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Effect of the *Hebei Spirit* oil spill on intertidal meiofaunal communities in Taean, Korea

Teawook Kang [a,b], Je Hyeok Oh [a], Jae-Sang Hong [b], Dongsung Kim [a,*]

[a] Marine Ecosystem and Biological Research Center, KIOST, Ansan, P.O. Box 29, Seoul 425-600, Republic of Korea
[b] Department of Oceanography, College of Natural Science, Inha University, Incheon 402-751, Republic of Korea

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ABSTRACT

In December 2007, approximately 10,900 tons of oil from a crude carrier spread rapidly onto the coast of South Korea. We studied the effects of oil on meiofauna by comparing two contaminated intertidal sites with an uncontaminated site. During 2008–2009, the density of meiofauna fluctuated among the contaminated sites but did not vary by season. Seasonal changes in density were observed at contaminated sites 3 years after the oil accident. Meiofauna appeared to be more sensitive to oil pollution stress at the more heavily contaminated site than at the less contaminated site. CLUSTER analysis showed that meiofauna communities in the 3 years immediately following the accident significantly differed from those sampled later. A non-metric multidimensional scaling analysis showed that nematode species composition in the first month after the accident significantly differed from those sampled later. Long-term monitoring is needed to assess the effects of oil on the meiofaunal community.

1. Introduction

On December 7, 2007, the M/V *Hebei Spirit* was struck by a crane barge on the Yellow Sea approximately 5 miles off the coast of Taean, South Korea. Approximately 10,900 t of crude oil spilled into the sea from the Hebei Spirit (Kim et al., 2010). The spilled oil spread rapidly in the water and onto the nearby coast due to strong winter winds and currents. The oil eventually extended along 70 km of the Taean shoreline (Yim et al., 2012; Kim et al., 2013). After the accident, >1.3 million volunteers participated in removing oil from the coast (Kim et al., 2010). Oil removal continued until October 2008, and an estimated 20% of spilled oil was recovered (Yim et al., 2012). The oil concentrations in intertidal seawater reached 16,600 μg/L after the initial accident, but decreased to <10 μg/L at most sites after 10 months (Kim et al., 2010).

Oil spills cause marine pollution worldwide. Most previous studies on the effects of oil-spill pollution on marine benthos have dealt with benthic macrofauna. Since the 1980s, interest has focused on meiofaunal communities (Boucher, 1980; Fleeger and Chandler, 1983; Friethsen et al., 1985; Bodin, 1988; Danovaro et al., 1995; Danovaro, 2000; Ansari and Ingole, 2002; Commito and Tita, 2002; Schratzberger et al., 2003). Compared with macrofauna, meiofauna have shorter generation times and higher metabolic rates, lack planktonic larval dispersal, and are more sensitive to changes in environmental conditions (Higgins and Thiel, 1988; Coull and Chandler, 1992; Mahaut et al., 1995; Kennedy and Jacoby, 1999). Due to these life history characteristics, marine meiofauna may be useful pollution indicators in routine biological monitoring (Heip, 1980; Platt and Warwick, 1980; Vincx and Heip, 1991). In particular, marine nematodes are considered sensitive biological indicators of pollution because they are taxonomically diverse, are ubiquitous in the ocean, and usually occur in high numbers (Croll and Mathews, 1977; Platt et al., 1984).

Studies on the impact of oil pollution on marine meiofaunal communities have yielded conflicting results. Hydrocarbon contamination has been found to have both negative and positive influences on different meiofaunal. Most meiofauna show a decline in population immediately after oil spillage (Boucher, 1980; Elmgren et al., 1983; Coull and Chandler, 1992; Danovaro et al., 1995; Peterson et al., 1996; Ansari and Ingole, 2002; Kang et al., 2014). For example, Danovaro et al. (1995) reported that meiofaunal density was lower following the release of crude oil from the *Agip Abruzzo* oil tanker than it was prior to the pollution event. Likewise, a study on the effect of the M/V *Sea Transporter* oil spill found a notable decline in the abundance of dominant taxa such as nematodes and harpacticoid copepods in the intertidal zone (Ansari and Ingole, 2002). In a controlled experiment, Kang et al. (2014) reported a drastic decrease in meiofaunal density at experimentally oiled sites during the initial period after oil application.

* Corresponding author at: Korea Institute of Ocean Science & Technology, Ocean Science Research Department, 787 Haeanro, Ansan, Gyeonggido 15627, Republic of Korea.
E-mail address: dskim@kiost.ac.kr (D. Kim).

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In contrast with these reports, other studies have observed a positive response by several meiofaunal taxa to oil application and did not identify oil-induced mortality (Fleeger and Chandler, 1983; Stacey and Marcotte, 1987). Naidu et al. (1978) observed a significant increase in the density of harpacticoid copepods (*Halectinosoma gothiceps*) in experimentally oiled sites on an Alaskan mudflat. Further studies indicated that the types and amount of oil released, the local environmental conditions, the weathering of the oil, the specific dynamics of the accident, and the type of clean-up techniques employed might be responsible for different ecological effects and toxicological impacts (Jewett et al., 1999; Edgar and Barrett, 2000).

The effects of oil spills on meiofaunal communities indicate vary depending on specific environments. In the present study, we evaluated the effects of an oil spill on meiofaunal communities in the sandy intertidal zone of Taean, Korea, and monitored the distribution of meiofauna monthly for 6 months and seasonally for 5 years. The purposes of the present study were (1) to examine the distribution and abundance of meiofaunal communities at different sites exposed to known amounts of oil contamination, (2) to investigate the changes in meiofaunal and nematode communities over time at study sites, and (3) to identify the changes in nematode species at a heavily oil-contaminated site (site 2, Mallipo). The goal of this work is to clarify how meiofauna communities recover from oil spills.

