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Trophic position and diet shift based on the body size of *Coreoperca kawamebari* (Temminck & Schlegel, 1843)

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Abstract

Background: Fish body size is a major determinant of freshwater trophic interactions, yet only a few studies have explored the relationship between the fish body size and trophic interactions in river upstream. In this study, we investigated the relationship between the body size and trophic position (TP) of *Coreoperca kawamebari* (Temminck & Schlegel, 1843) in an upstream of the Geum River.

Results: A stable isotope analysis (based on $\delta^{15}N$) was used to determine the TP based on the body size of *C. kawamebari*. The regression analysis ($n = 33$, $f = 63.840$, $r^2 = 0.68$) clearly showed the relationship between the body length and TP of *C. kawamebari*. The TP of *C. kawamebari* was clearly divided by body size into the following classes: individuals of size < 10 cm that feed on insects and individuals of size > 10 cm feed on juvenile fish. This selective feeding is an evolutionarily selective tendency to maximize energy intake per unit time. Furthermore, the diet shift of *C. kawamebari* was led by different spatial distributions. The littoral zone was occupied by individuals of size < 10 cm, and those of size > 10 cm were mainly in the central zone. The littoral zone can be assumed to be enriched with food items such as ephemeropterans and dipterans.

Conclusion: The TP of *C. kawamebari*, as a carnivorous predator, will have a strong influence on biotic interactions in the upstream area of the Geum River, which can lead to food web implication.

Keywords: Aquatic plant, Carnivorous fish, Freshwater food web, Stable isotope, Trophic guild

Background

In freshwater ecosystems, moving in and out of animal populations is strongly influenced by the interaction between biological communities (Thevenon et al., 2011; Craig et al., 2017). Biological interactions, such as competition and predation, have the potential to influence these fundamental demographic parameters and determine the trophic position (TP) of organisms (Brett and Goldman 1997). Animal community with a high TP (i.e., predator) regulates the distribution and population size of low level (i.e., prey) communities (Sih et al. 1985; Royauté and Pruitt 2015). Empirical studies investigating the determinants of community structure have shown that predation is one of the major influencing forces within a freshwater community (Power 1992; Stoks and

McPeek 2003). In particular, the influence of community structure on predation in freshwater ecosystems has been well documented between fish and zooplankton communities (Aksnes et al. 2004; Hintz and Relyea 2017). Therefore, understanding the ecological role of organisms based on biological interactions is essential for a wide range of ecological studies. Moreover, the TP of an organism provides the framework for studies on cascading trophic interactions (Parker and Schindler 2006; Post et al. 2008) and ecological energetics and efficiency (Shurin and Seabloom 2005).

Freshwater fish play important roles as top consumers utilizing food sources such as zooplankton, invertebrates, and juvenile fish. Some studies have suggested the influence of prey community distribution by fish predation (He and Kitchell 1990; Barnes et al. 2010; Kai and Marsac 2010). Fish predators have shown non-random consumption of available prey, which might result from differences in prey visibility, capture rate, and food

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preference (Figueiredo et al. 2015). Prey size has been the primary variable considered in studies on selectivity of fish (Gliwicz et al. 2010; Holmes and McCormick 2010). The variation in the length of fish and prey influences the relationship between foraging selectivity and relative prey size. This prey selectivity for large size leads to diet shift in accordance with the growth stage of fish, and consequently, adult fish are in a high TP as piscivorous predator in freshwater ecosystems (Szedlmayer and Lee 2004). However, a shift in fish diet depends not only on the body size, but also on food composition and abundance in a habitat. Duffy et al. (2010) suggested that the large mouse bass displays apparent diet shift between invertebrates and juvenile fish in accordance with spatial and temporal distribution of prey items. Although animals spend considerable time feeding, and their foraging success is essential for reproductive success and fitness, it is often difficult to quantify foraging in free-living aquatic organisms. Furthermore, the diet shift of fish leads to their ambiguous ecological role in a freshwater food web.

