Impact and recovery of an intertidal ecosystem from the Nakhodka heavy- oil spill

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ABSTRACT

A large heavy-oil spill from a Russian tanker, the *Nakhodka*, occurred in the Sea of Japan on 2 January 1997. We studied the impacts of heavy-oil, which stranded along the southern coast of the Sea of Japan, in a rocky intertidal ecosystem. Imago-Ura Cove was selected as a study site to observe the temporal change of an oiled rocky shore since there was little human intervention because cleaning was not emphasized there. Field surveys were conducted from the autumn of 1997 to the spring of 2000. We measured coverage of macroalgae in quadrats of 1 m x 1 m and counted animals in quadrats of 5 m x 5 m along the intertidal zone. The changes in the ecosystem caused by the oil spill accident was analyzed in the Sea of Japan for the first time by applying techniques using the Geographical Information Systems (GIS). Heavily polluted area was distributed in the sheltered area after the accident and decreased in three years. The coverage of macroalgae and the numbers of animals increased in three years and those of some species of algae with microscopic sporophytic generations and perennial animals were stable or decreased during the

study period. Species diversity of benthic animals increased in two years after oil spill.

INTRODUCTION

Marine oil spills from tanker vessels has been occurring more frequently in these two decades, causing huge and devastating impacts on coastal ecosystems (Peterson and Eates, 2001). Effects of spilled oil on intertidal benthic communities were investigated following large spills such as by the *Torrey Canyon* and the *Exxon Valdes*. Recovery of communities from oil impact sometimes require more than a decade not only due to the direct effects of spilled oil, but also due to indirect and chronic effects (Southwood and Southward, 1978, Fukuyama et al., 2000, Peterson, 2001). Heavy-oil pollution has not only a short term (one year) direct influence on species diversity and numbers of organisms in the intertidal zones but also indirectly influences through changes in population by altering survival, growth, reproduction, and recruitment of future generations (Fukuyama et al., 2000) in intermediate to long term periods of several years or more. In Japan, however, very few studies have investigated impacts by heavy-oil spills on coastal ecosystems and the subsequent recovery from the damage, although oil spills repeatedly occurred along the coast of Japan since 1970's.

The heavy-oil spill from the Russian tanker *Nakhodka*, occurring in January 1997, seriously affected coastal environments along the Sea of Japan for more than 500 km of shoreline (Komatsu et al., 1999). Along the coast facing the Sea of Japan, rocky shores with rich flora and fauna extends from Kyushu Island to Hokkaido Island through Honshu Island in Japan. Physical factors such as tidal ranges and waves in the Sea of Japan modify the duration of impacts by stranded oil on intertidal epibiota along the rocky shore in Honshu Island differently from other regions. The Russian tanker accident shows that potential risks of oil-spill accidents exist in the Sea of Japan in the future. To establish suitable actions to protect some areas of the coast from pollution, it is necessary to predict the impacts of spilled oil on intertidal ecosystems.

Accurate evaluation of impacts of oil spills on coastal ecosystems is difficult because it is virtually impossible to predict the time and space of accidents beforehand, and thus data on pre-disturbance conditions are hardly available (Peterson and Eates, 2001). In addition, the monitoring of benthic communities is generally conducted by collecting a small number of samples at some limited points arbitrarily chosen in the entire polluted area. It was demonstrated that different sampling designs sometimes lead to different conclusions on the effects of oil spills, even though they were carried out in the same site and period (Peterson et al., 2001). Long-term monitoring of intertidal communities over wide areas along shorelines containing both heavily polluted and less-polluted areas is one method to overcome these problems.

