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Sensitivity of benthic vegetation and invertebrate functional guilds to oil spills and its use in oil contingency management related negotiation processes

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Abstract. This paper gives an overview of the impact of an oil spill on the benthic vegetation and invertebrate communities of Nõva and Keibu bays, western Gulf of Finland. No negative effects of the oil spill on the species composition and depth distribution of macrophytobenthos were observed. The coverage of macrophytes and the coverage of *Pylaiella littoralis* were lower in the impacted than in reference areas. Among different invertebrate feeding guilds herbivores were the most sensitive to the oil spill, being tremendously reduced at sites of oil pollution. Deposit feeders and suspension feeders were positively affected by the spill. Based on the sensitivity of benthic communities, we explore the issue how this information can be used to support decisions and negotiations on the possible oil spill response actions.

Key words: oil spill, response action, benthic vegetation, macrozoobenthos, negotiation, Baltic Sea.

INTRODUCTION

The annual oil load into the Baltic Sea is estimated at 40 000–50 000 tonnes. More than 50% of this load originates from rivers and air and only a fraction of it is due to oil spills (Backlund et al., 1993). However, due to high concentrations each oil spill represents a serious threat to the integrity of coastal wildlife at local scale. The risk of being exposed to an oil spill is currently increasing. If about 80 million tonnes of oil were annually transported in the Baltic Sea area in 2000 then it is estimated that the value would exceed 130 million tonnes by 2015 (HELCOM, 2001).

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Oil spills potentially affect benthic communities in many ways, e.g. through modification of habitat characteristics, suffocation and/or toxification of flora and fauna, and removal of the key habitat forming species that may indirectly affect other components of benthic life (Baker, 2001). Earlier studies have shown that in some cases the impact of an oil spill is negligible whereas in other instances a complete breakdown of communities has been observed and a new stable state is not reached until 30 years (e.g. Mustonen & Tulkki, 1972; Elmgren et al., 1983).

In January 2006 an extensive oil spill was detected in the southwestern Gulf of Finland. Severe storms hindered the removal of the oil from the sea surface. According to the preliminary field survey it was estimated that approximately 10 t of heavy oil stranded to the shores of Keibu and Nõva bays (Martin, 2006). In this study we describe the effect of the oil spill on benthic plant and invertebrate communities in the area. Our hypotheses were as follows: (1) The brown alga *Fucus vesiculosus* is practically the only macrophyte species that can be found in the northern Baltic Sea during winter (Kiirikki, 1996; Kiirikki & Lehvo, 1997). Thus, only the brown alga is potentially affected by the spill. Earlier investigations show that the effect of an oil spill on fucoids is controversial and highly site specific (Crapp, 1971; Thomas, 1977; Notini, 1978; Highsmith et al., 1996; Stekoll & Deysher, 1996a, b). However, it is likely that the spill significantly increases the physical disturbance as the oil clumps stick on plant thalli and, thus, increase the probability of plants being washed ashore by severe storms. Therefore, the depth distribution and biomass (coverage) of *F. vesiculosus* are reduced in the impacted area. (2) The response of benthic invertebrates to the oil spill depends on their feeding mode. Benthic deposit feeders are likely to gain due to the increase of organic matter in the system (Elmgren et al., 1983; Berge, 1990). Herbivores such as amphipods and isopods are negatively affected due to characteristics of their escape behaviour and hydrophobic properties of their body (Notini, 1978; Bonsdorff & Nelson, 1981; Bonsdorff, 1983; Elmgren et al., 1983). Suspension feeders are also negatively affected due to their higher sensitivity to the decomposition products of oil together with the effect of clogging of their filtration system by oil particles (Tedengren & Kautsky, 1987; Berge, 1990; Kiørboe & Møhlenberg, 1981).

MATERIAL AND METHODS

Keibu and Nõva bays are situated in the southwestern Gulf of Finland. The bays are highly exposed to the sea. The prevailing depths remain between 5 and 20 m, salinity is between 6 and 8, and bottom deposits consist mainly of fine to medium sands. Hard bottoms, consisting of pebbles and boulders, are located in the vicinity of peninsulas and cover a small area.

The phytobenthos and associated benthic invertebrate sampling and sample analysis followed the guidelines developed for the HELCOM COMBINE programme (HELCOM, 2006). The fieldwork was performed in March 2006. The coverage of phytobenthos species was estimated on seven transects from the water edge to the maximum depth of occurrence of phytobenthic communities. The SCUBA diving technique was used at depths greater than 1.5 m (Fig. 1).