Stable isotopes can be used as natural tracers to help monitor the foraging history of fish. The natural stable isotopic composition of animals is determined by their diets. Isotopic variations are passed up the food web as animals accumulate tissue C and N from their diets. Most studies on stable isotopes have focused on determining the influence of potential food source on predator in freshwater food webs (Brooke et al. 2010; McCauley et al. 2012), but natural isotopic tracers can also be used to monitor animal behavior. For example, animals feeding in some locations acquire a unique diet shift in foods, resulting in the assimilation of different average isotopic compositions.

We hypothesized that the utilization of food source by *C. kawamebari* differs according to their body size and that it could influence the TP and ontogenetic diet shift pattern. The primary objective of our study was to understand the TP and diet shift of the carnivorous fish, *C. kawamebari* (Temminck & Schlegel 1843) using a stable isotope analysis. Furthermore, the interaction between animal community based on the TP and diet shift of *C. kawamebari* is discussed. This study will advance our current understanding of the ecological role of *C. kawamebari*, which was newly discovered or translocated in the upstream region of the Geum River.

Results and discussion
TP and diet shift of *C. kawamebari*
We used a stable isotope to analyze 33 individuals of different body sizes among a total of 89 *C. kawamebari* individuals collected during the fish survey. The body size of 89 *C. kawamebari* was within the range of 2.3–14.7 cm; individuals of diverse body sizes were observed. In empirical studies, considering *C. kawamebari* have shown body size less than 15 cm, the size range of collected *C. kawamebari* indicates that they were present in all life stages (Kim et al. 2012). The results also indicated that the newly discovered *C. kawamebari* in the upstream area of the Geum River has a stable settlement and continued population growth.

Kim et al. (2012) suggested that *C. kawamebari* commonly plays a role as a top predator that utilizes insects and juvenile fish as a food source within the freshwater food web. Among trophic guilds, detritivores had the lowest mean TP (2~3) followed by omnivores (2~4), insectivores (3~5), and piscivores (3~5) (Vander Zanden et al., 1997; Rybczynski et al. 2008; Ou et al. 2017). In this study, the TP of *C. kawamebari* reflected the trophic position proposed by previous studies. The results of the stable isotope analysis revealed that *C. kawamebari*
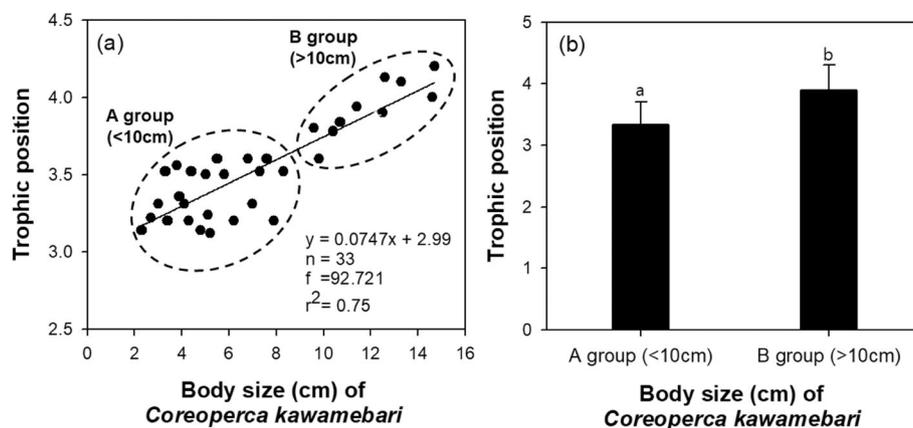
Fig. 1 Trophic position based on the body size of *Coreoperca kawamebari*. **a** Trophic position based on the gradient of body size (regression df = 1 and residual df = 31) and **b** trophic position of the two groups divided based on body size. Bars represent an average of replicates (± SE). Letters above the bars indicate statistically different mean values

mostly depended on insects such as ephemeropterans and dipterans, but some individuals consumed small fish such as *Pungtungia herzi* and *Coreoleuciscus splendidus*.

