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Running head: Early maturation of rosyface dace

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Abstract. Age at maturity is one of the key parameters of life-history. Whereas large variations in adult body size have been reported in *Tribolodon sachalinensis* (Nikolsky, 1889), age and size at first maturity have rarely been examined. Here, we report early maturation (+1 male) and sexual difference in age at maturity in an isolated population in Hokkaido, northern Japan, which is different from a previous study.

Keywords: live fast and die young, sexual size dimorphism, growth rate, promiscuous, reservoir.

Introduction

Life-history schedules of organisms, such as when to begin reproduction and when to die, are crucial to life-time fitness (Stearns, 1992). Age and/or size at maturity are known to vary within species (e.g. Morita and Fukuwaka, 2007) and understanding those variations is important because they significantly affect demography and extinction risk (Stearns, 1992). Rosyface dace *Tribolodon sachalinensis* (Nikolsky, 1889) (Cyprinidae, Cypriniformes), which are distributed from northern Japan (Tohoku and Hokkaido) to Sakhalin and Chishima Islands (Sakai et al., 2002), have large variations in body size of mature individuals both within and among populations: spawners range in size from 20–45 cm SL (i.e. standard length) in a large river in Sakhalin and from 8–22 cm SL in Japan and a small river in Sakhalin (Ito, 1975; Gritsenko, 1982). In this species, egg numbers of 8 cm, 20 cm and 40 cm SL females are approximately 1,100, 7,200 and 160,000, respectively (Sakai, 1995). Such large inter- and intra-population variations in fecundity strongly indicate the importance of life-history schedules in the rosyface dace, since age strongly affects body size in this fish (Sakai, 1995). However, the age of spawners has only been studied in one river (Mu river, central Hokkaido: Sakai, 1995) and the earliest maturation of this species is reported as age-3+ for both sexes (Sakai, 1995). Here, we report early maturation (+1 male) and sexual differences in age at maturity in a small isolated population in Hokkaido, northern Japan.

Materials and Methods

Study area. Our sampling sites were a tributary of the Shiodomari River (hereafter SH, 41°82' N; 140°93' E) in southern Hokkaido and the Yukutora-shupetsu River (hereafter YS, 43°19' N; 142°56' E) in central Hokkaido. SH is small (3–5 m wide) and separated from the

main stem by a waterfall (ca. 5 m high). YS is also a relatively small stream (5–10 m), draining into the Kanayama reservoir (920 ha, 57 m, constructed in 1967). SH and YS populations are isolated by a natural waterfall and man-made dam, respectively.

Sexing and age estimation. During breeding season (mid–late June) in 2016, we collected fish by using a backpack electrofisher (Model 12B, Smith-Root, Vancouver, Washington, USA). Fish collected were anesthetized with clove oil (FA100: DS Pharma Animal Health Co., Ltd.) and measured for fork length (FL) nearest to 1 mm. As SH was small habitat and thus population size could be small, non-lethal methods were employed for evaluating sexes and ages. Scales were used for age estimation (Sakai, 1995). Sex were determined by squeezing the abdomen to release gametes from the gonoduct. When no sperm or eggs were emitted, we classified fish as “unidentified”. These individuals were either immature juveniles or mature adults that had yet to become sexually active or were already spent.

Statistical analyses. All statistical analyses were performed using R (R Development Core Team, 2016). First, we compared the average size and age of spawning individuals between the populations and between sexes within the populations by Welch’s t-test. Second, to compare growth rates between the populations, the von Bertalanffy growth equation (VBGE) were fitted to the FL and estimated age using the nonlinear least-squares method (Kimura, 1980). VBGE is $L_t = L_\infty (1 - e^{-k(t-t_0)})$, where L_t is the length at age t , L_∞ is the asymptotic length, k is the growth coefficient, and t_0 is the theoretical age at $L = 0$. Using R package “fishmethods” (Nelson, 2015), likelihood ratio tests for the parameters (L^∞ , k , t_0) were conducted. This test compares likelihood of the null hypothesis (H_0), which assumes all VBGE parameters are same in two populations, and alternative hypothesis (H_1),

which assumes all parameters are different. When H_0 showed significantly lower likelihood comparing to H_1 , VBGEs are not same between two populations (Kimura, 1980).