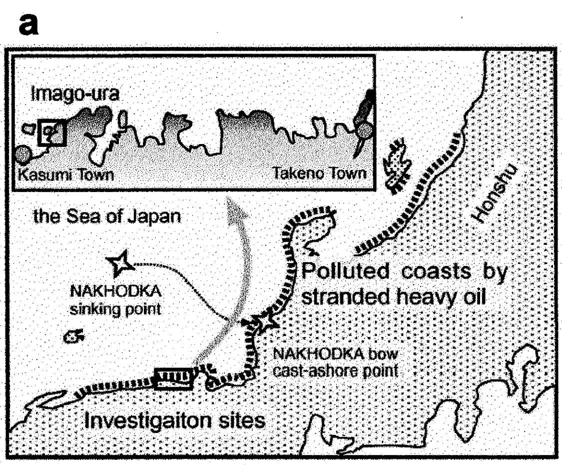
We conducted a research project to evaluate impacts by the heavy-oil spill from the *Nakhodka* on an intertidal community and to monitor the recovery of the community from the damage, based on a long-term census (5 years) covering a wide length of coastline (350 m). This paper examines temporal changes in species diversity and abundance of algae and benthic animals after the oil spill.

METHOD

Spilled heavy oil from *Nakhodka* stranded on the coast of Hyogo Prefecture, Japan, facing the Sea of Japan on 9 January 1997. Cleaning operations were conducted in many areas along the coast. Volunteers and citizens used ladles, shovels or even their hands to put oil into buckets (Sasaki, 1998). In some cases, they wiped away oil from stones, rock and bedrock with cloths. Because such a thorough operation wasn't conducted in Imago-Ura Cove, Kasumi, Hyogo Prefecture (Fig. 1a), oil had remained on the substrate since the stranding of oil. In this cove, intertidal organisms had been under continuous influence of heavy-oil and less influence from humans. That is why we selected Imago-Ura Cove as a study site to clarify a natural succession of flora and fauna in an intermediate time scale.

We conducted surveys every spring and autumn from 1997 to 2000. Autumn surveys were done from 15 November to 17 November 1997, from 9 October to 11 October 1998 and from 8 October to 11 October 1999. Spring surveys were done from 6 May to 10 May 1998, from 7 May to 10 May 1999 and from 12 May to 14 May 2000.

We monitored the benthic community over the entire range of the intertidal zone along the shoreline on the southern side of the cove (a total length of 350 m) to compare the changing process of intertidal flora and fauna depending on the difference in heavy-oil pollution. For this purpose, we established 70 quadrats (each 5 m width) continuously along the shoreline (Fig. 1b). Each quadrat covered either 25 m^2 (5 m long perpendicular to the shoreline) or 12.5 m^2 (2.5 m long perpendicular to the shoreline), depending on the width of the intertidal zone. For the 25 m^2 quadrats, data were taken for the upper and lower intertidal sections separately (each 5 m x 2.5 m in area). We observed flora and fauna within the coast length of 70 m in the autumn and 450 m in the spring, respectively. We grouped the quadrats into 9 sites (A1 to A9) according to location, topography and level of oil pollution observed by the Marine Life Research Group of Takeno in spring of 1997 (Table 2).



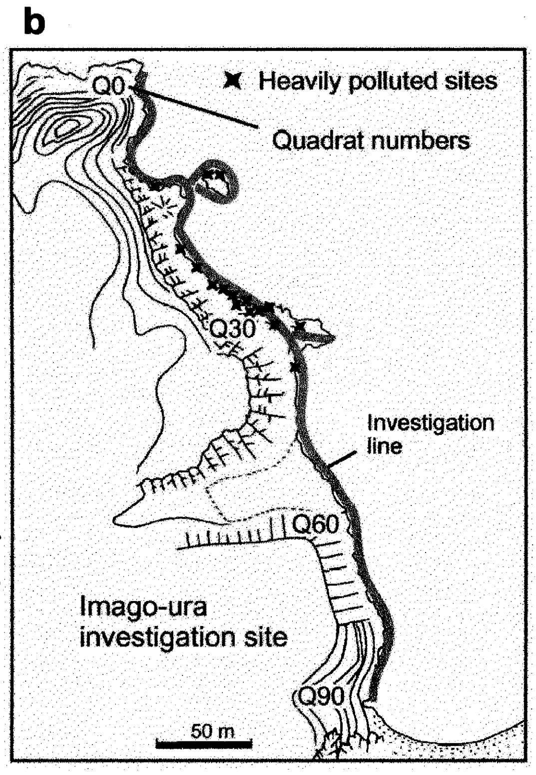


Figure 1 Maps of investigation site. a, Overview of the areas polluted by the *Nakhodka* oil spill. b, Investigation line in Imago-ura, Kasumi, Hyogo, Japan.