Prey selectivity of *C. kawamebari* depends on its body size (Fig. 1). The regression analysis (Fig. 2a; n = 33, f = 92.721, r^2 = 0.75) clearly showed the relationship between the body length and TP of *C. kawamebari*. The TP of *C. kawamebari* showed a tendency of increase with increase in body size. The small-sized fish (< 10 cm) stage showed characteristics of insectivores, but shifted to piscivorous in the adult stage. Based on this diet shift, *C. kawamebari* was clearly divided into the following groups: individuals of size < 10 cm that feed on insects and individuals of size > 10 cm that feed on small-sized prey fish. TP between two groups were display statistical different (one-way ANOVA, DF = 1, F = 148.2, p < 0.0001).

The food preference of *C. kawamebari* was different between the two groups divided based on the body size

Fig. 2 Proportional contribution (using an isotope mixing model) of each food item (mean ± 1 SD, n = 33) to the two groups of *Coreoperca kawamebari* divided based on the body size. **a** A group (< 10 cm) and **b** B group (> 10 cm). Ephe., Ephemeroptera; Dip., Diptera; Ondo., Odonata; J. fish, juvenile fish

(Fig. 2). *Coreoperca kawamebari* individuals of size < 10 cm mainly depended on ephemeropterans and dipterans as a food source, but individuals of > 10 cm tended to depend on small-sized fish. This diet shift has also been found in previous studies on food selectivity of other fish species. Barbiero et al. (2009) suggested that planktivorous fish often choose large prey items and drive the structure of plankton populations toward smaller taxa or smaller individuals within a taxon. Juvenile fish are less likely than adults to choose the largest available prey items (Galarowicz et al. 2006; Garrido et al. 2007), and the preferred prey size increases with fish size (Kawakami and Tachihara 2005). Selective feeding is an evolutionarily selected tendency to maximize energy intake per unit time (Schoener 1987). Thus, when fish increase in size, the size spectrum of ingested prey increases; it is probably an effect of low gape size (Nilsson and Brönmark, 2000). For small 0-group fish, it is important to consider that the size of the mouth might restrict their potential diet.
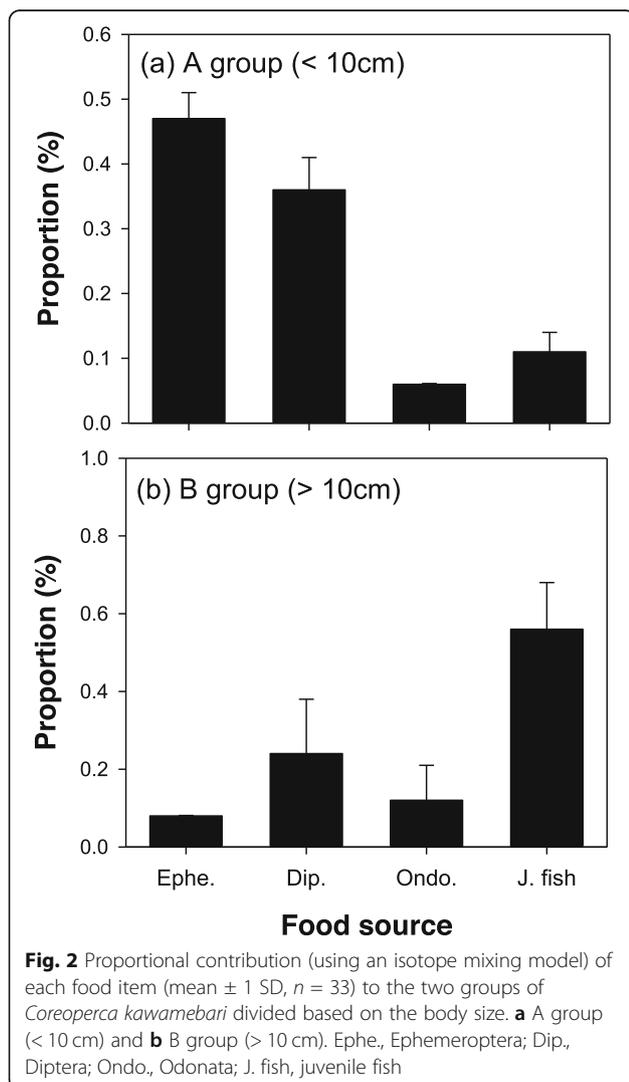
Spatial distribution related to body size of *C. kawamebari*

