Environmental Sensitivity of the Portuguese Coast in the Scope of Oil Spill Events – Comparing Different Assessment Approaches

C.F. Santos† and F. Andrade‡
†Guia Marine Laboratory
Sciences Faculty of Lisbon University
Laboratório Marítimo da Guia, 2750-374 Cascais, Portugal
cat_frazao_s@yahoo.com
‡ Oceanography Centre
Sciences Faculty of Lisbon University
Laboratório Marítimo da Guia, 2750-374 Cascais, Portugal
f.andrade@mail.telepac.pt

ABSTRACT


Oil spills can be one of the most damaging agents for coastal environments. The frequency at which oil spills have occurred, together with the hazardous environmental, cultural and socioeconomic impacts they cause, demonstrate the crucial need of management and prevention tools for the efficient resolution of such situations. Worldwide, especially during the last decade, a large number of projects have dealt with the assessment of coastal sensitivity in the scope of an oil spill event. The Portuguese coastline is highly at risk of being impacted by an oil spill due to the intense commercial vessel traffic that crosses the Portuguese Exclusive Economic Zone and Territorial Waters, and to its climatic and physiographic features. Its vulnerability relates both to the intense human use of the Portuguese coastal areas, and to the presence of important natural values. Despite these aspects, Portugal does not have a decision support tool that can be used in the event of a major oil spill. The main objective of the present work is to identify the best coastal sensitivity assessment approach for Portugal, in the scope of an oil spill event. Two different methods are compared: sensitivity maps and algorithm based sensitivity models. The development process and potential for use of these approaches in the Portuguese situation are considered and discussed. Although both approaches are viable to assess coastal sensitivity and the corresponding protection priorities, the proven feasibility and effectiveness of sensitivity maps grant them an operational advantage.

ADDITIONAL INDEX WORDS: Shoreline vulnerability, Hydrocarbons, Coastal management, Pollution, GIS

INTRODUCTION

Coastal environments have a high ecological, socioeconomic and cultural value, while being highly vulnerable to a wide range of impacting agents, whether natural or man induced. Within coastal hazards and pollutants, oil spills are among the most damaging. Their impacts vary according to a range of factors, from spill size and physicochemical characteristics of the oil, to weather conditions, namely winds and currents (The International Tanker Owners Pollution Federation, 2002). Specificities of the impacted areas are also a distinctive factor: in most cases, when the oil reaches the shoreline, impacts are more significant than if the spill is contained at sea; in addition, if sensitive biological or human-use resources are present in the impacted shoreline, the effects will be more damaging. A third aspect relates to the time before response and restoration actions take place, i.e., if they occur almost immediately after the spill, the impacts will not be as negative (JENSEN et al., 1998; DICKS, 1999; DICKS and WRIGHT, 1989).

Since oil can enter the natural environment through several paths, and the majority of spills cannot be avoided, the existence of management and prevention tools is crucial for a fast and well-organized response and solution of such situations (International Petroleum Industry Environmental Conservation Association, 2006), thus minimizing the hazardous environmental, cultural and socioeconomic impacts this polluting agent can cause.

In order to define priority protection areas, information on coastal environments must be available, and pre-existing characterization studies on coastal resources and subsequent assessment of the shoreline sensitivity provide the base information needed to develop accurate contingency plans (International Petroleum Industry Environmental Conservation Association, 2006; JENSEN et al., 1998).

The assessment of coastal sensitivity in the scope of oil spill events was started in the 1970’s in the U.S.A. (GUNDLACH and HAYES, 1978) and has evolved since then, mainly due to technology improvements; namely, Geographic Information Systems (GIS) and Remote Sensing techniques (EL-RAEY et al., 1996; KRISHNAN, 1995; JENSEN, 1990; DICKS and WRIGHT, 1989). Worldwide, a large number of projects have dealt with this field of research, especially during the last decade (SANTOS, 2008), showing the increasing importance of coastal sensitivity assessment.

The Portuguese coast faces a high risk of being impacted by an oil spill inside, or in the vicinity of, its Exclusive Economic Zone (MELO et al., 2002). In addition, the intense human use and occupation of the shoreline, together with the presence of high natural values along the coast (Ferreira, 2005), contribute to the high vulnerability of the Portuguese shoreline. An operational decision support tool – not yet developed – is, therefore, essential to the correct management and protection of coastal resources in Portugal.

