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

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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.

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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 ±0.1 mg/L. Bicarbonate ($HCO_3{}^-$) concentrations were determined using the pH 4.8 alkalinity measuring method (titration method) with error of ±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

Table 1
Chemical data of water samples.

A

River name	Sample ID	Sampling date	A.T. (deg.C)	W.T. (deg.C)	E.C. (mS/m)	pH	Li^+ (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$NO_3{}^-$ (mg/L)	$PO_4{}^{3-}$ (mg/L)	$SO_4{}^{2-}$ (mg/L)	$HCO_3{}^-$ (mg/L)	DSi (mg/L)	BSi (mg/L)	Flowrate (m^3/s)
Asami River	ASM0903	2009-03-30	10.6	13.0	20.0	7.5	0.1	23.9	3.8	3.3	10.1	20.9	n.d.	1.8	0.3	12.2	58.4	26.4	n.a.	n.o.
Asami River	ASM0904	2009-04-28	19.5	17.4	32.0	8.7	0.2	44.9	6.6	4.3	14.0	40.6	0.1	2.1	0.4	22.7	77.9	30.9	0.4	n.o.
Asami River	ASM0905	2009-05-25	23.8	23.2	33.0	8.7	0.3	46.7	6.6	4.1	13.3	57.8	0.2	1.7	0.4	22.5	64.4	28.8	0.4	n.o.
Asami River	ASM0906	2009-06-26	32.0	26.8	36.0	8.7	0.3	49.0	7.2	4.1	13.7	45.5	0.2	1.2	0.3	26.6	65.8	30.5	0.5	n.o.
Asami River	ASM0907	2009-07-27	29.5	26.1	27.0	8.7	0.2	36.5	5.4	5.1	17.6	30.3	0.1	2.5	0.2	24.0	74.5	20.9	0.3	n.o.
Asami River	ASM0908	2009-08-20	32.2	28.1	31.0	8.7	0.3	47.9	6.3	14.9	4.5	42.1	0.1	2.3	0.4	26.8	73.4	31.6	0.3	n.o.
Asami River	ASM0909	2009-09-25	27.9	24.2	20.0	8.7	0.2	34.3	4.9	3.4	11.4	29.2	0.1	2.1	0.2	19.0	62.1	31.7	0.3	n.o.
Asami River	ASM0910	2009-10-29	24.1	23.9	55.0	8.8	0.5	74.7	9.9	4.7	15.5	87.7	0.2	1.7	0.2	42.0	83.4	37.7	0.4	n.o.
Asami River	ASM0911	2009-11-26	19.5	15.3	20.0	8.4	0.1	23.6	3.7	3.4	10.7	21.7	0.0	1.7	0.1	12.1	54.6	26.6	0.5	n.o.
Asami River	ASM0912	2009-12-22	13.1	10.6	20.0	8.3	0.1	26.7	2.9	3.6	11.1	24.5	0.1	1.7	n.d.	12.6	58.9	26.2	0.1	n.o.
Asami River	ASM1001	2010-01-20	15.2	11.7	19.8	8.5	0.1	24.4	3.7	3.4	10.7	22.0	0.1	1.6	0.1	11.1	58.6	26.1	0.2	n.o.
Asami River	ASM1407	2014-07-16	26.5	24.5	16.1	8.4	0.2	32.8	5.1	4.9	15.6	28.6	0.4	3.6	0.9	22.3	72.0	31.1	n.a.	0.71
Asami River	ASM1411	2014-11-20	16.2	14.0	22.0	8.2	0.1	27.2	3.8	3.7	11.1	25.7	0.1	2.4	0.3	13.1	58.0	28.9	n.a.	1.37
Asami River	ASM1501	2015-01-07	12.4	11.2	20.7	8.0	0.1	24.6	3.7	3.8	11.0	22.2	0.1	2.7	0.3	13.8	56.1	29.8	n.a.	1.36
Haruki River	HAR0903	2009-03-30	15.7	21.1	109.0	8.6	0.9	168.9	23.4	6.4	20.0	241.7	0.6	8.6	1.5	59.9	73.9	48.4	n.a.	0.12
Haruki River	HAR0904	2009-04-28	20.6	21.5	113.0	8.5	1.0	190.8	24.4	7.1	22.5	266.1	0.8	8.9	1.6	54.5	87.3	55.9	0.7	0.11
Haruki River	HAR0905	2009-05-25	31.6	27.6	120.0	8.7	1.1	209.7	27.1	6.6	22.2	318.8	0.8	10.2	2.2	65.9	74.2	50.5	0.3	0.08
Haruki River	HAR0906	2009-06-26	32.7	29.6	116.0	8.1	1.1	193.7	24.5	6.7	22.5	296.0	0.8	7.8	1.9	65.5	78.1	49.8	0.7	0.08
Haruki River	HAR0907	2009-07-27	34.1	32.4	82.0	8.3	0.9	163.5	22.4	6.4	22.4	186.3	0.6	9.6	1.4	55.8	82.2	50.7	0.2	0.14

B

River name	Sample ID	Sampling date	A.T. (deg.C)	A.T. (deg.C)	E.C. (mS/m)	pH	Li^+ (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	$NO_3{}^-$ (mg/L)	$PO_4{}^{3-}$ (mg/L)	$SO_4{}^{2-}$ (mg/L)	$HCO_3{}^-$ (mg/L)	DSi (mg/L)	BSi (mg/L)	Flowrate (m^3/s)
Haruki River	HAR0908	2009-08-20	33.5	35.1	88.0	8.8	0.9	164.4	22.7	21.1	6.5	200.7	0.7	6.9	1.6	62.3	47.4	44.2	0.5	0.11
Haruki River	HAR0909	2009-09-25	29.6	30.1	73.0	8.6	1.0	186.5	24.9	6.5	21.2	256.7	0.8	10.6	1.4	64.1	83.2	70.7	0.2	0.09
Haruki River	HAR0910	2009-10-29	28.3	23.8	124.0	8.1	1.1	184.0	25.9	6.8	21.7	265.4	0.8	9.0	1.2	57.9	85.0	56.1	0.3	0.06
Haruki River	HAR0911	2009-11-26	18.7	20.4	118.0	8.1	1.0	178.6	25.1	7.4	22.6	258.1	0.7	9.1	1.0	62.2	83.3	59.1	0.3	0.15
Haruki River	HAR0912	2009-12-22	19.6	15.6	116.0	8.3	1.0	185.3	23.4	7.3	23.4	299.2	0.7	8.0	1.0	55.2	97.4	58.0	0.5	0.11
Haruki River	HAR1001	2010-01-20	16.5	17.2	128.0	8.1	1.2	210.7	27.3	7.1	23.3	298.0	0.9	12.8	1.6	56.8	82.4	58.2	0.2	0.09
Haruki River	HAR1407	2014-07-17	28.5	31.2	99.3	8.8	0.9	150.4	22.2	7.3	22.2	183.4	0.5	10.2	1.1	60.3	72.6	56.1	n.a.	0.14
Haruki River	HAR1411	2014-11-20	19.4	21.4	115.0	8.6	0.9	179.6	23.3	5.6	18.8	248.2	0.7	10.6	0.9	43.0	80.5	47.0	n.a.	0.24
Haruki River	HAR1501	2015-01-08	9.5	16.3	118.5	8.7	1.0	189.6	24.1	5.5	17.0	256.0	0.7	12.2	1.1	39.8	79.3	48.6	n.a.	0.17
Hirata River	HRT0903	2009-03-30	15.2	27.0	230.0	7.7	2.3	392.3	55.9	7.1	30.8	643.1	1.7	7.7	1.4	148.3	43.9	85.1	n.a.	0.26
Hirata River	HRT0904	2009-04-28	18.0	26.6	220.0	7.6	2.2	443.3	58.4	7.5	33.0	711.6	1.9	11.7	1.5	159.1	45.3	93.1	1.3	0.32
Hirata River	HRT0905	2009-05-25	27.9	30.9	250.0	7.4	2.7	474.9	63.0	7.0	32.1	808.0	2.0	8.0	1.8	170.1	38.0	97.0	0.9	0.26
Hirata River	HRT0906	2009-06-26	27.3	34.1	230.0	7.5	2.8	441.6	58.8	7.4	33.3	746.8	2.0	6.0	1.4	156.5	41.1	94.2	0.9	0.27

