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Validation trial of Japan's zinc water quality standard for aquatic life using field data

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ABSTRACT

This study sought to validate Japan's zinc water quality standard for aquatic life (algae and benthic invertebrates) based on field survey data. The effects of zinc on aquatic life, especially algae and benthic invertebrates, were investigated mainly in water areas with upstream basins that contain mines. Seven biological indicators (number of cells or individuals, number of taxa, number of EPT taxa, number of collector–gatherer taxa of benthic invertebrates, and Simpson index, Shannon–Weiner index, and Margalef index for algae and benthic invertebrates) were analyzed with respect to zinc concentrations and the zinc toxic equivalent quantity (Zn-TEQ), and additive contribution from other metals was assumed. The results showed that the number of taxa of algae and benthic invertebrates significantly decreased with increases in zinc concentration and Zn-TEQ. For benthic invertebrates, six of the metrics (all except the number of individuals) tended to decrease with increases in zinc concentration and Zn-TEQ. The effect level of biocenosis (ELB) was defined as the concentration at which the metrics decrease significantly with Wilcoxon's rank sum test. The ELB calculated for zinc was in the range of 16–54 μg/L for zinc concentration and 38–50 μg/L for Zn-TEQ; thus, Japan's environmental zinc standard for the protection of aquatic life, at 30 μg/L, was found to be a level consistent with these results.

1. Introduction

The effects of chemicals on aquatic life began to be studied through laboratory toxicity tests and field surveys in the 1980s, mainly in the United States and Europe. By the end of the 1980s, the United States, the United Kingdom, and Canada, among other countries, had implemented measures to protect aquatic life and had set environmental quality standards, criteria, and/or guidelines based on the results of these studies (U.K. Secretary of State for the Environment and Secretary of State for Wales, 1989; U.K. Department of the Environment and Welsh Office, 1989; CCME, 2007; USEPA, 2009). Japan's first standard for the protection of aquatic species was the environmental quality standard (EQS) for zinc (30 μg/L) established on November 5, 2003 (Expert Committee on Environmental Water Quality Standards for the Protection of Aquatic Life, Water Environment Committee, Central Environment Council, 2003). Until the development of the EQS, zinc had been regulated under the blanket limits for industrial wastewater (limit level: 5 mg/L); the latter limits, however, were more than 100 times the current environmental quality standards. The late development in Japan of environmental quality standards for the protection of aquatic life is attributable to a focus on the protection of human health and the prevention of eutrophication caused by organic pollutants.

Field survey data alone may not be a realistic basis from which to derive nationwide EQS for a toxic substance. This is obvious, because physical, chemical, and biological aquatic environments differ significantly from one another, and because many water quality factors other than the presence or absence of toxic substances, such as organic contamination and eutrophication, also affect the number of individuals and distribution of aquatic life (Meyer-Reil and Koester, 2001; Ohgaki et al., 2003). Nevertheless, the USEPA has considered verification and determination of water quality criteria based on field survey data (Cormier et al., 2008; USEPA, 2010), and its findings suggest that it may not be impossible to use field survey data to verify the validity of an EQS derived from toxicity test results. This study was therefore undertaken in an attempt to validate the zinc EQS for aquatic life by discovering the relationship between ecological effect levels and the zinc concentration in the actual environment. Immobile algae and benthic invertebrates were selected as target organisms since they grow for several months at the same location, and consequently the relationship between certain ecological metrics and local zinc concentrations may have ecotoxicological significance.

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Numerous laboratory studies have examined the effects of chemicals on living organisms from various perspectives. It has been found, for example, that the toxicity of zinc and other metals to aquatic life varies depending on pH and calcium ion concentration (Bradley and Sprague, 1985; Paulauskis and Winner, 1988; Heijerick et al., 2002, 2003; Hansen et al., 2002; De Schamphelaere and Janssen, 2004), as well as on the chelating action of a number of substances (Finlayson and Verrue, 1982; Biesinger et al., 1986; Franklin et al. 2002). It is likely that the phenomena elucidated in these laboratory tests also occur in the actual environment. In Europe and the United States, the water quality of rivers has been evaluated with the use of biological metrics (Barbour et al., 1999; European Commission, 2000; AQEM Consortium, 2002; USEPA, 2006). Although these metrics are used to indicate water quality, it appears possible to use them also to evaluate the effect level of zinc and other metals on the biocenosis, because they change in accordance with water conditions.

