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SHORT COMMUNICATION

Comparison of the reproductive traits of male and female Soleoidei fishes in Japan

Satoshi Katayama . Masayuki Yamamoto . Thomas A. Munroe

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Abstract In this study, we examined the seasonal reproductive traits and inter-sex differences in the gonadosomatic index (GSI) of four Soleidae fish species in Japan to gain insights into the life history traits of Soleoidei fishes. We found that the sex ratio of one of these species was significantly skewed toward females, whereas the other three species showed no significant differences in the frequencies of males and females. For all species, the GSI values for mature males were between 0.5 and 1.5, which were notably lower than those of mature females (GSI: 7-15), and the weight of testes was approximately 10% that of female ovaries, after normalizing for body weight. The lower GSI values of male Soleidae fish may be indicative of an effective energy allocation mechanism within populations.

Keywords GSI . Sex ratio . Life history . Age and growth

Introduction

Many flatfish species are sexually dimorphic, with males reaching a smaller maximum size, maturing at a smaller size and younger age, and investing less energy in reproduction than females. In contrast to females, the reproductive output (fecundity) of which increases with body size, the reproductive output of males does not increase beyond a specific size, as energy required for the production of semen and behavioral costs are typically less than those of female investment (Rijnsdorp and Witthames 2005). In this regard, the gonadosomatic index (GSI) has been widely used as a measure of the energy allocated to reproduction. Interspecific differences in GSI are assumed to be a consequence of differences in the timing of spawning and the optimal allocation of energy between reproduction and growth. However, these assumptions have largely been based on considerations of female traits, whereas inter-sex differences in energy allocation have rarely been examined. Examples of male GSIs, have however, been reported for the common sole (GSI < 1%; Deniel 1981) and plaice (GSI 5%; Barr 1963). The lower GSI for males and sexual dimorphism in life history are interpreted as being indicative of an energy surplus in males that lags behind that of females beyond a size that is greater than the size at first maturation (Rijnsdorp and Ibelings 1989). To characterize the reproductive life history of Soleidae fishes, Baeck and Kim (2004) and Park et al. (2013) examined the sex ratios and seasonal changes in the GSIs of males and females in robust Soleidae fish in Asian sea waters. Additionally, Rajaguru (1992) presented these ratios and changes for two tonguefish species in Indian waters. To date, however, there have been no studies that have systematically analyzed the inter-sex differences in reproductive traits among Soleoidei fishes, which are distributed throughout temperate and tropical coastal areas and often of commercial significance.

To address this deficiency in our current knowledge, in this study, we investigated the seasonal

Satoshi Katayama (✉)
Fisheries Biology and Ecology, Graduate School of Agricultural Science, Tohoku University, 468-1 Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi 980-8572, Japan.
e-mail: skata@tohoku.ac.jp

Masayuki Yamamoto
Kagawa Prefectural Fisheries Experimental Station, 75—5 Yashima-Higashi, Takamatsu, Kagawa 761-0111, Japan.

Thomas A. Munroe
National Systematics Laboratory, NMFS/NOAA, Smithsonian Institution, Washington DC, USA.

reproductive traits and inter-sex differences in the GSI of four Soleidae fish species in Japan, for which few publications on life history are available, and also discuss the biological significance of small testes.

Materials and methods

We studied four species of Soleoidei fishes, including three-lined tongue-soles (*Cynoglossus abbreviatus*), red tongue-soles (*Cynoglossus joyneri*), inunoshita tongue-soles (*Cynoglossus robustus*), and bamboo soles (*Heteromycteris japonica*). Only the bamboo sole is a non-commercial species, while the others are caught in fisheries. We collected fish samples using bottom trawling (≈2.0 cm mesh codend) and gillnets set in the Seto Inland Sea, Japan (Fig. 1). The sample sizes of males and females are shown in Table 1. We randomly sampled ~30 fish per month for most months from 2008 to 2011. Second, we measured the total length (TL), body weight (BW) and gonad weight (GW) of each fish to the nearest 1 mm, 0.1 g, and 0.1 g, respectively. The sexes were identified from the external appearance of gonads. GSIs were calculated as GW × 100/BW. The otolith sectioning method was employed for age determinations.