Table 1 (*Continued*)

B

River name	Sample ID	Sampling date	A.T. (deg.C)	A.T. (deg.C)	E.C. (mS/m)	pH	Li^+ (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	DSi (mg/L)	BSi (mg/L)	Flowrate (m^3/s)
Hirata River	HRT0907	2009-07-27	31.4	33.5	134.0	7.8	1.7	300.3	41.5	6.8	30.6	382.0	1.2	5.3	0.6	123.5	46.4	69.8	0.9	0.37
Hirata River	HRT0908	2009-08-20	34.2	37.1	193.0	8.1	2.3	385.7	50.1	32.1	7.3	545.5	1.7	5.7	0.9	146.3	11.3	84.3	0.6	0.31
Hirata River	HRT0909	2009-09-25	29.7	31.8	191.0	7.6	2.0	354.9	47.1	6.8	29.5	556.0	1.6	8.7	0.9	168.4	38.9	93.1	0.9	0.39
Hirata River	HRT0910	2009-10-29	21.3	29.8	280.0	7.1	2.9	483.4	66.4	6.8	31.1	819.6	2.3	6.2	0.5	164.2	28.6	83.7	1.0	0.33
Hirata River	HRT0911	2009-11-26	19.6	23.0	230.0	7.3	2.3	397.1	55.0	7.0	31.1	606.3	1.8	5.7	0.4	158.3	31.0	77.5	0.6	0.33
Hirata River	HRT0912	2009-12-22	14.6	24.2	220.0	7.6	2.4	409.7	54.0	7.8	33.4	590.2	1.8	6.5	0.4	154.4	32.6	78.4	1.0	0.32

C

River name	Sample ID	Sampling date	A.T. (deg.C)	A.T. (deg.C)	E.C. (mS/m)	pH	Li^+ (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	DSi (mg/L)	BSi (mg/L)	Flowrate (m^3/s)
Hirata River	HRT1001	2010-01-20	14.1	26.2	230.0	7.2	2.6	439.8	59.0	7.6	32.2	651.5	2.0	7.0	0.6	154.0	51.1	62.5	1.1	0.28
Hirata River	HRT1407	2014-07-14	27.2	30.3	169.7	7.4	1.6	268.6	40.1	8.3	27.6	335.8	1.0	6.0	0.3	147.2	20.1	69.2	n.a.	0.46
Hirata River	HRT1411	2014-11-19	15.3	25.4	172.0	7.5	1.6	320.5	42.6	6.0	25.0	449.8	1.2	6.6	0.5	158.2	31.7	48.6	n.a.	0.33
Hirata River	HRT1501	2015-01-06	11.1	23.1	193.2	6.9	1.5	329.6	37.4	5.5	21.8	461.8	1.4	7.4	0.5	160.5	26.8	76.4	n.a.	0.27
Hiya River	HIY0903	2009-03-30	11.4	12.0	11.1	8.2	n.d.	7.0	2.4	3.1	9.4	4.5	n.d.	0.7	0.2	3.9	56.6	24.3	n.a.	n.o.
Hiya River	HIY0904	2009-04-28	16.6	13.3	10.6	7.8	n.d.	7.7	2.7	3.5	10.5	4.4	n.d.	1.0	0.3	3.6	55.9	25.4	0.3	n.o.
Hiya River	HIY0905	2009-05-25	28.9	19.3	11.8	7.5	n.d.	9.9	2.6	3.4	10.6	7.5	n.d.	0.9	0.2	3.7	56.3	25.0	0.3	n.o.
Hiya River	HIY0906	2009-06-26	26.9	19.5	11.5	7.1	0.0	8.6	2.6	3.3	10.6	5.8	n.d.	0.8	0.2	3.4	54.3	26.0	0.4	n.o.
Hiya River	HIY0907	2009-07-27	29.2	21.2	11.3	7.8	n.d.	7.6	2.5	3.3	12.1	4.5	n.d.	1.7	0.1	6.0	56.8	21.1	0.2	n.o.
Hiya River	HIY0908	2009-08-20	32.4	21.8	12.7	6.9	n.d.	7.4	2.8	10.9	3.3	4.5	n.d.	0.9	0.3	3.8	51.4	20.3	0.2	n.o.
Hiya River	HIY0909	2009-09-25	27.7	20.1	12.1	7.5	0.0	8.5	2.6	3.3	10.3	6.7	n.d.	1.2	0.2	4.1	56.6	15.8	0.5	n.o.
Hiya River	HIY0910	2009-10-29	25.5	16.3	11.0	7.1	0.0	6.7	2.3	3.1	9.4	4.1	n.d.	0.8	0.1	3.1	39.0	22.4	0.3	n.o.
Hiya River	HIY0911	2009-11-26	18.0	13.8	11.3	7.8	n.d.	7.5	2.3	3.1	9.8	4.9	n.d.	1.0	0.1	3.5	44.0	19.2	0.3	n.o.
Hiya River	HIY0912	2009-12-22	17.6	9.6	11.1	7.6	n.d.	7.6	2.4	3.3	10.0	5.4	n.d.	0.9	n.d.	3.1	48.9	24.8	0.1	n.o.
Hiya River	HIY1001	2010-01-20	18.2	10.0	10.7	7.8	n.d.	7.1	2.4	3.3	10.0	0.2	n.d.	0.1	n.d.	0.2	51.1	22.1	0.1	n.o.
Hiya River	HIY1407	2014-07-15	27.3	20.5	13.5	7.3	n.d.	7.5	3.0	3.3	11.2	5.6	n.d.	2.0	0.9	5.8	53.7	25.6	n.a.	0.04
Hiya River	HIY1411	2014-11-20	18.1	13.7	11.7	7.5	n.d.	7.2	2.6	3.1	9.5	4.9	n.d.	1.1	0.3	2.7	50.0	27.8	n.a.	0.10
Hiya River	HIY1501	2015-01-07	12.0	10.4	12.4	8.3	n.d.	7.9	2.5	3.2	10.0	6.9	n.d.	1.1	0.3	2.8	51.3	27.2	n.a.	0.10
Sakai River	SAK0903	2009-03-30	13.8	20.2	63.0	8.8	0.4	89.2	13.1	9.5	18.1	94.7	0.3	8.6	1.6	42.2	110.7	40.1	n.a.	n.o.

D

River name	Sample ID	Sampling date	A.T. (deg.C)	A.T. (deg.C)	E.C. (mS/m)	pH	Li^+ (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	DSi (mg/L)	BSi (mg/L)	Flowrate (m^3/s)
Sakai River	SAK0904	2009-04-28	19.3	23.3	59.0	8.5	0.3	83.5	10.9	10.6	20.5	84.1	0.3	8.0	1.3	38.3	110.8	41.0	0.2	n.o.
Sakai River	SAK0905	2009-05-25	26.4	29.6	69.0	9.1	0.5	107.7	14.3	9.8	19.2	121.0	0.3	8.2	2.0	49.3	109.7	34.7	0.3	n.o.
Sakai River	SAK0906	2009-06-26	27.9	31.2	63.0	9.1	0.5	88.6	13.1	9.2	19.4	96.7	0.3	4.9	1.5	43.4	101.0	49.7	0.1	n.o.
Sakai River	SAK0907	2009-07-27	29.0	33.0	50.0	8.7	0.6	83.3	11.7	8.7	20.1	76.0	0.2	5.4	0.9	40.4	103.4	28.0	0.1	n.o.
Sakai River	SAK0908	2009-08-20	35.4	33.1	54.0	8.9	0.5	99.5	12.8	19.2	9.4	100.5	0.3	5.7	1.6	46.1	77.6	42.4	0.2	n.o.
Sakai River	SAK0909	2009-09-25	26.1	30.7	65.0	9.2	0.5	99.1	12.7	8.3	17.2	110.6	0.3	8.6	1.3	44.9	104.9	49.8	0.0	n.o.
Sakai River	SAK0910	2009-10-29	22.0	24.9	66.0	8.7	0.4	87.6	12.0	8.7	17.3	99.6	0.3	6.3	0.9	37.9	99.3	31.4	0.1	n.o.
Sakai River	SAK0911	2009-11-26	19.6	21.3	66.0	8.4	0.4	90.6	12.5	9.2	10.9	101.4	0.3	6.7	0.9	37.5	105.4	43.2	0.2	n.o.