Coverage of tarred spots from heavy oil was measured at 5 m x 2.5 m quadrats during the spring surveys since 1998 to 2000. The spots were classified into three categories: more than two spots, only one spot and no spot. Coverage of each macroalga was observed at 1 m intervals with a quadrat of 1 m side (1 m^2) along the top of subtidal zone. Benthic invertebrates in each quadrat were identified and counted by 2-3 observers without collecting animals. In quadrats with a boulder substratum, only the upper surface of the rocks were surveyed. Some co-occurring closely related species (such as *Chlorostoma lischkei* and *C. turbinatum*) were difficult to identify without collection. These species were grouped into one operational group (OG) and treated as equivalent to one taxon for analyzing changes in the diversity of the benthic community. Rare species were not included in any OG. Data from A1, A2 and A9, and all the data in the autumn were excluded from this paper.

A Geographical Information System (GIS) has been applied to monitor and analyze the change of intertidal ecosystem polluted by heavy-oil from the *Nakhodka* in a spatial scale of 10-100 m along the rocky shore in an intermediate temporal scale (Komatsu et al. 2003).

RESULTS

Heavy-oil was found in most quadrats in the spring of 1998, while more than half of the quadrats had no oil spots in 1999. Tarry oil had remained in sheltered areas rather than in exposed areas of the shoreline in 1998 and 1999 (Fig. 2a). Quadrats further from the water had more oil spots than those closer to the shore (Fig. 2a).

Species diversity of macroalgae in the autumn of 1997 were the lowest among the autumns of three years from 1997 to 1999 and were less than three species in 13 quadrats in 1997. The number of macroalgal species in more polluted areas were smaller than in less polluted areas just after the accident, and has recovered steadily until the spring of 2000 with 10-15 species in quadrats in the autumn of 1999.

Coverage of macroalgal species of 1 m^2 quadrats were grouped and averaged at 5 m intervals along the spring survey line (Fig. 2b). One of the most remarkable characteristics is low (< 50 %) coverage in the continuously polluted quadrats in the spring of 1998, one year after the stranding of oil. The gap of low continuous coverage has been gradually filled by seaweeds from 1999 to 2000. However, the quadrats with low seaweed coverage through three years were distributed in shoreline that corresponded to areas where oil remained.

We identified 76 invertebrate taxa including 57 species of mollusks and 10 species of crustaceans during the study, and categorized them into 42 OGs for the visual census (Table 1, see Table 2 in Yamamoto et al. 2003). Most of these species were herbivorous mollusks (limpets, periwinkles, chitons, and some species of snails) that feed on algae attached to rock surfaces. Other species were sessile suspension feeders such as mussels and barnacles, and carnivores such as dogwelks, starfish and crabs.

The taxa richness (represented by the number of OG per each 12.5 m^2 quadrat) varied greatly between 2 (minimum) to 25 (maximum) among quadrats and years (see Fig. 2 in Yamamoto et al. 2003). In general, the quadrats in the lower intertidal zone contained more species than those in the upper intertidal. The taxa richness in more polluted areas in 1997 (A3 and A4) was low in 1998 and increased rapidly in 1999 (Table 2). In contrast, the change in taxa richness of less polluted areas along the inner parts of the cove (A7 and A8) was not obvious during 1998-2000.

Table 1 List of benthic animals classified for the operational group (OG) for identification in the visual sensus.

