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Vulnerability Assessment of Svalbard Intertidal Zone for Oil Spills

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A system for estimating a coast's vulnerability to oil spills is presented, based on geomorphological maps and environmental data collected in the Svalbard intertidal. Since this European Arctic archipelago is nearly undisturbed and presents a ' natural environment ', its protection calls for a more detailed approach. As many as 19 factors were selected as important for oil spill assessment in the littoral. All factors have been grouped into different subject categories (physical parameters and biological parameters) and a different rank of importance was given for each factor (principal, important, secondary). Selected coast units may be described with regard to sensitivity to the oil spill by the index of vulnerability counted in each of the two categories. The western (Atlantic) coast has been described as more vulnerable when compared to eastern (Arctic) coasts of the archipelago. The physical parameters and biological parameters indices were often contradictory when vulnerable biota (e.g. rich crustacean assemblages) were connected with relative resistance to the oil spill physical environment (exposed stony beaches).

Keywords: intertidal; sensitivity mapping; Arctic

Introduction

The Svalbard archipelago is the largest European undisturbed wilderness, with an extensive coastline exceeding 3000 km in length. Despite its high latitude position, it is not isolated from European contaminants distributed through the sea currents and air masses (Rey & Stonehouse, 1982; Hansen *et al.*, 1996). More direct, local threats are from the potential oil grounds recently approved for exploitation in Northern Norwegian and Barents Seas, in the vicinity of Svalbard (Borresen *et al.*, 1988; Hansson *et al.*, 1990).

The first, descriptive, part of the project has been published previously (Weslawski *et al.*, 1993; Szymelfenig *et al.*, 1995). The second, conceptual, part of the work was done to design the model describing the vulnerability of the investigated coasts, and is the subject of this paper.

To define a vulnerability index, a number of factors from different fields, which are important for littoral oil spill assessment, have been considered. Some authors have dealt with only one group of factors, like coastal geomorphology (Gundlach & Hayes, 1978) or wildlife and economy threats (Hum, 1977; Taylor, 1980; Dicks & Wright, 1989; Taylor & Parker, 1993). On the other hand, most of the recent vulnerability studies described the whole complexes, including terrestrial environments and shallow shelf (Lindstedt-Siwa *et al.*, 1983; Hansson *et al.*, 1990; Brekke & Hansson, 1990). The present authors focused on the single, well-defined intertidal (littoral zone between high and low water marks). There have been a number of studies made on Arctic oil spills assessment (Atlas, 1977; Malins, 1977; Nelson-Smith, 1982; Engelhardt, 1985; Baker *et al.*, 1990), some based on experimental oil spills like BIOSP in Canada (Hodgson, 1987; Sergy & Blackall, 1987), as well as the monitoring surveys after catastrophic spills such as the Exxon Valdez in Alaska.

Study area

Svalbard is an European Arctic archipelago lying on the border between Atlantic (boreal) and Arctic biogeographical provinces (Figure 1). Its western coast is exposed to the warm, West-Spitsbergen current, while eastern coasts are washed by the Barents Current, carrying cold Arctic waters. At least 21 coast types have been defined in Svalbard (Hogvard & Sollid, 1988; Weslawski *et al.*, 1993). The predominant habitat is low gravel beaches, with scarce fauna. Sheltered skjerra are inhabited with a high biomass *Fucus* community, accompanied by at least 60 invertebrate species (Weslawski *et al.*, 1993). Meiofauna is numerically important, reaching high values comparable with those of temperate zones (Szymelfenig *et al.*, 1995).