Sakai River	SAK0912	2009-12-22	15.2	16.2	63.0	8.2	0.4	91.2	11.1	10.2	19.9	126.2	0.3	10.3	0.9	35.7	112.8	41.8	0.2	n.o.
Sakai River	SAK1001	2010-01-20	16.4	18.4	69.0	8.5	0.5	107.1	13.6	9.5	18.4	144.4	0.6	8.8	1.1	44.4	102.7	40.7	0.2	n.o.
Sakai River	SAK1407	2014-07-17	30.9	32.0	65.4	9.1	0.5	94.3	13.9	8.5	17.9	103.6	0.3	8.1	1.4	47.4	92.1	44.6	n.a.	0.15
Sakai River	SAK1411	2014-11-20	15.4	20.1	62.0	8.6	0.3	83.5	12.1	9.4	18.8	95.9	0.2	7.8	1.2	44.8	97.6	44.7	n.a.	0.13
Sakai River	SAK1501	2015-01-07	9.9	15.4	63.7	8.6	0.3	89.6	11.6	8.2	15.6	98.8	0.2	8.8	1.2	42.2	97.0	45.4	n.a.	0.14
Shin River	SIN0903	2009-03-30	14.6	17.5	73.0	7.5	0.4	97.9	18.3	6.1	19.8	115.8	0.4	3.8	0.2	88.9	22.9	39.9	n.a.	n.o.
Shin River	SIN0904	2009-04-28	19.5	19.6	65.0	7.3	0.4	96.4	15.3	6.5	21.0	111.9	0.4	3.7	0.3	86.1	24.5	37.7	0.4	n.o.
Shin River	SIN0905	2009-05-25	26.1	26.1	73.0	6.6	0.5	120.2	21.5	7.6	22.8	152.4	0.5	3.5	0.1	142.3	35.9	43.4	0.3	n.o.
Shin River	SIN0906	2009-06-26	27.8	27.7	210.0	6.2	0.5	368.3	26.3	40.7	29.9	684.8	2.2	4.7	0.1	146.1	25.0	38.2	0.3	n.o.
Shin River	SIN0907	2009-07-27	31.4	27.0	25.0	7.6	0.1	30.6	6.1	4.3	16.2	33.3	0.1	3.4	0.1	43.4	40.2	27.1	0.4	n.o.
Shin River	SIN0908	2009-08-20	34.0	31.9	78.0	7.2	0.4	99.6	16.0	20.4	7.7	110.3	0.4	3.2	0.3	107.5	9.3	38.7	0.2	n.o.

E

River name	Sample ID	Sampling date	A.T. (deg.C)	A.T. (deg.C)	E.C. (mS/m)	pH	Li^+ (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	Br^- (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	DSi (mg/L)	BSi (mg/L)	Flowrate (m^3/s)
Shin River	SIN0909	2009-09-25	30.7	28.0	67.0	6.6	0.5	108.7	19.0	7.0	20.8	129.4	0.4	5.8	n.d.	118.6	31.0	46.9	0.4	n.o.
Shin River	SIN0910	2009-10-29	23.4	20.0	38.0	7.1	0.2	46.8	8.8	4.6	14.2	45.5	0.2	3.3	0.2	52.7	24.2	31.3	0.4	n.o.
Shin River	SIN0911	2009-11-26	18.3	15.8	62.0	6.9	0.3	79.7	14.8	5.9	19.2	105.6	0.3	2.9	n.d.	91.2	15.5	36.6	0.3	n.o.
Shin River	SIN0912	2009-12-22	13.1	12.3	66.0	6.7	0.4	95.7	15.6	6.3	20.0	135.5	0.4	4.0	n.d.	97.3	11.0	35.4	0.2	n.o.
Shin River	SIN1001	2010-01-20	14.8	14.5	71.0	6.8	0.5	105.3	18.7	6.7	20.9	121.3	0.4	2.6	n.d.	109.6	54.7	36.3	0.2	n.o.
Shin River	SIN1407	2014-07-17	31.4	30.4	44.8	7.6	0.2	55.5	11.3	5.2	17.1	58.6	0.2	4.5	0.1	69.7	19.5	38.0	n.a.	0.15
Shin River	SIN1411	2014-11-20	20.7	18.6	53.0	7.3	0.2	66.8	12.4	4.7	15.9	79.2	0.2	3.7	0.1	84.8	15.3	41.4	n.a.	0.13
Shin River	SIN1501	2015-01-08	9.2	14.1	68.3	6.6	0.3	90.9	15.4	5.4	17.9	115.8	0.3	3.8	0.1	105.6	13.4	44.0	n.a.	0.15

A.T., air temperature; W.T., water temperature; E.C., electric conductivity; n.d., not detected; n.a., not analyzed; n.o., not observed.

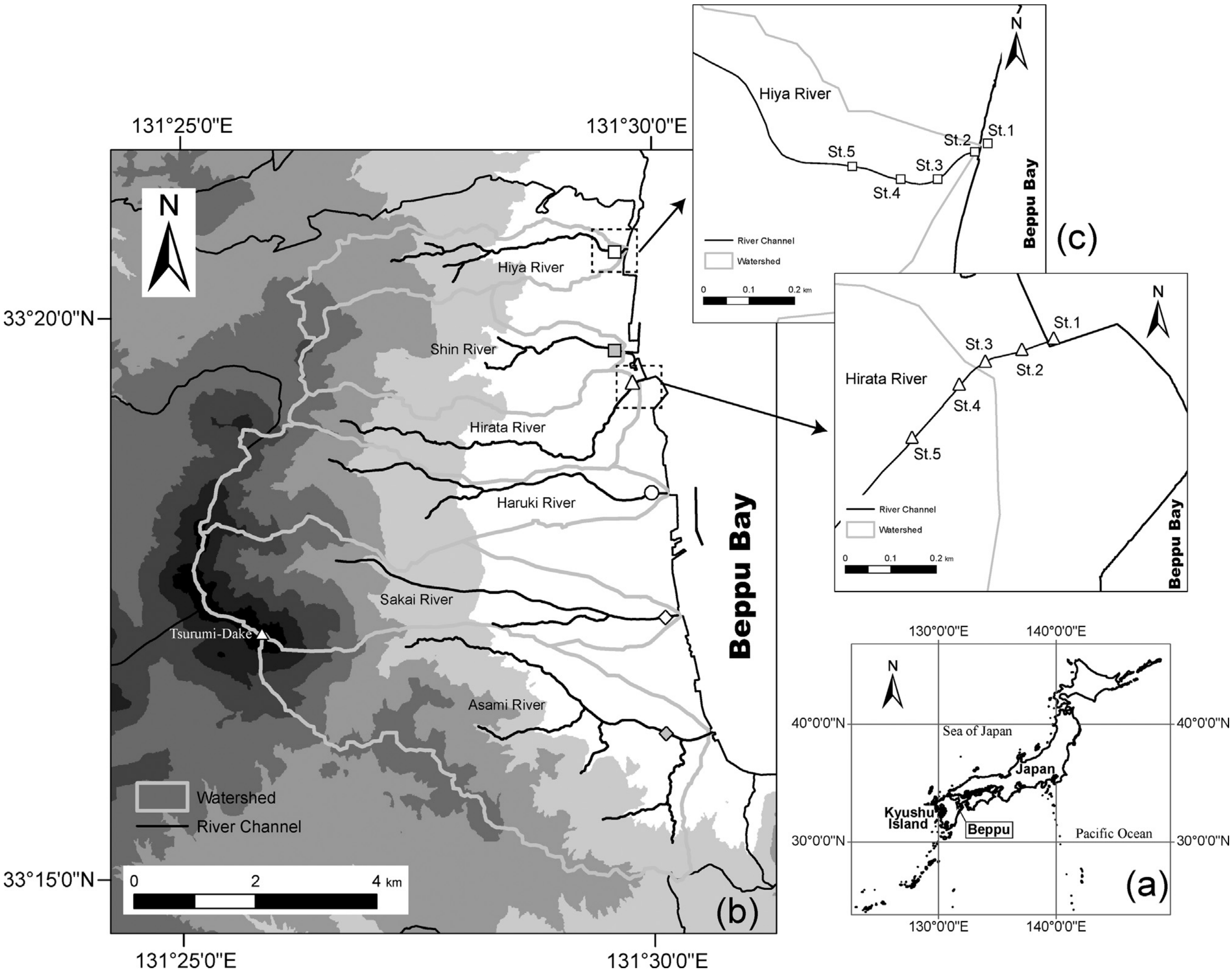

Fig. 1. Locations of study areas: (b) shows water sampling points; (c) shows fish sampling points.

to the shore. Fish samples were preserved in a 10% seawater formalin solution. In the laboratory, fishes were identified and assigned to the most detailed taxa.

