Daily Variations in Nutrient Concentrations of Seawater at 321 m Depth in Toyama Bay, Japan Sea

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Nutrient concentrations (nitrate + nitrite, phosphate and silicate) in deep seawater (321 m depth) of Toyama Bay, Japan, were measured from August 1996 to July 1997 to determine the magnitude of daily variations. Significant daily variations were observed; concentrations ranged from 4.42 to 22.4 μM for nitrate + nitrite, from 0.86 to 1.98 μM for phosphate, and from 9.91 to 47.7 μM for silicate, respectively. However, there were no significant relationships between nutrient concentrations and water temperature, or between nutrients and salinity. Since temperature and salinity in the >300 m depth layer were constant throughout the year, the results suggest that there may be water masses with different nutrient concentrations in the deep layers (at about 320 m depth) of the bay, and a horizontal advection of these water masses may be responsible for the observed daily variations.

1. Introduction

Deep seawater of the ocean has characteristic features that include high concentrations of soluble nutrients, low temperature, a constant salinity, and limited number of plankton. Research projects to consider ways to exploit this deep seawater began in Japan in 1989 and 1995. The projects are still underway, with the objective of developing technologies such as cultivation of cold-water fish and deep sea water fish during summer and throughout the year, cultivation of useful macro- and micro-algae, temperature control of the seawater used for cultivation and breeding, and production of energy and fresh water.

The Toyama Prefectural Fisheries Research Institute constructed a facility in 1995 with a capacity of 3,500 tons per day for supplying deep seawater from 321 m depth. Since then, basic research has been underway to develop effective technologies for using the deep seawater for fisheries. For example, studies have included the cultivation of Oncorhynchus masou and the breeding of Pandalus hyspnosus, as well as fundamental studies of cold water fish, deep sea fish, and other aspects of the deep sea environment (Fujita, 1998).

Toyama Bay is one of the large and deep bays, facing the Japan Sea, with a surface area of 2,120 km² and a depth of over 1,000 m at the center of the bay. Major geographical features include a steep coast, a poor continental shelf, and the existence of some drowned valleys. Seawater in Toyama Bay consists of a surface layer originating from the Tsushima warm current and a deeper layer (>300 m depth) called the Japan Sea Proper Water. This deeper layer accounts for about 65% of the total volume of Toyama Bay (e.g. Yamada and Kitani, 1994).

Although monthly variations in nutrient concentrations and their vertical profiles have been already reported at several stations in Toyama Bay (Nakura and Nagata, 1989), little is known about daily variations. Such information is critical for emerging technologies involving the use of deep seawater for the culturing of macro- and micro-algae. The objective of this study was to quantify daily variations in nutrient concentrations of the deep seawater (321 m depth) in Toyama Bay. Here we defined the seawater over 300 m depth as deep seawater in the Japan Sea.

2. Sampling and Analytical Methods

The mouth of the deep seawater intake pipe was fixed at 2,630 m distance from the shore and a depth of 321 m in Toyama Bay (Fig. 1). Temperature of the deep seawater was automatically measured every hour at the outlet on
land. For salinity and nutrient measurements, samples were collected at the outlet in two bottles at 9:00 a.m. on weekdays. The total number of days sampled was 245, from 1 August 1996 to 31 July 1997. Salinity was determined using water from one bottle, by means of an inductively coupled salinometer (601 MK-III, YEO-KAL Electronics Pty Ltd.). The other bottle of sample water was stored at -20°C until nutrient analysis were performed. Monthly vertical profiles of seawater temperature and salinity were also measured near the mouth of the deep seawater intake pipe using a CTD (AST500-DK, Alec Electronics Co. Ltd.).

Modified standard procedures were used to determine nutrient concentrations (Parsons et al., 1984). Detailed methods for nitrate + nitrite and phosphate are described in the Cruise Report of Tokyo University of Fisheries (Tokyo University of Fisheries, 1995) and the method for silicate determination was based on the reduction of a silicomolybdate in acidic solution (Technicon, 1976). Nutrient (NO$_3$ -N + NO$_2$ -N, PO$_4^{3-}$-P and SiO$_2$-Si) concentrations of unfiltered water samples were determined in duplicate using a Technicon AutoAnalyzer AAI. When the difference between duplicate values was greater than 2%, the analysis was repeated. Silicate analysis was performed after the samples were allowed to stand for more than 36 hours at room temperature (Dore et al., 1996).

Repeated measurements were made on selected samples after 96 hours to check for the effect of polymerization on silicate concentrations, but no significant increases were observed.

Calibrations were done using CSK standard solutions for nitrate (0.00, 10.0 and 20.0 µg atm L$^{-1}$ dissolved in 30.5% NaCl), phosphate (0.00, 0.50, 1.00 and 2.00 µg atm L$^{-1}$ dissolved in 30.5% NaCl), and silicate (0.0, 5.0, and 50.0 µg atm L$^{-1}$ dissolved in 30.5% NaCl). Additional standard solutions were prepared using artificial seawater to supplement the concentration ranges. Least square regression relationships with regression coefficients of more than 0.99 were obtained within these concentration ranges. The reproducibility at deep seawater levels was within ±2%. Ultrapure water (Milli-Q water) was used for preparations of all solutions to minimize contamination, and all reagents used were of analytical grade.

Phosphate concentrations on 2 August, 25 November and 29 November 1996 were substantially higher than those measured on other days, and N:P ratios were much lower (7.85, 3.60 and 4.87, respectively) than the Redfield ratio of 16. As a result, these data on phosphate were not included in the analyses.

We also measured total phosphorus concentration after peroxidisulfate digestion and nitrite concentration of randomly selected samples (36 samples for total phosphorus and 55 samples for nitrite) using the same methods as phosphate and nitrate without the passage of seawater sample through the copperized cadmium column.

3. Results and Discussion

3.1 The variations in nutrient concentrations

There were no clear seasonal variations in deep seawater salinity, temperature, or nutrient concentrations from August 1996 to July 1997 (Fig. 2), nor were changes in nutrient concentrations related to changes in temperature and salinity. Daily variations in nutrient concentrations during July 1997 indicated similar patterns for nitrate + nitrite, phosphate and silicate, with a nearly identical period of 7–10 days (Fig. 3). The patterns of daily variation in other months were similar. Significant daily variations in nutrient concentrations, ranging from 4.42 to 22.4 µM for nitrate + nitrite, from 0.86 to 1.98 µM for phosphate, and from 9.91 to 47.7 µM for silicate, were observed throughout the year. The lowest nutrient concentrations (4.42 µM for nitrate + nitrite, 0.86 µM for phosphate and 9.91 µM for silicate) were equivalent to those found in the 150–200 m depth layer in vertical profiles at the center of Toyama Bay (Nakura and Nagata, 1989).