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Combining Conservation Value, Vulnerability, and Effectiveness of Mitigation Actions in Spatial Conservation Decisions: An Application to Coastal Oil Spill Combating

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Abstract Increasing oil transportation and severe oil accidents in the past have led to the development of various sensitivity maps in different countries all over the world. Often, however, the areas presented on the maps are far too large to be safeguarded with the available oil combating equipment and prioritization is required to decide which areas must be safeguarded. While oil booms can be applied to safeguard populations from a drifting oil slick, decision making on the spatial allocation of oil combating capacity is extremely difficult due to the lack of time, resources and knowledge. Since the operational decision makers usually are not ecologists, a useful decision support tool including ecological knowledge must be readily comprehensible and easy to use. We present an index-based method that can be used to make decisions concerning which populations of natural organisms should primarily be safeguarded from a floating oil slick with oil booms. The indices take into account the relative exposure, mortality and recovery potential of populations, the conservation value of species and populations, and the effectiveness of oil booms to safeguard different species. The method has been implemented in a mapping software that can be used in the Gulf of Finland (Baltic Sea) for operational oil combating. It could also be utilized in other similar conservation decisions where species with varying vulnerability, conservational value, and benefits received from the management actions need to be prioritized.

Keywords Conservation · Management · Prioritization · Vulnerability · Sensitivity · Recovery · Oil spill · Valuation

Introduction

Increase in the transportation of oil and severe oil accidents such as the 1999 Erika in France and the 2002 Prestige in Spain have led to the development of numerous oil sensitivity or vulnerability maps of coastal and offshore areas in many countries all over the world. Since the classification of coastlines according to their vulnerability to oil spills was first suggested by Gundlach and Hayes (1978), various approaches have been used in sensitivity mapping. The first maps were based on the physical characteristics of shorelines (Owens and Robilliard 1981; Thomas 1986; Tortell 1992) while ecological consequences have been given a more central focus since the 1980s (e.g., Carter and others 1993; Safetec UK 1999; Hanna 1995; IMO/IPIECA 1996; Nansingh and Jurawan 1999; MacDonald and others 1999; Mosbech and others 2000; Petersen and others 2002; Tyler-Walters and Lear 2004; Brude 2005; Zacharias and Gregr 2005).

While the primary aim of oil combating is to stop the leakage and the spreading of oil, it is also extremely

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important to minimize the effects on the nature values. The decisions concerning the areas that should be safeguarded must be made quickly after an accident, especially when the marine shipping lanes run close to the shoreline. These estimates require a thorough analysis and must be available for such units which can be safeguarded with booms as there is usually only little time to consult experts specialized in different species or certain populations. Since the operational decision makers usually are not ecologists the evaluation procedure must be presented in a readily comprehensible form so that its results can effectively be utilized in operational oil combating.

Whilst weighting of species is a common procedure in the environmental risk assessment and the selection of conservation areas (Early and Thomas 2007) the oil spill contingency planning seems to often lack such an approach. Sensitivity mapping has often focused on collecting spatial data on the species or habitats that are economically important, are considered to be most vulnerable to marine pollution, or are plainly regarded as charismatic species. Also the selection method may have been unclearly defined (Mosbech and others 2000; Petersen and others 2002). This means that e.g. birds and pinnipeds are usually well represented while other taxa such as invertebrates or macrophytes are included only as a part of conservation areas. This may be due to the limited knowledge about the less well known taxa or alternatively such taxa may simply have been overshadowed by the more charismatic and/or economically valuable species. Evidently there is a need to clarify the selection process by utilizing ecological knowledge, international agreements and national legislation in prioritization between different species.

Once the oil is spilled, the proportion of population that will be exposed to oil is dependent on the behavior and location of the species, the environmental conditions such as the sea level, wind direction and wind speed affecting the wave height and the behavior of oil after the spill. When exposed to oil organisms can suffer from physical effects (e.g. smothering) and/or chemical effects due to toxic substances some species being more tolerable than others (Pezeshki and others 2000; Klerks, Nyman and Bhattacharyya 2004; Perkins, Rhoton and Behr-Andres 2005; Morales-Caselles and others 2006; Alonso-Alvarez and others 2007).

To date only few sensitivity maps have accounted for the recoverability of species following an oil accident (Mosbech and others 2000; Cooke and McMath 2001; Tyler-Walters and others 2001; Offringa and Lahr 2007) although it clearly should be one of the focal points in decisions regarding the operational oil combating. As the recovery of a species is dependent on its intrinsic features, oil spills are likely to have a relatively small impact on the populations of common species in the long term (e.g., a decade after the accident) (Lee and Page 1997; Kingston 2002; Nikitik and Robinson 2003; Juntunen and others 2008; Lecklin and others unpublished data) unless they have a clustered distribution pattern and thus a large proportion of the population can be contaminated by oil even after a small accident (Ford and others 1982). In contrast, recovery is often slow and uncertain for populations of rare species that may already suffer from other human impacts and are often nationally or internationally threatened.

Mechanical oil recovery is the primary combating method in the brackish Baltic Sea as the use of dispersants is not recommended because of the uncertainties regarding their effectiveness and effects on the ecosystem (HELCOM 2001). Unfortunately species with high vulnerability to oil or a high value in the media might be of a low priority in terms of a successful use of oil combating resources if they will be exposed to oil as a result of their behavior. As the limited time and resources emphasize the need for a utility oriented prioritization the combating efforts should not be directed to those populations for which they are totally ineffective or in extreme cases even harmful. Although this appears self-evident, it is surprising that the combating efficiency (our technical chance to decrease the oil impact) has not been taken into account in any previous oil contingency maps.

The aim of this study was to develop an index-based evaluation method that can be used to set priority values for adjacent populations threatened by a floating oil slick and thereby facilitate the decision-making on the allocation of oil booms in coastal areas. The indices take into account: (1) the degree of exposure and mortality due to an oil spill, (2) the recovery potential after the spill, (3) the relative conservation value compared to other species or populations, and (4) the technical possibility to safeguard the population with oil booms. To the authors' knowledge this type of a prioritization method has not been applied in any previous sensitivity maps.

Methods

The method and indices described in this paper are used in a map application developed for the spatial prioritization of oil combating with oil booms in the Gulf of Finland (Kokkonen and others 2010). The Gulf of Finland is the easternmost part of the Baltic Sea and has faced an enormous growth in oil transportation and other maritime traffic during the last 10 years (Hietala 2006). The application is developed to support decisions in a large scale oil spill. So far the worst case scenario has been assumed to be a spill of 30,000 t which has been estimated to smother approximately 50 km of shoreline in the Gulf of Finland (Hietala and Lampela 2007).