To understand the life history traits of male and female of these species, growth formulae and sex ratios were referred from previous studies. Difference of growth formulae of male and female and evenness of sex ratio were tested by F-test and t-test with significant level at 0.05, respectively, using MS-Excel 2016 (Microsoft Corporation, Redmond, WA).

Results and discussion

For *C. joyneri,* we found that the maximum total lengths of males and females were almost the same, whereas female *C. abbreviatus* appeared to be larger than conspecific males. Similarly, females of *C. robustus* and *H. japonica* were found to be larger than the respective males (Table 1). Interestingly, the males of *C. robustus* and females of *H. japonica* were somewhat older than the conspecific females and males, respectively, whereas the maximum ages of the sexes of the other two Soleoidei fish species were the same.

The sex ratio of *C. abbreviatus* was significantly skewed toward females (~60% of the total), whereas we detected no significant differences in the frequencies of males and females of the other three species. Seasonal changes in the GSIs of the males and females of each species are shown in Fig. 2.

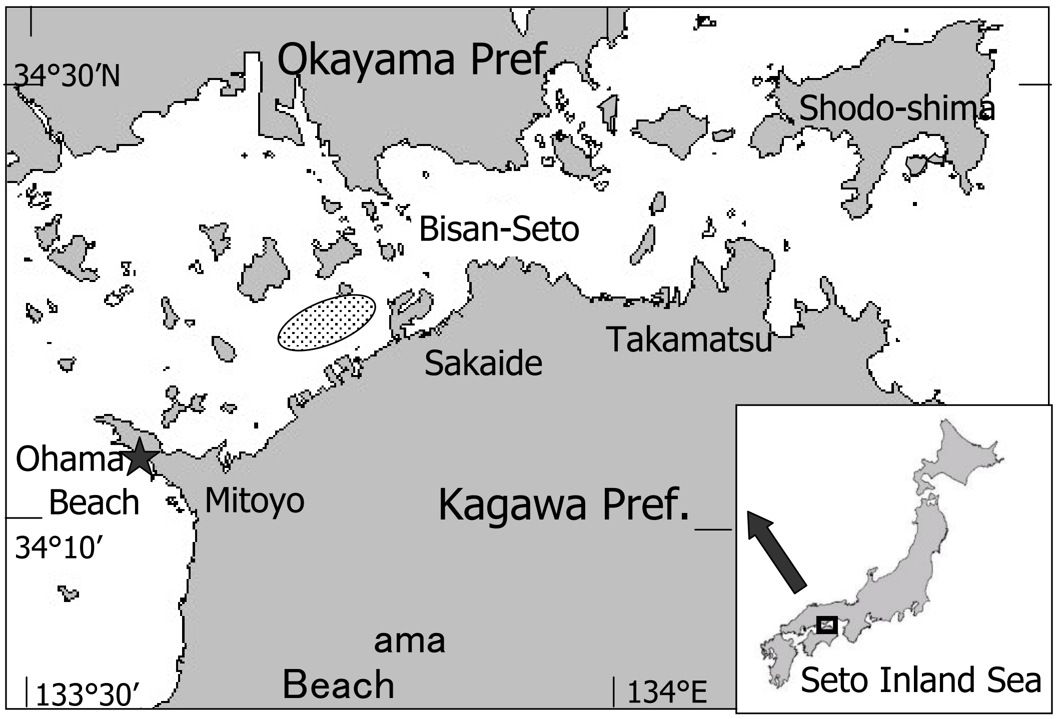

Fig. 1 Sampling area (a star symbol and a dotted area) for Soleoidei fishes

Table 1 Maximum total length and age, and number of males and females of four Soleidae fish species. The results of t-test for sex ratio (1:1) are also presented.

