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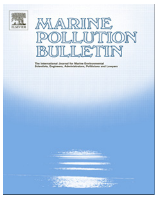

# Reevaluation of Minamata Bay, 25 years after the dredging of mercury-polluted sediments

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ABSTRACT

A detailed investigation of mercury concentrations in the bottom sediments of Minamata Bay was performed in May, 2012. A total of 691 sediment samples were obtained from 107 sampling points in the bay. The weighted average total mercury concentration and the total mass of mercury in the bottom sediments of Minamata Bay were estimated to be 2.3 mg/kg dry weight basis and 3.4 tons, respectively. The average concentration of total mercury in the surface layer of the sediments was 3.0 mg/kg dry weight basis, and the distribution pattern of total mercury concentrations in the surface layer was found to have changed little in comparison to results reported 25 years ago. In addition, based on the results of seawater monitoring in Minamata Bay from 2010 to 2012, the amounts of total mercury and methylmercury mobilized from sediments and dissolved in the water column were 0.7 and 0.1 kg/yr, respectively.

## 1. Introduction

A factory of the Chisso Corporation in Minamata, Japan, produced acetaldehyde from the hydration of acetylene, using mercury sulfate as a catalyst. Methylmercury (MeHg) was a by-product formed during the synthesis of acetaldehyde. From 1932 until 1968, the Chisso factory wastewater containing inorganic mercury and MeHg was discharged directly into Minamata Bay, completely damaging the rich marine environment there. Minamata disease, caused by the consumption of seafood polluted by MeHg, was first publicly recognized in 1956 (Environmental Health Department, Environmental Agency of Japan, 1999). Discharge of mercury (Hg) from the factory stopped in 1968, and total Hg (total-Hg) concentrations of fish in Minamata Bay decreased simultaneously (Kumamto prefecture, 1998). To restore the bay's marine environment and to prevent further dispersion of polluted sediments, a large-scale remediation project was carried out from 1977 to 1990. The remediation project included Minamata Bay, Marushima Port, and the Hyakken drainage water channel. The dredging of Minamata Bay was finished at 1985, and the remediation of Marushima Port and Hyakken channel were completed in 1990 (Kumamoto Prefecture, 1998). Remediation involved the dredging of all bottom sediments with total-Hg concentrations greater than 25 mg/kg dry weight basis (all sediment concentrations hereafter are reported on a dry weight basis). According to the project guidelines, bottom sediments with Hg concentrations below 25 mg/kg were allowed to remain in Minamata Bay. Before dredging, Hg concentrations in Minamata Bay sediments ranged from 0.04 to 553 mg/kg, as indicated by a survey performed in 1985 by Kumamoto prefecture. In 1987, Kumamoto prefecture reported that Hg concentrations in surface sediments had decreased to 0.06–16 mg/kg following the remediation project (Kumamoto prefecture, 1998). Approximately 25 years have passed since the remediation project ended. Nakata et al. (2008) and Tomiyasu et al. (2013) have provided recent summaries of Hg pollution in the sediments of Minamata Bay. However, there have been no detailed surveys in almost 25 years to characterize the current state of Hg pollution in Minamata Bay. Mercury monitoring in Minamata Bay has been performed every year by Kumamoto Prefecture using two fish species (*Sebastiscus marmoratus* and *Pseudolabrus japonicus*) as biomonitoring indicators. A recent study showed that total Hg concentrations in muscle tissue in Minamata Bay fish were several times higher than those for the same fish from other marine locations in Japan

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(Matsuyama et al., 2013). Additionally, questions about the health of the bay continue to circulate, causing damage to the reputations of local fisheries and those of the surrounding areas. To evaluate the current state of Hg pollution in the bottom sediments of Minamata Bay, we performed a detailed survey with the same sampling resolution as the survey performed 25 years ago by Kumamoto Prefecture. In related work also reported here, we evaluated seasonal variations in dissolved Hg concentrations in bottom seawater that might be influenced by the activity of benthic organisms, the amount of dissolved Hg eluted from sediments, and the spatial distribution pattern of dissolved total Hg in surface sediments. Analytical data used to examine these variations were from a 3-year period (2010–2012).