Selection of Species and Populations for Evaluation

The first task was to develop a generally acceptable way to select the species to be included in the analysis. Since the Convention on Biological Diversity (1992) the main concern in ecological evaluation has been the importance of a species for the diversity, complexity and stability of an ecosystem (Bengtsson 1998), rather than for its utilitarian values.

Charismatic animals such as marine mammals or large carnivores have been and still are the organisms that attract public attention. However, current legislation does not value them more than other threatened or rare species. We suggest that in the selection process all taxa should be considered with the same criteria despite of their taxonomical status, economic importance or aesthetic value. In this study, the selection was therefore carried out by experts of different species groups, varying from insects and other invertebrates to vertebrates and e.g. vascular plants or lichens. Four questions were considered in the selection process (Fig. 1): (1) Is the species vulnerable to oil spills in the Gulf of Finland, (2) Does the species possess a conservation value, (3) Is the national population of the species dependent on the coastal habitats i.e. can a 30 000 t oil spill result in a higher conservational status of the species, and (4) Is it possible to predict the location of the species during the accident in order to use oil booms effectively.

The evaluation of potential conservation value was based on the national list of threatened species according to the World Conservation Union criteria (IUCN 1994; Rassi and others 2001). All species inhabiting the coastline and having a national IUCN status of critically endangered

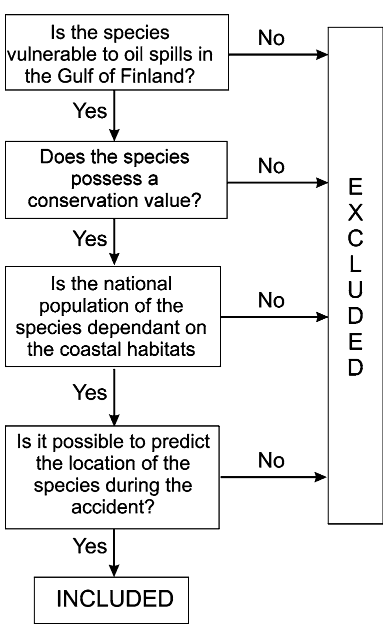

Fig. 1 Selection of the species to the evaluation process

(CR) and endangered (EN) were included in the analysis, because these species are so rare that a single oil spill could have devastating effects on the populations at the national level. Some vulnerable (VU) and near threatened (NT) species were excluded at this stage if they were considered not to be dependent on the coastal habitats in the Gulf of Finland taking into account the viability trend of all Finnish populations. Some extremely mobile threatened species (e.g., many hawk species and migrating fish species) were excluded from the analysis, as their location during the accident is extremely difficult or impossible to predict and hence they cannot be safeguarded with oil booms.

The data on the populations of the selected species was mainly gathered from the Finnish database of threatened species (Finnish Environment Institute 2007) but the information was supplemented with expert interviews. The population-specific data on the height of the occurrences above the average sea level affecting the exposure to oil, and the viability of the populations on a scale from 1 to 3 (1 = low, 2 = moderate, 3 = high) was gathered as well as the significance of the individual local populations for the survival of the species in Finland (1 = low, 2 = average, 3 = high, 4 = only occurrence).

Construction of Species and Population Specific Evaluation Indices

The next stage was to develop an index-based evaluation method that could be utilized in mapping software that provides decision support for operational oil combating with oil booms (Kokkonen and others 2010). Four main indices and several sub indices (Fig. 2) were developed, describing the relative weights of different decision criteria which should be considered in assessing where to lay oil booms.

Each population is weighted by assigning an index value between 0 and 1 for the recovery potential, the efficiency of oil booms to safeguard the species, and the conservation value. The index values were given by literature review and expert consultations of a couple to ten experts specialized on the species group in question. These indices can be used either separately or they can be combined. The combined priority index is referred to as the OILECO index (Fig. 2), according to the project where it was developed. Indices were not developed to give absolute estimates on the variables but they should rather be seen as relative weights that can be used as a means to set the populations in a relative order of significance.

Recovery Potential Index (REP)

The recovery potential index (REP) describes the comparative ability of a local population to recover from an accident through reproduction and/or recolonization when

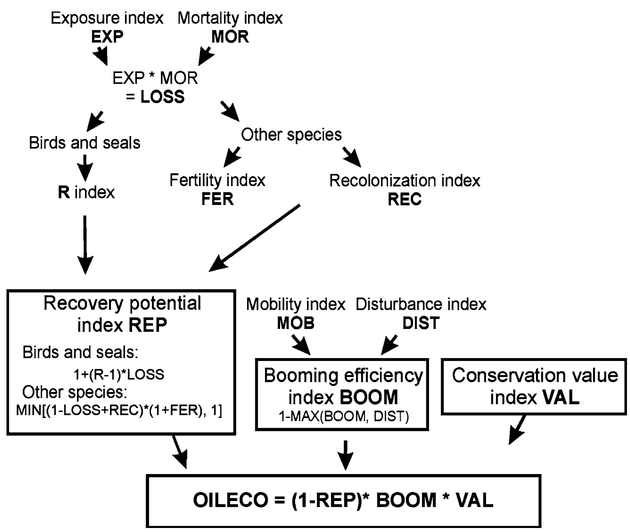

Fig. 2 Indices developed for the spatial prioritization of operational oil combating with oil booms. All the indices can have values between 0 and 1. The final OILECO index integrates the knowledge from population impacts, technical possibility to safeguard the population and the valuation of the population from the society's point of view

a certain proportion of the population has been lost due to oil exposure and subsequent mortality. Since recovery is dependent on the actual population loss, the REP index is calculated via the exposure index (EXP) and the mortality index (MOR).

Exposure Index (EXP)

Before defining the exposure index the species were divided into two subgroups: (1) birds and seals and (2) sessile or semi-sessile species such as plants, lichens, algae and invertebrates (Fig. 2). The main factors affecting the exposure of the former group are related to their behavior, whereas for the species in the latter group the proportion of the population above the average sea level in relation to the prevailing sea state is a more important determinant of exposure.