2. Materials and methods

The Hebei Spirit oil spill accident occurred in December 2007. After the accident, meiofauna from sandy intertidal areas were collected monthly for 6 months at two heavily affected locations, sites 1 and 2 (Shinduri and Mallipo). They were also collected seasonally for 5 years at the same two heavily affected sites and one unaffected location, site 3 (Mongsanpo) in Taean County, located in the western part of Korea (Fig. 1). The monthly samples were collected from January to June 2008. The seasonal samples were collected in January (winter), April (spring), July (summer), and October (autumn) of each year from 2008 to 2012.

Total petroleum hydrocarbon (TPH) concentrations in pore water from the sampling sites were determined in a previous study using a 10 AU Field and Laboratory fluorometer (Turner Designs, California, USA) by Kim et al. (2010, 2013).

The sediment in the study area may be characterized as follows. The mean grain size in the study areas varied from fine sand (phi 2.84) to coarse sand (phi 1.55). The median grain size at site 2 (Mallipo) was smaller than that at the other two sites (MLTM, 2012). The levels of total organic carbon (TOC) were low in the sediments from all three sites. Median TOC was lowest at site 2 (MLTM, 2012). After the oil spill accident, the TOC of site 1 ranged from 0.01% to 0.45% (mean 0.06%), depending on the sampling date. The difference was significant (Kruskal-Wallis, $p < 0.001$). Starting in 2008, the amount of TOC at site 1 declined. The TOC levels were typically lower at site 2 than at site 1 and tended to increase gradually from the intertidal upper area (farther from the water) to the lower area, with statistically significant differences between site 1 and site 2 (Kruskal-Wallis, $p < 0.001$). TOC levels at site 3 were similar to those at site 1.

As shown in Table 1, each site was divided into three stations: intertidal upper (station 1), central (station 2), and lower (station 3). Meiofauna were sampled by collecting three replicates using an acryl corer (10 cm^2) to a depth of 3 cm at each station, and the samples were preserved in 5% formalin. In the laboratory, the meiofauna were separated from the sediment by flotation using Ludox HS40 colloidal silica (DuPont) with a specific gravity of 1.18 (Burgess, 2001). The supernatant was passed through a sieve (38 μm) and the organisms that remained on the sieve were collected. The meiofaunas were manually sorted using a dissecting microscope (Leica MZ16), classified, and counted. Nematodes sampled during the winter season and 6 months after the accident were transferred to 3% glycerin. They were then mounted on microscope slides for identification and classified to the lowest possible taxonomic level (Platt and Warwick, 1983, 1988; Warwick et al., 1998) using an Olympus BX51 microscope. The nematodes were classified according to trophic group using Wieser's original groupings (Wieser, 1953): 1A, selective deposit feeders; 1B, non-selective deposit feeders; 2A, epistrate feeders; and 2B, predators/omnivores.

CLUSTER analyses, similarity profile analysis (SIMPROF), and non-metric multidimensional scaling (nMDS) analyses were carried out to delineate the meiobenthic community of each sampling site into different groups, using the Bray–Curtis similarity measure. The average density data of meiofauna and nematode species were used as original values or as fourth root transformations in these analyses. ANOSIM analysis was performed to determine whether meiofaunal taxonomic composition differed significantly between contaminated sites and the noncontaminated site. SIMPER analyses were performed to estimate the percentage dissimilarity in the composition of the meiofaunal and nematode communities, according to the investigated time or sampling sites. The SIMPER analyses also confirmed which of the taxa/species

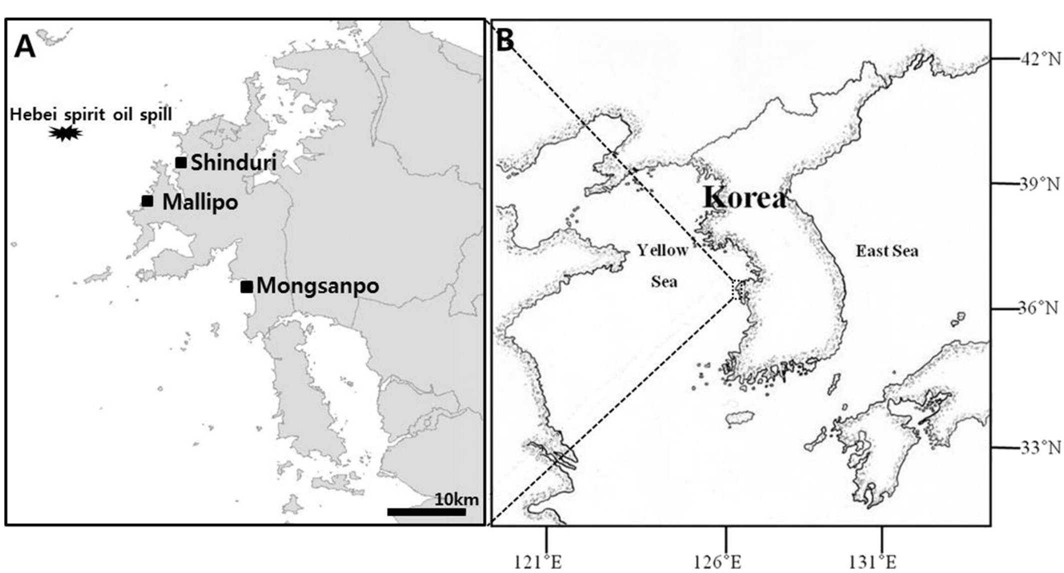

Fig. 1. Location of the study area in Taean County, Korea.