Results and Discussion

A total of 187 and 65 individuals were determined for age and sexual status in SH and YS, respectively (Fig. 1). The average FL of spawners (including both sexes) was more than two times larger in YS compared to SH (98.6 mm and 223.0 mm for SH and YS, respectively, $P<0.001$), whereas the average age was only slightly older in YS (age- 3.3+ and 4.6+ for SH and YS, respectively, $P<0.001$). The smallest and largest spawners were also much larger in YS than SH (smallest: 66 mm and 157 mm for SH male and YS male, largest: 158 mm and 390 mm for SH male and YS female, respectively). Although sample size is limited, estimated growth curves were different between the streams ($X^2=714.2$, $P<0.001$), indicating faster growth in YS (Fig. 1).

Both males and females first matured at age-3+ in YS, which is consistent with Sakai (1995). However, SH males generally matured from age-2+ (31 individuals) with one individual maturing at age-1+ whereas most female matured from age-3+. It is known that reductions in stream habitat size suppress fish body size (Jellyman et al., 2014) and genetically or environmentally induced lower growth rates are reported in small isolated populations of salmonids (Northcote, 1981; Morita and Fukuwaka, 2007). Younger age and smaller size at maturity in SH may be adaptive in the more restricted environment.

Although growth was much faster in YS, the average spawner age was similar. This may contradict with some theoretical and empirical studies that showed faster growth inducing earlier maturity (Stearns, 1992; Morita and Fukuwaka, 2007). It remains unknown why daces in YS do not mature earlier despite the higher growth rate. Because rosyface dace show large variations in body size among populations, further study considering biotic/abiotic environmental factors would contribute to a better understanding of life-history evolution.

Another potentially interesting topic is the inter-population variations in the sexual differences of age at maturity. Males matured younger in SH, whereas no sexual difference was observed in YS and other populations (Sakai, 1995). In many organisms, resources allocated to reproduction vs. survival/growth differ between sexes (Bonduriansky et al., 2008). With the fecundity selection, reproductive success should be significantly linked to body size in females. In males with alternative mating tactics (e.g. sneakers) or promiscuous mating behavior, the advantage of a large body size in reproduction will be weaker than for females (Parker 1992). Since rosyface dace are promiscuous (Ito, 1975), males would gain higher fitness when they invest in early reproduction rather than growth and longevity (i.e. ‘live fast and die young’ strategy). Additionally, since this fish shows linear growth (Fig. 1), females would gain higher fitness when they invest in growth and longevity rather than early reproduction (Bonduriansky et al., 2008). Inter-population variations of the sexual differences in body size and age at maturity may provide new insights into the theories of life history evolution.

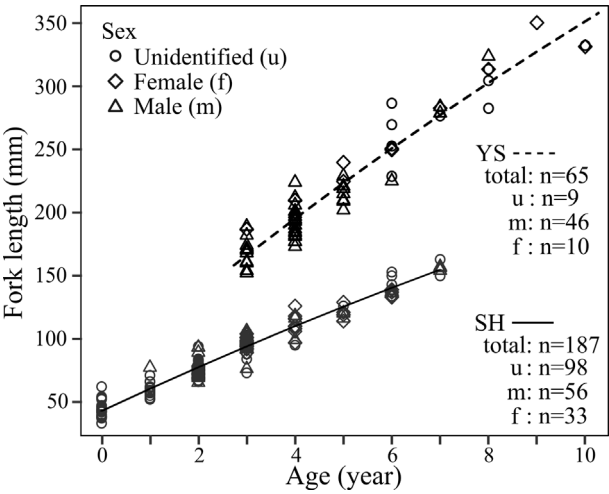
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Figures



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160 Fig. 1. Growth curve in a tributary of the Shiodomari River (SH) and the Yukutora-shupetsu River (YS).

161 Estimated VBGE are $L_t = 579.3 \times (1 - e^{0.0333(t-2.316)})$ in SH, and $L_t = 1064 \times (1 - e^{-0.0328(t-2.209)})$

162 in YS.