Sensitivity mapping of particular sensitive areas

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Abstract

The Wadden Sea, a region of tidal flats and salt marshes extending at the North Sea coast of the Netherlands, Germany and Denmark, is of enormous value as a cleansing site for North Sea water, as a nursery for young fish, and as a feeding ground for many bird species. The region is especially endangered by oil spills due to the proximity of important shipping routes and harbours.

Sheltered tidal flats, salt marshes and adjacent estuaries belong to the coast types most sensitive to oil pollution. As it is not possible to protect the entire German North Sea coast at equal levels, oil spill contingency planning requires a more detailed classification. For this reason, based on the results of field and laboratory studies, individual soft bottom habitats and communities (halophytes, macrofauna, meiofauna, microphytobenthos) as well as waterfowl and estuarine biotop types were evaluated and classified according to their vulnerability to oil pollution. The use of a synchronously developed data processing system including GIS allows the application of metadata on different aggregation levels: specific information can serve scientific purposes; information on spatiotemporal vulnerability to oil pollution is highly condensed to four classes to support the practicability of preventive, remedial and response measures. The resulting sensitivity maps are part of the German contingency plan. The basic concept may hold as a useful strategy to differentiate the sensitivity of similar coastal areas with high ecological vulnerability as a whole.

1 Introduction

Aside of the still urgent necessity to increase the security standards of vessels carrying crude oils and its products as well as the necessity to define Particular
Sensitive Sea Areas (PSSA) with regard to special legislative requirements and control, the risk of oil accidents will continue to exist. Consequently the knowledge on coastal sensitivity is not only useful in the control and management of industrial and urban development but also in contingency planning for responses to accidents.

Baker et al. [1] summarized some fundamental aspects concerning “coastal sensitivity mapping”. Among other authors they emphasized the importance of environmental sensitivity as a valuable and useful concept. Foreknowledge of both, sensitivity and vulnerability of habitats is essential to environmental planning and protection and in counteracting and minimizing the impact of unplanned activities. - With the development of an environmental sensitivity index (ESI) for intertidal systems, we tried to find spatial and temporal differences of vulnerability in an area that is highly sensitive as a whole.

1.1 General pollution policy in the FRG

The main topic for marine pollution control in the FRG, is the prevention of any pollution occurring from the marine transport. Therefore it is absolutely necessary to enable the safe and smooth voyage of ships to the German ports and/or through German territorial waters. To achieve this, a dense and sophisticated vessel traffic system has been installed in order

- to assist the master of the vessel in all parts of navigation,
- to recognize and avoid dangerous traffic situations in case of bad weather conditions and
- to control and regulate the traffic,

Furthermore a pilot system is established with the obligatory pilotage of all vessels with dangerous cargoes in bulk except smaller vessels permanently travelling in the respective area.

At sea, and of course on land, highest priority is given to the containment and minimizing of the spreading of spilled oil and the mechanical recovery. In line with the recommendations of the multinational regional agreements for the North Sea (Bonn Agreement) and the Baltic Sea (Helsinki Convention) the general policy about marine pollution control in Germany is oriented on a total recovery capability of

- 15,000 m³ in 14 days for the North Sea and
- 10,000 m³ in 14 days for the Baltic Sea

which is comparable to the maximum spillage of a typical 90,000 dwt - tanker after a slight collision with one wing tank damaged or the grounding with a rupture of two wing tanks and one central tank.

The following parts are integrated in the framework of an edp-aided marine disaster management system REMUS, which is currently under development. They shall give the required information to enable the responsible authorities to react adequately to any accident or pollution without any delay:

- the national contingency plan,
- the equipment and vessels available including their capability and present status,
- the slick movement trajectory,
• several databases regarding dangerous substances,
• the ECDIS (Electronic Chart Display),
• the radar display of the respective area,
• the sensitivity mapping.

Special attention is given to the shoreline of the North Sea with its important tourist industry and high ecological sensitivity along the so called “Wadden Sea”.

2 The Environmental Sensitivity Index for Wadden Sea areas

This area, a contiguous region of tidal flats, barrier islands, alluvial terrestrial zones and salt marshes, about 670 km long and up to 20 km wide, extends along the North Sea coast of Germany, the Netherlands and Denmark. The Wadden Sea is of enormous value as a cleansing site for the coastal water, as a nursery for young fish, and as a feeding and nesting ground for nearly all palaeartic species of wading birds and waterfowl. The proximity of important shipping routes and ports is a permanent threat, especially to the German part of the region, which became a national park in 1985/86. Large quantities of petroleum, for example, which can be spread over wide areas by tides and winds, present not only the danger of temporary damage but rather of permanent harm, since oil, bound to the sediment, is released very slowly and can therefore repeatedly contaminate those parts of the tidal flats that have become free of the oil [2].