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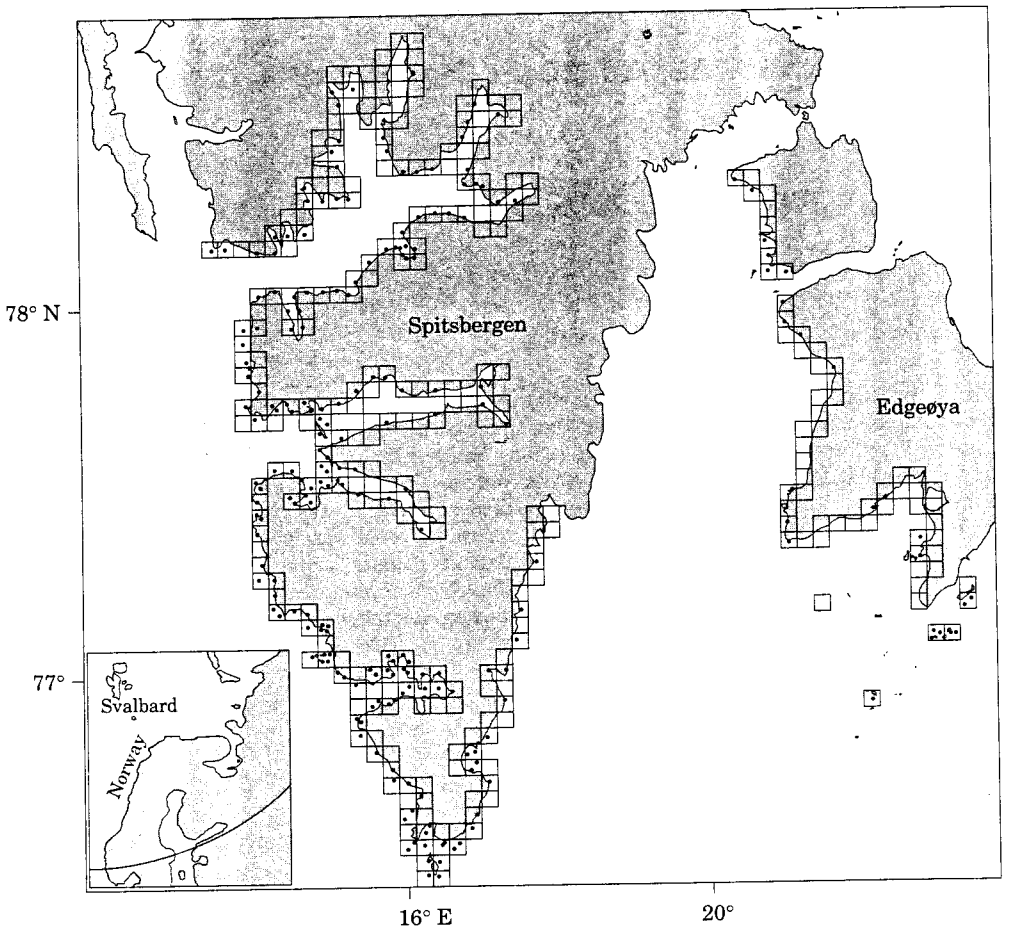

FIGURE 1. Sampling stations and squares 5 × 5 km grid in Svalbard littoral.

Methods

Marine biological data were collected during the 'Tidal Zone Project', a co-operative event of the Norsk Polarinstitutt and the Institute of Oceanology PAS, in Summers 1988–1993, under the umbrella of the AKUP project (Norwegian Ministry of Energy and Industry Assessment Programme of Petroleum Activities). The presented method applies to the areas where sufficient environmental information exists. The basis to the vulnerability assessment was the exact-point data (180 sampling stations), as well as the continuous observations (notes and photos) collected along the 2000 km of surveyed shoreline (Figure 1). For uniformity with other AKUP projects, the grid of 336 squares of 5 × 5 km has been inserted on the archipelago map (Figure 1). Each of the squares has its centre geographically oriented, so that the database may work under a GIS system. It is important to remember that described indexes represent an averaged value for each 5 × 5 km square, and not the point-specific data.

The first problem was the transformation and generalization of the data from single sampling stations to 25 km^2 squares. In many localities, contrasting features may occur within a 5 km unit. Sampling points were chosen to represent both the most typical and most interesting parts of the coast. For example, in a 10 km long stretch of low, gravel beach, with a single, small, rocky peninsula, the first sampling station was situated on the gravel beach, the second on the rocky outcrop. The automatic (computer) generalization of such data would lead to mistakes. To aggregate and to extrapolate the site-specific information, three steps were introduced:

(1) The selection of descriptive factors in such a way that they represent a wide, common vulnerability category. For example, coast types noted in the sampling stations were generalized into three vulnerability-related categories (Table 1).