Exposure Index (EXP) for Seabirds and the Gray Seal Exposure index values (EXP) were constructed separately for each bird species and for the Gray seal *Halichoerus grypus* (Fabricius) by expert interviews. Index values were compiled separately for heavy and light oil and for each month by considering the following factors: (1) the proportion of the yearly maximum population present at the site during a given month, and (2) the probability of oil exposure due to behavioral aspects such as foraging or breeding behavior. The probability was considered to be higher for those species that forage over long distances (e.g., King and Sanger 1979; Williams and others 1995). Since the map application was developed to support decision making in oil combating after a large 30,000 t oil accident, the EXP index values were based on the assumption that the cleaning operations on shore would require extended periods. For example, if an oil accident occurs in winter most of the shoreline will be smothered during the following summer and the EXP of the populations migrating to the area in spring will be high even though they would not be present at the time of the accident. The EXP for light oil was considered 10% lower than for heavy oil because some of the oil evaporates before the oil slick reaches the shoreline (Committee on Oil in the Sea 2003).

Exposure Index (EXP) for Sessile or Semi-Sessile Species For other species (e.g., algae, vascular plants, mosses, invertebrates) the EXP index was not determined by month-specific behavioral indices, but instead via estimating the proportion of the population to be inundated with oiled water. The method applies the fetch approach (Ekebom and others 2003; Hauser and others 2003; Tolvanen and Suominen 2005) in which the wave height onshore is calculated using the distance of water over which the wind can blow with the aid of the user-supplied wind direction and wind speed information. Simple interpolation with an inverse distance weighting is used to estimate the elevation of the sea level at each habitat based on the user-supplied sea level recorded by three mareographs located offshore from the cities of Hanko, Hamina and Helsinki. Details of the method are reported in Kokkonen and others (2010). While the EXP estimate is subject to substantial uncertainty, it does give a useful estimate of the fraction of a population that will be exposed to oil.

Mortality Index (MOR)

The mortality MOR index (Fig. 2) was determined for all species as the proportion of a population that would die due to oil exposure if all individuals were in contact with oil. The evaluation was based on expert judgment and literature, and both physiological factors and structural aspects were taken into account.

Calculation of the Recovery Potential Index (REP) Values

The fraction of the population lost (LOSS, Fig. 2) as a result of an oil accident is a crucial factor in determining the recovery potential. It is calculated as

$$\mathrm{LOSS} = \mathrm{EXP} * \mathrm{MOR} \tag{1}$$

where EXP is the exposure index and MOR is the mortality index.

Similar to the EXP index, construction of the final recovery potential index (REP) also differed between the two previously described groups. Recolonization was considered to be impossible to separate from reproductive efficiency when assessing recovery of birds and seals, but for other species the experts found it more practical to give separate estimates for recolonization and reproduction and then use these separate index values to calculate the REP index.

Recovery Potential Index (REP) for Seabirds and the Gray Seal The recovery potential REP index is calculated using the LOSS values and the species-specific recovery estimates (R) that take into account both recolonization and reproduction. While the recovery estimates were given the habitat was always assumed to be restored to the state preceding the accident.

The recovery estimates for birds and seals were determined by a panel of experts. Before consulting the panel the bird and seal populations were classified according to the number of breeding pairs at the site, which is crucial in determining the efficiency of reproduction. After classification the experts estimated for each population how large a percentage of the lost population (LOSS) would be recovered in five years if all surrounding coastal populations within the distance of 50 km were destroyed by the oil spill. Furthermore, as the share of the lost population can have a significant impact on the level of recovery the experts assessed the recovery for each population for the following four different LOSS ranges: LOSS = 0–20%, LOSS = 20–50%, LOSS = 50–80%, and LOSS = 80–100%, considering always the LOSS value of the upper limit of the bracket (Fig. 3). The estimate was given as one of the following four ranges: 0–20%, 20–50%, 50–80%, or 80–100% of the lost population will recover. For example, if the population LOSS was assumed to be between 0 and 20% the recovery estimate would be given for the LOSS value of 20% and the experts would estimate how large a proportion of this lost 20% would be recovered within 5 years (Fig. 3). The recovery estimates were given index values R (Table 1).

The recovery potential index (REP) values for birds and seals is calculated (Fig. 2) from

$$\mathrm{REP} = 1 + (R - 1) * \mathrm{LOSS} \qquad (2)$$

where LOSS is the proportion of the population lost due to the accident and R is the recovery estimate. The REP index thus declines linearly from the value of one as the share of the lost population increases.

Recovery Potential Index (REP) for Sessile or Semi-Sessile Species The recovery potential REP index for other taxa is calculated using the LOSS values and separate indices describing the estimates of recovery through reproduction (FER) and through recolonization (REC).

The estimates of recovery through reproduction were delivered by a panel of experts. Estimates were given separately (similarly as the recovery estimates for birds and seals) for four different categories of the share of the lost population (Fig. 4; Table 2). In addition, the population specific viability estimate (1 = low, 2 = moderate, 3 = high) was taken into account because the recovery of viable populations is much more certain than the recovery of weak populations where the extinction risk is higher due to the demographic stochasticity and the possible Allee effect (failure to mate successfully when the population size has diminished below a certain threshold) (Begon and others 2006). The estimate of recovery through reproduction is always 0% if LOSS is 100% because there are no individuals that could reproduce in the area (Fig. 4).

Table 1 R indices for the recovery estimates

Recovery potential estimate/5 years (%)	R
0–20	0.0
20–50	0.1
50–80	0.2
80–100	0.8

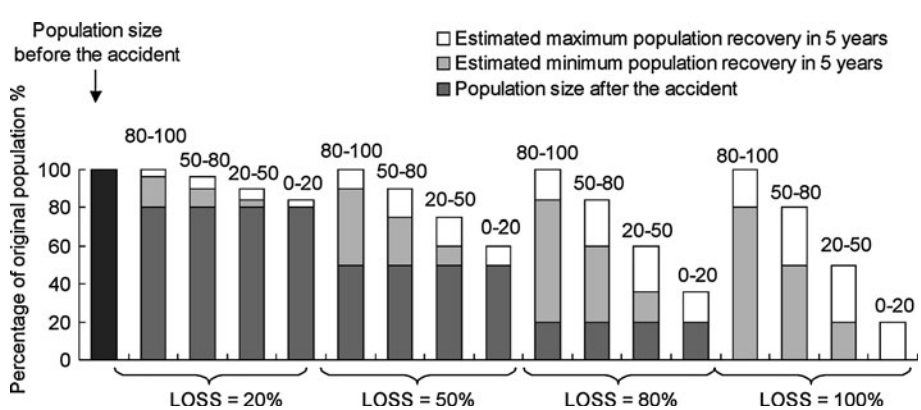

Fig. 3 Estimation of the recovery potential class for some sample birds and the *Gray* seal for heavy oil

