Journal of Asia-Pacific Biodiversity xxx (2017) 1–8

Contents lists available at ScienceDirect

Journal of Asia-Pacific Biodiversity

journal homepage: http://www.elsevier.com/locate/japb

Original article

Trophic gradients of two minnow species with similar eco-type and their relations to water chemistry and multimetric biological integrity

Q11 Seoyun Choi [a], Jeong-Ho Han [b], Ji-Woong Choi [a], Kwang-Guk An [a,*]

[a] Department of Biological Science, College of Biological Sciences and Biotechnology, Chungnam National University, Daejeon, Republic of Korea
[b] Research and Promotion Division, National Science Museum of Korea, Daejeon, Republic of Korea

ARTICLE INFO

Article history:
Received 24 November 2016
Received in revised form
19 June 2017
Accepted 20 June 2017
Available online xxx

Keywords:
fish
tolerance range
trophic gradient
water chemistry
Zacco

ABSTRACT

The objectives of this study were to determine tolerance ranges and trophic gradients of two fish populations of *Zacco koreanus* (Z_k) and *Zacco platypus* (Z_p) in relation to chemical water quality and ecological stream health, based on the biological integrity metric (BIM) model. Seventy-six streams and rivers were sampled for the analysis. The population of Z_k had a narrow chemical tolerance with a low phosphorus limit (< 300 µg/L as total phosphorus), whereas the Z_p population occurred within a high limit (up to 1,100 µg/L). Similar patterns in the two populations were shown in nitrogen, biological oxygen demand, suspended solids, and other parameters. The population of Z_p had significantly ($t = 5.25$, $p < 0.001$) greater chemical tolerance than the population of Z_k. The population of Z_k had a positive functional relation ($R^2 = 0.43$, $p < 0.001$) with insectivore species, but the Z_p population had negative linear function ($R^2 = 0.50$, $p < 0.001$), indicating a trophic difference in the food chain of two populations. Application of the biological integrity model indicated that the values of BIM, as an index of ecological health, were significantly greater ($t = 13.67$, $p < 0.001$) in the population of Z_k than the population of Z_p.

Introduction

The trophic gradient theory in aquatic ecosystems is a hot topic in demonstrating bottom-up interactions of the food chain, material cycling, and compositional changes of aquatic organisms (Chang et al 2008; Jeppesen et al 2000; Olin et al 2002). The trophic gradients are closely associated with nutrient dynamics such as nitrogen and phosphorus as limiting factors regulating primary production of phytoplankton and periphyton in streams and rivers, which directly or indirectly influences biomass and compositions of Q1 first to top consumers of macroinvertebrate and fish populations (Jeppesen et al 2000; Olin et al 2002). For this reason, biological assessment tools, based on various aquatic taxa, have been frequently used for evaluating trophic dynamics through food chains and ecological health (Karr 1981; US EPA 1993). Recently, the Q2 United States Environmental Protection Agency (US EPA 1993) has been applying the multimetric biological integrity model of fish to evaluations of water quality and ecosystem diagnosis. The model metrics consist of species characteristics and abundance, trophic and tolerance guilds, and individual health, indicating that trophic compositions and tolerance guilds are important elements in understanding the health of an ecosystem (Karr 1981; US EPA 1993).

Fish have been widely used as good ecological indicators in diagnosing the biological health of aquatic environments and trophic modifications. Fish communities reflect trophic states of feeding guilds (insectivores, omnivores, and carnivores) and tolerance conditions, therefore analyzing communities provides integrative information on stream environments (Karr 1981). Furthermore, fish show various responses from physiological conditions to ecological health symptoms over short-term and long-term changes of stream environments. Thus, ecological predictions on ecological structures and functions are possible by integrative evaluations of the fish species (An et al 2002; An and Kim 2005; Karr 1981). For this reason, classification of fish trophic compositions and tolerance guilds is important in demonstrating ecological structures and functions of aquatic ecosystems (Aarts and Nienhuis 2003; Jeppesen et al 2000; Karr 1981).

The abundance of specific feeding and tolerance guilds and their changes in response to chemical pollutants or habitat disturbance may influence structures of the food web and trophic cascade (Katano et al 2006; Katano 2011). Generalists in feeding guilds could have more advantages in survival than specialists could (Aarts and

* Corresponding author. Tel.: +82 42 821 6408; fax: +82 42 822 9690.
E-mail address: kgan@cnu.ac.kr (K.-G. An).

Peer review under responsibility of National Science Museum of Korea (NSMK) and Korea National Arboretum (KNA).

http://dx.doi.org/10.1016/j.japb.2017.06.008
pISSN2287-884X eISSN2287-9544/

Nienhuis 2003; Katano 2011). The insectivorous fish as food specialists distribute themselves relative to riffles with rich dissolved oxygen (DO) and pebbles or grabbles in the bottom substrate structure (Hong 1991). In contrast, omnivorous fish as food generalists distribute themselves to stagnant reaches of pools or runs with poor DO and rich silts or organic matter (Angermeier and Karr 1983). Thus, the relative abundance of these guilds represents the ecological integrity in aquatic ecosystems and predicts changes of the ecological health or trophic modifications along the continuous trophic gradients (Aarts and Nienhuis 2003; Karr 1981; Olin et al 2002).