(2) The dominant substratum was classified as the one representing the whole coast unit, e.g. the substratum of the 10 km of shoreline consisting of 9 km

TABLE 1. Physical parameters as defined in the present study

Parameter	Vulnerability			Comment
	Low (1)	Medium (2)	High (3)	
Principal parameters (multiplied by 6)				
Wave exposure	Exposed sea coast with strong wave action	Coast exposed to fjord or bay waves	Coast sheltered behind skjerra or inner fjord basin	The stronger the water dynamic, the faster the oil is processed (Gundlach & Hayes, 1978; Sergy & Blackall, 1987; Lein, 1992)
Geomorphological type of the coast	Cliffs with deep shelf, glacier cliffs	Cliffs with shallow shelf, low beaches	Tidal flats, sheltered rock pools	Coast types largely determine features such as substratum, sediment flux, accompanying fauna, its vulnerability follows scheme by Gundlach and Hayes (1978)
Important parameters (multiplied by 3)				
Substratum type	Rocks, fine sand, compact mud	Stones, boulders	Loose sand, gravel-sandy, gravel	More compact sediment inhibits penetration and persistence of oil (Straughan, 1977; Gundlach & Hayes, 1978; Sergy & Blackall, 1987)
Sediment flux	High sediment transport or exchange	Medium sediment transport	Low or neglible sediment transport	Faster sediment exchange, faster self-cleaning of the area (Gundlach & Hayes, 1978)
Ice-cover duration	Fast ice lasting less than 2 months	Fast ice lasting 2–6 months	Fast ice lasting over 6 months	Faster ice exchange, faster oil removal, ice may trap the oil and inhibit its natural degradation (Doerffer, 1992)
Ice cover type	Frozen sea-bed, removed each spring	Ice foot on the top of sediment	Loose ice or stacked ice with loose contact to the ground	Ice acting as surface sediment transporter removes oil from the ground (Sergy & Blackall, 1987)
Weathering potential	Coast exposed on relatively heavy precipitation (>1000 mm year^{-1})	Area of modest precipitation	Area with little precipitation (<400 mm year^{-1})	Melting snow or rain may act as washing factor (Mearns, 1993)
Stranded kelp on shore	None	Few or very local, fresh algae	Stranded multi-year kelp deposits	The more kelp, more oil is kept by 'sponges' of algal mats (Watt *et al.*, 1993)
Water transport/currents	High speed currents over 20 cm s^{-1}	Medium currents, 2–20 cm s^{-1}	Weak currents or stagnant waters	Higher the water exchange, faster the self-cleaning

TABLE 2. Biological parameters as defined in the present study

Parameter	Vulnerability			Comment
	Low (1)	Medium (2)	High (3)	
Principal parameters (multiplied by 6)				
Species-specific vulnerability	Low diversity and biomass assemblages (meiofauna dominated oligotrophic assemblages ' Oligochaeta ')	Relatively resistant species (*Fucus-Balanus*)	Vulnerable species (*Gammarus*)	Some species are more resistant to oil (e.g. fucoids) than others (e.g. amphipods[a])
Important parameters (multiplied by 3)				
Recovery potential of the intertidal	Area inhabited by fast-growing, *r* strategy breeding organisms	Area inhabited by mixture of fast- and slow-growing organisms	Area dominated by slow-growing, *K*-strategists.	Small, fast-growing Atlantic species resettle faster than large, slow-growing Arctic forms[b]
Macrophyte cover	<10% of littoral covered with macrophytes	11–50% of the coast covered with algae	>51% of the coast covered	Less cover, lower loss of algae associated fauna. On Svalbard, where macrophytes are relatively small, and never form a continuous cover over the ground, they do not form a protective belt[c]
Amphipod density	Low density (below 1 ind m^{-2})	Mean density (2–10 ind m^{-2})	>11 amphipods per m^{-2}	Higher the density, higher the losses, since amphipods were found to be very vulnerable to oil contamination[d]
Resettlement potential	Nearest square	6–20 km	>20 km	How far to the nearest recolonization source
Secondary parameters (multiplied by 1)				
Littoral supply from sublittoral	Negligible	Only dead organic matter	Both dead organic matter and living organisms	Smaller the contact, smaller the losses. Cross *et al.* (1987) have shown the low sensitivity of the shallow sublittoral to oil spills. The seasonal recolonization of the littoral by organisms from the waters below is typical in Arctic waters[e]
Export to sublittoral	Negligible	Only dead organic matter	Nursery ground for sublittoral organisms	Smaller the contact, smaller the losses. It represents the importance of some areas as nursery grounds for sublittoral fauna, which might be more sensitive to oil than adult organisms (Giere, 1993)
Bird moulting area in the intertidal zone	None	Occasional	Regular	Birds are easily affected by oil. Barnacle geese and eiders may gather in some places in the tidal zone during moulting (Mehlum, 1991)
Haul-out ground	None	Past or potential	Regular	Pinnipeds are easily affected by the oil on shore[e]
Seabird feeding ground	None	Kittiwake and Glaucous gull	Wading bird	Oil affects both the food and feeding seabird, opportunistic feeders are less affected (Percy, 1977; Riebel & Percy, 1990)