The macrozoobenthos sampling grid resembled that described in Kotta et al. (1999), and the season, grab type, sieving, and laboratory procedures were the same as in that paper. Sediment and macrozoobenthos sampling was performed by an Ekman type bottom grab (400 cm^2). A total of 63 stations were sampled and three replicate samples were taken in each station (Fig. 1).

Macrozoobenthos samples were sieved through a 0.25 mm mesh and the residuals were preserved in a deep freezer at –20 °C. In the laboratory, animals were counted and identified under stereo dissecting microscope. Dry weights of each taxa were obtained after keeping the material at 60 °C for 48 h. Macrozoobenthos was classified into feeding guilds – deposit feeders, suspension feeders, and herbivores – based on the literature (Bonsdorff & Pearson, 1999) and field observations.

In all stations the spatial extent of the oil spill, i.e. percentage coverage, dimensions of oil patches, and thickness of the oil layer were estimated by a diver. In addition, the amount of oil products in soft sediment was later assessed in the laboratory. This was done by placing a sediment sample in warm water for about half an hour. Then the volume of oil above the water was estimated.

The software ArcGis Spatial Analyst (ArcGIS 9, 2004) was used to model the extent of the stranded oil spill and the distribution of benthic invertebrate feeding guilds in 1997 (Kotta et al., 1999) and 2006 (data of the present study). When extrapolating data to the areas where samples were not collected, the information on local bathymetry and sediment characteristics was taken into account (Database of the Estonian Marine Institute). The magnitude of spatio-temporal changes in the benthic faunal communities was assessed by differences in the biomass grids of invertebrate feeding guilds between 1997 and 2006.

The operational decision support module is based on the modelling capacity of an incident response simulator PISCES II. Negotiation process related decision making algorithms and the corresponding natural language representation were imported from Karunatillake et al. (2005).

RESULTS AND DISCUSSION

Benthic communities and their sensitivity to oil spills

The majority of the study area is practically devoid of vegetation. Benthic vegetation was only found on hard bottoms. The phytobenthic communities in the area were typical of the western Gulf of Finland and the Baltic Proper. Phytobenthos communities had three distinct vegetation belts. The shallowest part of the coastal slope was occupied by a mixture of the filamentous green alga *Enteromorpha intestinalis* and the filamentous brown alga *Pylaiella littoralis*. However, the belt was not fully developed due to the early stage of seasonal succession. The belt of the brown alga *Fucus vesiculosus* was observed between 0.8 and 2.1 m in Nõva Bay and between 0.2 and 3.8 m in Keibu Bay. Besides *F. vesiculosus* the brown alga *P. littoralis* and the red algae *Polysiphonia nigrescens* and *Ceramium tenuicorne* were found. The vegetation belt was in a very good condition in all sites studied. In deeper areas the bottom was either devoid of vegetation or occupied by the red alga *Furcellaria lumbricalis*.

On hard bottoms the total coverage of macroalgae usually varied between 50% and 100%. The coverage of *F. vesiculosus* and *P. littoralis* were estimated at 20–80% and 10–90%, respectively. The coverage of other species was usually below 20%.

The prevailing benthic invertebrates were the suspension feeders *Mytilus trossulus* and *Cerastoderma glaucum*, the deposit feeders *Macoma balthica*, and the herbivores *Gammarus* spp., *Idotea baltica*, and *Theodoxus fluviatilis*. While the biomass of deposit feeders and suspension feeders exceeded 50 g dw m^{-2} then the biomass of herbivores was much lower hardly reaching 5 g m^{-2} (Table 1). Among the benthic invertebrates, *Calliopius laeviusculus* was first found in this region. Earlier the species has been only found once in Estonia in three single sites in the coastal sea of Hiiumaa Island (Yarvekyulg, 1979). In general, herbivores are the most abundant trophic guild above 4 m depth, suspension feeders prevail between 6 and 10 m, and further down the macrozoobenthic communities are dominated by deposit feeders.

The highest concentration of oil was observed in the eastern part of Keibu Bay. The deepest areas of the bays were practically not polluted (Fig. 2). The oil products do not enter the fine sediments but can easily be accumulated into gravel bottoms (Baker, 2001). In general this held true in our study area. However, in the sites near the coast we observed sometimes clumps of crude oil buried under a 20–40 cm layer of fine sand.

The macrophytes were covered by oil in the eastern part of Keibu Bay at 0.5–1.2 m depth whereas the algae were clean in the other studied sites. There were many oiled fucoids washed ashore in eastern Keibu Bay whereas algal wrack was missing in other parts of the shore. Thus, the oil spill increased the removal of fucoids by storm casts.