The main objective of the present work is to identify the best coastal sensitivity assessment approach for the Portuguese coast, in the scope of an oil spill event, through the comparative analysis of two different methods: sensitivity maps and algorithm based sensitivity models.
METHODS

Sensitivity Maps

The use of sensitivity maps to assess coastal sensitivity in the scope of oil spill events started with the “Environmental Sensitivity Index (ESI) Maps” project (PIERSON et al., 2002). This was a pioneer project and many of the following sensitivity maps developed at a worldwide level built on it (BAKER et al., 1995). ESI maps have shown – for more than three decades of use – an immense functionality and effectiveness, which make up the major reasons to assess their potential of use in the Portuguese case study.

The main objective of sensitivity maps is the a priori identification of the most sensitive coastal resources, so that protection priorities and clean-up strategies can be established beforehand (JENSEN et al., 1998).

ESI maps comprise three general types of information (PIERSON et al., 2002; JENSEN et al., 1998): shoreline type, biological resources, and human-use resources. In the ESI approach, shoreline type is the only type of information with an attached range of sensitivity values – the sensitivity index itself. All three types of information are mapped over a topographic base and organized into atlases.

Although information is always developed and compiled in digital databases using GIS techniques, sensitivity maps can be provided in two main formats: hard copy (colour paper maps organized into volumes) and digital, on-screen (GIS environment – ArcView). While in the first format accessory information (e.g., species names, legal status and seasonality) is listed on the back of each map, in the second, the information is accessed in the GIS database. In addition, sensitivity maps in GIS format can be used together with oil spill transport and dispersion models. Knowing the spill trajectory, size and characteristics, it is possible to predict, at any moment, the potential impact areas and, through the analysis of the different data layers, their overall sensitivity in view of the three types of general information used.

The development of sensitivity maps is an extensive and complex process, especially in what relates to data collection, compilation, standardization and mapping. Each type of information has its own specificities pertaining to the collection and compilation processes, which are discussed next.

Shoreline Type

A vast list of shoreline types was created and has been expanded since the development of the first ESI maps. Taking in account the relative degree of exposure to wave and tidal energy, shoreline slope, substrate type and biological productivity of different coastal environments, a rank was developed to illustrate the relative shoreline sensitivity to oil spills (PIERSON et al., 2002; JENSEN et al., 1998).

Using both aerial surveys and field data, the different coastal habitats along the shoreline are identified and delimited into topographic base maps. In order to produce a shoreline classification, a sensitivity value is attributed to each identified habitat. The range of values varies from 1 (lowest sensitivity) to 10 (highest sensitivity). Within each sensitivity class, subdivisions can be considered (e.g., 10A, 10B and 10C – “A” corresponding to the highest sensitivity and “C” to the lowest).

The mapping process is achieved using coloured lines or polygons (according to the width of each coastal environment) to represent the different shoreline types, and a standardized colour code is associated to each sensitivity value/class.

In addition, some subtidal habitats (e.g., coral reefs, bed rock reefs and submersed aquatic vegetation), either especially sensitive to oil spills or that are used by oil-sensitive species, are also identified and mapped, although not included in the sensitivity index (PIERSON et al., 2002; JENSEN et al., 1998).

Biological Resources

Unlike shoreline type, the ESI system does not include the need for specific field studies to gather information related to biological resources. Instead, information from scientists, resource managers and experts is used. In joint meetings, the most sensitive communities are identified and recognized, as well as their distribution patterns and other characteristics (e.g., seasonality, densities, individuals’ behaviour, most sensitivity life stages and their dependence on the shoreline) (PIERSON et al., 2002; JENSEN et al., 1998).

Maps including the complete distribution ranges of a large number of species will not constitute significant management tools, since they will have poor legibility (PIERSON et al., 2002). Therefore, the selection of a smaller number of species is more adequate, i.e., the ones with a higher vulnerability/sensitivity to oil spills or to the disturbance caused by clean-up activities. The objective is to identify: large concentrations of individuals or species; sensitive life stages and activities (e.g., early life stages and nesting activities); threatened, endangered or rare species and; species of commercial/recreational importance.

