Journal of Hydrology: Regional Studies 11 (2017) 69–83

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Hot spring drainage impact on fish communities around temperate estuaries in southwestern Japan

Makoto Yamada[a,*], Jun Shoji[c], Shinji Ohsawa[b], Taketoshi Mishima[b], Masaki Hata[c], Hisami Honda[a], Masahiko Fujii[d], Makoto Taniguchi[a]

[a] Research Institute for Humanity and Nature, 457-4, Kamigamo Motoyama, Kita-ku, Kyoto 603-8047, Japan
[b] Beppu Geothermal Research Laboratory, Institute for Geothermal Sciences, Graduate School of Science, Kyoto University, Noguchibaru, Beppu, Oita 874-0903, Japan
[c] Graduate School of Biosphere Science, Hiroshima University, 1-4-4 Kagamiyama, Hiroshima 739-8528, Japan
[d] Faculty of Environmental Earth Science, Hokkaido University, N10W5, Kita-ku, Sapporo, Hokkaido 060-0810, Japan

ARTICLE INFO

Article history:
Received 6 July 2015
Received in revised form
14 December 2015
Accepted 23 December 2015
Available online 17 February 2016

Keywords:
Hot spring drainage
Domestic sewage
River ecosystem
Diatom
Nile tilapia

ABSTRACT

Study region: We investigated in Beppu, Oita Prefecture, Japan. Hot spring drainage flows into a river and then flows into coastal areas in this area, a region in Japan with many hot springs.
Study focus: The effects of that drainage on river and coastal area ecosystems remain unclear. We evaluated the impact of the hot spring drainage on fish communities near the estuary.
New hydrological insights: Factor analysis results obtained using water quality data show that the scale of the hot spring drainage influence on rivers differs among rivers. The inflow of hot spring drainage into the rivers affects phytoplankton more than the inflow of domestic drainage, which increases the amount of phytoplankton. Furthermore, hot spring drainage creates a better habitat for Nile tilapia, a foreign species, by increasing food availability and water temperature.

1. Introduction

From ancient times, hot spring water has been used for various purposes such as drinking, heat utilization for cooking, space heating, and bathing. Generally, although hot spring waters that have already been used (hot spring drainage) are channeled into sewers, the hot spring drainage is channeled directly into rivers in areas where sewage systems are undeveloped, or in cases where the hot spring drainage is too hot. In Beppu City, Oita Prefecture, Japan, a large source of thermal spring water in Japan, some environmental studies of rivers (Kawano, 1998; Ohsawa et al., 2008, 2009) have shown that hot spring drainage that flows into a river and then to coastal areas strongly affects the river water quality. Tropical fish of several kinds that are not indigenous to Japan have been found in such rivers (Hiramatsu et al., 1994). In fact, non-indigenous fish are readily observable swimming there.

Since the Fukushima nuclear accident in March 2011, geothermal energy has increasingly attracted attention in Japan as a renewable energy source. Particularly, power generation facilities using hot spring water, called *Onsen-Hatsuden*, are used in areas with hot springs. Onsen-Hatsuden are promising for renewable energy generation, at least in part because they use energy that is radiated when high-temperature hot spring waters cool. This energy is exhausted conventionally as waste.

* Corresponding author. Fax: +81 75 707 2509.
E-mail address: myam@chikyu.ac.jp (M. Yamada).

http://dx.doi.org/10.1016/j.ejrh.2015.12.060

In the Beppu area described above, Onsen-Hatsuden have been introduced rapidly by corporations during the past several years. Because Onsen-Hatsuden facilities increase the demand for hot spring water, the utility value of the hot springs has increased.

As described above, the demand for hot springs has been growing in recent years. Additionally, we confirmed that the high temperature water is released to the river by the Onsen-Hatsuden type power plants that have been built recently in Beppu. Therefore, the effects of the hot spring drainage that flows directly into the rivers cannot be ignored. Increased demand for hot spring usage might cause an inflow of hot spring drainage into other rivers that were previously unaffected.