## 2. Materials and method

### *2.1. Survey locations and sediment sampling*

Minamata Bay, which includes Fukuro Bay (60 ha) in the inner bay, has an area of 382 ha, and an average depth of 16.7 m. Koiji Island, situated in the northwest part of the bay (Fig. 1), creates a channel with the mainland, affecting the flow of tides into and out of the bay. The tidal range of the Yatsushiro Sea is relatively large compared to tides elsewhere in Japan. In Minamata Bay, the tidal range is almost 4 m (Kumamoto Prefecture, 2005), among the largest in Japan. The bay receives treated, Hg-free wastewater from the still-operating Chisso factory, and no rivers flow directly into Minamata Bay. In this study, the survey area for sediment sampling included not only Minamata Bay (382 ha) but also the Nanatsuse area (60 ha) outside of Koiji Island, making a total survey area of 442 ha. Bottom sediment sample collection from Minamata Bay was performed from May 24–27 in 2012. The grid for sediment sample collection is shown in Fig. 1. The distance between sampling points was set at 200 m; this is the same distance used by Kumamoto Prefecture for the detailed survey conducted 25 years ago (Kumamoto Prefecture, 1998). The total number of sampling points was 115. A GPS system was used to navigate to the sampling points. Two areas, the entrance to Fukuro Bay and the northern part of Koiji Island (indicated by the pink zones in Fig. 1) were excluded from the remediation project because total Hg concentrations in sediments there were less than the tentative regulatory level for dredging and landfills (25 mg/kg) as approved by the Ministry of the Environment based on the results from the survey performed by Kumamoto Prefecture in 1985.

### *2.2. Sediment sample collection*

Undisturbed sediment cores were taken from the bottom of Minamata Bay using a gravity core sampler (Rigosha. Co, Ltd. No. 5167, Tokyo, Japan). Generally, there are two types of sediments in Minamata Bay, sand and silt. The sediment core sampler was incapable of obtaining cores of sandy sediments, so an EKMAN–BERGE bottom sampler (Rigosha. Co, Ltd. type 5141) was used in those cases. Sediments were not sampled from areas that are recognized as coral habitat for nature conservation purposes. To avoid oxidation by atmospheric oxygen, the samples collected using the sediment core sampler were kept in a vinyl bag that was evacuated using a small hand pump. The evacuated vinyl bag was cooled with brick ice in a cooling box. For surface sediments sampled using the EKMAN–BERGE bottom sampler, the entire sample was transferred to a plastic bag from the sampler, then small pebbles and shells were removed. The sediment sample was then thoroughly mixed using a four-way mixing method to obtain uniformity. After that, approximately 200 g of each sediment sample was taken and kept in an evacuated vinyl bag in a cooling box. Overall, 67 sediment core samples and 40 surface sediment samples were collected. Samples in the cooling box were transported to the National Institute for Minamata Disease (NIMD) within 1 h, and stored in a freezer (−40 °C). Core samples were then cut and divided into 2.5-cm sections for chemical analysis, so the total number of sediment samples was 691.

### *2.3. Determination of total Hg concentrations in sediments*

Sediment samples were thawed at room temperature. To avoid cross-contamination, the central part of each sediment core section was isolated for chemical analysis using a ring cutter. Total Hg

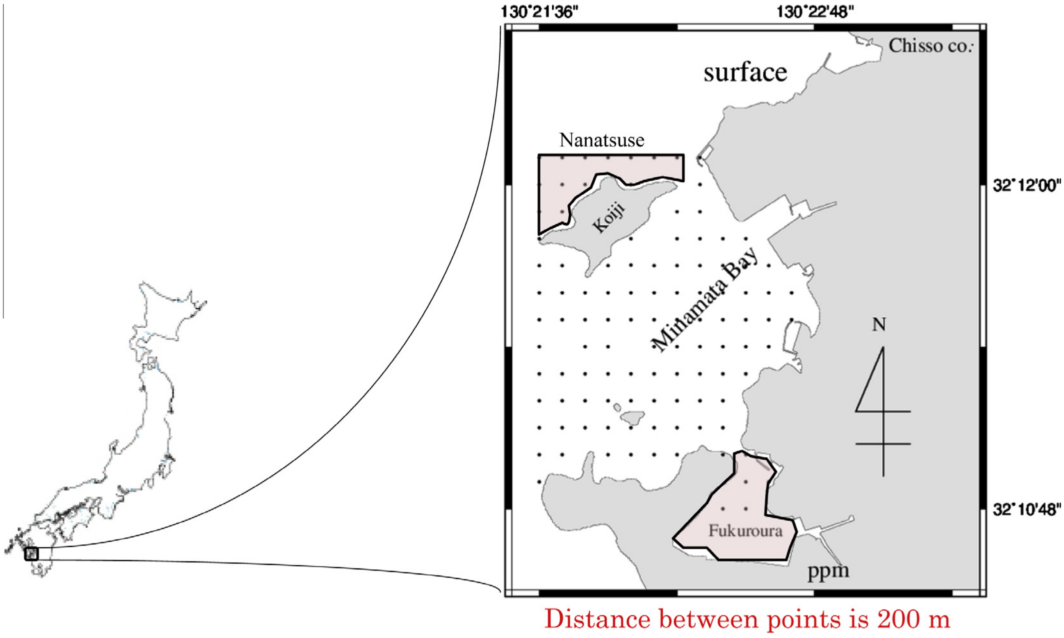

**Fig. 1.** Plan for sediment collection in Minamata Bay.