The two groups of *C. kawamebari* divided based on its body size were present in the littoral and central zones (Fig. 3). Individuals of size < 10 cm were mainly distributed in the littoral zone, and the central zone supported a relatively small number of those individuals. On the contrary, individuals of > 10 cm were mainly distributed in the central zone. This different spatial distribution of *C. kawamebari* related to body size is strongly associated with prey selectivity. The river littoral zone is supported by high abundance of aquatic plants and creates a heterogeneous microhabitat in the water, providing a suitable food supply for fish (O'Hare et al. 2006, Smokorowski and Pratt 2007). This different spatial distribution of food source related to aquatic plants explains why *C. kawamebari* individuals of body size < 10 cm are mainly distributed in the littoral zone. Previous studies (Heck and Crowder 1991; Warfe and Barmuta 2004; Choi et al. 2014) have also reported that the food source (zooplankton and small-sized invertebrate) mainly consumed by juvenile fish of size < 10 cm is abundant in spaces extensively covered by aquatic plants. Moreover, a complex habitat structure created by plants significantly regulates biological interactions such as predation and competition (Jeppesen et al. 2012; Hansen et al. 2013), and consequently, it contributes to the continuous population growth of juvenile fish. On the contrary, individuals of size > 10 cm might have difficulty in securing sufficient food source in the littoral zone from the perspective of optimal energy acquisition for a given cost. The foraging activity of individuals of size > 10 cm were clearly decreased in littoral area was highly covered by aquatic plants. However, they do not migrate far from the littoral area, and they utilize food
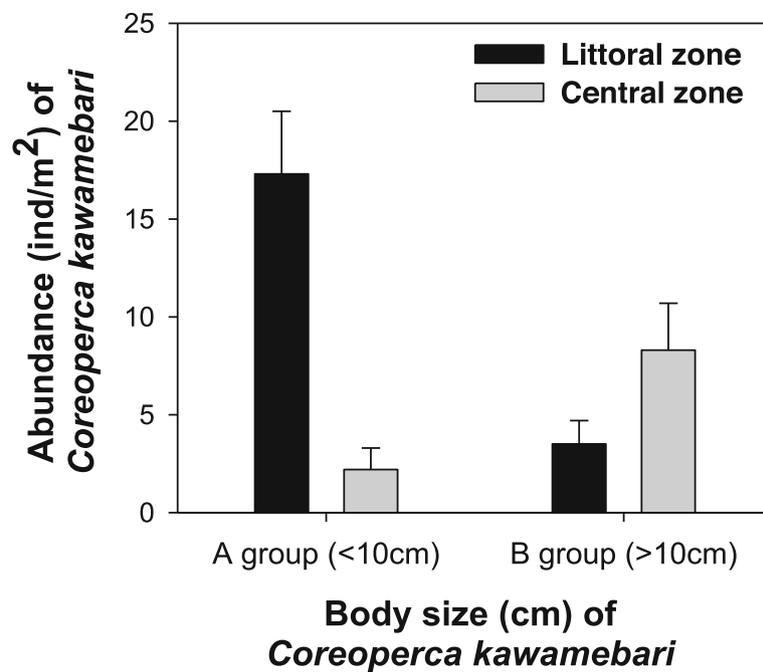
Fig. 3 Abundance of the two groups of *Coreoperca kawamebari*, divided based on the body size, in the littoral and central zones

source originated from the littoral area. The central area far from the littoral area was supported by low individuals of *C. kawamebari*. In relation to this, a previous study suggests that piscivorous fish have restricted foraging activity under high abundance of aquatic plants, and thus, they are distributed mainly in the open water zone or edge of plant beds (Jacobsen and Perrow 1998). Consequently, a high abundance of aquatic plants in the littoral zone can largely contribute to the sustainable growth and development of young *C. kawamebari*.