3. Results

3.1. River water temperature and chemical composition

Time series variations of the river water and air temperature are presented in Fig. 2. The water temperatures of all rivers showed a pattern that peaked in the summer. The water temperatures of the Shin River, Haruki River, and Asami River were usually similar to the air temperature, if not slightly lower. However, the water temperature of the Hiya River was markedly lower than the air temperature in the summer. The water temperatures of the Sakai River and Hirata River were higher than the air temperature throughout the year. Especially, the water temperature of the Hirata River never fell below 20 °C. It was notably higher than the air temperature in the winter. Although the water temperature of the Sakai River was slightly higher than the air temperature, the differences between the water temperature and air temperature were not so large.

No significant change was found throughout the year in the electrical conductivity of the river water, with the Shin River and Hirata River as exceptions (Fig. 3). An extremely high value was measured in June at the Shin River, but no apparent fluctuation occurred in other months. Although the fluctuations observed at the Hirata River were greater than in other rivers, it constantly showed a high conductivity value. On average, the value of electrical conductivities decreased in order of the Hirata River, Haruki River, Shin River, Sakai River, Asami River, and Hiya River. This trend was apparent in measurements made during 2009–2010 and in 2014–2015.

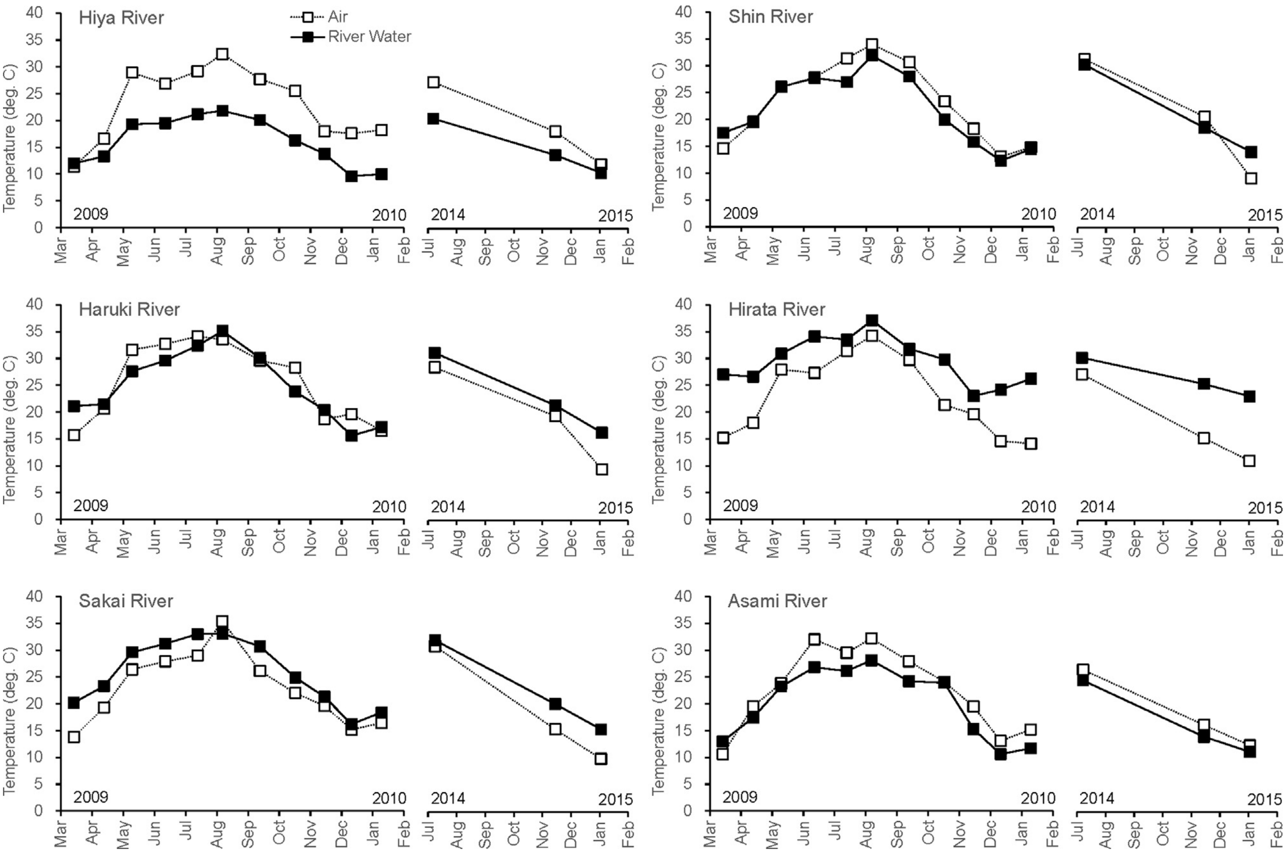

Fig. 2. Change in air temperature and water temperature with time. White squares show the change in air temperature. Black squares show the change in water temperature.

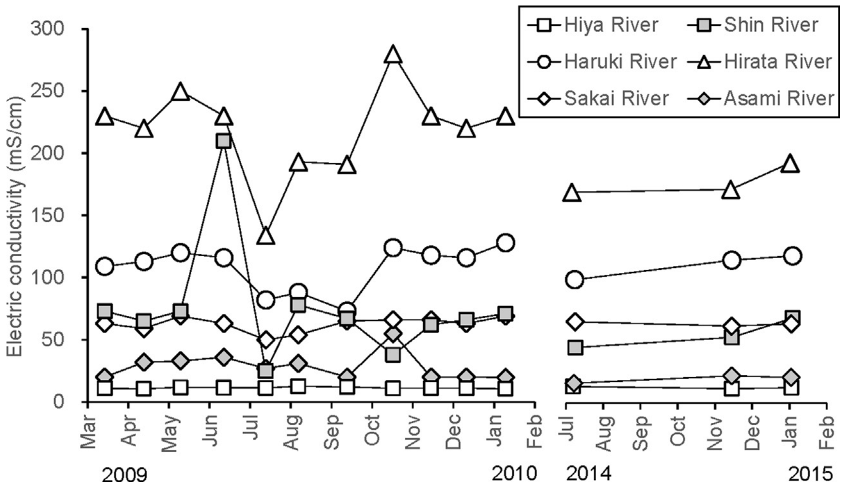

Fig. 3. Seasonal fluctuations of electrical conductivity in each river.