No.	Phylum	Class	Species Name	No.	Phylum	Class	Species Name
1	Cnidaria		Ceriantharia gen. spp.	22			*Thais clavigera*
2	Mollusca	Polyplacophora	*Acanthopleura japonica*	23			*Euplica* spp.
3			*Acanthochitona spp.*	24			*Niotha* spp.
4		Gastropoda	*Cellana treuma*	27			Sacoglossa gen. spp.
6			*Cellana nigrolineata*	25			*Aplysia kurodai*
5			*Cellana grata*	26			*Aplysia spp.*
7			*Patelloida saccharina lanx*	29			*Siphonaria sirius*
8			*Lottia dorsuosa*	28			*Siphonaria japonica*
9			*Lottia* spp.	31			another gastropoda
10			*Nipponacmea concinna*	30		Bivalvia	*Septifer virgatus*
11			*Nipponacmea* spp.	32			Ostreidae gen. sp.
12			*Chlorostoma spp.*	33	Arthropoda	Cirripedia	*Capitulum mitella*
13			*Omphalius spp.*	34			Balanomorpha gen. spp.
14			*Monodonta labio confusa*	35		Malacostraca	*Ligia exotica*
15			*Monodonta spp.*	36			Anomura gen. spp.
16			*Turbo coronatus coreensis*	37	Annelida	Polychaeta	Serpulidae gen. spp.
17			*Nodilittorina radiata*	38			*Cirriformia tentaculata*
18			*Littorina brevicula*	39	Echinodermata	Echinodea	*Hemicentrotus pulcherrimus*
19			*Serpulorbis imbricatus*	40		Asteroidea	*Asterina pectinifera*
20			*Ergalatax contractus*	41		Ophiuroidea	Ophiuroidea gen. spp.
21			*Thais bronni*	42		Holothuroidea	Holothuroidea gen. spp.

Table 2 Taxa richness of benthic animals after the heavy-oil pollution in 1997. Measurements were conducted in every May.

Area	Quadrat	Oil pollution grade in 1997	Oil pollution grade in 2000	Number of OG		
				1998	1999	2000
A3	Q18-23	heavy	light	23	30	27
A4	Q24-33	heavy	heavy	24	31	29
A5	Q34-39	heavy	light	24	26	28
A6	Q45-54	heavy	heavy	24	27	28
A7	Q60-65, 69	light	light	26	27	29
A8	Q71-82	light	light	32	33	30

Total number of all animals counted in a quadrat of 5 m x 5 m was plotted in the quadrat along the spring survey line (Fig. 2c). The number of animals in the more polluted areas were much smaller (< 700 individuals per 25 m^2) than in less polluted areas in 1998, and the density steadily increased from 1998 to 2000 at most of the quadrats. The quadrats with a small number of animals throughout the three years were distributed in areas that corresponded to quadrats with more polluted in 1997 or oil remaining in 2000.

DISCUSSION

The temporal change of stranded oil under less human intervention was monitored in Imago-Ura Cove. Oil, which was weathered and became tarry, remained in the quadrats of sheltered areas with less wave exposure for one year or more after the stranding of heavy-oil. According to the tide tables the highest high water was 51 cm (tidal range is 34 cm) in August and the lowest low water was –13 cm (tidal range is 37 cm) in January at Sakai about 100 km west of the Imago-Ura Cove. In the Sea of Japan, strong winter winds blow from the northwesterly and westerly directions and generates strong waves along the southern coast. Hayes (1996) stated that heavy wave action is the most effective natural process for cleaning shorelines of stranded oil although currents generated by tides and winds are also important. Thus, waves during the winter season are the main physical forces that act to remove the stranded oil on rocks along the southern coast along the Sea of Japan. Our observation shows that the stranded oil disappeared in three years in this region while the oil on the rocks in the relatively sheltered shoreline remained longer than in the exposed shoreline.

Coverage of macroalgae was reduced by stranded oil after the accident and has consistently increased from low coverage. Stekoll and Deysher (2000) also reported that coverage of the dominant species of intertidal macroalgae, *Fucus gardneri*, was generally reduced in most habitats affected by the *Exxon Valdez* oil spill in 1989. Driskell et al. (2001) followed the long-term dynamics of *F. gardneri* for seven years after the *Exxon Valdez* oil spill and observed that the change in *Fucus* cover at spill-disturbed sites were synchronous across all quadrats. They attained maximum in three to four years after the accident. Our study also shows steadly increase in coverage in three years after the accident.

Small seaweeds such as *Chondrus ocellatus* remained only in quadrats that did not have spilled oil one year after the accidents (Komatsu et al. 2003). Their coverage of the quadrats in sheltered areas rapidly increased since two years after the accident. Nakahara (1988) stated that small perennial seaweed species become dominant under low grazing pressure when disturbance due to mechanical forcing is intermediate and chemical stress, which physiologically influences algae, is great. In Imago-Ura Cove it is judged that mechanical disturbance is intermediate and chemical stress due to spilled oil is great after the oil spill accident. These results show that Nakahara's hypothesis is applicable to this study.