The biological resources to be mapped are then divided into different elements/categories according to functional or large taxonomic groups (e.g., birds, reptiles and mammals). Each of these elements can also be divided into sub-elements according to taxonomy, morphology and/or behaviour towards oil (e.g., division of the mammals into manatees, pinnipeds and polar bears). The mapping process is accomplished using coloured polygons and points, together with standardized colour symbols each identifying an element/sub-element.

Human-use Resources

The same expert meeting process is also used to gather information pertaining to human-use resources. These resources are divided into four categories (PIERSON et al., 2002; JENSEN et al., 1998): high-use recreational and shoreline access locations, management areas, resource extraction locations, and cultural resource locations.

High-use recreational locations include high-use recreational beaches, surf, kitesurf and windsurf areas, sport-fishing areas, and scuba-diving sites. Shoreline access locations must take into account ports, marinas, other boat ramps and access points for response activities. Management areas must comprise all coastal locations with legal protection status, either national or international. Resource extraction locations include aquaculture, commercial and subsistence fisheries, and water intakes. Finally, cultural resource locations comprise archaeological, historical and other sites of religious or cultural importance in the intertidal zone, or in other areas that can be directly impacted by the spill or disturbed by clean-up actions.

For each of these resources and corresponding locations, a responsible entity and an emergency contact must be identified.

The mapping process uses polygons and points together with standardized symbols which identify each type of resource.

Algorithm Based Sensitivity Models

The main objective of an algorithm based sensitivity model is to produce a sensitivity value that reflects simultaneously the environmental, socioeconomic and cultural importance of different shoreline units, thus allowing for the definition of priority protection areas (Edisoft, 2006). To accomplish this objective, the model must integrate a group of criteria (to which different standardized and
weighted variables are attached) into an algorithm, to produce the corresponding numerical sensitivity value.

Integration of the selected criteria is both an essential and a problematic process, since it conditions the model’s functionality (SANTOS, 2008). If the criteria are not properly integrated, the sensitivity value produced will not reflect the actual situation, and consequently will not be significant for the management of the corresponding area.

The length of different shoreline units is also a key aspect, and several possibilities can be considered, among which, segmentation based on morphologic or administrative criteria (resulting in the definition of shoreline units with varying extension), or the creation of equal size units (Edisoft, 2006). Inland extension of the units is another issue, since it must reflect the potential extension of impacts. Still, since each unit will receive a single numerical sensitivity value, variability within unit will be lost, which implies that units must correspond, as much as possible, to homogeneous coastal sectors. Based on different projects on coastal sensitivity assessment (e.g., CARVALHO and GHERARDI, 2008; SCHILLER et al., 2005; LENTING et al., 2004; MOSBECH et al., 2004; TYLER-WALTERS and LEAR, 2004; VAN BERNEM et al., 2000, and WESLAWSKI et al., 1997) and the recommendations from the projects INFOZEE (MELLO et al., 2002) and OceanEye (Edisoft, 2006) – which addressed coastal sensitivity modelling in Portugal – several criteria were identified. Subsequently, the most informative and relevant criteria were selected and compiled (SANTOS, 2008). It became clear that these criteria need to be complex enough, to include the natural, socioeconomic and cultural variability of each shoreline unit, and simultaneously be simple and objective, so that they can be easily and effectively integrated into a numerical algorithm. While the relevance of some criteria could be easily assessed and weighted, for others that was not so evident.

Coastal Morphology
For each shoreline unit, coastal morphology influences both the maximum extension of the impacted area, and its natural clean-up potential. A group of variables can be used, including: maximum tidal range, tidal and wave energy, coastal topography, substrate type, and coastal dynamics. Some of these variables may have a dual, and opposed, contribution to coastal sensitivity. Tidal and wave energy, for example, can promote the natural clean-up of the shoreline and, simultaneously, the upshore and inland deposition of the oil.

Natural Values
The criterion ‘Natural values’ relates to the presence of important and vulnerable habitats or biological resources in each shoreline unit. It takes into account a group of variables: biological groups and habitats, legal protection status, and ecosystem ecological quality. The first two variables must be ranked, respectively, according to their sensitivity to the oil spilled, and relative importance.

The ranking process of different biological groups is complex and subjective, and so is the definition of the ecological quality of any given site.

Human Activities
This criterion corresponds to the socioeconomic and cultural human dependence on the marine and coastal environments. Again, a group of variables must be considered: human-use resources, marine and coastal dependent activities, and planning options defining pending specific uses.

