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Baseline

Variations in the concentrations of heavy metals through enforcement of a rest-year system and dredged sediment capping at the Yellow Sea-Byung dumping site, Korea

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ABSTRACT

In 2014, the concentrations of 13 heavy metals in surface sediments from 14 sampling stations were analyzed and compared to samples from previous years to evaluate the remediation effectiveness of the "rest-year" (RY) system and capping with dredged material at the Yellow Sea-Byung dumping site offshore Korea. Since the 2006 introduction of the RY system, annual variations in metal concentrations at stations within the RY zone have gradually decreased over time. Heavy metal concentrations at most stations were lower than sediment quality guidelines, indicating the success of the RY system. Additionally, the effects of capping the contaminated sediment with dredged materials were investigated. The results indicate that dredged materials successfully capped the contaminated sediment within the dredged material dumping area, as the concentrations of Cr and total organic carbon were significantly reduced. We conclude that dredged materials may be used as capping materials for the remediation of contaminated sediments.

Waste dumped into the oceans includes sewage sludge, organic materials of natural origin, fish waste, and dredged materials. Some of this waste contains hazardous materials, such as organic contaminants and heavy metals. Consequently, accumulated waste not only contaminates the sedimentary environment, but also creates serious problems for human health and marine ecosystems.

Contaminated solid and dissolved material introduced via ocean dumping settles gravimetrically or is associated with organic and inorganic matter. At the sediment-water interface, heavy metals present in these materials influence the bioavailability of sediments and are readily taken up by benthic organisms. Heavy metals that accumulate in the bodies of these organisms will be transferred to higher trophic levels through the food web, including to humans, and will affect the cycling of metals through different compartments of aquatic ecosystems (Griscom et al., 2000; King et al., 2005; Luoma, 1989).

Korea began ocean dumping in 1988, under the Marine Pollution Prevention Act (1977), to reduce the burden of mass waste treatment on land, and to protect rivers and coastal areas. However, with steadily growing international demand for environmentally friendly practices and ocean conservation, including the London Convention of 1972 and the London Protocol of 1996, many countries have banned ocean dumping, beginning with Norway in 1972 and followed by the US in 1992, most member states of the EU in 1998, and the UK in 1999. In Asia, such bans were enacted by China in 1994 and by Japan in 2007 (IMO, 2007; OSPAR, 1998; Swanson et al., 2004; Yu et al., 2005).

The Korean government constructed the "Master Plan of Ocean Dumping Management" in 2006 to propose rules for ocean dumping that are compatible with the London Protocol. Specifically, the primary aim of this plan was to phase out ocean dumping of sewage sludge by 2015. The Korean government also developed the "rest-year" (RY) system, which, as of 2006, banned ocean dumping activities during a set period in areas with concentrated contamination. Moreover, starting in 2013, certain sectors within the RY zone that were heavily polluted were designated as dredged material dumping areas (DMDAs) to investigate the possibility of improving contaminated areas by capping them with dredged material.

The objectives of this study were to use the results of a 2014 field survey to evaluate the operational effectiveness of the RY system as a contamination reduction policy for the Yellow Sea-Byung (YS-B) dumping site, and to investigate the environmental effects of dredged

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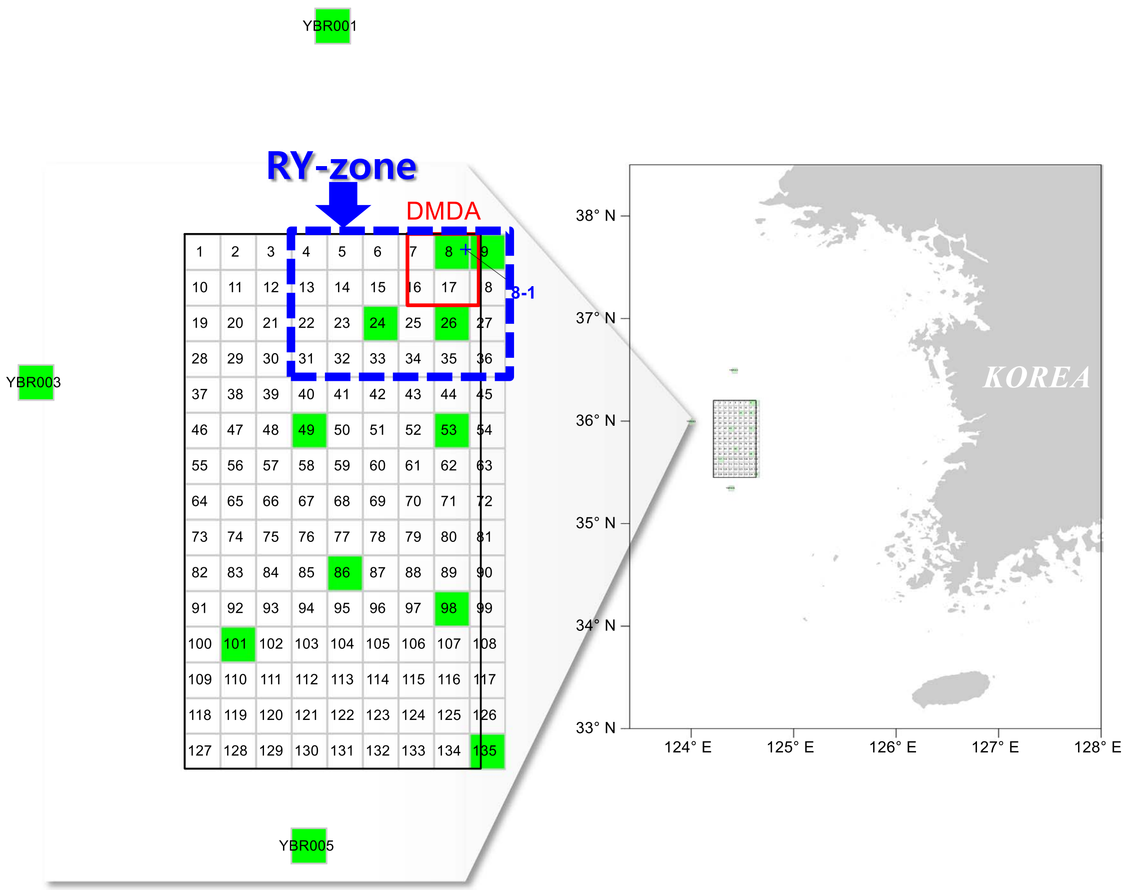

