INCORPORATING BIODIVERSITY INTO SENSITIVITY MAPS OF THE NIGER RIVER DELTA

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ABSTRACT: *Using the basis that communities having high biodiversity are inherently more valuable as an ecological resource, the authors have derived a preliminary system of classifying the tropical environments of the oil-producing delta regions of Nigeria based on a number of field-collected parameters that measure the degree of biodiversity as well as potential spill persistence and difficulty of cleanup.*

Physical parameters to be measured include type of substrate, presence of near-surface groundwater and inhibiting layer, and extent of surface debris. Biological parameters include tree density (stocking), coverage by grasses and shrubs in the understory, plant condition, species richness and diversity (mammals, reptiles, amphibians, birds), important medicinal or endangered species, and special or unique biological features. Each factor is given assigned weighting values based on over 20 years of oil spill experience.

The weighting given to spill persistence factors is 25%, while 75% is given to biological parameters. The sum of species richness and diversity is one-third of the entire valuation. Once all parameters are measured and tallied, sensitivity classification will be divided into five to ten categories. Initial data collection was undertaken during 1999. Additional fieldwork to collect and test each factor is planned for the year 2000. Sensitivity maps, including the classification of both coastal and inland habitats, will then be prepared in a GIS (Geographic Information System) format.

Background

This work is sponsored by the oil industry in Nigeria with the participation of the Nigerian government, and proposes to develop and implement a standardized, sensitivity-mapping project using GIS (Geographic Information System) technology within the oil-producing region of the Niger River Delta and environs. A principal element of the project is to expand the mapping area from coastal and riverine shorelines to include *interior* habitats, and to use a realistic approach that can be implemented to incorporate biodiversity as an element in determining "sensitivity" to spilled oil. The methodology and concepts discussed here have been developed after the collection of initial field data but before full testing and implementation, which is planned for later in 2000. Further modifications to the proposed ranking methodology are expected.

Sensitivity mapping in Nigeria

Environmental sensitivity mapping was first initiated in Nigeria in the early 1980s. Gundlach *et al*. (1981) describe the ESI system of mapping and symbology, and suggest the shoreline categories that could be used for Nigerian shorelines. Over the years, sensitivity mapping it has been accepted on a fairly universal level (e.g., IMO and UNEP) (see Baker *et al.*, 1998; Gundlach and Hayes, 1978; Gundlach and Murday, 1987). Although nuances exist between the versions of sensitivity maps (e.g., depending on the area of study and project objectives), the basics of the mapping have remained constant throughout almost all ESI projects, which supports the validity of its original conceptual design and format. These basic concepts include the following:

- Sensitivity maps are designed to provide the necessary environmental information to the user from which a decision can be reached regarding spill response priorities and cleanup methods to be applied.
- Sensitivity encompasses three primary components: physical/geomorphic, biological, and socioeconomic.
- The sensitivity of socioeconomic and biological components may vary widely depending on season or other factors (e.g., high sensitivity only when the migratory species is present).
- The physical/geomorphic attribute (of the shoreline type or interior habitat) is ranked in order of increasing sensitivity, most commonly (but not exclusively) on a scale of 1 to 10.

- The biological attributes associated with the geomorphic component are included in the sensitivity evaluation of that component (e.g., mangrove shorelines are a coastal geomorphic type and show high biological diversity).
- Other biological attributes (e.g., bird colonies, fishing grounds, etc.) are mapped as point localities or polygons, but are not given a sensitivity value.
- Socioeconomic attributes (e.g., villages, shrines, boating areas, etc.) are similarly mapped as a point locality or polygon but not given a sensitivity value.

Mapping shorelines in Nigeria

"Shoreline type," "shoretype," or "coastal habitat" are used for areas affected by marine, brackish, or riverine processes. Shoretypes are assigned by geomorphology and associated biota into well-established categories having a known sensitivity ranking. Rapid survey procedures are needed to characterize the specific biota and other features of each shoreline type but are usually not used to rank it according to sensitivity. Common shoretypes in Nigeria are presented in Table 1 based on sensitivity projects in Nigeria and North America (ERML, 1996; NOAA, 1996).