Influence of native fish community on size-dependent trophic level of *C. kawamebari*

A previous study has reported that *C. kawamebari* is distributed across a narrow area of Tamjin, Youngsan, and Nakdong Rivers in South Korea (Kang et al. 2013). This distribution pattern is less effective for fish community, even though they are carnivorous predators. In the upstream area of the Geum River, however, we considered that the invasion and stable settlement of *C. kawamebari* affected in distribution and interaction of native fish community. Although small individuals consumed invertebrates in the littoral area, adults stayed in the middle of the river and utilized the large food source such as small-sized fish. Generally, ontogeny and invasion of individuals in ecosystems lead to changes in the food web structure, which strongly influences trophic levels. It has often been proposed that the characteristically high levels of recruitment variability that exists in most freshwater systems can obscure any evidence of

underlying processes, and there has been considerable debate over whether post settlement or pre settlement processes result in the patterns observed in community structure (Vilà et al. 2011). There has also been considerable debate over whether "top-down" or "bottom-up" processes are important in governing these communities (Power 1992; Shurin et al. 2012). Based on these findings, the presence of top predators, such as *C. kawamebari*, leads to potentially limited available food resources and thus factors affecting abundance will cascade up the system and affect population dynamic of prey and their predators (Zavaleta et al., 2001). Therefore, translocation and sustainable population growth of *C. kawamebari* in the Geum River can influence not only the food web change upstream of the Geum River, but also the ecosystem health. Based on the data obtained in this study, there is a need to continuously monitor the effects of *C. kawamebari* distribution and trends in the ecosystem food web.

Conclusions

The isotope values of *C. kawamebari* showed its TP as a piscivorous fish. The TP of *C. kawamebari* showed increasing tendency with increased body size (regression analysis; $n = 33$, $f = 63.840$, $r^2 = 0.68$), showing mainly piscivorous characteristics in the adult stage. The TP of *C. kawamebari* was clearly divided by body size as individuals of size < 10 cm that feed on insects and individuals of size > 10 cm that feed on small-sized fish. This diet shift is an evolutionarily selected tendency to
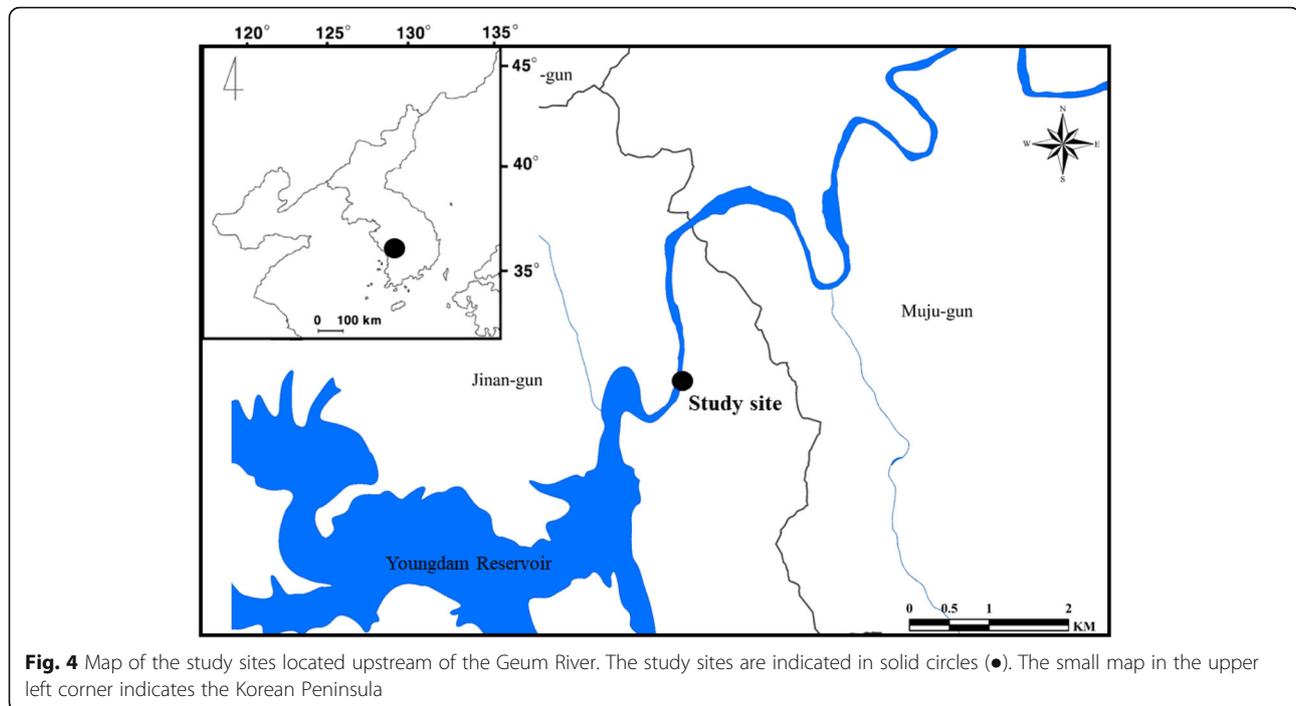
Fig. 4 Map of the study sites located upstream of the Geum River. The study sites are indicated in solid circles (●). The small map in the upper left corner indicates the Korean Peninsula