Despite differences in storm casts, the occurrence of oil in sediment had no effect on the species composition, coverage of *F. vesiculosus*, and depth distribution of macrophytes (one-way ANOVA, $p < 0.05$). On the other hand, the coverage of macrophytes and the coverage of *P. littoralis* were significantly lower in the impacted than in the reference areas (one-way ANOVA, $p < 0.05$; Fig. 3). Thus, we may conclude that the recent oil spill had only a slight effect on the benthic vegetation. Along with no effects of oil on macrophytes (Notini, 1978; Crothers, 1983), there are numerous examples of negative impacts both on species and community level: a decrease in *F. vesiculosus* was observed after the *Chryssi P. Goulandris* spill in Wales (Crapp, 1971); the vertical distribution of *Fucus* spp. was dramatically reduced following the *Arrow* spill (Thomas, 1977); the coverage of *Fucus gardneri* was found to be significantly less at oiled sites than at unoiled sites in many areas immediately after the *Exxon Valdez* spill (Highsmith et al., 1996); the upper boundary for *F. gardneri* populations in areas oiled by the *Exxon Valdez* had not recovered to equivalent heights of those in unoiled areas 5 years after the

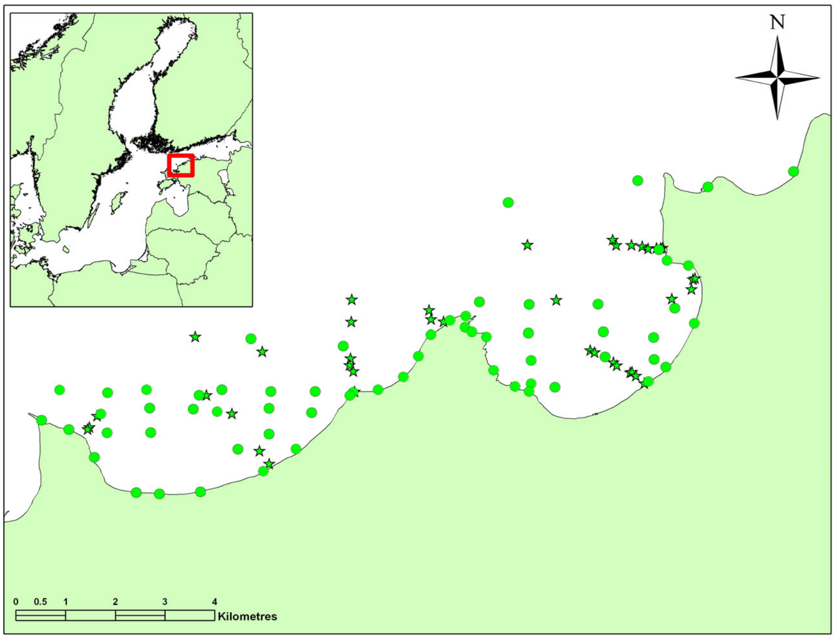

Fig. 1. Map of the study area. Phytobenthos sites are marked as stars and zoobenthos sites are marked as dots.

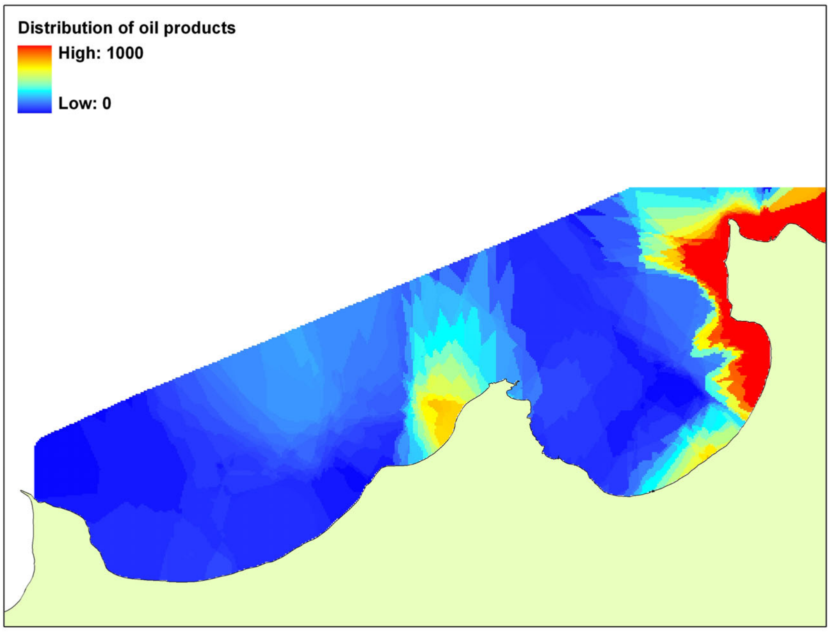

Fig. 2. Amount of the decomposition products of oil in the bottom deposits of Nõva and Keibu bays (mg m^{-2}).

