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Stable isotope analysis of a newly established macrofaunal food web 1.5 years after the *Hebei Spirit* oil spill

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A B S T R A C T

We examined trophic relationships in a newly established community 1.5 years after the *Hebei Spirit* oil spill on the west coast of Korea. Carbon and nitrogen stable isotope ratios in consumers and their potential food sources were compared between the oil-spill site and reference site, located 13.5 km from the oil-spill spot. The isotopic mixing model and a novel circular statistics rejected the influx of petrogenic carbon into the community and identified spatial consistencies such as the high contributions of microphytobenthos, food-chain length, and the isotopic niche of each feeding guild between sites. We suggested that high level of trophic plasticity and the prevalence of omnivory of consumers may promote the robustness of food web against the oil contamination. Furthermore, we highlighted the need of holistic approaches including different functional groups to quantify changes in the food web structure and assess the influence of different perturbations including oil spill.

1. Introduction

Coastal ecosystem provides several services such as erosion control, recreation, habitat and refugia for a diversity of life (Costanza et al., 1997). Coastal areas receive a variety of anthropogenic activities due to the increasing human population toward these areas (Barbier et al., 2008; Barbier, 2011). For example, toxic chemicals, radioactive disposals, sewage discharges, and garbage from human habitat near coastal zones have threatened biodiversity of coastal life (Kennish, 2002). Particularly, oil pollution by wrecked tanker or natural seepage become more problematic as industrial demand for petroleum increased (Peterson et al., 2003). Oil spill can affect the survival of aquatic organism through the direct contact causing death or incorporation of sub-lethal amount that may reduce resistance to infection (Gin et al., 2001). In this context, it is increasingly critical to assess the ecosystem response to different perturbations including oil spill in order to predict future changes in the ecosystem structure and suggest management and conservation policies that promote the ecosystem sustainability.

Stable isotope (SI) ratios have been used to examine trophic relationships in different aquatic food webs because they provide time-integrated information on consumers' diet (Fry, 2006). The tissues of aquatic fauna including macrobenthos and fish species usually have turnover periods that range from weeks to months, and thus SI measurements can compensate for the deficiencies of long-term time-series datasets when assessing an ecosystem's status (Buchheister and Latour, 2010). The stable carbon isotope ratio ($\delta^{13}C$) in the tissues of a consumer reflects that of its prey with a slight modification ($\leqslant$1‰), thereby indicating the dietary composition of consumers (McCutchan et al., 2003). The stable nitrogen isotope ratio ($\delta^{15}N$) in the tissues of a consumer generally increases by 3–4‰ compared with that of its prey, which can delineate the trophic position (TP) of the consumer (Post, 2002). In particular, SI ratios of petroleum have a small carbon fractionation factor (0.5‰) even through evaporation, microbial decomposition, or physical weathering process (Macko et al., 1981; Chapelle, 2001; Jeffrey, 2006). Furthermore, previous works showed that the isotopic signatures of spilled petroleum persist with small fractionation even 2 years after an oil spill accident (Macko et al., 1981). This fact together with the well-known reference isotopic values of fresh oil (approximately −30‰ to −20‰) allowed us to use SI ratios in

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oil-contaminated regions for evaluating the incorporation of petroleum-derived carbon by the aquatic biota, as observed in other coastal ecosystems (e.g. Fuex, 1977; Hartman and Hammond, 1981; Mazeas and Budzinski, 2002a,b; Griebler et al., 2004; Reddy et al., 2012). Previous works using SIs showed the small incorporation of oil by pelagic consumers such as herbivorous fish Pacific herring, walleye pollock, filter feeding barnacles and mussels can occur in oil-contaminated regions (Kline and Thomas, 1999; Fry and Anderson, 2014). Despite this information, we still have much to learn about the consequences of an oil spill accident on coastal benthic food web including all trophic levels (Gin et al., 2001; Peterson et al., 2003).

In the present study, we evaluated the SI values of the resident biota and diverse sources of organic matter to examine the consequences of oil contamination on an intertidal food web structure in the west coast of Korea 1.5 years after the *Hebei Spirit* oil spill (HSOS). Previous studies identified the effects of the HSOS in various ecosystem components separately including algal, invertebrate and fish species from individuals to community level (Ji et al., 2011; Lee et al., 2011). For example, at the community level the abundance of phytoplankton within two weeks after the HSOS was only half of the 10-year winter average, whereas the magnitude of the following spring blooms was three times greater than previous years (Lee et al., 2009). Massive accumulation of PAHs and the induction of hepatic PAH catabolism was observed in both demersal and pelagic fish at heavily oiled sites (Jung et al., 2011). Furthermore, the density of the dominant species of macrobenthic communities significantly decreased in the oil-affected sandy tidal flats (Yu et al., 2013). In addition, new macrobenthic and fish communities established immediately after beach clean-up efforts in 2008 (MLTM, 2009; Kim et al., 2013). However, the effects of the HSOS have not been assessed in the fauna using a more holistic approach and including different trophic levels. In this work we examined: (1) if petrogenic carbon was incorporated into the coastal food web, and (2) if the trophic niches of the consumers in the rebuilt community were similar to those in the unaffected community. Given that previous works showed that feeding habits may change after the oil spill accident, we tested the hypothesis that isotopic niche of benthic feeding groups at the impacted site changed owing to the effect of the oil contamination.