The recovery of taxa richness of benthic animals continued until 1999 in heavily polluted areas (Table 2). On the other hand, the total density of benthic animals continued to increase from 1998 to 2000 in most of the quadrats in these areas (Fig. 2c). These findings suggest that it took at least two years for the diversity and three years for the abundance of benthic animals to recover to original levels after the oil spill. However, we could not exclude the possibility that some confounded factors unrelated to the oil effects (such as temporal changes in environmental conditions) also caused the same tendency, because we have no data about the abundance of benthic animals before the oil spill. We need a longer-term survey to ascertain whether the observed temporal change in the benthic animals was due to the recovery from the oil spill, or merely reflecting natural fluctuation of the environment. In the case of oil spills from the *Exxon Valdez* in 1989, benthic animals increased their number at once and reached a peak after three or four years, then decreased again (Houghton et al., 1997, Skalski et al., 2001).

Sensitivity to oil pollution and the recovery pattern from oil impact were different among species. It can be said that this difference was caused by a difference in behavior, habiat use and life history. Increase in coverage of some macroalgae such as S*cytosiphon. lomentaria*, *Colpomenia sinuosa* and *Lethesia difformis* was not observed after the accidents. Although low coverage of the seaweed, *S. lomentaria,* was distributed in polluted quadrats (Komatsu et al., 2003), they disappeared from polluted areas and increased in coverage in areas where there was no heavy oil. They have a common life history of heteromorphic alternation of generations, in which the sporophyte is microscopic and settles on the substrate. Such kinds of algae is easily damaged during the microscopic generation due to heavy oil cover on the substrate and the influence of this damage appears in the next season with the absence of the macroscopic generation.

The difference among species was also observed in benthic animal communities. One limpet, *Cellana treuma*, increased after the oil spill and contributed to increase in total number of animals (Yamamoto et al. 2003). This species is very sensitive to heavy-oil pollution, because it has a habit moving up and down under awash conditions (Iwasaki, 1992), and it was observed to dislodge very easily (Yajima, 1997). Since this limpet is annual, they can quickly increase in number through very active reproduction and settle in the area where the other snails are absent. Thus this species can be an index of heavy-oil pollution in short-term period. When a snail is perennial, it takes several years to mature for spawning. If spawning snails are damaged and/or settling of their planktonic larvae are obstructed by heavy-oil cover, their recruitment is not successful. In this case, they remain in population and disappear from the polluted area. The same tendency was observed for populations of *Patelloida saccharina lanx* in the autumn even though the number of seaweed species increased since the autumn of 1997 (Yamamoto et al., 2003).

CONCLUSION

This study shows that the intertidal ecosystem of flora and fauna generally recovered in three years after the accident, but recovery speed was influenced by the oil that remained on the substrate. Each species showed different sensitivity to oil pollution and recovery patterns from damages depending on their habitat use, migration ability and life history, *i.e.*, annual or perennial. GIS analysis suggested that the topography along the coast was strongly related to stranded oil remaining on the substrate through wave action.

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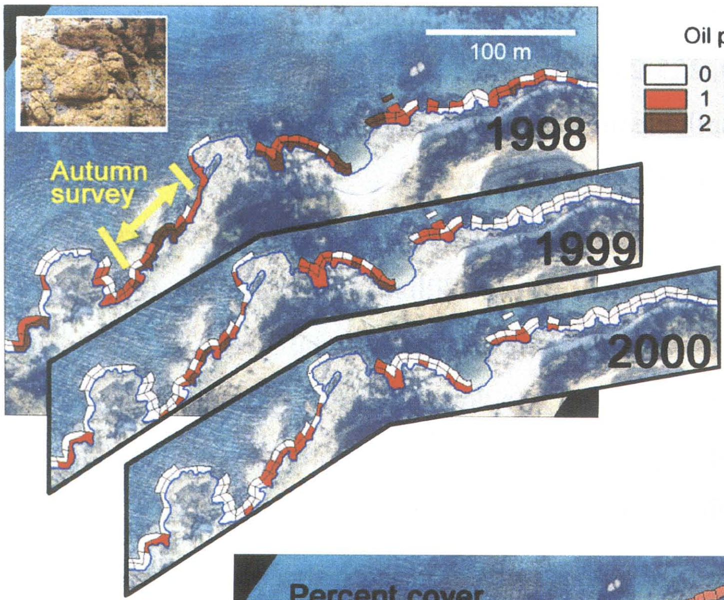