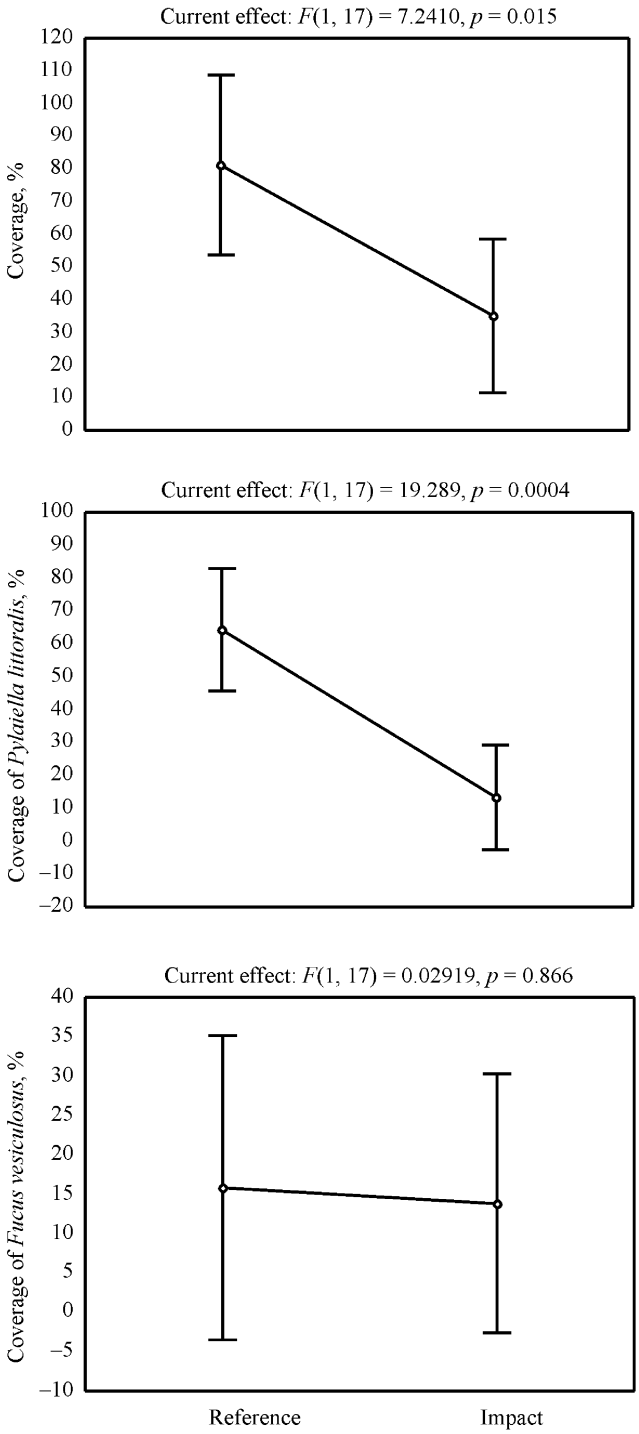

Fig. 3. The results of one-way-ANOVA analysis of the effect of the oil spill on the coverage of macrophytobenthos.

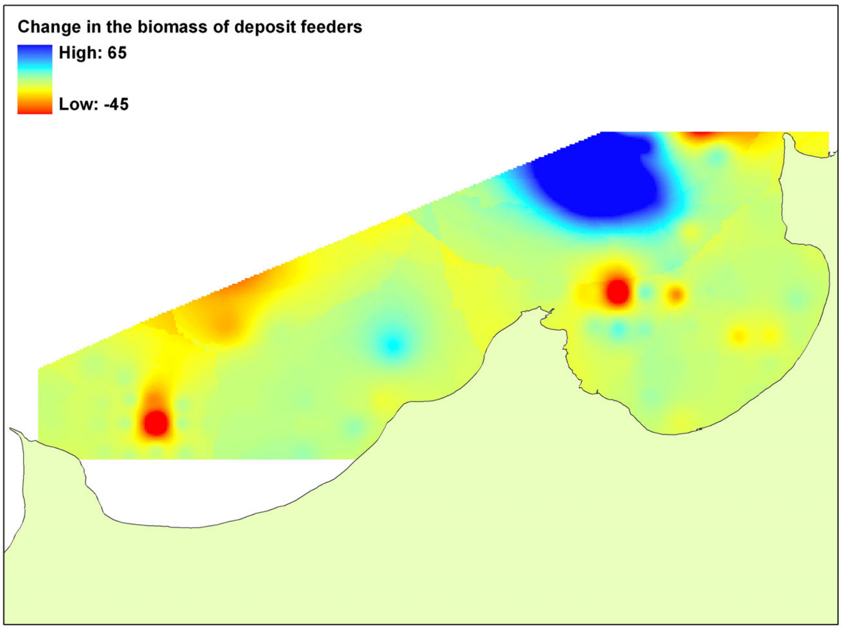

Fig. 4. Changes in the biomass of deposit feeders (in g dw m^{-2}) in Nõva and Keibu bays between 1997 and 2006.