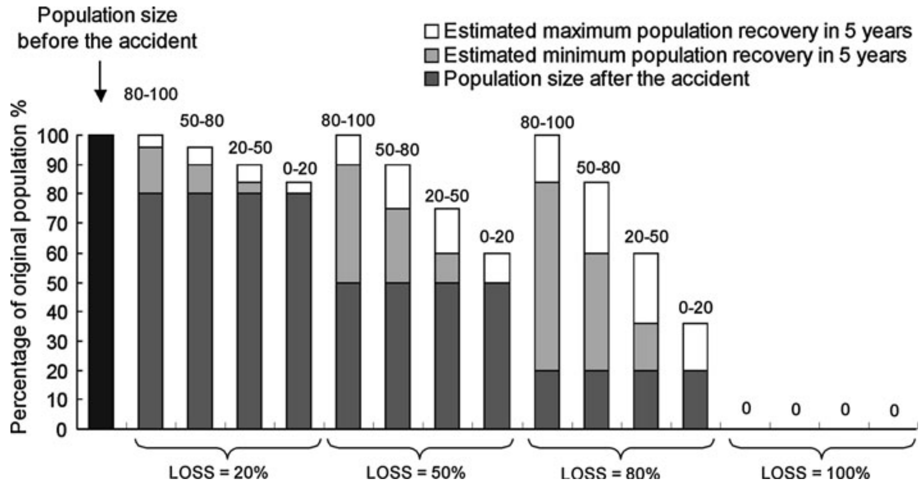

Fig. 4 Estimation of the recovery class through reproduction for sessile or semi-sessile species for different loss ranges

Table 2 FER indices for recolonization estimates

Reproduction estimate	FER
0–20% of population loss will be recovered through reproduction five years after the accident	0.0
20–50% of population loss will be recovered through reproduction five years after the accident	0.1
50–80% of population loss will be recovered through reproduction five years after the accident	0.2
80–100% of population loss will be recovered through reproduction five years after the accident	0.8

Table 3 REC indices for recolonization estimates

Recolonization estimate	REC
The population has no potential to recover through recolonization	0.00
Individuals begin to recolonize the habitat over 8 years after the accident	0.01
Individuals begin to recolonize the habitat 4–7 years after the accident	0.11
Individuals begin to recolonize the habitat 1–3 years after the accident	0.50

For the recolonization REC index the experts were asked to estimate the time period after which individuals would begin to recolonize the particular habitat, if all coastal populations within the range of 50 km were destroyed by the oil spill but the habitat would be restored to the state preceding the accident in one year. This approach was needed in order to take into account the intrinsic differences in migration capacity as well as the fact that some species have viable populations inland that are not susceptible to oil spills and which thus may act as efficient source-populations for recolonization. Recolonization was estimated using four classes (Table 3).

The estimates on recovery through reproduction and recolonization were transformed into the fertility index (FER, Table 2) and the recolonization index (REC, Table 3), respectively. The combined recovery potential index (REP) representing the relative recovery of populations is calculated as:

$$\mathrm{REP} = \min[(1 - \mathrm{LOSS} + \mathrm{REC})(1 + \mathrm{FER}), 1] \quad (3)$$

where LOSS is the index value describing the proportion of the population lost due to the accident, REC is the recolonization index, and FER is the fertility index value. The first term of the multiplication represents the recovery through recolonisation and the second term through reproduction. The index may get values of over 1 in cases where LOSS is very low and recovery through reproduction and recolonization is very fast but the maximum index value was limited to 1 as the values of all sub-indices forming the OILECO index are limited between 0 and 1.

Booming Efficiency Index (BOOM)

The booming efficiency index BOOM (Fig. 2) describes the efficiency of safeguarding species with oil booms at close ranges (max. 400 m from the habitat). The BOOM index values were assigned for each month with the help of experts using two sub-indices: the mobility index (MOB) describing the mobility of a species (e.g., foraging) and the disturbance index (DIST) describing the disturbance from oil-combating activities. The BOOM index was determined as

$$\mathrm{BOOM} = 1 - \mathrm{MAX}(\mathrm{MOB}, \mathrm{DIST}) \quad (4)$$

Operational decisions on the allocation of oil booms are always prone to weather conditions and shoreline characteristics and such decisions are made on site after the accident. The BOOM index was therefore based solely on the behavioral aspects of a species disregarding the technical aspects related to the site specific use of oil booms.

Table 4 Conservation value indices were determined by a species-specific IUCN classification (CR, EN, VU, NT), status as a directive or responsibility species, and the population specific significance (S) for the survival of the species in Finland (L, M, H)

(A) Neither directive nor responsibility species				(B) Directive or responsibility species			(C) Directive and responsibility species		
S	L	M	H	L	M	H	L	M	H
IUCN									
CR	0.48	0.84	0.93	0.51	0.89	0.97	0.52	0.91	1.00
EN	0.09	0.28	0.70	0.10	0.31	0.78	0.11	0.32	0.80
VU	0.02	0.06	0.17	0.02	0.07	0.21	0.02	0.07	0.22
NT	0.00	0.01	0.03	0.00	0.01	0.05	0.00	0.01	0.05

CR critically endangered, *EN* endangered, *VU* vulnerable, *NT* near threatened, *L* low, *M* medium, *H* high

Conservation Value Index (VAL)

The conservation value VAL index (Fig. 2) was defined according to the species' national IUCN classification (CR, EN, VU, NT) and its status as a directive species (annex II and III) or a responsibility species in Europe (Rassi and others 2001). The final population specific VAL index was determined by weighting the occurrences according to the significance of the population (S) for the national survival of the species (low = 1, medium = 2, high = 3) (Table 4).

The index values were determined by a panel of conservation biology experts. At the first stage the experts had to compare the value of species that have different national IUCN classes in a case were the population has a medium significance for the survival of the national population (Table 4, column A), The experts were asked e.g. how many populations of an NT species have the same value as one population of a CR species. The values were adjusted until each delegate agreed with the result. At the second stage the experts were asked to consider how much the value is lowered or raised when the occurrence has either a low or a high significance for the national population.

At the third stage the experts assessed how much additional value is given if a species has a directive or a responsibility species status in addition to the IUCN classification of CR, EN, VU or NT (Table 4, column A). At the final stage the experts had to consider the additional value when a species is both a directive and a responsibility species (Table 4, column C). The status of being a directive or a responsibility species had only a minor effect on the index value. The membership in either of these two groups was considered to have a similar additional value because the criteria for including a species in these groups are broad. For species belonging to the lower IUCN classes, the status as a responsibility species or directive species had, however, a slightly more pronounced effect on the VAL index. This was because national CR or EN species are so rare that other criteria were considered insignificant since for many CR species and some EN species there is a significant risk that the entire national population may become extinct as a result of a single large-scale oil accident.