Fig. 1. Locations of the Yellow Sea-Byung dumping site and 14 surface sediment survey stations in 2014 (green boxes). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

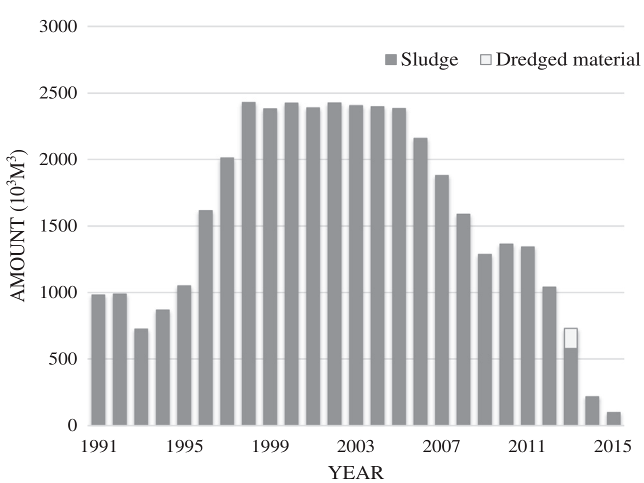

Fig. 2. Amount of waste and dredged material dumped at the Yellow Sea-Byung dumping site by year (MOF, 2015).

material capping in polluted areas within the RY zone. Therefore, the distribution of heavy metals, sediment grain size, and total organic carbon (TOC) concentrations were investigated, and correlations between these measurements were analyzed.

The Yellow Sea is a relatively shallow, semi-enclosed continental sea with a total area of approximately 460,000 km^2, a total capacity of 18,000 km^3, a maximum water depth of 105 m, and an average depth of 44 m. In the central part of the Yellow Sea, including the YS-B dumping site, there is a patch of fine-grained mud with a vertical sediment flux below 0.33 $g/(cm^2 \cdot a)$ and bottom water known as the Yellow Sea Bottom Cold Water, which has a temperature below 10 °C throughout the year. These are key parameters for the natural recovery of contaminated sediment (Choi, 2011; Chough et al., 2000).

The YS-B dumping site, where dumping began in 1988, lies at latitudes of 35°27′N to 36°12′N and longitudes of 124°13′E to 124°38′E, and has a total area of 3165 km^2 and an average depth of 80 m. The total area of the YS-B dumping site was divided into 135 sectors, at 3-min intervals of latitude and longitude. These sectors define the sampling stations used in this study (Fig. 1). Prior to 2012, surveys were conducted biennially at 30–35 stations, but since 2012, surveys were performed annually on 12–14 stations, which included those identified as more heavily polluted based on previous survey results, as well as some reference stations.

The initial annual amount of sewage sludge dumped at the YS-B dumping site was 547,000 m^3 in 1988. This amount increased over time until being limited to 2,400,000 m^3 in 2005. Subsequent government policies for reduction of ocean waste dumping led to a continual decrease to the recent (2014) level of 183,000 m^3, which represents a decrease to 8% of the peak level (Fig. 2). To date, the total amount of waste dumped at the YS-B dumping site is 39,021,000 m^3. In 2013, dredged material was dumped at the YS-B site for the first time, with a total volume of 149,000 m^3, which was drastically reduced, by approximately 50-fold, to 3000 m^3 in 2014.

Because most waste dumped at the YS-B site is liquid, such as sludge, it is dumped using a diffusive method to enable spreading over a wide area, while solid waste such as dredged material is dumped using a concentrated method, which is expected to have a direct impact on the sedimentary environment. In 2013, dredged material was dumped at station YB-008-1, within the YS-B site, to verify for the first time the effectiveness of intensive capping methods.