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Stronger impact of dispersant plus crude oil on natural plankton assemblages in short-term marine mesocosms

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ABSTRACT

To assess the effects of crude oil and dispersant on marine planktonic ecosystems, analyses were performed in 1000-L mesocosm over a period of nine days. Triplicate experiments were conducted for two different treatments, namely, addition of crude oil alone and oil plus dispersant. In the mesocosm with oil plus dispersant, high concentrations of total petroleum hydrocarbon (TPH) were soon found in the bottom layer. In addition, most planktonic communities responded drastically to the presence of dispersant acting to disperse TPH: total bacterial abundances increased for the first two days and then decreased rapidly for the remainder of the experiment. The abundance of heterotrophic flagellates increased rapidly in association with the increase in bacterial cells. The abundance of phytoplankton and zooplankton communities decreased clearly within two days. Time-delayed relationship also revealed that the TPH concentration had a significant negative relationship with phyto- and zooplankton communities within two days. However, most planktonic communities were affected less adversely in the mesocosms treated with crude oil alone than in those treated with both crude oil and dispersant. The present results demonstrate that the planktonic ecosystem was damaged more severely by the introduction of dispersant than by the harmful effects of crude oil itself. Therefore, caution should be taken when considering the direct application of dispersant in natural environments, even though it has the advantage of rapidly removing crude oil.

1. Introduction

Spills of large quantities of crude oil have the potential to cause severe short- and long-term damage to marine ecosystems. In general, organisms that are injured chronically due to oil pollution are large, and include macrobenthos and fishes. On the other hand, small organisms such as bacteria, phytoplankton, and zooplankton are affected rapidly upon exposure to oil pollution [1,2]. Plankton form the foundation of food webs, and are the primary source of food for many macroscopic organisms. Over the last 30 years, although numerous studies have examined the effects of oil on planktonic communities [3], most studies have focused on the effects of exposure in the water-accommodated fraction (WAF) in laboratories or investigated variation in organisms within natural areas that have been affected by oil spills [4]. However, WAF tests have been of limited use in understanding the potential effects of oil exposure on ecosystems because interactions between biotic and abiotic factors in natural environments are very complex and the investigation of oil spills in natural ecosystems poses enormous logistical challenges, which include high costs and the need for long-term study. To overcome these problems, mesocosm studies are an effective approach to bridge the gap between information obtained from laboratory studies and the responses of organisms in ecosystems. In addition, mesocosm studies can improve our understanding of the impact of oil spills on ecosystems and possibly enable prediction of the effects of oil on entire ecosystems [5].

The use of chemical dispersants can be an effective method to remove crude oil at sea. These dispersants are capable of rapidly removing large amounts of certain types of oil from the sea surface and transferring it into the water column [6]. Despite the many studies related to the effects of oil that have been conducted over the past decade, researcher' opinions are diverse on the effectiveness of dispersants at sea, because the interplay of surfactants and solvents in commercial formulations of dispersant with crude oil is very complex [7,8].

On 7th December, 2007, 6.5 nautical miles off the coast of Taean, Southwest Korea, an estimated 12,547 kL (10,900 M/T) of three

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different types of crude oil, namely, oil from the Upper Zakum oil field (UAE), Kuwait export crude, and Iranian heavy crude, were released after a collision between the oil tanker *M/V Hebei Spirit* and a barge carrying a crane. The spill led to the rapid spread of oil along the coastline of Taean owing to severe weather conditions, which included waves of up to 4 m and a prevailing north-westerly wind (10–14 m/s). More than 70 km of the coastline of Taean was impacted heavily by the spill, and natural marine communities and aquaculture facilities were destroyed. To remove the oil, approximately 298 tons of dispersant was released into the area and clean-up operations were initiated immediately after the spill [9]. The accident, which resulted in serious damage to the Korean coast, ranks alongside spills from the *Prestige* off the coast of Spain in 2002, the *Tasman Spirit* off the coast of Pakistan in 2003, and the *Solar 1* off the Philippines in 2006 as one of the largest tanker spills in recent years [10].

In a previous study, we introduced Iranian heavy crude oil at several concentrations of 10, 100, 1000, 5000 and 10,000 ppm (v/v) into a small-scale field microcosm and investigated whether it inhibited or stimulated the growth of microbial communities [11]. When the crude oil was added to the microcosm at a concentration higher than 1000 ppm (v/v), microbial communities changed dramatically that the growth of specific bacteria appeared to be stimulated. Although the results from this previous study using a microcosm suggest that assessments of the risks posed by oil pollution should consider the level of oil exposure in a specific situation, these results could not be extrapolated fully to marine planktonic ecosystems because we did not measure the effects of a dispersant, changes in petroleum hydrocarbon, or fluctuation in environmental factors and plankton communities. In addition, we did not carry out experiments on a large scale and throughout the water column. To address these limitations, we conducted a vertical mesocosm study and focused on interactions of planktonic communities and environmental factors upon exposure to the spilled crude oil and the dispersant. A possible scenario that describes the responses of biotic/abiotic factors to oil pollution is discussed.

