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Initial impacts of the *Hebei Spirit* oil spill on the sandy beach macrobenthic community west coast of Korea

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ABSTRACT

Petroleum hydrocarbon contamination and macrobenthos in the sandy tidal flats of Taean were monitored for 1 year to assess the impacts of *Hebei Spirit* oil on the macrobenthic community. A total of 207 macrobenthic fauna was collected, and the mean density and biomass of macrobenthic fauna continued to decrease until 12 months after the oil spill, but macrobenthic density at the most heavily affected sites increased by about twofold. In January 2008, the dominant species occurred at very low densities in strongly affected sites. The macrobenthic communities differed between oil-affected and unaffected sites. In particular, differences in community structure at Mallipo beach were larger than those at Shinduri. We suggest that long-term monitoring is needed to assess the specific effects of oil pollution on the sandy intertidal macrobenthic community.

1. Introduction

The anchored oil tanker *Hebei Spirit* collided with a barge carrying a crane on December 7, 2007 on the west coast of Korea, releasing approximately 10,900 tonnes of Middle East crude oils into the waters of Taean County. The northwesterly winds and currents drove the spilled oil toward the shore, affecting more than 375 km of coastlines, among which approximately 70 km of the Taean Peninsula shoreline was heavily impacted by thick stranded oil (Yim et al., 2012; Kim et al., 2013). The concentration of crude oil varied across low to high tidal areas based on different tidal rhythms and geographical conditions. Clean-up activities proceeded rapidly after the oil spill and continued for several months; most of the surface visible oil had been removed from the Taean intertidal area 8 months after the oil spills, with only low levels (<100 ppb) of total petroleum hydrocarbon (TPH) measured in interstitial seawater except for some heavily oiled hot spots (Kim et al., 2010). However, values of TPH in some intertidal areas were more than fivefold higher relative to other areas.

Ganning et al. (1984) demonstrated that the effects of oil on macrofaunal communities were much higher in sandy intertidal areas than in rocky intertidal areas. Additionally, McLachlan and Brown (2006) reported that the effects of an oil spill on macrofaunal communities in a sandy intertidal area were high during the initial period of the spill because of the deep absorption of oil by the sandy sediments via the bio-disturbance and burrows of infauna, which allowed oil to penetrate to great depths. Recovery is initiated as soon as conditions are no longer acutely toxic, but the time to recovery varies widely, ranging from several months to several years (Dauvin, 1998, 2000; Irvine et al., 2006; Defeo et al., 2009). Although a considerable amount of information is available related to the recovery of macrofaunal communities after oil spills (e.g. Dauvin, 1998, 2000; Teal and Howarth, 1984; Kingston et al., 1995; Jones et al., 1998; Guidetti et al., 2000), fewer data are available regarding macrofauna within oil-contaminated sandy intertidal areas (Ganning et al., 1984; Jones et al., 1998; Junoy et al., 2005).

Macrofauna in sandy intertidal areas exhibit a clear zonal distribution that is controlled by direct responses to changes in the physical environment (McLachlan, 1983; McLachlan and Brown, 2006). Clean-up efforts after oil spills result in changes in sediment conditions, which in turn affect macrofaunal distribution patterns. For example, Huz et al. (2005) demonstrated that variation in the distribution of macrofauna in an upper tidal area was greater than that in a lower tidal area. Several studies have also shown that disturbances due to clean-up activities can be more damaging than the oil spill and may delay recovery times (Peterson, 2001; Whitfield, 2003; Huz et al., 2005). In contrast, the removal of oily sediments and replacement with similar sediment conditions have led to positive recovery results (Watt et al., 1993).

In this study, we evaluated the initial effects of an oil spill on macrobenthic communities in sandy intertidal areas of Taean and monitored the distributional pattern of macrofauna for 1 year in both unaffected and heavily oil-contaminated areas.

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2. Materials and methods

Macrofauna within sandy intertidal areas were collected seasonally for 1 year after the oil spill at two heavily impacted sites (Shinduri and Mallipo) and three nonimpacted sites (Yunpo, Mongsanpo, and Baramarae) in Taean County, which is located in the western part of Korea (Fig. 1). At each site, macrofauna were sampled along transect lines extending from the high tidal zone to the low tidal zone. The transect lines were divided into six or seven stations according to the width of the intertidal area (Table 1). At each station, two replicates were collected using a can core (0.1 m^2) to a depth of 30 cm and then sieved through 1-mm mesh. Residues on the mesh were preserved in 10% seawater formalin. In the laboratory, macrofauna were sorted from the sediments and identified to the lowest possible taxon. Bulk wet weight (WWt) was measured. Gastropods and bivalves were weighed with their shells.

Sediment samples for grain-size and total organic content analysis were collected at each station and frozen until analyses. Prior to grain-size analysis, organic content and carbonates were removed using 10% H_2O_2 and 0.1 N HCl solutions, respectively. Sediment grain sizes were determined by wet sieving for the sandy fraction (diameter <4 phi) using a Ro-tap sieve shaker and by gravity settling for the finest fractions (diameter >4 phi) using an X-ray granulometer (SediGraph 5000D). Total organic carbon was determined for oven-dried samples that had been finely powdered and homogenized using a CN elemental analyzer after removal of carbonate.