[a]Rice *et al.* (1977), Percy (1977), Thomas (1977), Bodin (1980), Falk Petersen *et al.* (1983), Seip (1984), Shaw and Hameedi (1988), Brown and McLachlan (1990), Aunaas *et al.* (1990), Riebel and Percy (1990), Lein *et al.* (1992), Giere (1993), Mearns (1993).
[b]Chia (1970), Southward and Southward (1978), Brown and McLachlan (1990).
[c]Carr and Reish (1977), Percy (1977), Weslawski *et al.* (1993).
[d]Percy (1977), Percy and Wells (1984), Aunaas *et al.* (1990).
[e]Born (1984), Krawczyk and Weslawski (1987), Fjeld and Mehlum (1988), Gjertz and Wiig (1993).

gravel beach and 1 km rocky cliffs was classified as 'gravel'.

(3) A given feature is of special site-specific importance, e.g. a seal haul-out noted in particular coast units gives the highest vulnerability class for the whole square (5 × 5 km).

Nineteen parameters have been divided into physical (Table 1) and biological (Table 2) parameters. Each individual parameter was qualified with regard to its importance to the oil spill as principal, important or secondary. The principal parameters were those of decisive influence for the oil spill sensitivity, as described by Gundlach and Hayes (1978). Important parameters are more specific to the Svalbard region, and characterize the regional sensitivity. Secondary parameters do not influence the oil spill assessment directly, but may have some meaning in holistic, environmental terms. Furthermore, after allocation of a parameter to one of the three groups of importance, it was given the value 1, 2 or 3, meaning low, medium or high vulnerability, respectively. The values of principal important and secondary parameters were multiplied by factors of 6, 3 and 1, respectively. Such multiplication was chosen to secure the proper balance between principal and secondary parameters so the highest values of secondary parameters may influence the lowest values of principal parameters.

The physical parameters (Table 1) characterize the physical ability of the environment to resist the oil spill. For example, the exposed, steep stony beaches are less vulnerable than sheltered shores because the oil is easily washed out by the wave action. To calculate the physical parameters index, the mean valued of principal and important factors were added. The lowest possible sum is 9 ($1 \times 6 + 1 \times 3$) for the least fragile coasts, and the highest sum is 27 points ($3 \times 6 + 3 \times 3$) for the most sensitive coasts.

The biological parameters (Table 2) characterize the potential biological impact in case of oil spill. For example, the rich fauna connected with the vegetation on skjerra was contrasted with the low-biomass oligotrophic beach. The first was described as the most vulnerable, and the second was described as the least vulnerable with regard to the potential biological impact. The calculation of the biological parameters index was arranged in the same way as described for physical parameters: mean value of principal parameters + mean value of important parameters + mean value of secondary parameters. The lowest value of all parameters is 10, representing lowest biological vulnerability, the highest value is 30 points for the most fragile biota.

TABLE 3. The percent frequency of concurrence of coast type with littoral assemblage type in the investigated area

Assemblage	Oligotrophic	*Fucus-Balanus*	Gammarus
Coast type			
Cliffs	10	1	0
Beaches	50	23	4
Tidal flats	6	4	2

Results

Among 336 pairs of principal parameters of the physical and biological groups, the following interrelations were found. In 50% of cases, the moderately vulnerable cliff with abrasive shelf and beaches (coast type 2 in Table 1) was associated with the least vulnerable oligotrophic community (assemblage type 1 in Table 2). There were no cases where the least vulnerable coasts (cliffs) were associated with the most vulnerable *Gammarus* community (Table 3).