Plans for vulnerability or sensitivity indices were firstly developed, among others, by Gundlach and Hayes [3]. They established a concept that was mainly based on spatial geomorphological parameters. In figure 1 the main parts of this concept are depicted. The degree of sensitivity of coastal areas is marked by distinct interactions which occur if they are polluted by oil slicks: a high degree of wave energy will soon reduce the oil coverage of rocky shores and sandy beaches, the correspondingly high content of oxygen will guarantee a fast degradation of the oil. Low hydrological energy in sheltered coastal areas will cause longer-lasting coverage and penetration of sediments, in some cases leading to stable oil-layers in different sediment depths. Both, coverage and penetration, will hinder the oxygen exchange and so enlarge the persistence of pollution. The only biological factor in these assumptions, aside from microbial degradation processes, is the mortality of sensitive organisms. This factor is marked as damage without further differentiation (figure 1). As a result of these conceptual assumptions the following kinds of habitats can be listed in increasing order of vulnerability: 1. Exposed rocky headlands; 2. Erosive wave-cut platforms; 3. Fine-grained sandy beaches; 4. Coarse-grained sand beaches; 5. Exposed tidal flats; 6. Mixed sand and gravel beaches; 7. Gravel beaches; 8. Sheltered rocky coasts; 9. Sheltered tidal flats; 10. Salt marshes and mangrove swamps.

Although this concept could be validated by comparing the results to real effects of several oil accidents, its applicability is limited. Areas which are geomorphologically more or less homogenous, for example the Wadden Sea, contain only a few of the habitats depicted (Nr. 5, 9, 10) and a temporal differentiation is absent.
This situation made it essential to greatly modify the concept for the German North Sea coast because a total protection of the wide spread habitats classified by this model was estimated as being impossible. The areas and seasons of this region for which special protection is required should be identified by including a greater number of ecological parameters. In order to do this, the results of field and laboratory studies could be used (a.o. [4, 5, 6, 7, 8]). They showed that the short and long-term consequences of oil pollution in Wadden Sea areas clearly depend on a much wider range of habitats affected and are determined by both, abiotic and biotic parameters, as interrelationships among toxicity, turbation, and persistence.

![Coastal forms with different degrees of exposure and different morphological characteristics](image)

**Interactions:**
- Wave energy
- Penetration of sediments
- Development of oil-layers
- Degree of biological mortality
- Persistence of oil

**Range of different area-sensitivity to oil pollution**

Figure 1: Concept of spatial oil-sensitivity of coastal forms

Thus a classification of species and habitats was developed which comprised sufficient details to serve scientific purposes and demands of the national park authorities. For use in contingency planning the results of the underlying evaluation were summarized to 4 classes of increasing protection priority in cooperation with experts of oil spill response, coastal ecology and natural resource protection [9].

2.1 Examples for the evaluation of individual categories

All compartments of the evaluation: - sediment-conditions, benthic organisms, fishes, shrimps, birds and saltmarshes - were assigned indices, calculated from individual values. With regard to temporal differences, the values for juvenile fishes as well as values for nesting and resting birds are added to the basic vulnerability class “benthos-sediment” during the months of their presence. Spatial differences were defined by an assignment of the individual class-values to a map of intertidal habitats taking the different radius of action of bird-species
into consideration. Fish and shrimp species, not represented in the following, are similar evaluated like benthic organisms, adding the category “economic value”.

2.1.1 Benthos-sediment

When evaluating the vulnerability of the species and communities to petroleum, giving consideration to their significance in the ecosystems, the following categories were established: 1. physiological sensitivity, 2. ecological sensitivity, 3. importance as food, 4. metabolic importance, 5. capability of dispersal, and 6. duration of reproductive period. Within these categories, every species was assigned a weighted value ranging from 1 to 3, where 1 signified weak or minor, and 3 strong or high. An example is provided in the following evaluation of macrofaunal benthic organisms:

**Physiological sensitivity** was judged according to the experience gained by research in situ and in vitro. This scale includes the following levels:

1 - Species with little change in abundance after exposure to petroleum.
2 - Significant decline in abundance.
3 - Very significant decline in abundance.