Petroleum hydrocarbon concentrations in pore water of the sampling sites had been previously determined on site using a portable fluorometer (Turner Model 10AU) by Kim et al. (2010). These values were used to determine the extent and temporal variation of oil contamination at the sampling sites. The analytical methods are described in detail in Kim et al. (2010) and the concentrations of petroleum hydrocarbon in pore water are given as equivalents of spilled crude oil (μg/L). A petroleum hydrocarbon concentration of 10 μg/L is the marine water quality standard in Korea.

Density and biomass data were recalculated per square meter. The Shannon–Wiener diversity index H' (Shannon and Wiener, 1963) was calculated for the density data of each sample. Cluster analyses on macrofaunal community data for each sampling period were analyzed using the Bray–Curtis index of similarity on fourth-root transformed data. Similarity profile (SIMPROF) permutation tests were performed to determine the statistically significant clusters among samples. Nonmetric multidimensional scaling (nMDS) was carried out from the Bray–Curtis similarity matrices on fourth-root transformed data to produce an ordination plot. The above analyses were performed using the PRIMER software package (version 6.0).

3. Results

3.1. Sediment conditions

The mean grain size in the study areas varied from fine sand (phi 3.82) to coarse sand (phi 0.58). The median grain size at site 3 (Mallipo) was smaller than that at the other sites, followed by site 2 (Shinduri) and site 4 (Yunpo) (Fig. 2); median grain size did not significantly differ between the latter two sites. The total organic carbon of the sediment was relatively low across sampling sites and ranged from 0.1% to 0.98% (Fig. S1, SM). The median total organic carbon (%) was lowest at Mallipo, followed by Shinduri.

Oil concentrations in pore water ranged from 0.13 to 1260 μg/L, with an average of 101 ± 235 μg/L (Fig. 3). After the oil spill, oil concentrations at two impacted sites (Shinduri and Mallipo) were relatively high at more than 10 μg/L, which is the marine water quality standard of Korea. The concentration of oil at Shinduri decreased with time, although some fluctuations occurred due to shoreline clean-up activities; however, the oil concentration at Mallipo remained high over all sampling periods. In contrast, the

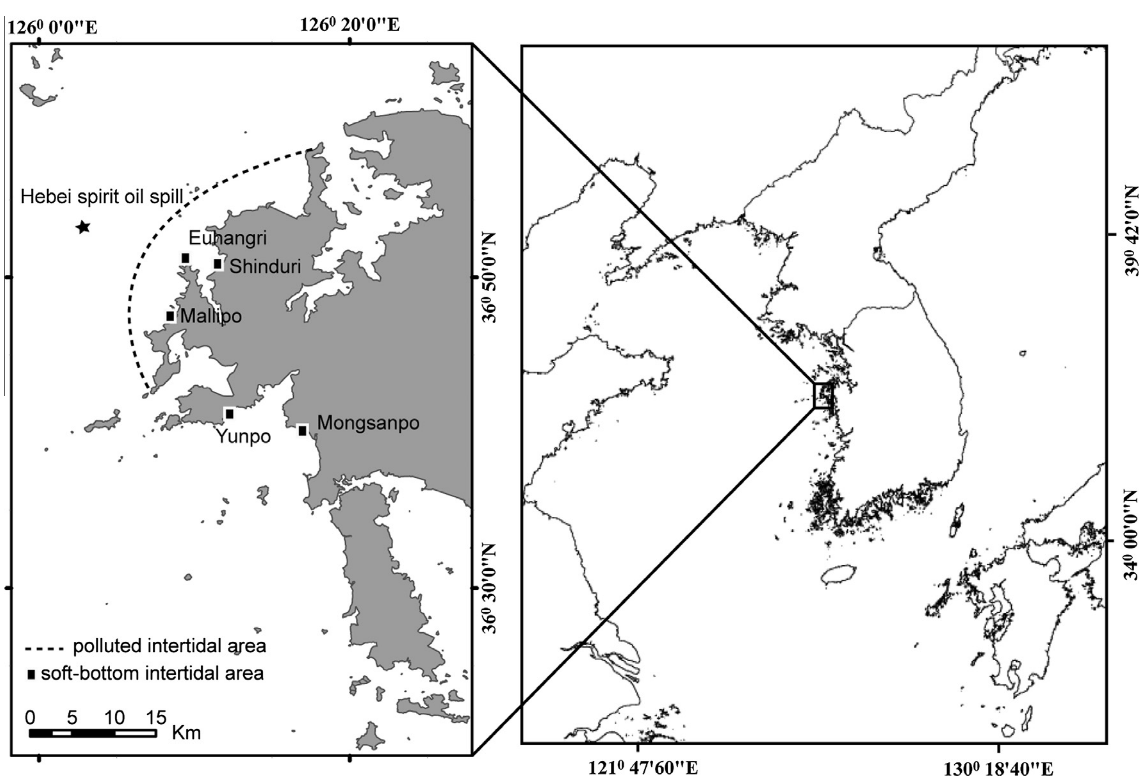

Fig. 1. Location of the study area in Taean County, Korea. Dashed line indicates the heavily oiled shoreline.