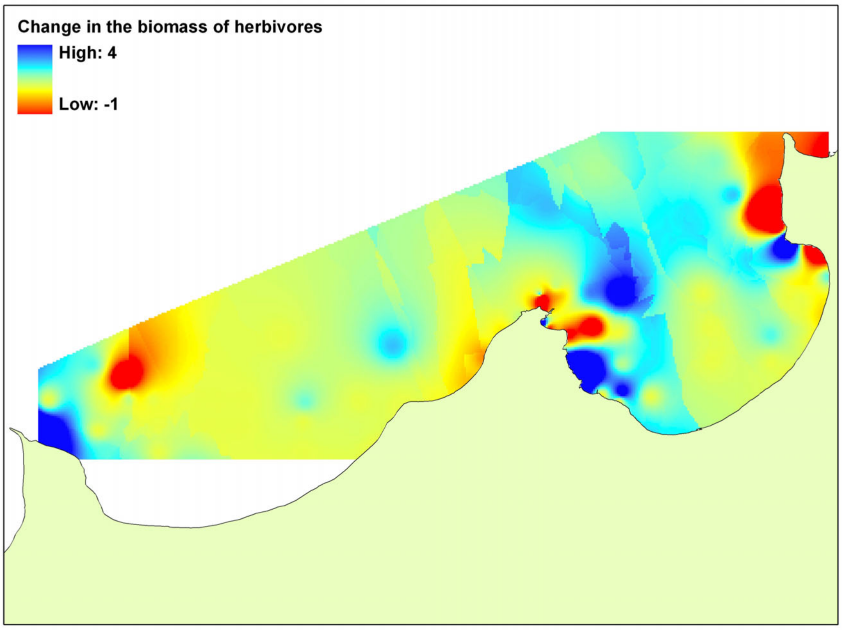

Fig. 5. Changes in the biomass of herbivores (in g dw m^{-2}) in Nõva and Keibu bays between 1997 and 2006.

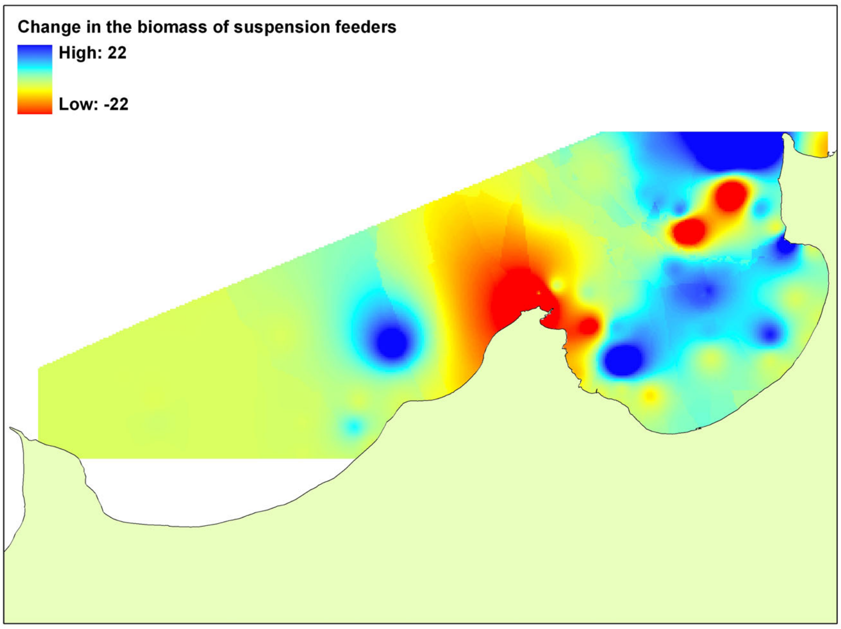

Fig. 6. Changes in the biomass of suspension feeders (in g dw m^{-2}) in Nõva and Keibu bays between 1997 and 2006.

Fig. 7. Sensitivity of the sea area based on the impact of the oil spill on different macrozoobenthos feeding guilds.