Regarding conventional research related to hot spring water and its effects on surrounding ecosystems, many studies of microorganisms have been conducted to assess the effects of chemicals in the hot spring water (King et al., 2006; Rzonca and Schulze-Makuch, 2003). Furthermore, regarding studies of wastewater temperatures and their effects on ecosystems, studies have examined effects of heated wastewater from power plants on surrounding ecosystems (e.g., Chuang et al., 2009; Jiang et al., 2013; Li et al., 2014). Assessments of general wastewater effects on river ecosystems have been conducted (e.g., Burd et al., 2013; Kendouci et al., 2013; Parker et al., 2012). Nevertheless, no report in the literature describes a study of environmental effects of hot spring water, which has particular chemical properties and temperatures, when mixed into a different water system. Although it is readily assumed that thermal energy and materials derived from hot spring drainage strongly affect surrounding ecosystems, the relation between hot spring drainage and fish communities has not been investigated in past studies.

We investigated the water quality and physical properties of six rivers in this region. Additionally, we investigated fish communities near the estuaries of two rivers, one of which is strongly affected by hot spring drainage. The other is unaffected by hot spring drainage. We attempted to evaluate the impact of thermal energy and materials derived from hot spring drainage on the fish communities near the estuary.

2. Site description and methods

2.1. Site description

The Beppu area is near the center of the southwestern Japan volcanic arc in the northeastern part of Kyushu Island. Beppu, the largest hot spring area in Japan (Fig. 1-a), has eight major hot springs and many others. Hot springs in the Beppu area, called *Beppu Onsen*, are typical volcanic hot springs that gush from the eastern flank of Tsurumi Volcano, a Quaternary active volcano in Japan.

The Beppu area has six small river basins: sequentially from the north, they are the Hiya River, Shin River, Hirata River, Haruki River, Sakai River, and Asami River (Fig. 1-b). These rivers generally flow eastward from the west, eventually flowing into Beppu Bay. With the exception of the Hiya River, these streams are lined with concrete. The lengths of these rivers, including their tributaries, are 3–6 km. The depths of these rivers are less than 0.5 m, but the Hiya River is exceptionally deep, reaching 0.6–0.9 m depth. Except for the Hiya River Basin, each basin has numerous hot springs.

2.2. Water sampling and analyses

We sampled water at the river mouths of the six rivers once a month from March 2009 through January 2010, in July 2014, November 2014, and January 2015, and measured the air and water temperature, electric conductivity, and pH. These samples, collected to produce chemical composition datasets, were collected in polyethylene bottles after filtering of the water through a 0.45 μm membrane filter. These samples were stored in a refrigerator at 5 °C until chemical analyses were conducted. Major chemical compositions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, Br^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}) of these samples were determined using DX-120 ion chromatography (Dionex Corporation) with error of $\pm$0.1 mg/L. Bicarbonate (HCO_3^-) concentrations were determined using the pH 4.8 alkalinity measuring method (titration method) with error of $\pm$5 mg/L. Dissolved silica (DSi) and biogenic silica (BSi) of the suspended solid component in the river water as Si concentration were ascertained using molybdenum blue method (absorptiometric method) with error of 1 mg/L and 0.1 mg/L, respectively. We used a solution extracted using the alkali extraction method (DeMaster, 1981; Nakajima and Iseki, 2006) for BSi analysis.

The flow rates of the Hirata River and Haruki River were recorded during water collection. For the Hiya River, Shin River, Sakai River, and Asami River, we measured the flow rates in July 2014, November 2014, and January 2015. A current meter was used for all measurements. All measured results are presented in Table 1.

2.3. Fish community investigation

Fish samplings were conducted with a small seine net (2 m wide, 1 m high, and 1 mm mesh aperture) at five locations from the fresh water area to the seawater area near the river mouths of the Hiya River and Hirata River (Fig. 1-c). Furthermore, near the midpoints of the located points of each river (Hiya River: St. 3, Hirata River: St. 3), a large seine net (30 m wide, 2 m high, and 4 mm mesh aperture) was used to collect larger fish. The small seine was towed by two people for 20 m at a velocity of about 2 knots while maintaining distance of 1.5 m between the two people, so that the area covered by each tow was 30 m^2. Three sides of a square (10 m side length) were surrounded using the large seine net, with the other side facing