The physical parameters index is grouped into four classes (below 13 points, 14–18, 19–23 and 24 points). The most sensitive areas (vulnerability index >24) are tidal flats in the innermost fjord basins, with weak currents. There are 19 such squares (6% of the area). The least vulnerable were exposed cliffs (both glaciers and rocks) in areas of strong currents. Such areas occurred in 4% of the examined squares (Figure 2, Table 4).

The biological parameters index showed only 2% of the area classified as most vulnerable (index >25 points). These are sheltered bays with abundant amphipod fauna, accompanied by macrophyte assemblages. The least vulnerable areas were exposed beaches with poor fauna which occupied 70% of the investigated coastline (Figure 3, Table 4). Such habitats occurred more often on the eastern coast, giving a lower vulnerability to the Arctic side of the archipelago. There was no direct correlation between the physical parameters and the biological parameters indices. The comparison of 336 pairs of indices gives a regression coefficient of 0·07, indicating that the indices describe the phenomena independently.

Discussion

It should be stressed that the method applied in this study is quasi-objective, and other persons may give different ranking to different factors or select the new factors of importance. Secondly, no seasonal aspect was directly considered. Most of the presented factors might be observed or are valid in summer only (e.g.

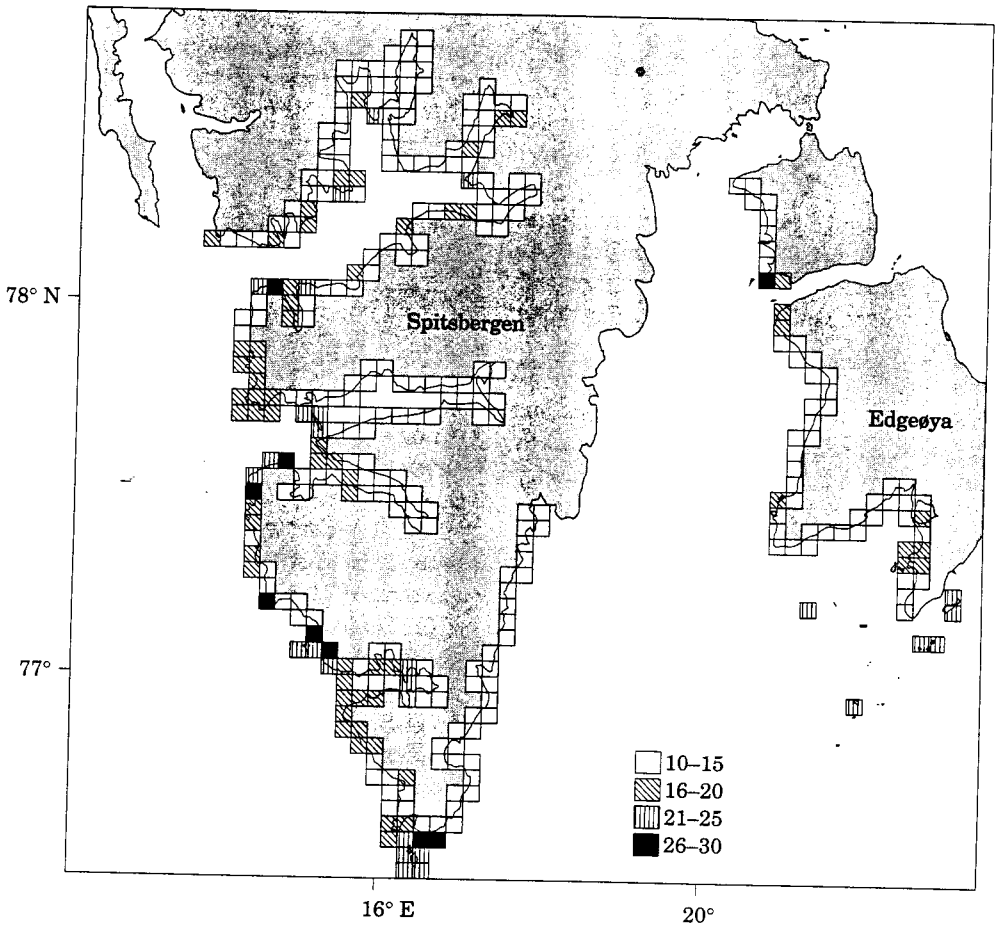

FIGURE 2. Biological parameters index.