Table 1. Sensitivity Values assigned to common shoreline types in Nigeria.

ESI sensitivity	Shoreline type (includes marine, brackish, and freshwater)
1a	Exposed Rocky Shore or Banks
1b	Exposed seawalls and solid man-made structures
2a	Eroding mud scarp on exposed beach
2b	Exposed wave-cut platforms
2c	Rocky shoals, bedrock ledges
3a	Fine sand beach
3b	Scarps or steep slopes in sand
4a	Medium to coarse sand beach
4b	Sandy bars and gently sloping bank
5	Mixed sand and gravel beach, bar or bank
6a	Gravel beach or bar
6b	Riprap
7	Exposed tidal flat
8a	Sheltered rocky shore or scarp
8b	Sheltered riprap or solid structure
8c	Vegetated steeply-sloping bluff
9a	Sheltered tidal flat of sand or mud
9b	Vegetated low bank
10a	Mangrove swamp
10b	Salt marsh
10c	Brackish/freshwater swamp

Mapping interior/inland habitats

Interior or inland habitats are land-based areas that are not well defined as to sensitivity and ranking. Inland or interior habitats do not have the same history of sensitivity analysis as coastal environments, primarily because spills that occur on land are commonly locally controlled, cleaned up, and replanted. Effects are relatively short lived. Inland habitats in Nigeria previously have been categorized based on image interpretation and publication of 1:250,000 scale maps of Nigeria. These habitats are listed in Table 2 and provide a basis for the initial GIS classification of interior habitats for this effort.

Table 2. Previously designated categories for inland/interior habitats in Nigeria

Category by satellite image interpretation
Urban
Major
Minor
Agriculture
Intensive—small holder, rain-fed
Extensive—small holder, rain-fed
Extensive–small holder, rain-fed with denuded areas
Floodplain
Rain-fed arable crops
Irrigation project
Livestock project
Tree crop plantation
Woodland/shrubs/grassland
Dominant trees/woodland/shrubs, subdominant grass
Dominant grasses with discontinuous shrubs/scattered trees
Grassland
Discontinuous grassland dominated by grasses and bares surfaces
Forest
Undisturbed
Riparian
Montane
Plantation
Teak/gmelina plantation
Wetlands
Grass/sedge freshwater marsh
Shrub/sedge/grass freshwater marsh/swamp
Forested freshwater swamp
Mangrove forest
Salt marsh/tidal flat
Water
Natural water bodies
Canal
Reservoir

Sensitivity parameters for interior/inland habitats

The proposed parameters used to determine the sensitivity of interior or inland habitats are:

- *Persistence of oil and cleanup difficulty:* Persistence is related to several factors, including porosity of the substrate, type, and density of vegetation; amount of surface debris; and proximity to groundwater. Areas that are inherently more difficult to clean (e.g., porous areas of dense undergrowth) have a higher sensitivity than areas easily cleaned. Aquatic habitats (swamps and mangroves) and areas having either fast or slow moving streams are classified as part of the shoreline/coastal habitat classification and not as part of inland/interior habitats.
- *Impact on biota:* Higher sensitivities are related to higher species' (vegetation, mammal, birds, and reptiles and amphibians) density and richness, and the status of the species present (medicinal, protected, endangered, etc). Areas of low species diversity and richness are ranked lower.