2. Materials and methods

2.1. Experimental mesocosm setup

To evaluate the responses of planktonic communities to the introduction of crude oil and dispersant, nine marine vertical mesocosms were immersed in the water column at a site (34° 59′ 37.48″ N, 128° 40′ 27.53″ E) used by the South Sea Branch of the Korea Ocean Research and Development Institute located off the coast of Geoje Island, South Korea. Each cylinder-shaped mesocosm (0.5 m in diameter and 5 m in depth) comprised a 1200-L enclosure that contained 1000 L of seawater, and was made of a transparent polyethylene material reinforced with a polyester grid (Fig. 1). To supply identical masses of water to each mesocosm, a single body of seawater filtered through a net with a 200-μm mesh to eliminate large particle substances, including organisms that were mixed in a tank with a volume of 10,000 L was supplied slowly to all mesocosms. Zooplankton (>200 μm in size) were inoculated into each mesocosm at a density of 150 individuals/L, which is the same density found in natural waters, using a net with a 200-μm mesh. The water in the mesocosms was exposed to crude oil alone (Iranian heavy crude; the type of oil that was predominant among that spilled from the *Hebei Spirit*) at a concentration of 1000 ppm (v/v; hereafter, OIL group) or a mixture of crude oil and dispersant, namely, Hi-Clean (Daeil Chemical. Co., Korea; O + D group). Crude oil (1000 ppm; v/v) was dispensed directly onto the surface of the seawater, to form a slick. In the O + D group, 100 ppm (v/v) dispersant was then dispensed directly onto the slick, which gave a dispersant-to-oil ratio of 1:10. This was the dispersant-to-oil ratio that was used in general to disperse the oil spill formed by the *Hebei Spirit* accident. A control mesocosm, to which no oil or dispersant was added, was also prepared. In addition to natural wave action, the water in the mesocosms was mixed by artificial vertical mixing for 5 min twice a day. Each experiment, namely, OIL group, O + D group, and control group, was carried out in triplicate over nine days from 16 to 24 April, 2009.

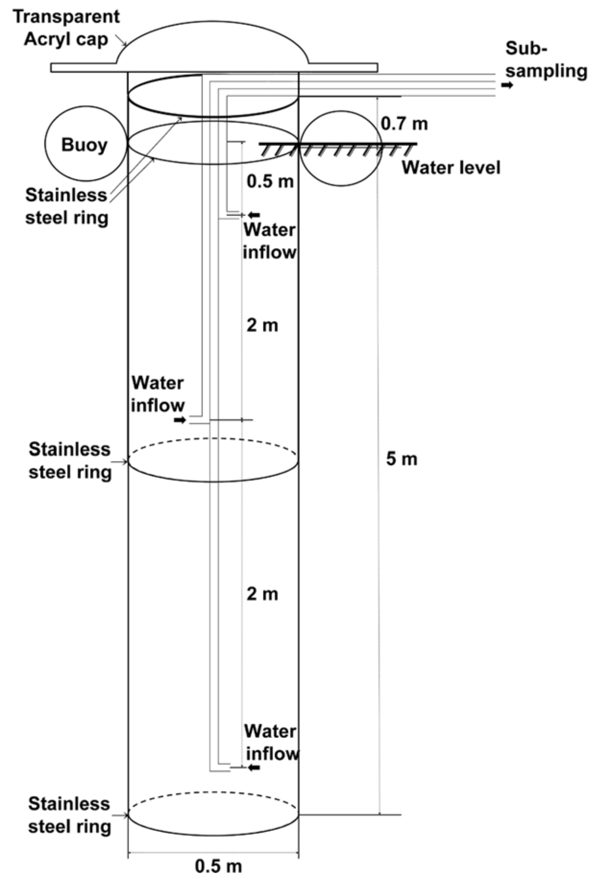

Fig. 1. Schematic diagram of the mesocosm used.

2.2. Measurement of environmental factors and total petroleum hydrocarbons

Subsamples from the surface (depth of 0.5 m), middle (2.5 m), and bottom (4.5 m) of the water column were collected using a pump-based sampler with a Master Flex L/S peristaltic pump (Cole Parmer, USA), which minimized the risk of contamination from the layer of oil on the surface. Samples were taken daily from each mesocosm at 9:00 AM. Water temperature, pH, salinity, and dissolved oxygen (DO) content were measured immediately in the subsamples using a portable multi-parameter meter (556 MPS, YSI, USA) and light intensity was measured using a quantum meter (LI-189, Li-Cor, USA). To analyse inorganic nutrient concentrations [dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), and dissolved silica (DSi)], a 250-mL sample filtered through a 47-mm Whatman GF/F filter was stored in an acid-cleaned polyethylene (PE) bottle at −80 °C. Nutrient concentrations were analysed using a nutrient auto-analyser (Lachat Quickchem, Lachat Instruments, USA). To analyse chlorophyll *a* concentrations, a 250-mL sample was filtered through a GF/F filter under low vacuum pressure. The filter was then soaked in 15 mL of cold 90% acetone-distilled water (v/v), sonicated to break cell walls, and