Two minnows, *Zacco koreanus* (Z_k) and *Zacco platypus* (Z_p), which are classified as order Cypriniformes, family Cyprinidae, and genera *Zacco*, are widely reported in Japan, China, and Korea (Winfield and Nelson 1991). These two species are most widely distributed in Korea (Kim 1997; Lee and Noh 2006), however, there exists only minor studies on their food preference (Chang et al 2008; Horinouchi et al 2008; Urabe and Maruyama 1986), habitat suitability, and ecological distributions (Hong 1991). According to previous ecological studies on Z_k and Z_p populations, these two populations showed differences in food selectivity (Kim 1997; Lee and Noh 2006), tolerance guilds (Hong 1991; Choi et al 2005; Shin et al 2009), and habitat preference (Hong 1991; Hur et al 2009; Hur and Seo 2011), despite similar morphology and genetic phylogeny (Kim 1997). The studies also found that Z_k populations prefer riffle zones with the high current velocity of mid-to-upstream reaches and their major diet consists of aquatic insects. In contrast, Z_p populations prefer run-riffle zones with the low–high current velocity of mid-to-downstream reaches and their major foods are organic matter as well as zooplanktons, periphytons, and aquatic insects (Hong 1991; Jang et al 2007; Lee and Noh 2006; Urabe and Maruyama 1986). Also, previous studies on the population dynamics of Z_k and Z_p according to water quality and habitat disturbance (Hong 1991; Seo 2005, Jang et al 2007; Shin et al 2009) showed that the relative abundance and condition factor of Z_k populations decreased with the water pollution and habitat modifications associated with weir constructions, and were greater in reaches with high forest covers than agricultural and urban reaches. Meanwhile, Z_p populations had a wide tolerance range over water quality and their abundance increased with increased habitat destruction (Choi et al 2005; Hong 1991; Jang et al 2007; Shin et al 2009). Therefore, because these two species are two of the most abundant species in Korea, the different characters of tolerance and trophic feeding between the two species may be used as a key indicator to identify degradation of water quality (Hong 1991), and provide good clues in evaluating the structures and biological integrity of a stream ecosystem.

Despite these previous studies, little is known about distribution patterns, trophic gradients, and tolerance gradients in relation to water chemistry between the two populations and their relation to ecological health conditions, based on biological integrity (Hong 1991; Jang et al 2007). In this study, we analyzed trophic gradients and tolerance guilds of Z_k and Z_p populations sampled from 76 streams and rivers in relation to chemical water quality gradients and biological integrity. This research determined the tolerance ranges and trophic gradients of two species, which could provide valuable ecological information on how fish populations in aquatic ecosystems are distributed along trophic and chemical gradients.

Materials and methods

Sampling watersheds and site descriptions

This study was conducted in 76 streams and rivers of four major river watersheds in Korea during 2004–2005. The sampling regions for the ecological comparisons of two populations (Z_k and Z_p populations) were categorized as four watersheds of Region I (Han River, HR), Region II (Nakdong River, NR), Region III (Geum River, GR), and Region IV (Yeongsan Rivers, YR) as shown in Figure 1. Total river lengths in HR, NR, GR, and YR are 514 km, 525 km, 414 km, and 348 km, respectively, and the basin areas in HR, NR, GR, and YR are 2.6×10^4 km^2, 2.4×10^4 km^2, 9.9×10^3 km^2, and 8.3×10^3 km^2, respectively. For this study, 76 sampling sites were selected, based on regional proportions for the fish habitats, from the HR (20 sites), NR (18 sites), GR (18 sites), and YR (20 sites) watersheds, and all stream sizes from first to sixth order streams were included in the data analysis. We collected samples twice at pre-monsoon (May–June) and post-monsoon (September–October) seasons from four river regions.

Sampling design and identifications

Fish samples were collected from 76 streams and rivers of four major river watersheds during 2004–2005 and the sampling followed a modified approach of a wading method (Ohio EPA 1989). Fish sampling and handling techniques were based on catch per unit effort methods (US EPA 1993). All habitat types, including riffle, run, and pool, were sampled in an upstream direction for a distance of 200 m for 50 minutes. Sampling gear of handheld nets (4 mm × 4 mm), casting nets (7 mm × 7 mm), and electro-fishing devices (25A, 12V) were used for the fish collections. Sensitive and tolerant species were classified based on the previous studies of An et al (2002). All fish were examined for deformities, erosions, lesions, and tumors (DELT) according to the approach of Sanders et al (1999). All specimens were preserved in neutral buffered 10% formalin and returned to the laboratory for identification (Kim and Park 2002; Nelson 2006).

In addition, fish samples were collected from 39 reference streams and rivers within the four watersheds to derive a maximum species richness regression against the stream orders. The reference sites were selected based on the approach of Hughes et al (1994). These reference sites were used for assessment of the multimetric biological integrity metric (BIM) model.

BIM model

Ecological health, based on the BIM model after the approach of An et al (2002), was evaluated from stream and river environments co-occurred with each population of Z_k and Z_p. An eight-metric model was applied for the regional applications of the watersheds. The model metrics consisted of three components of species richness and compositions, trophic/tolerance guilds, and fish abundance and health. Species richness and compositions were made of four metrics covering the number of native species (M_1), riffle-benthic species (M_2), number of sensitive species (M_3), and the proportion of tolerant species (M_4). Trophic compositions were composed of the number of omnivores (M_5) and insectivores (M_6). Fish abundance and health condition consisted of the total number of individuals (M_7) and % DELT abnormality (M_8). Metric scores of 1, 3, or 5 were assigned to each raw metric value after the approach of Barbour et al (1999). These scores were then summed to obtain a site-specific model value that ranged from 8 to 40, and were judged by the modified criteria of Barbour et al (1999).

Tolerance / trophic guilds analysis

Classifications of trophic guilds and tolerance guilds followed the approach of US EPA (1993), and the endemic species were classified based on a previous classification system for ecosystem health assessments (An et al 2002). The classifications of trophic

Please cite this article in press as: Choi S, et al., Trophic gradients of two minnow species with similar eco-type and their relations to water chemistry and multimetric biological integrity, Journal of Asia-Pacific Biodiversity (2017), http://dx.doi.org/10.1016/j.japb.2017.06.008