Identification, quantification and standardization of the actual and potential uses of a shoreline unit, as well as its socioeconomic, cultural and historical value can be difficult.

Mitigation/Intervention Potential
‘Mitigation/intervention potential’ should correspond, for each unit, to the actual intervention possibilities in an oil spill scenario, plus the operational limitations of use of response methods. The following variables are considered: shoreline accessibility, available clean-up methods, and substrate removal capacity.

For any given place, actual intervention potential depends on its degree of accessibility, i.e., if the cleaning methods cannot reach the shoreline the intervention potential is null. The actual clean-up potential is also a distinctive factor: an oiled salt marsh cannot be easily cleaned due to both poor accessibility and risk of further damaging the affected environment. Therefore, it is also necessary to indentify the suitability of the available cleaning methods to the shoreline specificities, and then standardize the information.

Spill Characteristics
Spill characteristics correspond to the singularity of each oil spill. The following variables are considered: oil type, spill size, distance to the shoreline, and weather conditions.

The type of impacts from an oil spill varies according to its own characteristics (e.g., oil properties, volume spilled and spill location) and the surrounding conditions, especially, wind, currents and wave regime. Knowing the spill dimension, trajectory and physicochemical potential impacts, the situation significance can be assessed.

RESULTS
Table 1 compares the logical model for each of the two coastal sensitivity assessment approaches discussed: sensitivity maps vs. algorithm based sensitivity models.

ANALYSIS
The aim of sensitivity maps (according to the ESI system) is the cartographic representation of vulnerable shoreline resources. Based on that information, protection priorities are assessed and established by the responsible entities. To achieve this data, for the three general types of information must be collected and compiled: shoreline type, biological resources and human-use resources. The most sensitive data are then mapped.

By contrast, the aim of algorithm based sensitivity models is the automatic production of a relative sensitivity value for each shoreline unit, integrating both its environmental, social and economic value; and the actual conditions of a given oil spill. Such a sensitivity value should allow for the corresponding ranking of protection priorities. This process requires the selection, standardization and weighting of the criteria to be integrated into the algorithm previously to actual data collection and compiling.

After summarizing the specificities of the two approaches, the potential of use of each of them in the Portuguese case must now be analysed.

Sensitivity Maps
The first step to develop sensitivity maps for the Portuguese coast will be the collection of the three types of general information – shoreline type, biological resources and human-use resources – according to the methodology used in the ESI system.
Table 1: Main characteristics of the two analysed approaches concerning coastal sensitivity assessment in Portugal.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Objective</th>
<th>Process</th>
<th>Results</th>
<th>Protection Priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity maps</td>
<td>Identification of the most sensitive resources present in the shoreline.</td>
<td>Data collection and compilation on coastal resources (physical, biological and socioeconomic); Hierarchical mapping of the most sensitive data.</td>
<td>Cartographic representation and valuation of the potentially impacted coastal resources.</td>
<td>Priority protection of the most sensitive coastal resources – as assessed by the responsible entities, based on the information available on the sensitivity maps.</td>
</tr>
<tr>
<td>Algorithm based sensitivity models</td>
<td>Production of a sensitivity value for each shoreline segment/unit, which reflects its environmental, social and economic value.</td>
<td>Data collection and compilation on coastal resources (physical, biological and socioeconomic); Selection of criteria and variables to integrate into a unique algorithm; Standardization and weighting of the criteria.</td>
<td>Dynamic relative sensitivity value for each shoreline unit.</td>
<td>Priority protection of units with higher sensitivity values – automatically assessed by the algorithm, according to a pre-defined sensitivity scale.</td>
</tr>
</tbody>
</table>

The ESI shoreline type list must be analysed and adapted to the Portuguese specificities. While some categories (e.g., mangroves) will be excluded, others must be added and correspondingly mapped; such as coastal dunes, common along the Portuguese coast (Ferreira, 2005) and highly sensitive to oil spills.

According to the ESI methodology, an effort must be made in order to identify the Portuguese entities, with the relevant expertise, to be involved in the gathering process of biological and human-use resources information. For biological resources, a good starting point should include both environment protection and conservation agencies, and the academic world. For human-use resources, local government bodies and information available in characterization studies of planning instruments may be a good starting point.

Although for certain coastal areas some of the information will be easily available (e.g., protected areas), for other areas, even if contiguous to the first ones, information is scarce and inaccurate. In addition, some of the available information is out of date, which will also be a constraint.