Table 1. The most characteristic macrozoobenthos species by biomass in Keibu and Nõva bays in 2006

Bay	Taxon	Abundance, ind. m^{-2}	Biomass, g dw m^{-2}
Keibu Bay	*Mytilus edulis*	292	22.47
Keibu Bay	*Macoma balthica*	487	22.19
Keibu Bay	*Mya arenaria*	235	10.66
Keibu Bay	*Theodoxus fluviatilis*	650	6.56
Keibu Bay	*Balanus improvisus*	141	3.84
Keibu Bay	*Cerastoderma glaucum*	255	2.99
Keibu Bay	*Lymnea peregra*	100	1.97
Keibu Bay	*Gammarus zaddachi*	564	1.49
Keibu Bay	*Hydrobia ulvae*	89	0.39
Keibu Bay	*Bathyporeia pilosa*	1104	0.29
Keibu Bay	*Halicryptus spinulosus*	72	0.28
Keibu Bay	*Hediste diversicolor*	86	0.17
Keibu Bay	*Gammarus salinus*	71	0.12
Keibu Bay	Oligochaeta	497	0.08
Keibu Bay	*Neomysis integer*	50	0.07
Keibu Bay	Chironomidae	128	0.05
Keibu Bay	*Jaera albifrons*	66	0.02
Keibu Bay	*Gammarus* juv	47	0.02
Keibu Bay	*Corophium volutator*	47	0.01
Nõva Bay	*Mytilus edulis*	400	17.13
Nõva Bay	*Macoma balthica*	91	8.12
Nõva Bay	*Crangon crangon*	50	6.37
Nõva Bay	*Lymnea peregra*	188	2.84
Nõva Bay	*Mya arenaria*	71	1.34
Nõva Bay	*Theodoxus fluviatilis*	47	1.06
Nõva Bay	*Bathyporeia pilosa*	1724	0.61
Nõva Bay	*Hediste diversicolor*	74	0.46
Nõva Bay	*Gammarus salinus*	47	0.20
Nõva Bay	*Hydrobia ulvae*	86	0.17
Nõva Bay	*Neomysis integer*	49	0.10
Nõva Bay	Oligochaeta	498	0.08
Nõva Bay	*Prostoma obscurum*	47	0.05
Nõva Bay	*Marenzelleria neglecta*	47	0.04
Nõva Bay	*Gammarus oceanicus*	47	0.03
Nõva Bay	*Corophium volutator*	47	0.01
Nõva Bay	*Jaera albifrons*	50	0.01

spill (Stekoll & Deysher, 1996a). In contrast to our study Stekoll & Deysher (1996b) found an increased coverage of epiphytes on oiled fucoids. The earlier experimental evidence showed no direct effect of oil on *P. littoralis* (Cross et al., 1987). It is possible that due to the higher size and volume the fucoids that had a high cover of the epiphytic *P. littoralis* got oiled more easily than the epiphyte free fucoids. Due to increased friction these algae were selectively removed from the algal belt by storms resulting in a lower coverage of epiphytes in the impacted sites. Lack of clear effect of oil on perennial macrophytes in Nõva and Keibu bays is likely due to moderate quantities of stranded oil and the high exposure of the region. The fucoids inhabiting the area are acclimated to high wave disturbance and the increased storm casts due to oil spill did not exceed the natural removal of algae.

The benthic invertebrate communities were more uniform in 2006 than in 1997. The rare species had become rarer and the prevailing species had become more dominant. The most severe changes were observed in the Keibu Bay areas that had the highest oil load. The biomass of deposit feeders had clearly increased in areas adjacent to stronger oil loads (Fig. 4). The biomass of herbivores had tremendously declined in the sites of the most severe oil pollution. In the eastern part of Keibu Bay we failed to find any specimen of amphipod or isopod despite intensive sampling (both quantitative grab sampling and qualitative dredging) (Fig. 5). Similarly to deposit feeders, the biomass of suspension feeders had increased in Keibu Bay whereas the values had decreased in Nõva Bay (Fig. 6). Figure 7 generalizes the impact of the oil spill on macrozoobenthos. In this figure the significant impact is defined as more than 50% change in the biomass of a feeding guild. The changes in the abundances of the feeding guilds followed the pattern of their biomasses.

Thus, our hypotheses held true for deposit feeders and herbivores but not for suspension feeders. The positive effect of oil pollution on suspension feeders may be linked to increased phytoplankton productivity adjacent to the sites of the most severe oil pollution. Similar blooms of phytoplankton have been earlier documented in sites affected by oil pollution and have been explained by reduced grazing pressure by pelagic grazers (Johansson et al., 1980). Thus, the improved feeding regime (Kotta, 2000) may shade the potential negative effects of oil spills on the suspension feeders (Tedengren & Kautsky, 1987).