The delegates agreed that the value of a species that is both a directive and a responsibility species equals 1.5 times the value added when a species is either a directive or a responsibility species. This is because the fulfillment of both criteria was not considered to be an important determinant of the conservation value and the value should therefore not rise significantly higher compared to those species that have only an IUCN status (CR, EN, VU or NT).

OILECO Index

The OILECO index (Fig. 2) describes the final prioritization value of the population based on the REP, the BOOM, and the VAL of the population, i.e. summarizes all information to one number to be used in the ranking. The OILECO index is calculated as:

$$\text{OILECO} = (1 - \text{REP}) * \text{BOOM} * \text{VAL}, \quad (5)$$

where REP is the recovery potential index (dependent on the loss), BOOM is the booming efficiency index, and VAL is the conservation value index.

The mapping software also provides a possibility to use sub-indices comprising the OILECO index, in case a decision maker wishes to compare how the use of different criteria alters the ranking (Kokkonen and others 2010).

Results and Discussion

Altogether 669 populations representing approximately 120 threatened or near threatened species were included in the analyses (Fig. 1) amongst them representatives of vascular plants, algae, lichens, invertebrates, fish, birds and mammals. It is evident that such a physiologically and ecologically heterogeneous group of organisms has major differences in mortality, exposure to oil, ability to recover after the accident, and efficiency to be safeguarded with oil booms. Later in this section we will demonstrate with an imaginary oil spill scenario and with three species vulnerable to oil, how the index values vary between species and how the map application may be used.

The exposure index EXP for seabirds was highest for an accident taking place in the summer months varying somewhat between the species (Fig. 5). Because of the species specific migration behavior, the largest differences in EXP for seabirds are found in the autumn values. For the Gray seal the index values were highest in the summer months due to their low mobility. During other months seals forage over long distances and are often impossible to be safeguarded by oil booms and can also migrate to non polluted areas. For the sessile species the EXP varies according to the sea level and the wave height (Kokkonen and others 2010).

The MOR index varied both between higher taxonomic groups but also between species within the same family. The European marram grass *Ammophila arenaria* (L.) was given a somewhat lower mortality than other similar macrophytes (Table 5). It is a perennial species having strong runners (Mossberg and Stenberg 1995) extending several meters to the ground and therefore a majority of individuals will probably survive even when smothered in oil. All bird species were given index values 1.0, whereas for the Gray seal the value is only 0.5 since the individuals will probably survive even if contaminated by oil.

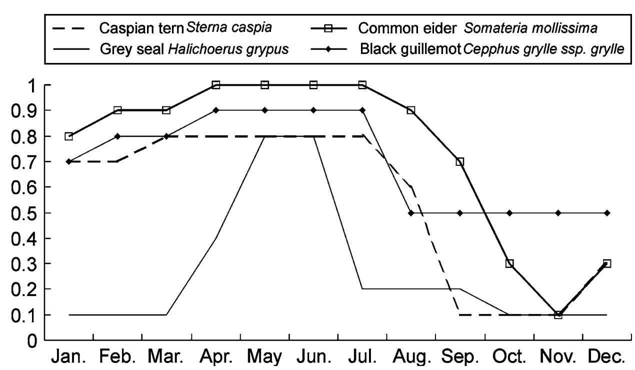

Fig. 5 Month-specific exposure (EXP) index for some sample birds and the *Gray* Seal for heavy oil

Table 5 Estimated mortality indices for some sample species

Class	Species	MOR
Vasculales	European marram grass *Ammophila arenaria*	0.1
	Prickly saltwort *Salsola kali* ssp. *kali*	1.0
Coleoptera	*Aegialia arenaria*	1.0
Lepidoptera	*Eupithecia orphnata*	1.0
Aves	Black guillemot *Cepphus grylle* ssp. *grylle*	1.0
Mammalia	Gray seal *Halichoerus grypus*	0.5

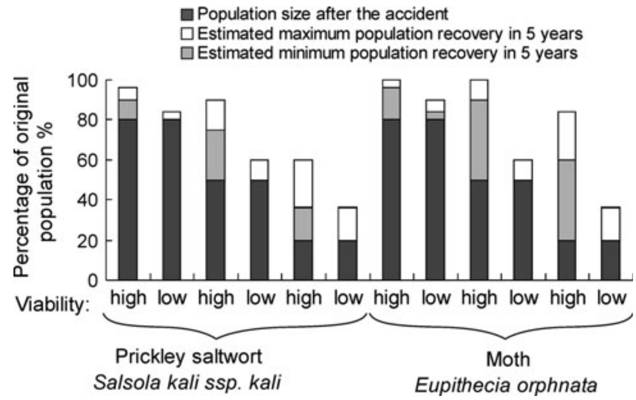

Fig. 6 The recovery potential estimates varied both between species and populations of varying viability

There were also major differences in the recovery potential REP especially between higher taxonomic groups. In addition, the viability of the population before the accident affected the estimate of the REP index. Populations with a low viability were considered to have a lower recovery potential (Fig. 6).

Also the booming efficiency index BOOM varies widely depending on the species and often also on the season (Fig. 7). Sessile and semi-sessile species are easy to safeguard with oil booms compared to the mobile species such as seabirds. The Common eider *Somateria mollissima* (L.) was the only bird species having a somewhat higher BOOM index during the breeding season, whereas for other birds the booming efficiency was considered quite low throughout the year.

In the following, we illustrate how the indices can be used in the spatial prioritization of oil combating with an example from the eastern Gulf of Finland. We present a simplified scenario in which an imaginary oil slick is floating towards three islands in June and only limited time is available to decide which island should be safeguarded with oil booms (Fig. 8) This example shows only the principle of the software map application which is discussed in further detail in Kokkonen and others (2010).