While this study aims to find effect levels of zinc concentration on aquatic life, in the field other toxic metals will also affect the aquatic biota. Therefore, it is necessary to evaluate the combined effect of other metals on aquatic life. The combined effects of chemicals may be antagonistic, additive, or synergistic (also referred to as ‘‘less than additive’’, ‘‘strictly additive’’, and ‘‘more than additive’’, respectively) (USEPA, 2007). Generally, the toxic effect of metals in a mixture on an aquatic species can be presumed to be additive. Information on such effects may be compiled to predict toxicity using toxic units (TUs) or toxicity equivalence factors (TEFs), in which the concentrations of all the metals present are converted to a single metal concentration (USEPA, 2007). In this study, the combined effects of metals are assumed to be additive.

The field survey plan for this study paid particular regard to the following points:

1. the relationship between the biological metrics and the concentration of zinc;
2. conversion to express the effects of other metals on aquatic life in terms of the influence of zinc, based on the hypothesis that zinc, cadmium, lead, and copper have combined additive effects on biological metrics; and
3. discovery of ecological effect levels for zinc.

Using the results of the field survey, and drawing also on previous observations, the study compared effect levels of zinc on the biocenosis with Japan’s EQS.

2. Methodology

2.1. Field survey

2.1.1. Site selection

The survey was conducted at 36 stations in 11 streams across the country from 2002 to 2004. Nine of the streams had mines in their upper reaches; two were unpolluted sites. Data from an investigation conducted by the author and coworkers for the Japanese Ministry of the Environment (E&E Solutions, 2003; NIES, 2004, 2005) were included in the present study. The streams were selected mainly on the basis of concentrations of zinc and other metals reported by the Ministry of the Environment in its Water Quality Survey of Public Water Areas (2000–2002) (Ministry of the Environment, 2002, 2003, 2004) and of a geological survey report (Geological Survey of Japan, 1956). Since one objective of this study was to find ecological evidence with respect to Japan’s zinc EQS, the sampling streams were selected nationwide across a wide geographical range, at latitudes varying from 33°N to 40°N. High concentrations of zinc and other metals had been detected in the nine streams that had mines in their upper reaches (Table 1). Some of these mines were active, while others were long abandoned (Geological Survey of Japan, 1956). The streams were: Osanai, Iwate Prefecture (Tarou mine: copper, zinc, and pyrite); Namari, Miyagi Prefecture (Hosokura mine: lead and zinc); Kaishu and Yagisawa, Yamagata Prefecture (vicinity of Takahi mine: copper, lead, and zinc); Miyata, Ibaraki Prefecture (Hitachi mine: copper); Watarase, Tochigi Prefecture (Ashio mine: copper); Sasu and Shiine, Nagasaki Prefecture (Taishu mine: lead, zinc, and magnetic pyrite); and Okutake, Oita Prefecture (Ohira mine: tin, copper, and arsenic). Yagisawa Station 2 in Yamagata Prefecture was also surveyed in 2002 and 2004, and the results were treated as separate sets of data. Two streams in unpolluted locations, Hananuki in Ibaraki Prefecture and Itadori in Gifu Prefecture, served as reference sites for low potential stress areas.

Table 1
Location map, stream name, number of stations, and date of this study. Nine streams have mines in their upper reaches and two streams are unpolluted sites.

No.	Stream name	Number of stations	Date of survey	Main mine in the upper reaches
1	Osanaigawa	4	Oct. 2004	Tarou
2	Namarigawa	3	May 2002	Hosokura
3	Kaishugawa	3	May 2002	Takahi
4	Yagisawagawa	1	May 2002	Takahi
		3	Oct. 2004	
5	Hananukigawa	3	Oct. 2003	
6	Miyatagawa	3	Oct. 2003	Hitachi
7	Watarasegawa	5	Jun. 2003	Ashio
8	Itadorigawa	2	Nov. 2003	
9	Sasugawa	3	Sep. 2004	Taishu
10	Shiinegawa	2	Sep. 2004	Taishu
11	Okudakegawa	4	Dec. 2003	Ohira