maximize energy intake per unit time. Such prey selectivity of *C. kawamebari* led to an apparent variation in spatial distribution in the upstream area of the Geum River. The littoral zone supported individuals of size < 10 cm, and individuals > 10 cm in size were mainly distributed in the central zone. Empirical studies suggested that the littoral zone is enriched with food items such as ephemeropterans and dipterans preferred by juvenile fish. As a carnivorous predator, the TP of *C. kawamebari* influences biotic interactions in the upstream area of the Geum River and is expected to lead to food web changes.

Methods

Site description and fish collection

The Geum River, which has an approximate drainage area of 9885 km^2, is one of the largest river systems in South Korea and is approximately 394.79 km long. Water flow in the upstream area of the Geum River is regulated by the Youngdam Dam. The riversides were reorganized by the River Refurbishment Project in 2012; large areas of waterside have vanished due to the expansion of human society.

The study sites are the riverside areas located in the upstream region of the Geum River, 11 km downstream of the Youngdam Dam (Fig. 4). The fish were collected from late September to early October 2018 (over a period of 4 weeks). We randomly selected the following 12 sampling points in the study site considering the habitat characteristics of *C. kawamebari*: six points were in the littoral zone (area covered by aquatic plants) and

six were in the open water zone (area covered by boulders, and there are no plants). The sampling points were randomly selected based on virtual grids constructed over the map of the upstream region of the Geum River.

The target species *C. kawamebari* individuals were caught using cast nets (7 mm × 7 mm mesh size) and scoop net (5 mm × 5 mm mesh size). We used only scoop nets in the sampling points extensively covered by aquatic plants and boulders. In the other sampling points, the cast and scoop nets were used for 30 and 20 min, respectively. The body length (cm) of fish was measured after being classified and counted according to Kim and Park (2002). The body length was used to analyze the TP of *C. kawamebari*. The influence of TP on the body size of *C. kawamebari* was analyzed using a regression analysis. The individuals were divided by body size into two groups based on the TP and food utilization of *C. kawamebari*. We analyzed using ANOVA test the differences of TP between two groups related to body size of *C. kawamebari*. All statistical analyses, including regression and ANOVA, were conducted using the statistical package SPSS version 20 (IBM Corp., Armonk, NY, USA).