There are three IUCN classified species occurring on adjacent islands threatened by the drifting oil slick (Fig. 8): *Eupithecia orphnata* (moth), Black guillemot *Cepphus grylle* (L.) (bird) and Prickly saltwort *Salsola kali ssp. kali* (L.) (terrestrial vascular plant). The MOR is high for all species, but the EXP varies. The EXP for the Prickly saltwort and *E. orphnata* species is dependent on the elevation of the population compared to the sea level. The exposure for the Black guillemot is dependent on its behavior. In this example the EXP is the same for the Prickly saltwort and the Black guillemot (0.80), whereas

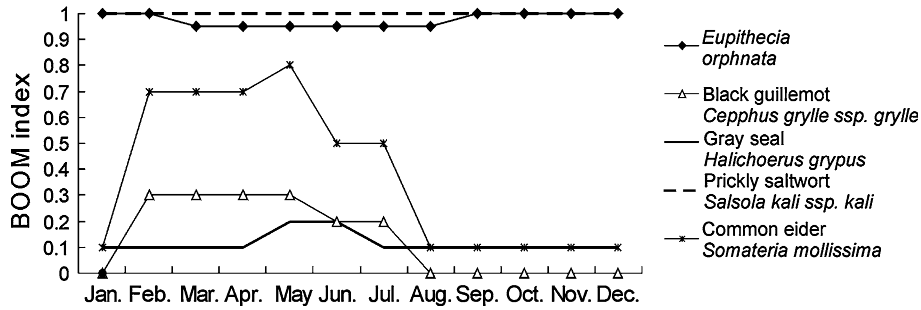

Fig. 7 BOOM index values for some sample species and months

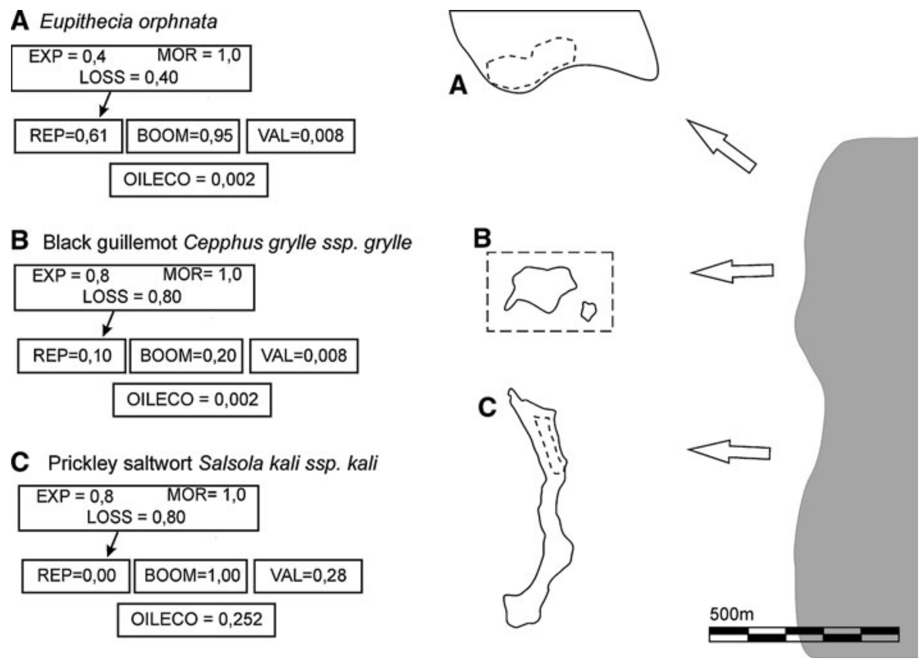

Fig. 8 Population-specific indices for three sample species. The use of the indices in the decision is described in the text

the *E. orphnata* habitat occurs so high above the sea level (30–200 cm) that the EXP rate is lower (0.40). While comparing only the LOSS (EXP * MOR) index, the Prickly saltwort and Black guillemot have the highest ranking (0.80), whereas the index value is only 0.40 for the *E. orphnata*.

Since the short term mortality and population decrease can be regarded less relevant than a long-term population decline, we compare how these species recover after the accident. If the LOSS is 0.80–1.00 for the Prickly saltwort it will have a very low REP (0.10) since the population is separated from other saltwort populations in the Gulf of Finland and recovery will be dependent on the spreading of seeds for this annual plant. For the Black guillemot the REP is zero because a large accident will destroy most populations of this species and the recolonization is therefore uncertain. For the *E. orphnata*, on the other hand, the REP is higher (0.61) since the EXP is low and as a polyphagous species it most likely will easily recover through reproduction if less than 50% of the original population is lost and the population is viable before the accident.

If we consider the BOOM values for the populations we can conclude that the value is five times higher for the Prickly saltwort (1.00) and for the *E. orphnata* (0.95) than for the Black guillemot (0.20). This is due to the fact that during the breeding season in June the Black guillemots tend to fly around and land on the near shore waters while disrupted and therefore the oil combating activities might even raise the risk of contamination.

The VAL index is 35 times higher for the Prickly saltwort (0.280) than for other species. This is mainly because it is classified as an EN species in the national red list of threatened species, whereas the Black guillemot (0.008) and the *E. orphnata* (0.008) are classified as NT species. All occurrences have an average significance for the survival of the national population of the species.

The OILECO index, describing the final prioritization value for the populations, is highest for the Prickly saltwort

(0.252) because this population has a low recoverability (low REP), is easily safeguarded with oil booms (high BOOM), and has a high conservation value (high VAL). The other two species have much lower OILECO index, because they both have low VAL. Furthermore, the BOOM is low for the Black guillemot and the REP is high for the *E. orphnata*. As a conclusion of this imaginary scenario, the oil booms should be directed firstly towards the areas inhabited by the plant species and secondly towards the areas occupied by the other two species.

Conclusions and Implications

When making decisions regarding the hierarchy of vulnerable areas to be safeguarded after an oil spill there is a need to compare the biological impact and recovery potential, the relative value of the population among other impacted populations, and the technical possibilities to help the population. The presented method can be used to combine the above mentioned criteria in a relatively simple and practical way. Our results indicate that the weighting of species according to the species or population specific recovery potential, conservation value and mitigation potential has a great importance in the prioritization of oil combating.

Different approaches, methods and spatial scales are needed when developing maps for oil-combating purposes compared to constructing maps for compensation assessment. Therefore, the aim of sensitivity mapping should be highlighted before constructing any priority maps. The operational feasibility should be emphasized if the tools will be used in the spatial prioritization of oil combating. Large marine conservation areas often cannot be safeguarded with oil booms and thus it would be preferable to identify the internal differences within conservation areas using smaller scales such as habitats. As the gathering of nature values to a common database is an extremely important ground for contingency planning (Petersen and others 2002; Pogrebov and others 2006, Natural England 2008) it might offer little support for decision makers with no ecological education. Development of prioritization tools is therefore crucial in order to facilitate a more targeted oil combating.