Finally, Portuguese IGeoE (military geographical institute) topographic maps and navy charts (at a scale of 1:25000 or 1:50000) can be used as the sensitivity maps’ topographic base, or larger scale available maps can be used for specific locations. A new base map can also be digitized.

Algorithm Based Sensitivity Models

Once the algorithm’s weighting and standardization factors are defined for the different criteria, all the required information must be collected and compiled.

Given that the information available is heterogeneously distributed along the coastline, an extensive and adequate database must be developed. This database must integrate all the variables in the algorithm. Since developing the starting platform for an extensive database is a complex and difficult task, an alternative option can be the use of pre-existing data, together with the development of field studies solely for the areas where information is insufficient.

While information for some of the criteria (e.g., coastal morphology and spill characteristics) is likely to require field work, other (e.g., natural values, human activities and mitigation/intervention potential) can likely be gathered through literature research.

DISCUSSION

Each of the approaches considered (sensitivity maps and algorithm based sensitivity models) has its own advantages and disadvantages – both during the development and implementation processes – although some are more relevant than others.

Sensitivity maps have a long history of effectiveness and success (they were first developed in the 1970’s) in a wide and diverse extension of coastal areas, which is clearly an advantage. In addition, they provide an objective and synthetic view of decisive information which is also an advantage, since it facilitates the decision making process. The main disadvantages of sensitivity maps are the lack of a pre-defined ranking system for the sensitivity of biological and human-use resources and the need of expert interpretation to define areas of prioritized protection. These disadvantages can be overcome by the previous development of general contingency plans and the subsequent addition of specific information related to each event (e.g., oil type and spill size, presence of species in a nesting period, time of the year and high-use beaches).

The use of an algorithm based sensitivity model produces a computed value that corresponds to a protection priority rank, which is an advantage, since it makes the assessment process quicker and less subjective. The main disadvantage of this approach comes from the fact that the sensitivity value for each coastal unit reflects an "average" contribution of each criterion and its variables. Segmentation into units may not allow for the identification of important values which otherwise would constitute a protection priority. The viability of an algorithm based sensitivity model will also depend on the fact that the definition of protection priorities is automatic and non-personal, which may generate conflicts amidst the decision makers. This disadvantage may be overcome by also identifying the key criteria/variables behind each sensitivity value computed.

If, on one side, the use of an algorithm based sensitivity model provides a unique sensitivity value for each shoreline unit and oil spill event, the assessment process, in itself, is not adaptive. Also, the quantification and numeric integration of the criteria and variables into the algorithm comprises a great complexity degree which may imply a long process.

By contrast, although sensitivity maps are an adequate means to provide crucial information, they require an interpretation in order to define prioritized protection areas. Although said interpretation may allow for subjective reading, it is usually carried out by the best experts. In addition, the proven feasibility and effectiveness of sensitivity maps (which reflect the maturity of this approach) grant them an operational advantage.
CONCLUSION

Oil spills can be extremely harmful, both to the environment and to society, especially when the spilled material reaches coastal areas. In order to prevent and minimize their impacts, an effort should be made to improve prevention and intervention tools, and their effectiveness. Pre-existing information on coastal resources, and prioritized protection areas allow for a faster response and a better distribution of the protection and clean-up efforts, thus allowing for a correct coastal management. Portugal is at high risk of being impacted by an oil spill occurring in or near its coastal areas. For that reason, the existence of a decision support tool for the assessment of coastal sensitivity and subsequent definition of protection priorities is critical.

A comparative analysis of sensitivity maps and algorithm based sensitivity models, and their potential of use in the Portuguese context showed the advantages and disadvantages of each approach. Considering all the discussed aspects, and although not assuming the character of a deterministic conclusion, the development and use of sensitivity maps (with their proven feasibility and effectiveness) appears to be potentially more effective for the assessment of the Portuguese coastal sensitivity.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Jacqueline Michel, Jill Petersen and Ed Levine for all the effort and help in understanding the ESI system and other aspects of oil spill response. As well, to all the staff from RPI and NOAA-OR&R Sand Point, Seattle. To FLAD/IMAR for the financial support to visit the previously referred entities. To Camila Henriques, Margarida Ferreira and Rui Carvalho for all the help in the development of this paper.

LITERATURE CITED