The nutrient (NO_3^-, PO_4^{3-} and DSi) concentration results are portrayed in Fig. 4. Although the NO^- concentrations of the Hirata River, Haruki River, and Sakai River fluctuate seasonally, they were constantly higher than in the other rivers throughout the year. They increased in the order of the Haruki River, Sakai River, and the Hirata River. These three rivers also showed high concentrations of PO_4^{3-}. During 2009–2010, the concentrations increased in order of the Haruki River, Sakai River, and the Hirata River (the same trend as NO_3^- concentrations), but during 2014–2015, the Sakai River concentration was the highest. The DSi concentration in the Hirata River was markedly higher than those in the other rivers, above the Haruki River, which had the second-highest concentration. Rivers with the highest DSi, NO_3^-, and PO_4^{3-} concentrations

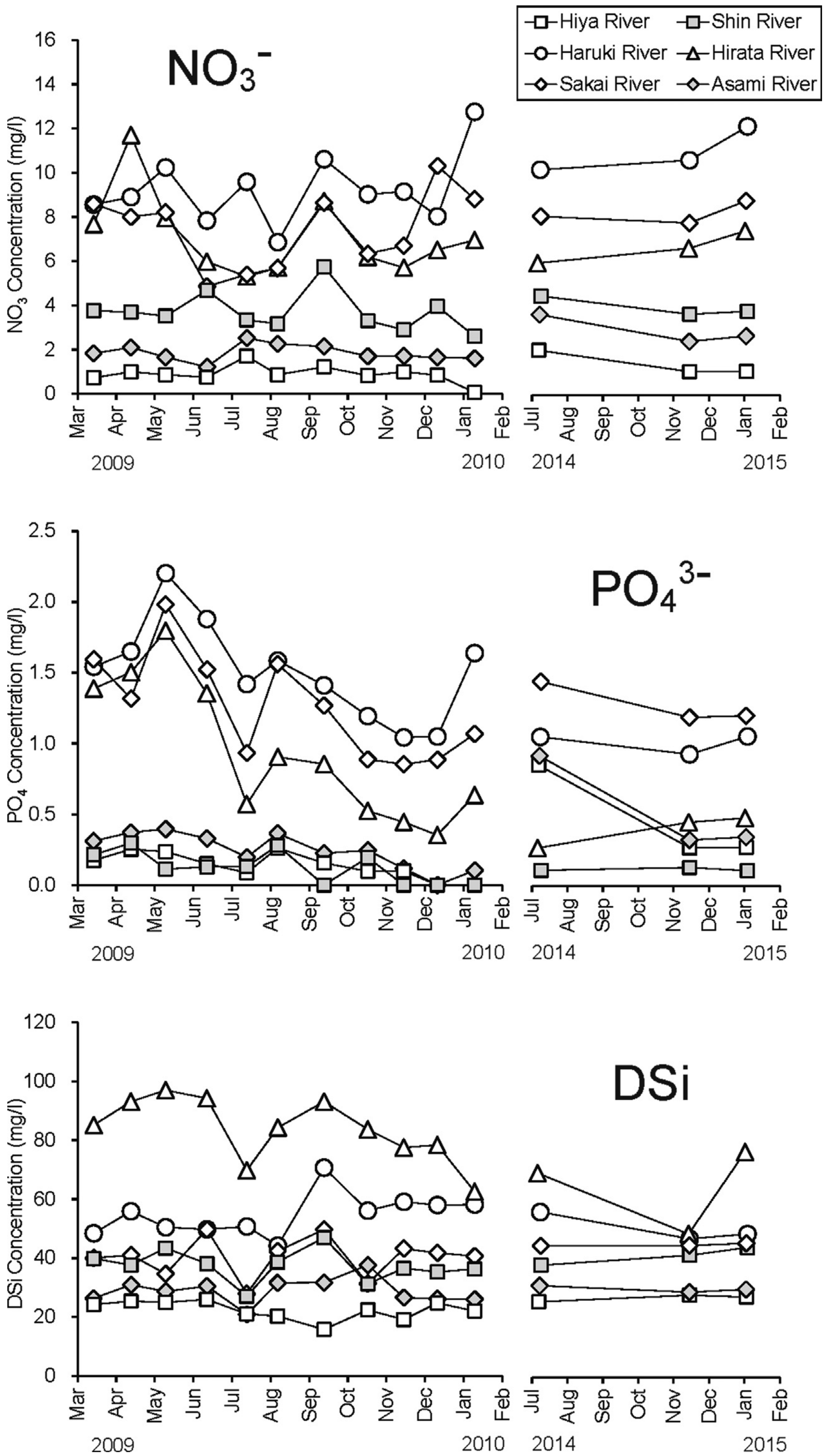

Fig. 4. Seasonal fluctuations of NO_3^-, PO_4^{3-}, and DSi concentrations in respective rivers.

Table 2
Number of species and number of fish collected using a small seine net.

	Hiya River										Hirata River									
	St. 1		St. 2		St. 3		St. 4		St. 5		St. 1		St. 2		St. 3		St. 4		St. 5	
	July	Jan	July	Jan	July	Jan	July	Jan	July	Jan	July	Jan	July	Jan	July	Jan	July	Jan	July	Jan
Rudarius ercodes	1																			
Thamnaconus modestus	1																			
Platycephalus sp.	1										2				1					
Acentrogobius virgatulus	1										5									
Parablennius yatabei	1																			
Luciogobius sp.											1									
Tridentiger sp.							6						1							
Gobiidae sp. Type 1											1									
Gobiidae sp. Type 2			1												2					
Gobiidae sp. Type 3							2													
Nuchequula nuchalis			3																	
Mugil cephalus							2													
Pungtungia herzi									6											
Takifugu niphobles					1	1						7								
Rhinogobius giurinus					1		26										2		2	
Rhinogobius								2		4										
Anguilla japonica																1				
Oreochromis niloticus													2	1			5		161	1

were all different. The Hirata River showed a considerably high BSi concentration. The Haruki River showed a slightly high concentration, but all other rivers except for the Sakai River had mutually similar values.

3.2. Fish sampling

From using a small seine net from the fresh water area to the seawater area near the river mouths (Table 2), 14 species of fish collected at the Hiya River (July: 13, January: 2) and 10 species at the Hirata River (July: 10, January: 3). In addition, 60 specimens (53 in July, 7 in January) were obtained from the Hiya River; 195 specimens (185 in July, 10 in January) were obtained from the Hirata River. At the Hiya River, 42% of the fish collected were *Rhinogobius giurinus*. At the Hirata River, 87% were *Oreochromis niloticus* (Nile tilapia). Oceanic species were dominant at St. 1 and St. 2 of each river, where the salinity is high. These species were not found towards St. 3 and upriver reaches, where the salinity is low. Nile tilapia in the Hirata River were found even at St. 2, where the salinity is somewhat high, and were found at all points other than St. 1, located in a coastal area. However, Nile tilapia fish were not found at any point or time of the Hiya River. Most of the Nile tilapia specimens collected in the Hirata River in July were juveniles: roughly 10 mm long. However, at St. 2 in July and St. 2 and St. 5 in January, fully grown fish greater than 100 mm long were collected. Various specimens, from young to adult fish, were collected (Table 3).

No fish were collected at the first 50 m^2 area at the Hiya River using the large seine. Four species and eight fishes with lengths of less than 100 mm were collected at the 30 m^2 area, but all species were either estuarine or coastal fish. Sampling with the large seine in the Hirata River collected 11 specimens of 2 species in the 50 m^2 area and 5 specimens of 2 species in the 30 m^2 area: a total of 16 specimens of 3 species. Of those fishes, 4 specimens of 2 species were brackish and coastal species, whereas the remaining 12 specimens were Nile Tilapia. All specimens collected at the Hirata River exceeded 100 mm length (Table 4).

The wet weights per unit area of fish collected using a small seine net at the points are 0.85 g/m^2 in the Hiya River, 5.67 g/m^2 in the Hirata River in July, and 0.09 g/m^2 in the Hiya River and 6.65 g/m^2 in the Hirata River in January. The wet weights of the fish collected with a large seine net in January were 0.29 g/m^2 in the Hiya River and 142.50 g/m^2 in the Hirata River. The wet weights of fish collected per unit area in the Hirata River were significantly greater than in the Hiya River in summer and winter (Table 5).

4. Discussion

4.1. Distinguishing and determining factors of rivers

Water temperature fluctuation patterns in the Shin River, Haruki River, and Asami River closely matched air temperature fluctuations. It can be inferred that this fluctuation is attributable to the shallow depths of these rivers (roughly 200 mm). While flowing, the water can easily reach thermal equilibrium with the air. Several possible reasons for the markedly low water temperature compared to the air temperature at the Hiya River in summer are the following: the Hiya River is short; it is deep (greater than 500 mm); and left in its natural state, it allows the inflow of groundwater. The water temperature of the Hirata River never falls below 20 °C, probably because of the constant inflow of heat via hot spring drainage, as stated

Table 3
Species of sampled fish collected with a small seine net: average, maximum, and minimum lengths. Columns of maximum and minimum length are left blank if only one specimen was collected.