TABLE 4. Percent share of coasts with different vulnerability indices

Physical parameters			Biological parameters		
Index range	Number of squares	Percent of all squares	Index range	Number of squares	Percent of all squares
9–13	14	4	10–15	238	70
14–18	168	50	16–20	63	19
19–23	135	40	21–25	26	8
24–27	19	6	25–30	9	2

birds moulting), while others are only relevant to the winter situation (ice). In general, factors representing the year average have been selected, taking into consideration the long-lasting persistence of oil spills in the Arctic (Nelson-Smith, 1982). The Svalbard coasts vulnerability as defined in the present study is generally low, similar to the Canadian Arctic, reported as an area of low littoral vulnerability (Sergy & Blackall, 1987). On the other hand, the Arctic coasts are not completely barren, as has been stated frequently in the literature. There are a number of dispersed littoral sites on Svalbard which are very rich in biodiversity and biomass (Weslawski *et al.*, 1993). This is why the present authors have designed this rather complex and complicated model for the vulnerability assessment. The more simple methods are better suited for industrialized and populated areas where presence or absence of minor ecosystem elements is of little practical meaning. In Arctic coastal environments poor in diversity and biomass, the minor ecological elements

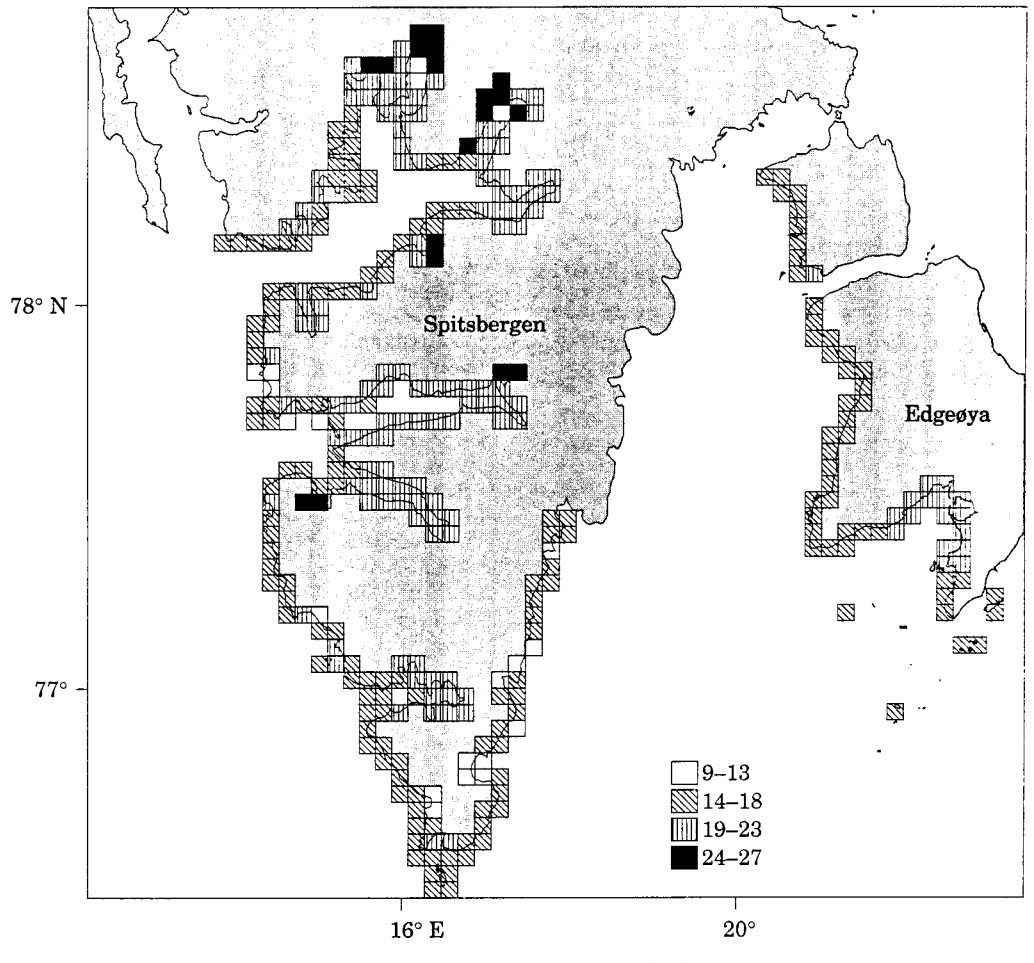

FIGURE 3. Physical parameters index.

may play a more important role when compared to temperate waters (Szymelfenig *et al.*, 1995).

The physical and biological indices were often contrasting. Often the coast sensitive to the oil spill from the physical standpoint (e.g. a sheltered inner fjord basin at the moraine lagoon) is very insensitive from the biological standpoint since it represents a barren, oligotrophic site with scarce life. Both indices are high in the tidal flats and sheltered bays of the western and southern coast. There, the rich fauna (usually tidal amphipods) occurs in sites of little self-cleaning potential.

Conclusions and recommendations

During field studies, the present authors have covered a large part of the Atlantic part of Svalbard coast, while north and eastern coasts remained unstudied. These areas are so different from those studied previously that they may represent some phenomena of local importance only (such as multiyear ice deposits with specific fauna). Other important gaps in the estimation of Svalbards coastal vulnerability are the coasts of large and important islands: Jan Mayen, Bjornoya, Hopen. These should be carefully studied for their biogeographical importance e.g. as bridges for European coastal fauna advancing north with climate change. Another reason for the vulnerability of islands may be their low resettlement potential, due to the long distance to the nearest source of tidal fauna. The extrapolation of the existing data (and model) to unstudied areas of north and east Svalbard is difficult if not impossible. The reason is the lack of some key data permitting valuation of the coastline. The 19 factors used in the vulnerability assessment might be grouped in three categories related to their availability:

(1) Factors which might be read from the maps, archival or other published sources; e.g. geomorphological type, ice cover duration and type, weathering potential, bird moulting areas, animal haul-out grounds.

(2) Factors which are partially available in archives, but their verification in the field would be valuable

(wave exposure, although it might be read from the map that the character of the storm bar and debris on shore shows the actual exposure of a given coast unit; substratum, general information is available for most of the Svalbard coastline, but the important feature of substratum ' compactness ' can be estimated only in the field; sediment flux, partly a function of exposure, substratum and coast type, but actual estimation is by far more precise in the field; feeding ground for birds, some key areas but by no means all are known from the literature; water transport/currents, for some areas, data are available but not for the whole coastline).

(3) Factors which can be evaluated only after specific fieldwork.

The type of littoral community is mostly associated with a given geomorphological shore type (e.g. skjerra are usually associated with fucoids). On the other hand, there are many localities where the coast type is not associated with the ' expected ' animal assemblage; e.g. the Edgeoya coast contains a number of typical localities of gammarid and fucoid assemblages, but there are only a few of them in that region. Other factors not found on the maps are: stranded kelp deposits; recovery potential; macrophyte cover; amphipod density; resettlement potential; littoral supply from sublittoral; and export to sublittoral.

The differentiation of the Svalbard archipelago, and the existence of two climatic-hydrographic regimes (Atlantic and Arctic), as well as a number of separate island ecosystems (like Bjornoya), makes data extrapolation impossible. The inter-annual variability is very pronounced in the Svalbard marine ecosystem (Weslawski & Adamski, 1987). Such natural climate related changes have to be taken into account for their implications in monitoring programmes (Culliname & Whelan, 1983). The major zoogeographical boundary runs through the South Spitsbergen as indicated by Dunbar (1968) and Weslawski (1994). There are no published marine ecological data on the true Arctic coast of Svalbard, except for faunistic notes on particular animal groups (e.g. Amphipoda, Stephensen, 1936–40).

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