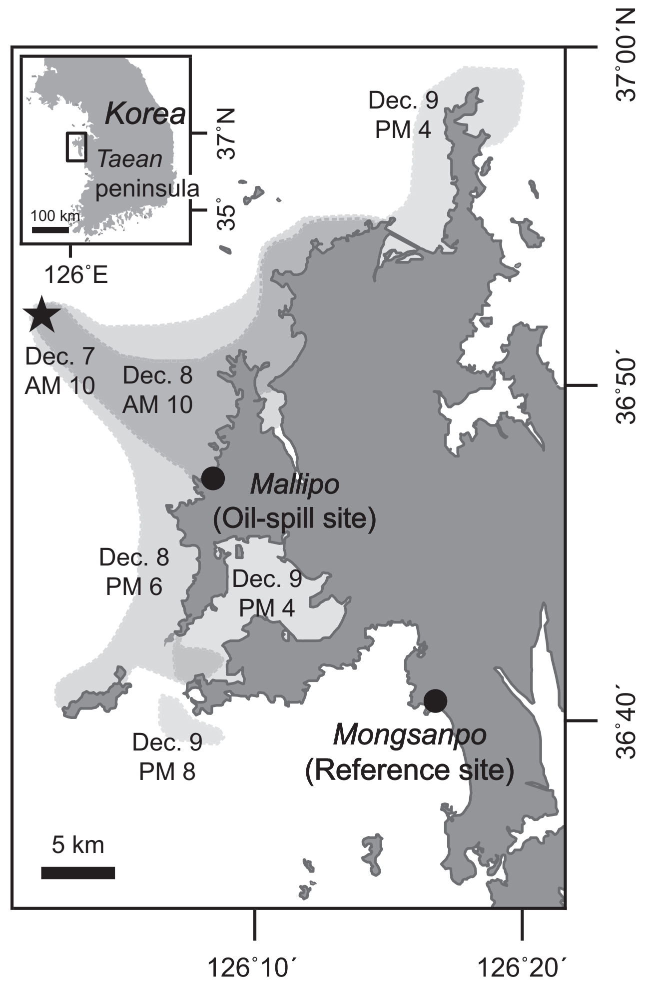

Fig. 1. Map of study site in the west coast of Korea showing the sampling sites for consumers and food sources: Mallipo and Mongsanpo in the Taean peninsula. Data for tracking the *Hebei Spirit* oil spill accident were obtained from MLTM (2009) and are shown in the map. Star represents the oil-spill spot by the wrecked *Hebei Spirit* oil tanker. The gray-colored area with date and time indicates the whole stretched area of the oil spill for a short period of time.

2. Materials and methods

2.1. Hebei Spirit oil spill

On December 7, 2007, the oil tanker *Hebei Spirit* was wrecked off the Taean coast of South Korea (36°53′34.97″N; 126°03′31.70″E). The tanker released a total of 12,547 kL of crude oil, a large fraction of which washed along a 375 km stretch of shoreline (Kim et al., 2013). The magnitude of the HSOS was quite extensive, its total volume being roughly one-third of that of the *Exxon Valdez* oil spill (Peterson et al., 2003), and the overall extent of the affected coastline being close to one-fifth. However, as a consequence of immediate beach clean-up efforts, the petroleum hydrocarbon concentrations in the water column off the Taean coast decreased rapidly from an average of 732–31.0 $\mu g\,L^{-1}$ after one month, and the concentration on the affected beaches dropped below the environmental standard (10 $\mu g\,L^{-1}$) within 10 months after the accident (Kim et al., 2013).

2.2. Site description

Mallipo beach (36°47′29″N, 126°08′27″E; Fig. 1) which was located 13.5 km from the oil-spill spot was selected as the oil-spill site for this study because it was heavily affected by the HSOS (Kim et al., 2010). The oil concentration in the water column at the oil-spill site ranged from 8.84 to 2700 $\mu g\,L^{-1}$ immediately after the HSOS. The concentration dropped abruptly to 9.16 $\mu g\,L^{-1}$ in the following month and fluctuated between 1.38 and 69.0 $\mu g\,L^{-1}$ until June 2008. Since July 2008, the oils spill concentration was approximately 1.0 $\mu g\,L^{-1}$ in the aquatic environment. By contrast, the oil concentration at Monsanpo beach (36°40′14″N, 126°17′12″E), which was selected as a reference site and located 32 km from the oil-spill spot, ranged from 0.34 to 2.27 $\mu g\,L^{-1}$, which is less than the values that are generally observed in natural coastal conditions (10 $\mu g\,L^{-1}$). When the HSOS occurred, northwesterly or northeasterly winds prevailed and the tidal currents were reversing (Lee et al., 2009). These physical forces spread the spilled oil north-eastwards or south-westwards. However, natural environment of two study sites (i.e., the oil-spill and reference sites) were similar as shown in their nearly identical values in salinity (30.9–31.8 vs. 30.7–31.6) and temperature (6.1–22.2 vs. 6.2–22.3 °C) of surface water, texture of sediment (median grain size = around phi 2 at both sites), and morphodynamics of beach during the sampling period (MLTM, 2009; Yu et al., 2013).

The species richness (S), diversity (H'), and evenness (J') of macrofauna and fish species were estimated in Taean beach 1.5 years after the HSOS (MLTM, 2009; Yu et al., 2013). The invertebrate