It has been well documented that the appreciation of the public towards nature is often restricted to charismatic species (Kellert 1993). It is thus evident and understandable that the media, public and oil combating personnel will sympathize oiled birds and seals. However, these species do not have a higher hierarchical importance in legislation, unlike threatened species. In addition, oil booms are unfortunately very inefficient for safeguarding most bird species, particularly when operating near the shoreline. Hence the efficiency of oil booms and other combating equipment to safeguard different species should be considered when producing operational maps. Surprisingly, the present study seems to describe the first method where the efficiency of oil booms has been taken into account in the prioritization assessments.

Many sensitivity maps have discarded the proportion of a population that will be lost as a result of an accident. Instead, they have focused on intolerance of species to toxic substances and the recovery potential related to the intrinsic reproductive potential (Cooke and McMath 2001; Tyler-Walters and others 2001). If there are no individuals left after the accident and recolonization is not possible, the recovery is impossible despite the high reproductive potential. Furthermore, small populations might suffer from the Allee effect (Begon and others 2006). It is therefore crucial to include estimates of the lost population in the analysis before considering the recovery potential. In addition, the exposure due to the behavior of a species or to its habitat type should be considered as it varies considerably between different species and populations, and also in time for the same species.

It is not viable to include all species vulnerable to oil in the analysis. Hence it is essential to develop objective methods for selecting the species for ecological evaluation. In our study the vast majority of species would have been excluded if we only had gathered information on the populations that are commonly considered to be vulnerable to oil and if we had not taken the list of threatened species as a starting point. During the study we discovered that all national populations of some insect species could be destroyed as a result of a single oil accident in the Gulf of Finland. Most of them do not have any publicity value but instead they have a high value for the biodiversity.

The method described here has been implemented in a map application (Kokkonen and others 2010) which can be utilized in oil spill contingency planning. The rescue services responsible for the coastal operational oil combating in Finland have complimented the method for its simplicity and practicality in operational decision making. Still it is recommended that the map application is used in co-operation with experts in ecology. In case of a real accident the decision tool might lead to a stronger weight for e.g. a couple of individuals of a very rare species compared to hundreds of individuals of a common species. In such cases, time allowing, an expert should be consulted before the final actions are taken.

Oil accidents are a worldwide problem. While our method has been specifically developed to be used in the Gulf of Finland, and for the case of floating oil slicks, we feel that the logic or the application is easy to apply and supports well to the variable scientific knowledge available for rare and threatened species. The concepts developed in this study are very likely to be a useful aid in supporting oil combating decisions in other susceptible regions, too. In addition to oil combating, we suggest that a similar approach could be utilized in related environmental management questions where people must prioritize between actions to minimize the effects on the environment. The proposed methodology could be useful in e.g. selecting cost-efficient conservation areas where non-monetary values of the society, which are stated in the existing legislation and agreements, and the benefits from different conservation procedures, are considered.

Our approach is a clear step forward, but requires further ameliorations. Research is needed to determine the value of key or keystone species, endemic species and genetically differentiated populations compared to the rare and threatened species, as well as the value of those common species which can suffer from the effects of oil because of their clustered distribution pattern. Most of the index values were delivered by expert judgment as knowledge about the rare and endangered species is often very limited. This might lead to bias but in the future, the indices can be ameliorated as knowledge is improved.

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References

Alonso-Alvarez C, Pérez C, Velando A (2007) Effects of acute exposure to heavy fuel oil from the prestige spill on a seabird. Aquatic Toxicology 84:103–110

Begon M, Townsend CR, Harper JL (2006) Ecology: from individuals to ecosystems, 4th edn. Blackwell Publishing, Oxford

Bengtsson J (1998) Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. Applied Soil Ecology 10:191–199

Brude OW (2005) Areas vulnerable to acute oil pollution in the Norwegian Barents Sea. Report for WWF Norway. Report No. 2005-0456

Carter IC, Williams JM, Webb A, Tasker ML (1993) Seabird concentrations in the North Sea: an atlas of vulnerability to surface pollutants. Joint Nature Conservation Committee, Aberdeen, p 39

Committee on Oil in the Sea: Inputs, Fates, and Effects, Ocean Studies Board and Marine Board, Divisions of Earth and Life Studies and Transportation Research Board and National Research Council of the National Academies (2003) Oil in the Sea III: inputs, fates, and effects. The National Academies Press, Washington

Convention on Biological Diversity (1992) Rio de Janeiro. http://www.cbd.int/convention/convention.shtml. Accessed 24 September 2010

Cooke A, McMath A (2001) Sensitivity mapping of inshore marine biotopes in the southern Irish Sea (SensMap): development of a protocol for assessing and mapping the sensitivity of marine species and benthos to maritime activities. Ecoserve, Dublin, pp 1–103

Early R, Thomas CD (2007) Multispecies conservation planning: identifying landscapes for the conservation of viable populations using local and continental species priorities. Journal of Applied Ecology 2:253–262

Ekebom J, Laihonen P, Suominen T (2003) A GIS-based step-wise procedure for assessing physical exposure in fragmented archipelagos. Estuarine, Coastal and Shelf Science 57:887–898

Finnish Environment Institute (2007) Database on threatened species. 12.01.2008

Ford RG, Wiens JA, Heinemann D, Hunt GL (1982) Modelling the sensitivity of colonially breeding marine birds to oil spills: Guillemot and kittiwake populations on the Pribilof Islands, Bering Sea. Journal of Applied Ecology 19:1–31

Gundlach ER, Hayes MO (1978) Vulnerability of coastal environments to oil spill impacts. Marine Technology Society Journal 4:18–27

Hanna RGM (1995) An approach to evaluate the application of the vulnerability index for oil spills in tropical red sea environments. Spill Science & Technology Bulletin 2:171–186

Hauser D, Branger H, Bouffies-Cloche S, Despiau S, Drennan WM, Dupuis H, Durand P, Durrieu de Madron X, Estournel C, Eymard L, Flamant C, Graber HC, Guerin C, Kahma K, Lachaud G, Lefevre J-M, Pelon J, Pettersson H, Piguet B, Queffeulou P, Tailiez D, Tournadre J, Weill A (2003) The FETCH experiment: an overview. Journal of geophysical research 108:1–15

HELCOM (2001) Restricted use of chemical agents and other non-mechanical means in oil combating operations in the Baltic Sea Area. HELCOM Recommendation 22/2. Helsinki Commission, Helsinki

Hietala M (2006) Oil transportation in the Gulf of Finland. Finnish Environment Institute, p 4. http://www.environment.fi/download.asp?contentid=53583&lan=fi. Accessed 24 September 2010