The response of invertebrates to oil pollution is similar to that of organic pollution (Spies et al., 1988) and this is likely due to similar decomposition products including also H_2S. However, the direct toxic effect of oil cannot be neglected (Leppäkoski, 1975; Josefson, 1990; Heip, 1995). In this study the effects of oil pollution resembled the effects of moderate organic enrichment such as decrease in diversity, reduction of phytophilous species, and increase in pollution tolerant species observed in other Estonian coastal areas (Kotta, 2000; Kotta et al., 2000). The magnitude of oil spill was likely not so large as to induce strong intoxification reaction due to the formation of H_2S (Berge, 1990). Besides, the toxic effect of oil was also reduced by the high exposure to waves (Mustonen & Tulkki, 1972).

It is suggested that the recovery of benthic communities is faster in pristine areas than in eutrophicated areas (Baker, 2001). As the studied bays are ranked among the least impacted areas in Estonia (Kotta et al., 1999) we believe that the recovery of communities takes place in a short time period from some months to a year. The high recovery potential is also supported by the high exposure of the study area. Herbivores were the most impacted trophic guild in the area. Due to their large mobility and high reproduction potential (Chambers, 1977; Orav-Kotta, 2004), however, their populations can be quickly restored through the immigration from the adjacent unimpacted bays.

Information on the sensitivity of various benthic organism groups can be used in oil contingency management related negotiation processes by building on the Distributed Artificial Intelligence and Multi-Agent Systems conceptual framework (Jennings, 1993; Panzarasa & Jennings, 2001; Panzarasa et al., 2002; Rahwan et al., 2004). In particular, we explore the issue of negotiating the possible towing destination of the spilling vessel.

Based on the results of this study herbivores were the most sensitive feeding guild as already a low concentration of oil wiped out the whole assemblage. The impacts were stronger on less exposed areas and where the key habitat building macrophytes (such as *F. vesiculosus*) had a high density. Thus, the most rewarding areas in terms of habitat protection are those less exposed and with a high macrophyte coverage. On the other hand, the exposed sandy bottoms with a low vegetation coverage are those where the oil spill is likely to have the lowest impact on benthic assemblages.

Response actions

In the early phase of an accident and depending on its nature, one of the feasible combat measures is to tow the spilling vessel towards the indicated places of refuge regarded as ecologically less sensitive areas. In many cases actual decisions on the possible towing destination of a spilling vessel are negotiated between coastal entities concerned with the aim to select the best towing destination alternative through weighing the advantages and disadvantages of the different towing destinations and their expected net benefit towards or net reduction of the overall environmental impact.

The language for expressing arguments and decision making algorithms formalizing the engagement of negotiating parties in argumentative dialogues to resolve conflicts are imported from Karunatillake et al. (2005). It is assumed that (1) the negotiating parties are self-interested, (2) proposals that they generate are viable on their behalf, and (3) they do not intentionally attempt to deceive each other with offers that they do not believe feasible on their behalf.

The negotiation domain is defined by how the negotiating parties evaluate their decision-related costs and benefits. According to Liu & Wirtz (2005), it is the negotiating party's willingness to pay (WTP) and willingness to accept (WTA) in money terms its most and least preferred towing option, respectively. Agreement is possible if one negotiating party's maximum WTP for a specific towing option is not less than its counterpart's minimum WTA. In order to determine the relevant levels of proposed WTP and WTA it is important for the negotiating parties to have good knowledge about the ecological sensitivity of marine and coastal areas, about the vulnerability of the human uses in that area, and about the environmental outcome of a proposed response.

The decision-making algorithm for *PROPOSE*:

$$if\,(capable(do(a_i, e_i)) \wedge B^{a_i}_{do(a_j,e_j)} \rangle C^{a_i}_{do(a_i,e_i)})\ \ then\ PROPOSE(do(a_j, e_j)), (do(a_i, e_i))\ end\ if$$

where $a_i, a_j, \ldots$ denote the negotiating parties; $e_i, e_j, \ldots$ denote actions; $B^{a_i}_{do(a_j,e_j)}$ denotes the individual benefit to a_i of performing $do(a_j, e_j)$, this includes also the benefits of keeping the natural communities undisturbed; and $C^{a_i}_{do(a_i,e_i)}$ denotes the individual cost to a_i of performing $do(a_i, e_i)$, this includes also the costs of recovering natural communities.

PROPOSAL may be for a single or a composite action.