Field measurements

The Field Team is comprised of at least one expert each in flora, wildlife, and geomorphology and spends about 4 to 6 hours at a given site to collect the required field data. General and very specific information is collected. General information includes a description of the site, a field sketch, and photographs. All data collected at a site are entered into a series of forms. Specific information to be collected includes parameters associated with oil spill persistence and cleanup difficulty, and biodiversity and potential impacts on biota. Related to *spill persistence and cleanup*, the following data are collected:

- *Type of substrate:* Three samples for grain size and total organic carbon analysis are taken of the top 15 cm of sediment.
- *Presence of near surface groundwater:* Groundwater levels may fluctuate by wet and dry season. Based on observations during the middle of the rainy season, groundwater present within 1 m of the surface is determined by visual inspection of the area noting the presence and level of water in drainage ditches or ponds. If no surface water is visible, a 1.2-m hole is dug at the same three locations described above to determine the type of substrate.
- *Inhibiting penetration layer (top 50 cm):* Clay and silt layers inhibit oil penetration into the sediments. In the same hole as noted above, the observer notes (yes or no) whether there is a clay layer over 10 cm in thickness within the top 50 cm.
- *Surface debris:* The site is visually inspected for the amount of surface debris covering the site, including leaf litter, dead trees, and broken branches.

The parameters to be measured in reference to *biodiversity and potential impacts on biota* include the following:

- *Tree density (stocking):* The population density of trees is determined using the quadrat method.
- *Coverage by shrubs and grasses in the understory:* Percent cover of grasses and shrubs of the understory is estimated using the line intercept method. For shrubs, 2-m diameter coverage is used. For grasses and low-lying plants, a 1-m^2 point quadrat is placed at each 25-m interval. Important, medicinal, protected, and endangered plants are noted. For determination of the vegetation structure, a sketch is made to indicate the height and position of all primary vegetation along the transect.
- *Plant condition:* Each plant species is visually inspected to detect notable levels of fungal or bacterial infestation and defoliation because of disease.
- *Mammal species richness and diversity:* While at the station, all observations of wild mammals are recorded.
- *Bird species richness and diversity:* While at the station, all observations of wild birds are also recorded. To supplement observations, previous records of bird species from the locality are obtained from the literature (e.g., Elgood *et al.,* 1994; Smith, 1966) and from local knowledge. Important, protected and endangered species are noted.
- *Reptile and amphibian species richness and diversity:* While at the station, all observations of wild reptiles are recorded. Previous records of reptile species from the locality are obtained from the literature (e.g., Romer, 1953a, b; Schiotz, 1963, 1967, 1969; Villiers, 1958) and local knowledge. Important, protected, and endangered species are noted.
- *Important, medicinal, protected, and endangered species:* These are recorded in the analyses described above for plants, mammals, and reptiles and amphibians.
- *Special biological features:* Notes of unique or special occurrences of flora or fauna are noted in text format. This includes vegetation condition if particularly damaged or healthy, bird colonies, especially high productivity, etc.

Sensitivity analysis

The methodology below presents the “rules” by which sensitivity is determined using the data collected in the field. These rules are based on the field results and a series of weightings that indicate the relative degree of sensitivity. Weightings are based on professional experience in oil spill response and cleanup. The weightings listed here will be tested by field data, after which these values may be altered.

Four parameters related to spill persistence and cleanup difficulty are measured in the field:

- *Type of substrate:* The top 15 cm is taken for grain size analysis from three core or pit samples.
- *Presence of near surface groundwater:* This is visually inspected at the study site and in three pits dug to 1.2 m if no surface water is visible.
- *Presence of inhibiting penetration layer:* This is inspected and measured in three pits.
- *Presence of surface debris:* Coverage by more than 30% is noted at each site.

In general terms, oil can be expected to persist longer in areas having mud- or loam-dominated sediments, more surface debris and dense vegetation, and with groundwater close to the surface. Surface debris includes leaf and vegetation litter. Areas characterized by a porous substrate underlain by groundwater systems are also sensitive. Oil that enters the groundwater has notably long-term persistence because of limited biodegradation. Additionally in the Niger River delta contaminated groundwater may lead to a health hazard as many communities take their drinking water from shallow wells.