Hietala M, Lampela K (2007) Oil pollution preparedness on the open sea—final report of the working group, p 42. The Finnish Environment 41/2007. Finnish Environment Institute

IMO/IPIECA (1996) Sensitivity mapping for oil spill response, IMO/IPIECA Oil Spill Report Series: 1, p. 24

IUCN (1994) The IUCN Red List of Threatened Species. Categories and criteria. http://www.iucnredlist.org/. Accessed 24 September 2010

Juntunen T, Rosqvist T, Rytkönen J, Kuikka S (2008) Assessment of oil combating technologies using Bayesian networks—an application in the Baltic Sea. ICES CM 2005/S:02

Kellert SR (1993) The biological basis for human values of nature. In: Kellert SR, Wilson EO (eds) The biophilia hypothesis. Island Press, Washington, pp 42–69

King JG, Sanger GA (1979) Oil vulnerability index for marine oriented birds. In: Bartonek JC, Nettleship DN (eds) Conservation of marine birds of northern North America. Wildlife Research Report 11. Fish & Wildlife Service, Washington, pp 227–239

Kingston PF (2002) Long-term environmental impacts of oil spills. Spill Science and Technology Bulletin 7:53–61

Klerks PL, Nyman JA, Bhattacharyya S (2004) Relationship between hydrocarbon measurements and toxicity to a chironomid, fish larva and daphnid for oils and oil spill chemical treatments in laboratory freshwater marsh microcosms. Environmental Pollution 129:345–353

Kokkonen T, Ihaksi T, Jolma A, Kuikka S (2010) Dynamic mapping of coastal nature values to support the prioritization of coastal oil combating. Environmental Modelling & Software 25(2010): 248–257

Lee RF, Page DS (1997) Petroleum hydrocarbons and their effects in subtidal regions after major oil spills. Marine Pollution Bulletin 34:928–940

MacDonald A, Mc Geechan C, Cain M, Beattie J, Holt H, Zhou R, Farquhar D (1999) Identification of marine environmental high risk areas (MEHRA's) in the UK, Occupational Health & Safety Information Service, 8639, p 83

Morales-Caselles C, Jiménez-Tenorio N, Canales M, Sarasquete C, DelValls TA (2006) Ecotoxicity of sediments contaminated by the oil spill associated with the tanker prestige using juveniles of the fish sparus aurata. Archives of Environmental Contamination and Toxicology 51:652–660

Mosbech A, Anthosen KL, Blyth A, Boertmann D, Buch E, Cake D, Grøndahl L, Hansen KQ, Kapel H, Nielsen N, Von Platen F, Potter S, Rasch M (2000) Environmental oil spill sensitivity atlas for the West Greenland coastal zone, pp 1–341. Internet version. http://www.geus.dk/departments/quaternary-marine-geol/oliespild_v_gr/atlas.pdf. Accessed 24 September 2010

Mossberg B, Stenberg L (1995) Suuri Pohjolan Kasvio (Den nya nordiska floran). Tammi, p 928

Nansingh P, Jurawan S (1999) Environmental sensitivity of a tropical coastline (Trinidad, West Indies) to oil spills. Spill Science & Technology Bulletin 5:161–172

Natural England (2008) Coastal and marine resources atlas. http://www.magic.gov.uk. Accessed 24 September 2010

Nikitik CCS, Robinson AW (2003) Patterns in benthic populations in the Milford Haven waterway following the 'Sea Empress' oil spill with special reference to amphipods. Marine Pollution Bulletin 46:1125–1141

Offringa H, Lahr J (2007) Safetyatsea. An integrated approach to map ecologically vulnerable areas in marine waters in the Netherlands (V-maps). Report No. A09

Owens EH, Robilliard GA (1981) Shoreline sensitivity and oil spills—a re-evaluation for the 1980's. Marine Pollution Bulletin 12:75–78

Perkins RA, Rhoton S, Behr-Andres C (2005) Comparative marine toxicity testing: a cold-water species and standard warm-water test species exposed to crude oil and dispersant. Cold Regions Science & Technology 42:226–236

Petersen J, Michel J, Zengel S, White M, Lord C, Plank C (2002) Environmental sensitivity index guidelines, version 3.0. NOAA Technical Memorandum NOS OR&R 11, Seattle. Hazardous Response and Assessment Division, National Oceanic and Atmospheric Administration, pp 1–192

Pezeshki SR, Hester MW, Lin Q, Nyman JA (2000) The effects of oil spill and clean-up on dominant US gulf coast marsh macrophytes: a review. Environmental Pollution 108:129

Pogrebov V, Sagitov R, Dmitriev N (2006) Nature conservation atlas of the Russian part of the Gulf of Finland. Tuscarora, St. Petersburg, p 60

Rassi P, Alanen A, Kanerva T, Mannerkoski I (eds) (2001) The 2000 Red List of Finnish species. Ministry of the Environment, p 432

Safetec UK (1999) Identification of the environmental high risk areas MEHRA'S in the UK. Department of the Environment, Transport and Regions

Thomas MLH (1986) A physically derived exposure index for marine shorelines. Ophelia 25:1–13

Tolvanen H, Suominen T (2005) Quantification of openness and wave activity in archipelago environments. Estuarine, Coastal and Shelf Science 64:436–446

Tortell P (1992) Coastal zone sensitivity mapping and its role in marine environmental management. Marine Pollution Bulletin 25:88–93

Tyler-Walters H, Lear D (2004) The Marine Life Information Network for Britain and Ireland (MarLIN). Sensitivity mapping for oil pollution incident response, report to Cyngor Cefn Gwlad Cymru / Countryside Council for Wales from the Marine Life Informations Network (MarLIN). Plymouth: Marine Biological Association of the UK, pp 1–50. Internet version. http://www.marlin.ac.uk/PDF/CCW_Oil_SensMap_Rpt.revised_SCREEN.pdf. Accessed 17 march 2011

Tyler-Walters H, Hiscock K, Lear D, Jackson A (2001) Marine life information network (MarLIN) identifying species and ecosystem sensitivities. report to the department for environment, food and rural affairs from the marine life information network (MarLIN). Marine Biological Association of the United Kingdom, Plymouth, pp 1–98

Williams JM, Tasker ML, Carter IC, Webb A (1995) A method of assessing seabird vulnerability to surface pollutants. IBIS 137: 147–152

Zacharias MA, Gregr EJ (2005) Sensitivity and vulnerability in marine environments: an approach to identifying vulnerable marine areas. Conservation Biology 19:86–97