Sampling site			Species	Average (mm)	Maximum (mm)	Minimum (mm)
Hiya River	July	St. 1	*Platycephalus* sp.	12.7		
			Acentrogobius virgatulus	46.1		
			Rudarius ercodes	54.2		
			Thamnaconus modestus	60.3		
			Parablennius yatabei	85.2		
		St. 2	*Nuchequula nuchalis*	10.1	11.0	9.6
			Gobiidae sp. Type 2	16.9		
		St. 3	*Takifugu niphobles*	125.7		
			Rhinogobius giurinus	52.9		
		St. 4	*Mugil cephalus*	46.1	48.8	43.4
			Tridentiger sp.	46.0	74.5	14.8
			Gobiidae sp. Type 3	23.2	29.2	17.1
			Rhinogobius giurinus	54.9	72.2	42.5
		St. 5	*Pungtungia herzi*	48.8	55.6	42.2
	Jan	St. 3	*Takifugu niphobles*	91.0		
		St. 4	*Rhinogobius*	34.9	42.1	27.7
		St. 5	*Rhinogobius*	36.0	50.6	24.1
Hirata River	July	St. 1	*Gobiidae* sp. Type 1	13.9	16.5	11.3
			Luciogobius sp.	13.1		
			Platycephalus sp.	18.6	23.5	13.7
			Acentrogobius virgatulus	56.0	60.8	49.5
		St. 2	*Oreochromis niloticus* (adult)	330.0		
			Oreochromis niloticus (juvenile)	10.7		
			Tridentiger sp.	12.1		
		St. 3	*Gobiidae* sp. Type 2	16.2	17.8	14.6
			Platycephalus sp.	12.8		
		St. 4	*Oreochromis niloticus* (juvenile)	11.4	13.3	9.7
			Rhinogobius giurinus	108.5	114.6	102.4
		St. 5	*Oreochromis niloticus* (juvenile)	10.5	11.8	9.3
			Rhinogobius giurinus	69.5	73.5	65.4
	Jan	St. 1	*Takifugu niphobles*	95.8	121.7	77.7
		St. 2	*Oreochromis niloticus* (adult)	171.0		
		St. 3	*Anguilla japonica*	208.8		
		St. 5	*Oreochromis niloticus* (adult)	400.0		

Table 4
Species of sampled fish collected with a large seine net: average, maximum, and minimum lengths.

River & point	Species	1st (50 m^2)				2nd (30 m^2)			
		Average (mm)	Maximum (mm)	Minimum (mm)	Number of specimens	Average (mm)	Maximum (mm)	Minimum (mm)	Number of specimens
Hiya River (St. 3)	*Takifugu niphobles*					70	71	69	3
	Favonigobius gymnauchen					50	55	44	3
	Gymnogobius heptacanthus					48			1
	Platycephalus sp.					75			1
Hirata River (St. 3)	*Rhyncopelates oxyrhynchus*	166	175	158	3				
	Caranx sexfasciatus					145			1
	Oreochromis niloticus	355	405	315	8	284	358	203	4

Table 5
Wet weights of collected fish.

			Total number of samples	Total wet weight (g)	Total tow area (m^2)	Number of samples per unit area	Wet weight per unit area (g/m^2)
Small seine net	Hiya River	July	53	128.1	150	0.35	0.85
		Jan	7	18	200	0.04	0.09
	Hirata River	July	185	850.37	150	1.23	5.67
		Jan	10	1330	200	0.05	6.65
Large seine net	Hiya River	Jan	8	23	80	0.10	0.29
	Hirata River		16	11,400	80	0.20	142.50

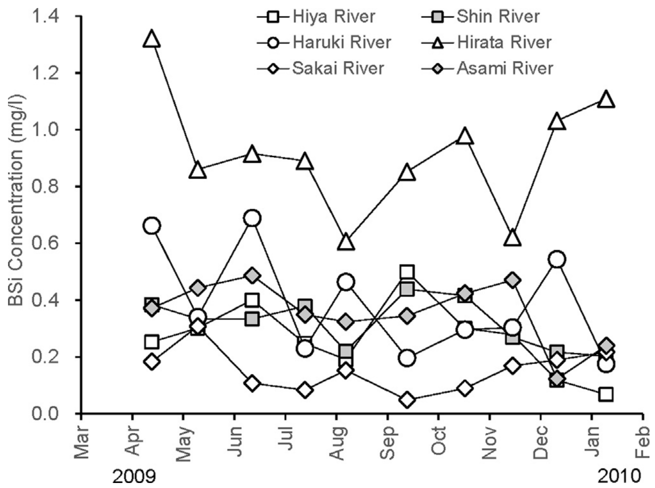

Fig. 5. Seasonal fluctuations of the BSi concentrations in respective rivers.

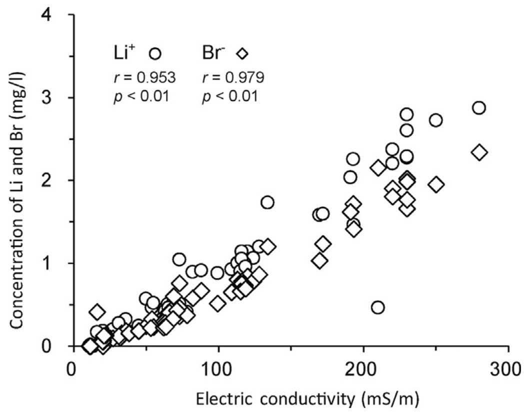

Fig. 6. Correlation between electrical conductivity: Li^+ (in circles); Br^- (in diamonds); *r* is the correlation coefficient. *p* denotes the significance level.

earlier. Similarly, the Sakai River water temperature is invariably higher than the air temperature. However, because it never exceeds 20 °C in the winter, unlike the Hirata River, and because it has similar fluctuation patterns to those of the air temperature, one can infer that although an inflow of heat might occur, the amount of heat inflow is probably smaller. (Fig. 5)

The respective correlation coefficients between electrical conductivity and Li^+ and Br^- ions, which are abundant in hot springs, are extremely high: 0.953 and 0.979 (Fig. 6). The electrical conductivity of the Hirata River is the highest, followed by that of the Haruki River (Fig. 3). This result suggests that these two rivers, especially the Hirata River, are affected by hot spring drainage. During the data collection period, the electrical conductivity of the Shin River spiked upward only once, perhaps because hot spring drainage is exhausted irregularly into the Shin River. Three days before one investigation, the rainfall in Beppu reached 27.5 mm per day. At the upper reaches of the Shin River, hot spring water of *Chinoike Jigoku* (a hot spring pond) overflows easily during heavy rains. This phenomenon might be the reason for the EC spike.

Results show that the NO_3^- and PO_4^{3-} concentrations at Haruki River and Sakai River were high. In general, hot spring water lacks NO_3^- and PO_4^{3-}, which are usually found in domestic sewage. Because rivers with high NO_3^- and PO_4^{3-} concentrations and rivers strongly affected by hot spring drainage differed, it is apparent that hot spring drainage and domestic sewage are exhausted into the rivers as separate sources. However, strong correlation was found between DSi concentration and electrical conductivity. This correlation might be explained by hot spring drainage: hot spring water contains large amounts of DSi. Nutrients such as NO_3^- and PO_4^{3-} are thought to derive from domestic sewage.

4.2. Statistical approach of the quantitative evaluation of contamination

As stated earlier, the rivers in the investigated region were affected both by hot spring drainage and domestic sewage, with each river having different levels of contaminants. However, which source more strongly affects the rivers is not quantitatively defined. Factor analysis, a type of multivariate analysis, was applied to the chemical component data to elucidate the factors affecting water quality and how each factor quantitatively affects water properties. From the chemical

Table 6
Factor loading and factor contribution rate. Factor loadings above 0.7 in absolute value are shown in a bold-face.