To analyze the TP of *C. kawamebari*, we conducted additional collections on potential food sources in sampling points of collected *C. kawamebari*. Potential food collection was also conducted for approximately 30 to 40 min using a stainless steel sampler (200 mm diameter, 600-μm mesh size). The collected individuals were divided as four food sources such as ephemeropterans, dipterans, odonates, and juvenile fish.

Stable isotope analysis and trophic position calculation

To determine the TP of *C. kawamebari* on the gradient of body length, we implemented the stable isotope analysis. For the stable isotope analysis, the fish muscle tissue samples were obtained from the flank near the base of the dorsal fin. We were permitted by the Ministry of Environment to obtain the tissue samples from the endangered species. Furthermore, we collected only little tissue (0.1~0.3 g) of dorsal fin to avoid the risk of an endangered species being injured or killed. Most of the individuals survived after the removal of tissue, and there was nothing wrong with swimming. The fish tissue samples were preserved in salt and processed following the method of Arrington and Winemiller (2002). In the laboratory, the tissue samples were soaked in distilled water for 4–5 h, rinsed, and dried in an oven at 60 °C for 48 h (Post 2002). Dried samples were ground into fine powder using an electronic ball-mill grinder, and then stored in clean glass vials. Subsamples were weighed (0.02 mg) and packed into Ultra-Pure tin capsules. All samples were freeze-dried and homogenized using a mortar and pestle, and the powdered samples were maintained frozen (− 70 °C) until further analysis. Carbon and nitrogen isotope ratios were determined by continuous-flow isotope mass spectrometry. Dried samples were combusted in an elemental analyzer (EuroVector), and the resultant gas (CO_2 and N_2) was introduced into an isotope ratio mass spectrometer (CF-IRMS, Isoprime Micromass) via continuous flow, with helium gas as a carrier. Data are expressed as the relative concentration (‰) difference between sample and conventional standards of Pee Dee Belemnite carbonate (PDB) for C and atmospheric N_2, according to the following equation:

$$\delta X(‰) = \left[\left(R_{\text{sample}} / R_{\text{standard}} \right) - 1 \right] \times 1000$$

where X is ^{13}C or ^{15}N and R is the ^{13}C:^{12}C or ^{15}N:^{14}N ratio. Secondary standard of known relation to the international standard was used as a reference material. The standard deviations of δ^{13}C and δ^{15}N for 20 replicate analyses of the peptone standard were ± 0.1 and ± 0.2 (‰), respectively.

Stable isotopes of N have been widely used to estimate the TP of target fish species in food web studies (Post 2002). The TP of *C. kawamebari* was calculated using the following formula (Zanden and Rasmussen 1999): TP = (δ^{15}N$_{\text{consumers}}$ − δ^{15}N$_{\text{food source}}$)/2.5 + 1, where δ^{15}N$_{\text{consumers}}$ is δ^{15}N signature of *C. kawamebari* and δ^{15}N$_{\text{food source}}$ is the mean δ^{15}N value of potential food sources, namely, ephemeropterans, dipterans, odonates, and juvenile fish. The value of 2.5 represents trophic fractionation of the isotopic ratio (the shift that occurs in material between its ingestion by a consumer and its assimilation in the consumer's tissue); here, we used the mean trophic fractionation value derived from a meta-analysis of laboratory feeding studies involving diverse metazoan consumers (Vanderklift and Ponsard 2003). When calculating the TP of *C. kawamebari*, the mean δ^{15}N of primary production sources was based on samples obtained from the same survey locality where the fish were collected.

To determine the potential food sources predominantly assimilated by *C. kawamebari*, we calculated the proportional contribution of each food source using an isotope mixing model (Parnell et al. 2010). The fractionation factors (average ± SD) used for *C. kawamebari* were 0.5 ± 0.2‰ for δ^{13}C and 3.0 ± 0.5‰ for δ^{15}N (Syväranta et al. 2011).

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