Using the four measured parameters, the weightings defined in Table 3 are applied to define the relative level of sensitivity. The combined results, shown at the bottom of Table 3, indicate a range of sensitivity from low to high that will be incorporated with biologically based parameters to yield final relative sensitivity of the habitat type for these parameters.

In terms of potential impacts to flora and fauna, field analyses include counts of tree density, vegetation coverage, and presence of wildlife. Table 4 provides the weightings involved with each parameter measured and provides the overall biological sensitivity that will be combined with the parameters discussed above to yield the final relative sensitivity for parameters related to biota and biodiversity.

Calculating species richness and diversity

Researchers have proposed numerous indexes of diversity. The simplest measure of diversity is richness (Margalef Diversity; Margalef, 1961):

$$D_a = s\text{-}1/\log N \quad (1)$$

where s equals the number of species and N equals the total number of individuals.

Richness alone does not give the complete picture, since it does not allow differentiation between the diversities of different

Table 3. Rules to determine sensitivity based on oil spill persistence and cleanup difficulty.

Parameter	Weighting	How measured
Type of substrate (top 15 cm) >30% fine-grained or loam = 1 0< 30% fine-grained or loam = 0	1	Field sample taken and measured in lab
Presence of near surface groundwater <1 m = 1 >1 m = 0	2	Field observation, hole, pit, or trench if necessary
Inhibiting penetration layer (top 50 cm) <10 cm (mud/clay) = 1 =>10 cm (mud/clay) = 0	1	Field observation of hole, pit, or trench
Surface debris >30% coverage = 1 <30% coverage = 0	1	Field observation

Valuation of oil spill persistence and cleanup difficulty

Low = 1	Moderate = 2	High = 3
<3	3–4	5

communities with the same s and N. It is also directly related to sample size, with larger samples likely to have more species.

Shannon diversity is used when sampling species abundance from a larger community (Pielou, 1966; Shannon and Weaver, 1949). In this case:

$$H' = (N \log N - \Sigma[n_i \log n]) / N \quad (2)$$

where N equals the total number of individuals and n_i equals the number of individuals in species i (abundance).

Final sensitivity evaluation

Once values based on oil spill persistence/cleanup difficulty and potential impact on biota are determined, a final set of values is calculated to provide the total overall sensitivity. Table 5 presents a summary of the methodology to determine overall environmental sensitivity of inland/interior habitats. As indicated, once values based on oil spill persistence/cleanup difficulty and potential impact on vegetation and animals are obtained for each site in each habitat category, a final sensitivity value for the habitat category is calculated based on the average of each parameter. Sample values are provided in Table 6. These values will be divided into five or more categories based on the range of data obtained from the field. A sample division of sensitivity values is presented at the bottom of Table 6.

Implementation

The program for implementation of this process in the Niger River delta calls a multistage process of data review, collection and analysis, and development of a GIS. The stages are summarized below and Figure 1:

- Acquire base data
- Review literature database for existing data
- Identify/acquire available data
- Evaluate new data sources and enter them into the database
- Incorporate sources into the GIS database structure
- Build first-level GIS
- Field verification
- Plan the field data collection process
- Collect and analyze ESI-relevant data from the field
- Convert field data into GIS database structure
- Build second-level ESI map

This methodology will be first applied to a complete lease area in the Delta and then, using the lessons learned from the experience, will be carried into other lease areas.

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Table 4. Rules to determine sensitivity based on impact to biota.