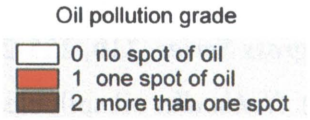
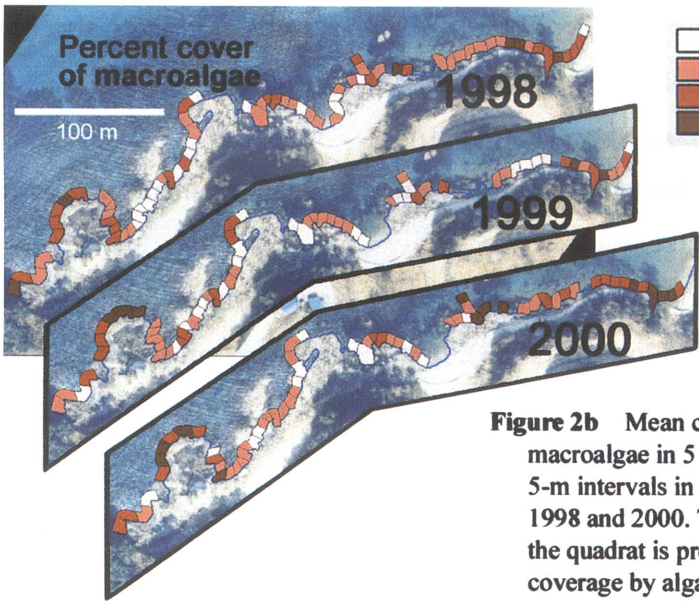


Figure 2a Coverage by heavy oil in 5 x 2.5-m quadrats in the intertidal zone along the shoreline of Imago-Ura Cove, Japan, in spring, between 1998 and 2000 (drawn using GIS software). Density of oil coverage is shown as three grades: no oil coverage (open), one spot of oil (intermediate), and more than one spot (dense).



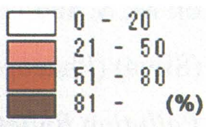
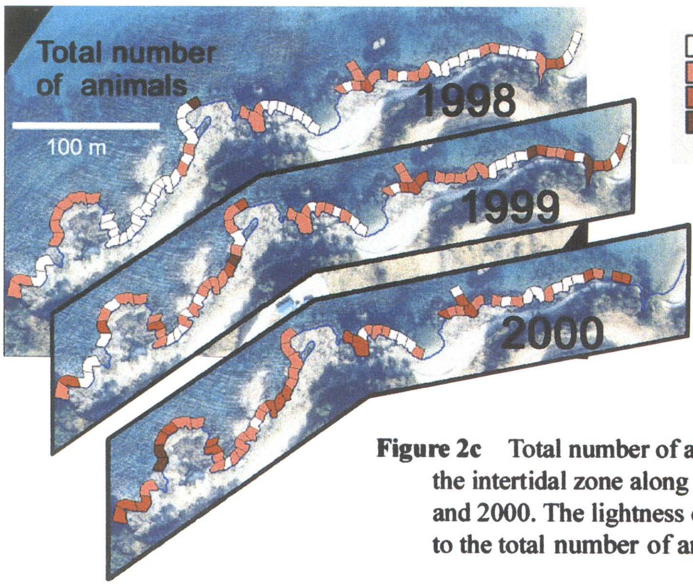


Figure 2b Mean coverage of macroalgae in 5 x 1-m quadrats, at 5-m intervals in spring between 1998 and 2000. The darkness of the quadrat is proportional to coverage by algae.



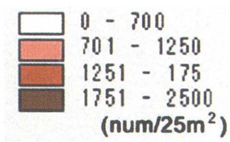


Figure 2c Total number of animals counted in 5 x 5-m quadrats in the intertidal zone along the shoreline in spring between 1998 and 2000. The lightness of the quadrat is inversely proportional to the total number of animals.