	Factor 1	Factor 2	Factor 3
Li^+	**0.958**	0.138	0.049
Na^+	**0.971**	0.105	0.194
K^+	**0.988**	0.08	0.094
Mg^{2+}	0.164	0.067	**0.941**
Ca^{2+}	**0.842**	0.188	−0.084
Cl^-	**0.958**	0.073	0.194
Br^-	**0.95**	0.051	0.243
NO_3^-	0.507	**0.723**	0.093
PO_4^{3-}	0.28	**0.859**	0.124
SO_4^{2-}	**0.906**	−0.147	0.202
HCO_3^-	−0.327	**0.802**	−0.084
DSi	**0.915**	0.23	0.073
Factor contribution rate (%)	**62.4**	**17.2**	9.2

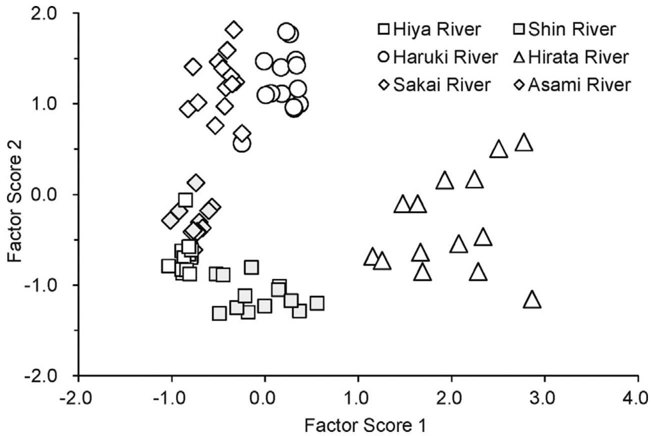

Fig. 7. Factor scores of respective rivers (Factor Score 1 vs. Factor Score 2).

component data, one can readily infer that the two sources of hot spring drainage and domestic sewage flow into the rivers, but an analytical method must be used to ascertain whether the factors determined through factor analysis are applicable to the two sources. Statistical analysis software (PASW Statistics 18; IBM Corp.) was used for factor analyses. All concentrations of dissolved matter (Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, Br^-, NO_3^-, PO_4^{3-}, HCO_3^-, SO_4^{2-}, DSi) were entered into the dataset. Varimax rotation was done using the principal factor method with a minimum number of factors of 1 to determine the factors. Three factors were identified through factor analysis (Table 6). Of those 3 factors, 2 factors had a cumulative contribution ratio of 79.6%. These two were found to be the main factors that shape the river water properties. Focusing on individual factors, the factor loading of Li^+, Na^+, K^+, Ca^{2+}, Cl^-, Br^-, SO_4^{2-}, and DSi were significant for Factor 1. For Factor 2, the factor loadings of NO_3^-, PO_4^{3-}, and HCO_3^- were large. As stated earlier, Li^+ and Br^-, as well as the substances with a large factor loading in Factor 1 are found in high concentrations in hot spring water. Therefore, it is thought that Factor 1 represents hot spring water. Because it is clear that the hot spring water found in the rivers originates from hot spring drainage, it was inferred that Factor 1 represents the effects of hot spring drainage. Substances that had a large factor loading were N, P, and C, all of which are found abundantly in domestic sewage. Consequently, it was inferred that Factor 2 represents the effects of domestic sewage. Results of factor analysis supported the interpretation presented above, demonstrating that hot spring drainage and domestic sewage are poured into rivers as two sources.

The factor score, a measure of the strength of the effect of each factor, of Factor 1 is shown on the *x*-axis. The factor score of Factor 2 is shown on the *y*-axis (Fig. 7). The Hirata River is shown on the positive side of the *x*-axis. The Haruki River and Sakai River are shown on the positive side of the *y*-axis. This result shows that, of the six rivers in Beppu, the Hirata River is the most affected by hot spring drainage. The Haruki River and Sakai River are the most affected by domestic sewage. The Haruki River is shown on the positive side of the *x*-axis. The Sakai River is shown on the negative side. This result indicates that the Haruki River is affected to a greater degree by hot spring drainage. Because the Hiya River and Asami River are shown on the negative sides of both the *x*-axis and *y*-axis, they are presumably less affected by hot spring drainage and domestic sewage. Different from other rivers, the plot for the Shin River and the Hirata River spreads out towards the *x*-axis. Presumably, this is an effect of hot spring drainage that changes arbitrarily. As explained earlier in this report, hot spring drainage into the Shin River is thought to occur irregularly, but factor analysis results show that hot spring drainage occurs even when no remarkable change is apparent in water quality. The effects of hot spring drainage change depending on the time period.

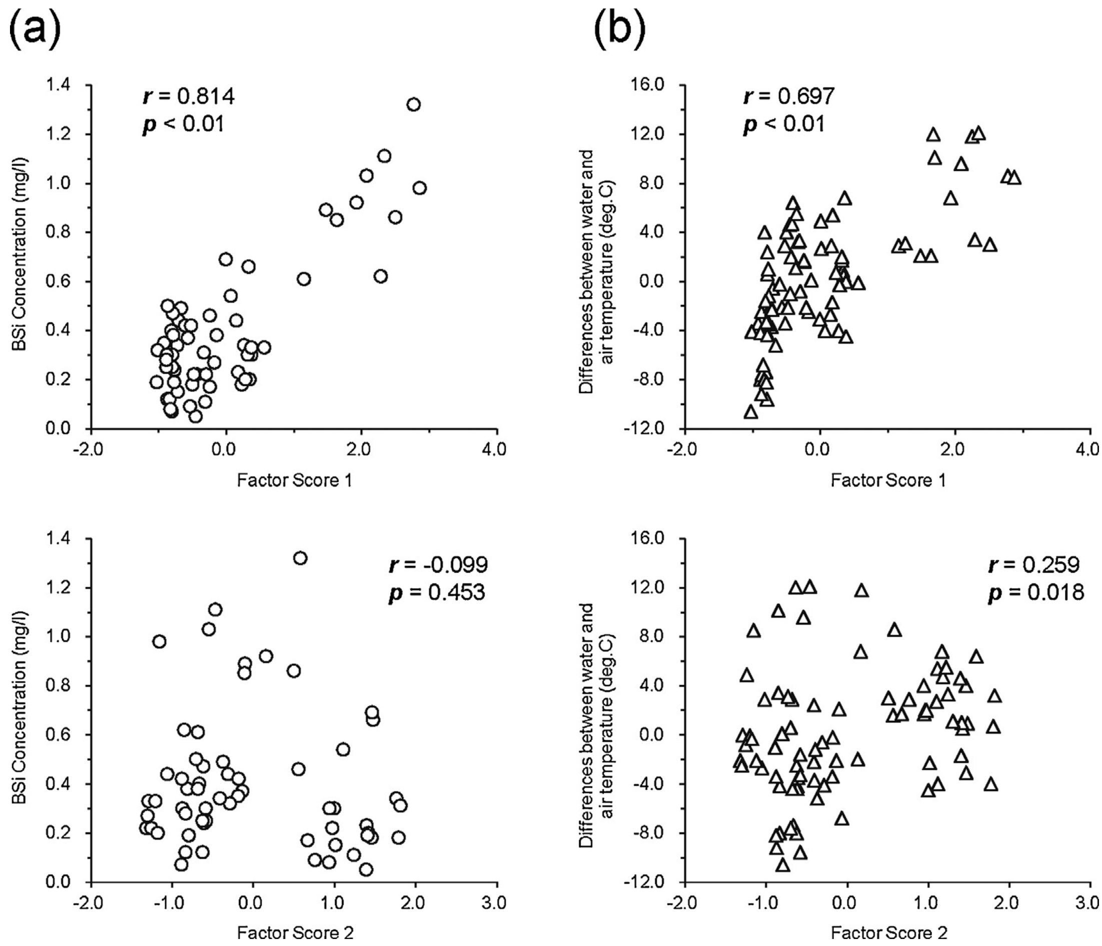

Fig. 8. (a) Relation between factor score and BSi. (b) Relation between factor score and the difference between water and air temperatures. Upper row shows the relation with Factor 1. Lower row shows the relation with Factor 2 for both diagrams.