Parameter	Weighting	How measured
Tree density (average of three 100 m^2 stations) >30 = 2 >10 - <30 = 1 =<10 = 0	1	Measured in the field
% coverage by tree canopy (average of five stations along 100-m transect) >60 = 2 >30–<60 = 1 = <30 = 0	1	Measured in the field
% coverage by shrubs/understory (average of five stations along 100-m transect) >60 = 2 >30–<60 = 1 = <30% = 0	2	Measured in the field
% coverage by grasses/low-lying plants (average of five stations along 100-m transect) >60 = 2 >30–<60 = 1 = <30% = 0	1	Measured in the field
Plant condition % normal (average of measured trees, shrubs and grasses from five stations along 100-m transect) >67 = 1 33–67 = 0 <33 = –1	1	Field observation
Sum of species richness (see below)	3	Observed in the field, supplemented by literature and local information
Sum of species diversity (see below)	3	Observed in the field, supplemented by literature and local information
Sum of important, medicinal, protected, or endangered species (see below)	2	Observed in the field, supplemented by literature and local information

Valuation of potential impact to biota

Low = 1	Moderate = 2	High = 3
<10	10–20	>20

For insert into the table above. ***Species richness*** *(margalef; specific values to be determined after field study)*

	Low = 1	Moderate = 2	High = 3
Plants	<10	10–40	>40
Mammals	<5	5–10	>10
Birds	<10	10–20	>20
Reptiles and amphibians	<5	5–10	>10

Total species richness (sum of low, moderate, and high values)

Low = 1	Moderate = 2	High = 3
<5	5–10	>11

Species diversity (Shannon-Wiener; specific values to be determined after field study)

	Low = 1	Moderate = 2	High = 3
Plants	<3	3–5	>5
Mammals	<2	2–3	>3
Birds	<3	3–5	>5
Reptiles and amphibians	<2	2–3	>3

Total species diversity (sum of low, moderate, and high values)

Low = 1	Moderate = 2	High = 3
<5	6–10	>10

Number of important, medicinal, protected, or endangered species (values to be determined after literature review and targeted field study)

	Low = 1	Moderate = 2	High = 3
Plants	<5	5–10	>10
Mammals	<5	5–8	>8
Birds	3	4–8	>8
Reptiles and amphibians	3	4–5	>5
Others	3	4–5	>5

Total important, medicinal, protected, or endangered species (sum of low, moderate, and high values)

Low = 1	Moderate = 2	High = 3
<6	6–10	>10

Table 5. Inland/interior sensitivity calculation model.

Parameter	Scale	Weighting
Sensitivity to oil persistence and cleanup		
% fine grained sediment	1–10	3
Percent stations having near surface groundwater	1–10	4
Percent stations having 10 cm inhibiting layer within top 50cm	1–10	–1
Percentage coverage of all stations by surface debris	1–10	3
Sensitivity to impact on vegetation		
Number of trees	1–10	3
Number of small trees	1–10	3
Percent coverage by shrubs	1–10	3
Percent coverage by grasses	1–10	3
Tree condition (% normal)	1–10	1
Small tree condition (%normal)	1–10	1
Shrub condition (%normal)	1–10	1
Grass condition (%normal)	1–10	1
Tree species richness (no. species present)	1–10	1
Small tree species richness (no. species present)	1–10	1
Shrub species richness (no. species present)	1–10	1
Grass species richness (no. species present)	1–10	1
Tree species diversity	1–10	1
Small tree species diversity	1–10	1
total species richness (total no. plant species)	1–10	1
Combined total tree + small tree vegetation species diversity	1–10	4
Important, medicinal, protected, or endangered plants (total no. plants all categories)	1–10	4
Sensitivity to impact on animals		
Mammal species richness (no. species present)	1–10	4
Bird species richness (no. species present)	1–10	3
Reptile and amphibian species richness (no. species present)	1–10	2

