38
300	South Louisiana	20.0% mortality; survivors with fewer new leaves.	38
300	Kuwait crude	No mortalities: increased number of new leaves	38
1,000	Diesel	Growth deformities	37
10,000	Diesel	Lethal	37
38,600	Bunker C No. 2 Kuwait crude	Fewer new leaves, depressed weight gain	29
100,000	Diesel	Lethal	37

During a spill, the presence of a "bio-sysmbol" elevates the particular shoreline type over the adjacent shores of similar value. The symbol also designates that an appropriate response (e.g., bird hazing and cleanup centres) will be necessary. Althought attempts have been made to rank bird types in terms of oil sensitivity, e.g., by Manuwal et al[28], there is insufficient scientific evidence to rank all ecological groups and species.

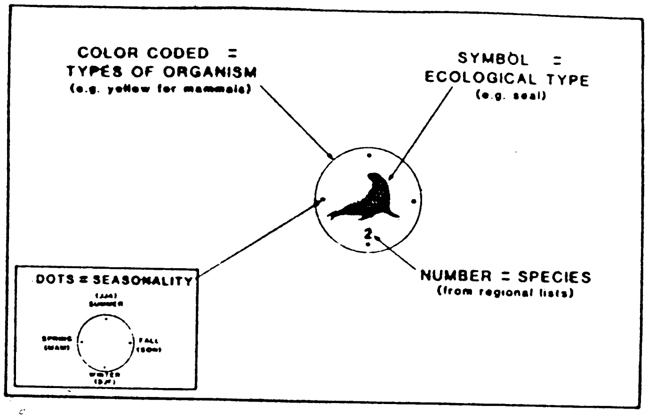

Figure 3: Key for biological information Contained on the ESI Maps

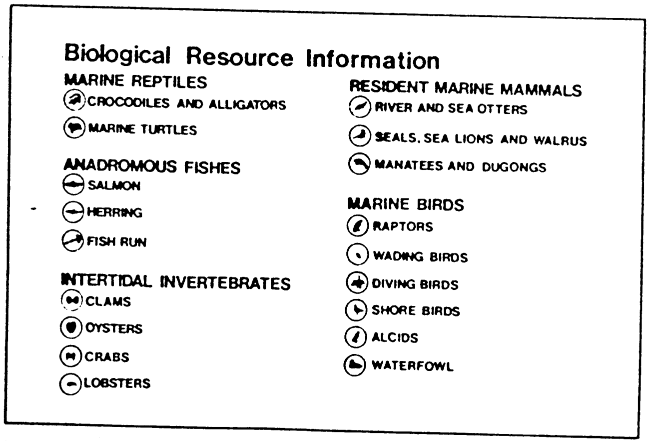

Fig. 4: Example of "bio-symbols" used on the ESI maps to represent spill-sensitive wildlife.

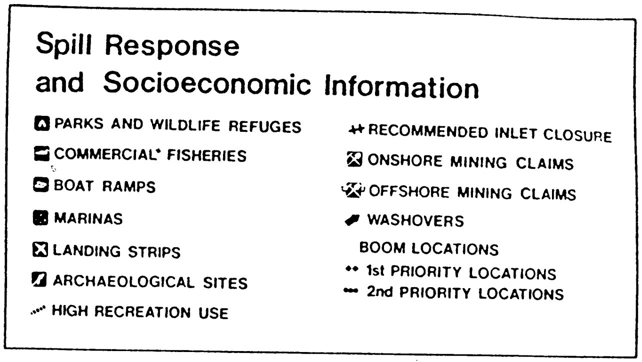

Fig. 5: Examples of typical, spill response and socioeconomic information applied to ESI maps.

Socioeconomic Resource and Spill Response Information

Information concerning particularly important recreational or historical sites is also necessary to effectively plan against and combat an oil spill. These sites are also indicated by special symbols (Fig. 5). A sensitivity or response ranking is not employed since seasonal aspects of tourism may vary greatly. A list of whom to contact concerning each particular site, as well as a predesignated cleanup plan, is important.

Spill response methods are also evaluated and sited during the aerial and ground surveys. This includes positioning for open-water and harbour booms, open-water skimmers and areas where the inlet is small enough to be infilled to protect the interior sensitive area (Fig. 5). A priority ranking of spill protection is indicated on the created maps: first priority = open-water booms and skimmers to prevent offshore oil from entering major inlets (dispersant application should also be considered), second priority = harbour and absorbent booms, and inlet closure to prevent oil from entering sensitive small creeks and mangrove areas.

LIKELIHOOD OF OIL IMPACT

Even though a shoreline may be primarily composed of sensitive environments, nearshore current and wind regimes, or the absence of a potential pollution source, may severely reduce the likelihood of oil impacts in that region. In order to allocate financial resources best, it is helpful to designate potential spill locations (i.e., offshore rigs, pipelines, terminal facilities and tanker routes) and potential impact areas. With a minumum of current and climatic data, a computer program can either (1) indicate potential impacts starting at the designated spill site and grinding through the various weather and current possibilities to indicate shoreline impact areas, or (2) as was particularly effective in the U.S. government response to IXTOC I, the model can be run backwards to consider where a spill would have to occur to impact the designated sensitive area[39]. Under fortunate conditions, it may turn out that a truly unique set of winds and currents may be necessary for oil to reach certain areas. In this case, primary expenditures and planning to protect these sites would be ruled out.

COST ANALYSES

Since financial resources available for spill protection are not unlimited, it is necessary to utilize allocated funds most effectively. Expenditures to protect against unlikely spill scenarios are not necessary. Equipment should be geared to protect specifically designated priority areas. Expenditures for equipment when the known current conditions indicate that they will not work are, likewise, not effective prespill planning. In most cases, equipment is only effective in calm waters with conditions under one knot. Upon entering offshore, open-water conditions, costs rise substantially and equipment effectiveness drops. In a properly coordinated effort, the analysis of protection versus cost should be based on the previous two studies: protection of designated priority spill-sensitive areas and likelihood of impact.

ACKNOWLEDGEMENT

We would like to acknowledge the continuing support of John Robinson and his staff at the National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment. Many of the ideas presented in this paper were generated through our interaction with this agency.

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