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Higher species richness and abundance of fish and benthic invertebrates around submarine groundwater discharge in Obama Bay, Japan

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ABSTRACT

Study focus: There have been far more studies on how the variability in surface water discharge affects production of animal communities in aquatic ecosystems while less information has been accumulated on the mechanisms of how the groundwater supply works.
Study region: Physical and biological surveys were conducted to test the hypothesis that high level of submarine ground water discharge enhances species richness, abundance and biomass of fishes and invertebrates in coastal waters of Obama Bay, Japan, where a high contribution of nutrients (ca. 65% of phosphorus) to total provided through all freshwater has been reported. Survey for horizontal distribution of radon-222 (^{222}Rn) concentration showed high levels of submarine groundwater discharge in the west part of survey area. Fish and invertebrate communities were compared within a relatively small spatial scale (ca. 100 m) in relation to level of submarine groundwater discharge.
New hydrological insights: Species richness, abundance and biomass of fishes and abundance and biomass of turban snail and hermit crab were significantly higher in the area with high ^{222}Rn concentration. Abundance of gammarids, the most major prey item of the fishes, was 18 times higher in the area with high ^{222}Rn concentration. Since the turban snail, hermit crab and gammarids feed on producers (phytoplankton and benthic microalgae), submarine groundwater are concluded to increase species richness and production of fishes and invertebrates through providing nutrients and enhancing primary production.

1. Introduction

Increase in freshwater supply can enhance biological production and species diversity in coastal ecosystems though providing nutrients (Burnett et al., 2003; Crecco and Savoy, 1984; North and Houde, 2003; Okazaki et al., 2005; Shoji et al., 2006; Valiera et al., 1990). Freshwater which runs from the terrestrial area to coastal water is composed of surface water

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and groundwater. There have been far more studies on effects of the variability in surface water on biological production in aquatic ecosystems while information on the mechanisms of how the groundwater supply affects the production process is very limited (Hwang et al., 2005; Miller and Ullman 2004; Sanders et al., 2011; Valiera et al., 1990). In general, submarine groundwater is more abundant in nutrients than surface water. A recent study in a temperate bay in Japan showed a high contribution (ca. 65% of total) of phosphorus provided through submarine groundwater to total (provided through all freshwater: Sugimoto et al., 2015). In addition, temperature of submarine groundwater is more stable throughout year than waters in surrounding coastal area. Therefore, spatial and temporal variabilities in submarine groundwater discharge are expected to affect biological production and community structures of plants and animals in the coastal area. High levels of submarine groundwater discharge have been shown to correspond with elevated primary production in coastal waters of the world (Hwang et al., 2005; Sanders et al., 2011). However, there is still limited information on the effects of submarine groundwater on animals at higher trophic levels (primary and secondary consumers) in coastal ecosystems (Miller and Ullman, 2004). Biotic and abiotic properties of submarine groundwater such as nutrient concentrations and temperature would directly and indirectly influence distribution and abundance of primary and secondary consumers through effects on organisms at lower trophic levels. Clarifying the mechanism how submarine groundwater discharge affects biodiversity and biological production can contribute to comprehensive understanding of the interactions among the water and major ecosystem services such as food and energy (The water-food-energy nexus: Taniguchi et al., 2013) in coastal ecosystems that provide highest ecosystem services in the world's ecosystems (Costanza et al., 1997).

In the present study, physical and biological surveys were conducted in Obama Bay in order to test the hypothesis that submarine groundwater discharge increases species richness and production of fish and invertebrate community (primary and secondary consumers). Horizontal distribution of radon-222 (^{222}Rn) was examined to understand spatial variability of submarine groundwater discharge in the survey area. Two sampling stations were fixed according to results of the survey for horizontal distribution of ^{222}Rn for comparison of animal community in relation to submarine groundwater discharge within a fine spatial scale (about 100 m). Stomach contents analysis of fishes was conducted to understand the major trophic flows. Number of species, abundance and biomass of fishes and epibenthic invertebrates including the major prey items of the fishes were compared between the two stations.

2. Site description

Obama Bay is a semi-enclosed embayment located north coast of mid Japan (Fig. 1). The bay has a surface area of 58.7 km^2 and a volume of 0.74 km^3. Maximum depth of the bay is 35 m with a mean depth of about 13 m. The tidal range is <0.2 m (Isobe and Aihara, 1976). Annual precipitation around the region is >2000 mm, most of which occurs during the summer (rainy season) and winter (snowy season). There are abundant groundwater resources in the basin around Obama City, which contains more than 100 flowing artesian wells near the coast.

In 2013, survey for seasonal change in submarine groundwater discharge (SGD) and associated nutrient fluxes by the use of ^{222}Rn and salinity mass balance model was conducted. The SGD rates estimated show a large intra-annual variability of 0.05×10^6 to 0.77×10^6 m^3 d^{-1} (Sugimoto et al., 2015). The highest SGD fraction (>40%) in total terrestrial freshwater fluxes was estimated to occur in summer rainy season due to low discharge of surface river water. Nutrient fluxes from the SGD were about 42%, 65%, and 33% of all terrestrial fluxes of dissolved inorganic nitrogen, phosphorous, and silicate. Phosphorous-enriched nutrient transport through SGD is suggested to enhance biological production of Obama Bay since primary production is restricted by phosphorous (Sugimoto et al., 2015).

3. Methods

3.1. Radon-222 measurements

Physical and biological surveys were conducted in shallow waters in east part of Obama Bay (Fig. 1). Prior to biological survey, spatial variability of ^{222}Rn concentration was investigated at 13 stations on 22 July 2014 using the radon detector (RAD7, Durridge Co.) in order to detect submarine ground water discharge in the survey area. ^{222}Rn is a powerful tracer of groundwater inputs to oceans that is a naturally occurring radioactive gas and is typically 2 – 3 orders of magnitude higher in groundwater than surface waters (Church, 1996; Kim et al., 2005; Taniguchi et al., 2002). Glass bottles (3500 mL) of bottom water kept in an isothermal bath at 25 °C were aerated for 45 min via a closed-air loop using the Big-Bottle RAD H_2O system (Durridge Co.: De Simonea et al., 2015), an accessory for the RAD7 that allows higher-sensitivity ^{222}Rn measurement. After air-water equilibrium was established, the equilibrated air was measured by the RAD7 with at least six runs of 15 min, and the results were averaged. All samples were analyzed immediately after collection, and the decay effect was corrected using the ^{222}Rn decay constant ($\lambda_{222} = 0.181$ d^{-1}) and time elapsed after collection. Count uncertainty of ^{222}Rn measurements was less than 20%. According to the results from the ^{222}Rn measurements (see the results), two stations (sts. 1 and 2: Fig. 1) were fixed in order to compare species richness and abundance of fish and benthic invertebrates between areas with high and low submarine groundwater discharge within a relatively short distance (ca. 100 m).

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