The decision making algorithm for *ACCEPT* and *REJECT*:

$$if\,(capable(do(a_j, e_j)) \wedge B^{a_j}_{do(a_i,e_i)} \rangle C^{a_j}_{do(a_j,e_j)})\ \ then\ ACCEPT(do(a_j, e_j), do(a_i, e_i))\ else\ REJECT(do(a_j, e_j), do(a_i, e_i))\ end\ if$$

When deciding on *ACCEPT* or *REJECT* the particular *PROPOSAL* the negotiating party is evaluating the proposal by balancing its individual benefit $B^{a_i}_{do(a_j,e_j)}$ and cost $C^{a_i}_{do(a_i,e_i)}$ attributed to the proposed WTP and WTA combination. However, either of those elements can be zero and the negotiating parties can express proposals that are mere requests or offers.

The decision making algorithms for *CHALLENGE*:

$$if\,(REJECT(l) \in \Delta^{a_i} \wedge reason(REJECT(l)) \notin \Delta^{a_i})\ then\ CHALLENGE(REJECT(l))\ end\ if$$

where Δ^{a_i} is the knowledge base of negotiating party a_i.

Upon rejection of a proposal $REJECT(l)$ of the negotiating party a_i by its counterpart a_j, the negotiating party a_i may choose to either forward the modified proposal or to challenge a_j's decision in order to identify the reasons for the rejection (reasons for rejection do not belong to the knowledge base Δ^{a_i} of negotiating party a_i).

Negotiating parties proceed according to the dialogue game protocol (*PROPOSE*; *ACCEPT*; *REJECT*; *CHALLENGE*) until all of them *ACCEPT* and a consensus is reached. Negotiating parties are only accepting the proposals that they believe to have the capability to hold. If accepted, they will incur commitment to perform their respective actions.

The minimum condition required in order for negotiations to be successful is that one negotiating party's maximum WTP for a specific towing option is not less than its counterpart's minimum WTA.

Let us assume that the spilling vessel is situated adjacent to Nõva and Keibu bays and the negotiating parties represent Nõva and Keibu counties. Figure 6 can be used as an example to quantify the costs in arbitrary units of recovering the natural communities in the case of oil spills as the investments for restoring the damaged natural communities increase proportionally with the sensitivity of the community. If none of the feeding guilds is affected then the sensitivity value is set as zero, if one of the feeding guild is affected then the value is one, etc.

Table 2. Possible scenarios of negotiations on oil spill response actions. It is assumed that the spilling vessel is situated adjacent to Nõva and Keibu bays and different negotiating parties represent Nõva and Keibu counties. Willingness to pay (WTP) and willingness to accept (WTA) are expressed in arbitrary units and computed according to the sensitivity of the bay ecosystem to oil spill (see also Fig. 6)

Nõva County	Keibu County	Negotiation outcome
Max WTP ≤ 6104	Min WTA ≥ 6104	Spilling vessel is towed to Keibu Bay
Min WTA ≥ 4675	Max WTP ≤ 4675	Spilling vessel is towed to Nõva Bay
Max WTP < Min WTA		No agreement

Summing up the sensitivity of macrozoobenthic communities by areas gives the value 4675 for Nõva Bay and 6104 for Keibu Bay. Despite the smaller surface area the costs of recovering the communities are higher in Keibu Bay than in Nõva Bay. Therefore it is environmentally more beneficial to tow the spilling vessel to Nõva Bay than to Keibu Bay. However, under certain agreement the alternative, i.e. Keibu Bay, can be selected as a possible towing destination (Table 2).

CONCLUSION

To conclude, oil has a negligible effect on macrophytes and a moderate effect on macrozoobenthos in Nõva and Keibu bays provided a small or moderate spill and high wave disturbance. The knowledge on the sensitivity of benthic communities can be used to reduce the overall environmental impact of an oil spill through oil contingency management related negotiations.

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Põhjataimestiku ja suurselgrootute funktsionaalsete rühmade tundlikkus naftareostusele ning selle teadmise kasutamine õlireostusega seotud läbirääkimistel

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On antud ülevaade naftareostuse mõjust põhjataimestikule ja suurselgrootutele Nõva ning Keibu lahes Soome lahe lääneosas. Naftareostus ei avalda mõju põhjataimestiku liigilisele koosseisule ega sügavuslevikule. Põhjataimestiku ja *Pylaiella littoralis*'e katvused on foonialadega võrreldes naftast mõjustatud rannikumeres väiksemad. Herbivoorid on naftareostuse suhtes kõige tundlikumad suurselgrootud ja nende arvukus on naftaga reostunud merealadel oluliselt madalam. Naftareostus avaldab positiivset mõju detrivooridele ja filtreerijatele loomadele. Saadud infot elustiku tundlikkuse kohta võib kasutada lekkiva laeva pukseerimiskoha väljaarvutamisel õlireostusega seotud läbirääkimiste ajal.