4.3. Relation between BSi, hot spring drainage, and domestic sewage

Putative relations between the factor score and BSi and between the difference in water temperature and air temperature and the factor score are presented respectively in Fig. 8a and b. The BSi concentration and hot spring drainage factor showed a strong positive relation (correlation of 0.814). However, no clear correlation was found between BSi and the domestic sewage factor, which shows that diatoms within the suspended solid per unit of water volume are more numerous in water that is more affected by hot spring drainage. Furthermore, we infer that domestic sewage does not affect the concentration of diatoms within the suspended solids because no correlation was found between BSi and domestic sewage. In other words, the diatom concentrations in the rivers are more affected by hot spring drainage than by domestic sewage. The same can be said for water temperature. Positive correlation between the hot spring drainage factor and differences between water temperature and air temperature indicate that the temperature removed the influence of air temperature, but no clear correlation is apparent with domestic drainage. Factor analysis shows that the water temperatures of rivers are more affected by hot spring drainage than by domestic sewage. Consequently, hot spring drainage affects the water quality, water temperature, and diatom production, all of which are factors increasing diatom production.

4.4. Hot spring drainage effects on fish communities

The Nile tilapia, *O. niloticus* dominated the fish community of the Hirata River, accounting for more than 80% of total fish biomass, whereas *R. giurinus* dominated the fish community of the Hiya River (Table 2). Nile tilapia, an invasive species transported for aquaculture, has settled in rivers in Japan (Suzuki, 1981). In the Beppu area, air temperatures are usually lower than 10 °C during winter, which makes the waters of rivers without hot spring drainage cooler than 10 °C. Hiya River waters occasionally become cooler than 10 °C in winter, which is much lower than the temperature of Nile tilapia habitats (FAO, 2015). We infer that hot spring drainage in the Hirata River provides habitats with temperature conditions that are suitable for Nile tilapia residence throughout the year.

The occurrence of juvenile and adult stages of Nile tilapia in summer (Table 3) indicates reproduction of this species around the Hirata River. However, Nile tilapia juveniles were less abundant during winter. Nile tilapia spawn in water that is warmer than 24 °C (FAO, 2015). Therefore, hot spring drainage produces temperature conditions under which Nile tilapia can support reproduction, although waters sometimes become cooler than 22 °C during winter.

Fish biomass obtained using sampling with the small and large seines were much higher in the Hirata River than in the Hiya River in both summer and winter. Fish of the most dominant species in the Hirata River, omnivorous Nile tilapia, feed on phytoplankton (Shalloof and Khalifa, 2009). Diatoms in the Hirata River were more numerous than in other rivers because of hot spring drainage. Diatom concentrations in the flowing suspended solids per unit time (average concentration × averageflow rate) were 0.022 g/s at the Hiya River, and 0.295 g/s at the Hirata River, with the amount in the latter being roughly 13 times greater than in the former. The suitable food supply promoted by hot spring drainage is apparently an important supporting factor of the high fish biomass in the Hirata River. Results show that hot spring drainage in the Hirata River increases fish biomass because it increases water temperature and increases diatom production.

5. Conclusion

The inflow of hot spring drainage into rivers has a stronger influence than domestic sewage on river ecosystems. Furthermore, results of this study show that hot spring drainage exhausted into rivers creates a more suitable habitat for Nile Tilapia, a foreign species, in terms of both food and temperature. If new power generation facilities increase the amount of exhausted hot spring drainage, then the possibility exists that other rivers will show similar outcomes to those found for the Hirata River. This study did not examine the degree to which specific substances in hot spring drainage affect diatoms in the rivers, or what aspects of hot spring drainage affect fish the most. Based on the current status, several concerns arise related to increased hot spring drainage resulting from power generation. Detailed quantitative analyses must be made of the effects of such damage on specific aspects of hot spring drainage. These tasks are left as subjects for future studies.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ejrh.2015.12.060.

References

Burd, B., Macdonald, T., Bertold, S., 2013. The effects of wastewater effluent and river discharge on benthic heterotrophic production, organic biomass and respiration in marine coastal sediments. Mar. Pollut. Bull. 74, 351–363.

Chuang, Y.L., Yang, H.H., Lin, H.J., 2009. Effects of a thermal discharge from a nuclear power plant on phytoplankton and periphyton in subtropical coastal waters. J. Sea Res. 61, 197–205.

DeMaster, D.J., 1981. The supply and accumulation of silica in the marine environment. Geochim. Cosmochim. Acta 45, 1715–1732.

FAO, 2015. Fisheries & Aquaculture—Cultured Aquatic Species Information Programme—*Oreochromis niloticus* (Linnaeus, 1758). http://www.fao.org/fishery/culturedspecies/Oreochromis_niloticus/en.

Hiramatsu, T., Matsuo, T., Sato, S., 1994. Aquatic life in freshwater in the Beppu Region. Nat. Beppu, 323–344, in Japanese.

Jiang, Z., Liao, Y., Liu, J., Shou, L., Chen, Q., Yan, X., Zhu, G., Zeng, J., 2013. Effects of fish farming on phytoplankton community under thermal stress due to a power plant in a eutrophic, semi-enclosed bay: induce toxic dinoflagellate (*Prorocentrum minimum*) blooms in cold seasons. Mar. Pollut. Bull. 76, 315–324.

Kawano, T., 1998. The water system and water quality of the Beppu Bay Area A Comprehensive Collection of Regional Research Papers. Beppu Bay Area: Nat. Soc. Educ., 29–38 (in Japanese).

Kendouci, M.A., Kharroubi, B., Maazouzi, A., Bendida, A., 2013. Study of physic-chemical quality of wastewater discharged into the natural environment the case of Bechar River Algeria. Energy Proc. 36, 287–292.

King, S.A., Behnke, S., Slack, K., Krabbenhoft, D.P., Nordstrom, D.K., Burr, M.D., Striegl, R.G., 2006. Mercury in water and biomass of microbial communities in hot springs of Yellowstone National Park, USA. Appl. Geochem. 21, 1868–1879.

Li, X.Y., Li, B., Sun, X.L., 2014. Effects of a coastal power plant thermal discharge on phytoplankton community structure in Zhanjiang Bay, China. Mar. Pollut. Bull. 81, 210–217.

Nakajima, S., Iseki, K., 2006. Evaluation for the measurement of biogenic silicon in coastal waters and the distribution in suspended matters of Suo-nada, Seto Inland Sea. J. Grad. Sch. Biosp. Sci. Hiroshima Univ. 45, 21–29.

Ohsawa, S., Watanabe, K., Takamatsu, N., Kato, N., 2009. Basic research and investigation of untapped hot spring resources (II): the amount of useful metal elements flowing into rivers. Oita Prefect. Hot Spring Res. Soc. 59, 13–19 (in Japanese).

Ohsawa, S., Yamasaki, H., Takamatsu, N., Yamada, M., Amita, K., Kato, N., 2008. The inflow of useful metal elements into rivers: basic research and investigation of untapped hot spring resources. Oita Prefect. Hot Spring Res. Soc. 58, 21–30 (in Japanese).

Parker, A.E., Dugdale, R.C., Wilkerson, F.P., 2012. Elevated ammonium concentrations from wastewater discharge depress primary productivity in the Sacramento River and the Northern San Francisco Estuary. Mar. Pollut. Bull. 64, 574–586.

Rzonca, B., Schulze-Makuch, D., 2003. Correlation between microbiological and chemical parameters of some hydrothermal springs in New Mexico, USA. J. Hydrol. 280, 272–284.
Shalloof, K.A.S., Khalifa, N., 2009. Stomach contents and feeding habits of *Oreochromis niloticus* (L.) from Abu-Zabal Lakes, Egypt. World Appl. Sci. J. 16 (1), 1–5.
Suzuki, K., 1981. Tilapia: the problems with popularizing the new farmed fish. The Japan Society of Cookery Science 14 (3), 162–165 (in Japanese).