**Ecological sensitivity** can be determined by observing settlement patterns and food consumption:

1 - Endobenthic sand dwellers, substrate feeders, or predators.
2 - Sand flat dwellers that feed on the surface, nonfiltering inhabitants of mixed sand and mud flats, and residents of mud or sandy mud flats that can tolerate oxygen deficits.
3 - Predators with tentacles, filter feeders, and species that live on the surface of mud flats.

The average weight of macrofaunal biomass in the Wadden Sea amounts to about 27g ash-free dry weight per m². Almost 99 percent of this, about 26g, was accounted for by only 14 species. Relying on the average weights of the dominant species in the biomass, the importance as food of the macrofauna species was estimated according to the following scale:

1 - Species with less than 0,1g ash-free dry weight/m² that are rarely preyed upon.
2 - Species with less than 0,1g ash-free dry weight/m² that are frequently preyed upon by fishes or birds.
3 - Species with greater than 0,1g ash-free dry weight/m².

Several species increase the oxygen supply in the sediment by their movements, while certain sediment and epistrate feeders have a controlling or destructive effect on populations. The following levels were used for the criterion metabolism of organic substances:

1 - Inhabitants of detritus-poor sand sediments or suspension feeding sessile species.
2 - Species active in bioturbation with feeding habits that scarcely contribute to the breakdown of organic substances.
3 - Substrate and epistrate feeders greatly active in bioturbation.
In the recolonization of tidal flats, very mobile species and those with planktonic larval stages have an advantage. The following scale is used for evaluating the dispersal capability of species:

1 - Actively swimming species with a life history that includes a planktonic larval stage.
2 - Actively swimming species that develop in the benthos.
3 - Species with a limited locomotory capability without planktonic larval stages.

Duration of the reproductive period is an additional criterion to consider. Species that produce larval stages for long periods of time have an advantage in being able to rapidly resettle unpopulated areas, as reflected in the following scale:

1 - Reproduction throughout almost the entire year.
2 - Reproduction during four to six months of the year.
3 - Reproduction during one to three months of the year.

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Figure 2: Relationships among the values influencing the compartment “benthos-sediment”.
The index for the compartment “benthos-sediment” is calculated by regarding the arithmetic values for individual species, their estimated abundance and the sediment conditions at corresponding locations according to van Bernem et al. [9]. Figure 2 shows the conceptual relationships among these parameters.

2.1.2 Bird populations
Of the nesting bird species mainly present, 13 proved especially vulnerable. A “minimum breeding pair” number is assigned only to these species. The distinction between “suspicion of breeding” and “proof of breeding” provided other qualitative differences. All three qualities were assigned weighted values according to the model used for benthic organisms and fishes:

1 - Suspicion of breeding.
2 - Proof of breeding.
3 - Reaching or exceeding the minimum number of breeding pairs.

The abundance of non-nesting species that usually might occur can reach or exceed a predetermined minimum. Because the qualitative criterion “suspected” is discarded in this category, only two values remain:

2 - Proof of presence.
3 - Reaching or exceeding the minimum abundance.

For the collective evaluation, the individual class values for each month were added, and the sums were assigned new class values ranging from 1 to 4.

The highly sensitive moulting population was assigned a class value directly, without arithmetic calculations.

2.1.3 Saltmarshes
Based on research on the sensitivity of halophytes to petroleum [8], evaluation criteria for the individual species were also developed comparably to those for the other compartments represented.

Area of contact: Weighted values were 1 = small, 2 = medium, and 3 = large.

Position of the regenerative organs: 1 = underground (geophytes), 2 = more than 50 cm above the sediment-surface, 3 = 10 to 50 cm above, 4 = 1 to 10 cm above (hemicyryptophytes), 5 = plants forming rosettes, and 6 = small (therophytes). Position of regenerative organs and location of new shoots after oil contamination were considered.

Physiological reaction: 1 = little, 2 = medium, 3 = strong, and 4 = very strong.

Regeneration: 1 = very rapid, 2 = rapid, 3 = medium, 4 = slow, and 5 = no regeneration.

Degree of endangerment: 1 = low, 2 = medium, and 3 = high (evaluation of the exposure to harm in case of an accident, the main zone of endangerment is assumed to extend as far as the mid-tide level or a little beyond).

The points in the individual evaluation criteria are added and the sum is divided by the number of criteria (5). The quotient is assigned to one of eight classes corresponding to particular indicator values [8]. For areas subject to grazing by cattle, this species sensitivity index is increased by two points, because contamination is intensified in the absence of protective leaf cover. To give proper emphasis to the population density distribution of each species, a
community vulnerability index was employed which is calculated according to the food value method of Klapp [8]:

\[
CV_i = \frac{\text{distribution of species} \times \text{vulnerability value}}{\text{total settlement density}}
\]

The value for oil sensitivity of the specific kind of plant association (CVi) calculated by this method is then placed in one of four classes scaled according to vulnerability.