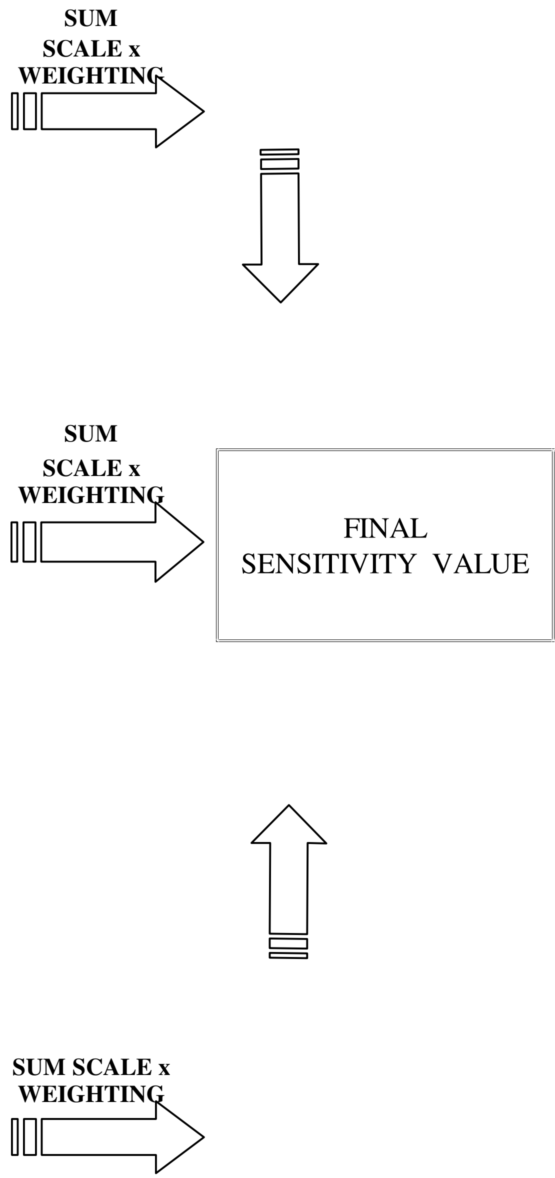

Table 6. Calculation of overall inland habitat sensitivity with sample values.

Parameter	Low sensitivity	Moderate sensitivity	High sensitivity
Oil persistence and cleanup difficulty	9	45	99
Impact on vegetation	34	170	380
Impact on animals	13	65	120
Total	56	280	699

Estimated ranges for five sensitivity categories (low to high) (with sample values)

1	2	3	4	5
56–150	151–220	221–420	421–570	>571

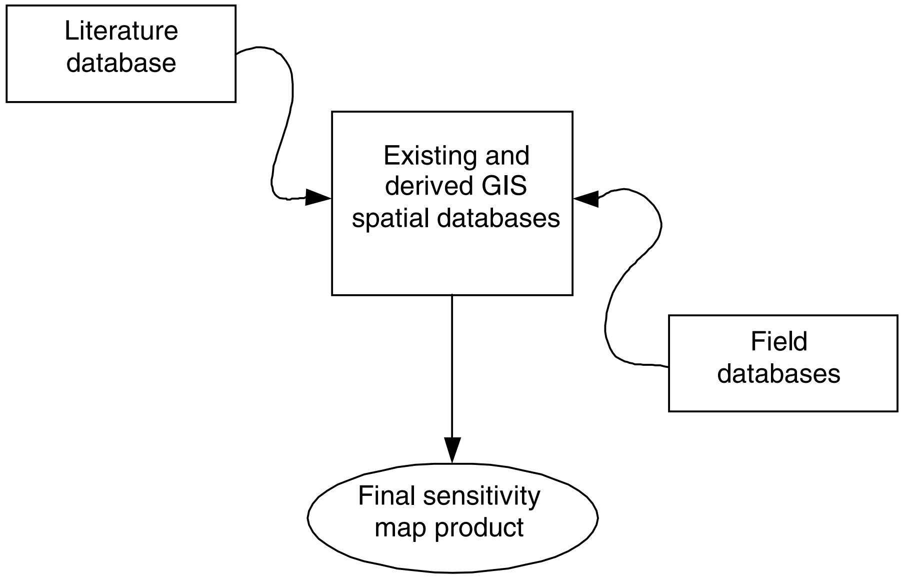

Figure 1. Process of linking existing and field-derived information to develop final sensitivity maps.

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