2.1.4 General evaluation

By summarizing the class values achieved according to the compartments demonstrated above (1-4 each), a maximum of 12 points can be obtained (benthos-sediment + fishes + birds + saltmarshes). This range is additionally divided into 4 classes, indicated by different colors on the sensitivity maps. Thus the general spatiotemporal vulnerability is fixed, but can be secured regarding the vulnerability of individual compartments, or, in the case of still existing doubts, by reverting to the fundamental values and data, making use of WATiS. (examples of different thematic maps are accessible via internet URL: w3g.gkss.de/watis/skoeli/skoeli.html).

2.2 The data base and the Wadden Sea Information System (WATiS)

The derivation of a sensitivity index was not done for short term evaluation, but should serve for a longer period. Thus data management is supposed to play an important part for long term and flexible usage. Profound data management begins with data taking, describes data, and stores data for short and long term periods and allows various evaluations. These objectives for data management, also true for this project, were achieved with the Wadden Sea Information System [10].

Data evaluation in research is generally not a fixed method but more a process of “finding the best way”. In this context data management has to make several attempts of evaluation feasible. This flexibility needs an appropriate concept of data structuring. A project-oriented data management realized within WATiS, allows for a new task, which often coincides with a new project, new data structures. This project-oriented data structure is capsulated from each other project but on the other hand strictly connected to all other data by common metadata, i.e. data describing these data, and by a common representation of georeferences via a name triplet.

Metadata gives more information and understanding than pure numbers. It has two main aspects. First it is the key for understanding data within a database and it secondly enables a user to find data of interest. In WATiS the latter is possible by questioning a project with a specific location, time, or theme. The data are easier to understand with additional general descriptions of the project, methods used, and all parameters involved and used within the tables.
For the sensitivity index WATiS deals with point measurements, paths of observation and areas of sensitivity. All these kinds of georeferencing the data are handled in special “internal projects” on locations (ORTE). The coupling to the specific project data, here the sensitivity study, is done via a location name triplet: projectname, position, and data of location definition. Within the internal project ORTE all coordinates and necessary structures are managed and an interface for transfer of all topological data to and from the GIS ARC/INFO is provided.

The GIS is used for map and topology creating, manipulating and plotting. For example the sensitivity index for the entire Wadden Sea area is plotted. All data are available online and a piloting system, which uses the metadata, helps to find the interesting data. The capability and flexibility of the data management system WATiS enables also an integration of data in further computer supported decision systems like the above (1.1) mentioned REMUS.

3 Conclusions

The high variability of complex biological interactions causes large statistical and systematical errors which make it impossible to realistically reflect nature using complex simulation models. An adequate correspondence with reality, however, is a prerequisite when considering the tolerance of ecosystems to man made disturbances and countermeasures. If we restrict the underlying problems to soundly investigated systems, simplified qualitative conceptual models can be a very helpful tool when considering ecological topics in decision making processes. These “idealizing” models help to clarify principles and trends which can be validated by means of empirical findings [11].

This vulnerability study was specially prepared for the Wadden Sea with regard to its ecological characteristics and established research data. It has been put into practice as part of the German Oil Spill Contigency Plan. As an operational model it demonstrates the possibility to establish gradual differences of morphologically similar areas to oil pollution if we possess a sound knowledge of the oil-sensitivity of species/communities/habitats and their distribution in space and time. However we need monitoring at systems-dependent scales to adapt the evaluation to environmental changes.

The methods developed provide the possibility of putting the necessary data from field investigations to use with very little supplemental effort. They also permit further refinements of the evaluation technique, the assignment of values to the basis data, and the determination of the interrelationships among the different data groups. It is possible to confirm the importance attached to the individual data and the influence of evaluation procedures on final conclusions. In this way, a comprehensive concept of plausibility can be developed with a view towards the practical needs of the user. To find the parameters that reflect differences in an environment that is generally highly sensitive ecologically, it was found necessary to rely on the largest set of data that could be assembled and to involve representatives of science, natural resource protection, and oil spill response units. A summary of all available general information has been provided for contingency planning to give a basis for precaution measures and
permit a quick reaction to oil spills. Temporal and spatial peculiarities within the ecosystem can be considered using the specific information in the data base or provided by specialist consultants. Furthermore, the system can impart a detailed set of pertinent facts to scientists and governmental agencies.

References