Species	Sex	Maxmum length (mm)	Maximum age	Sample size	*t*-value for sex ratio	*p*
Cynoglossus abbreviatus	Male	266	6	345	8.21	< 0.01
	Female	339	6	597		
Cynoglossus joyneri	Male	236	5	481	0.003	> 0.05
	Female	239	5	480		
Cynoglossus robustus	Male	326	11	483	1.31	> 0.05
	Female	353	7	443		
Heteromycteris japonica	Male	124	9	427	1.95	> 0.05
	Female	138	11	486		

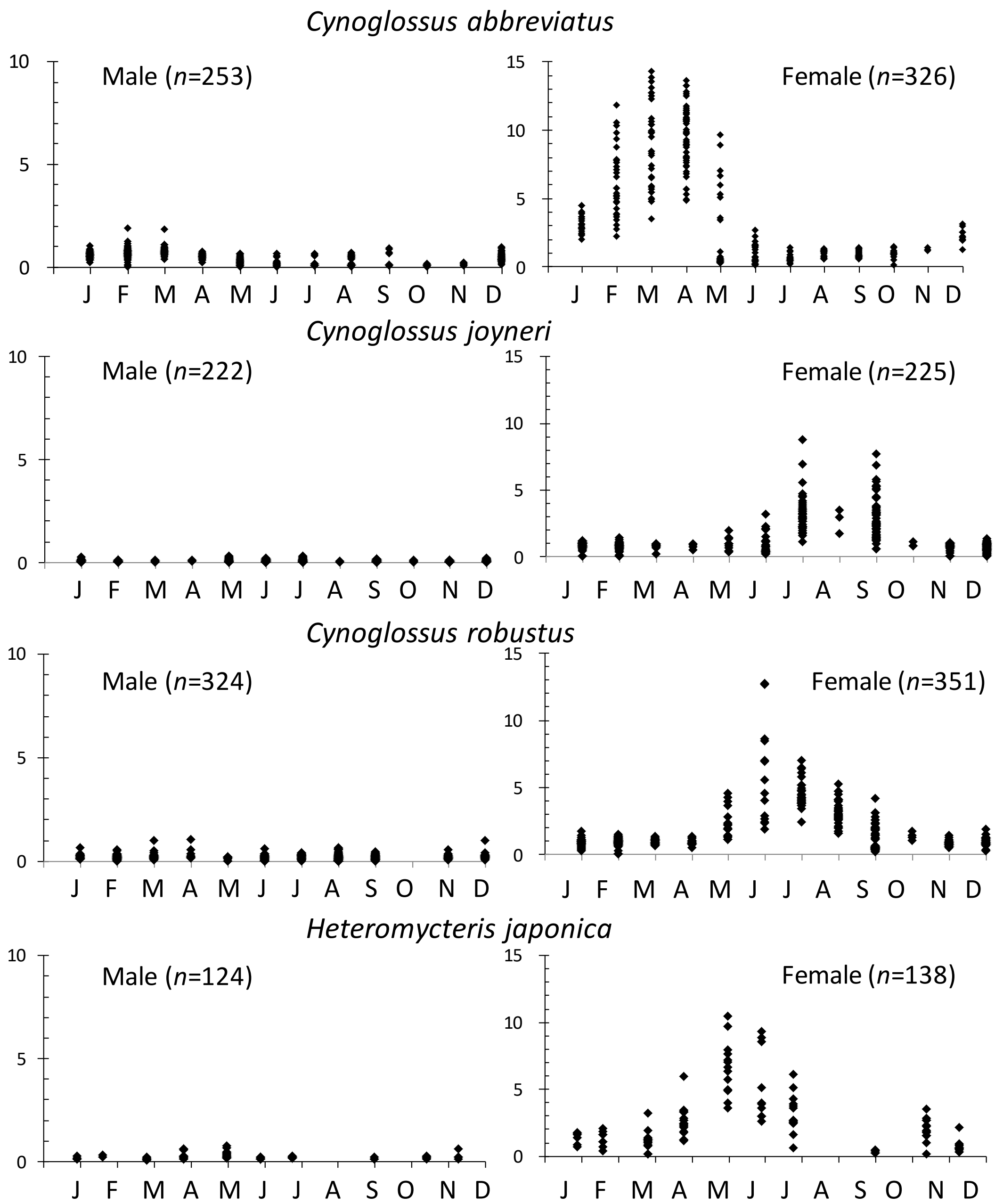

Fig. 2 Seasonal changes in the GSIs (Gonadosomatic index) of males and female from the four Soleoidei fish species

Cynoglossus abbreviates

The GSIs of many female *C. abbreviatus* evaluated from February to April ranged from 2 to 15. In contrast, although some males captured in February and March had GSI values of approximately 2, the GSIs of the overwhelming majority of males were less than 1.5 throughout the entire year.

Cynoglossus joyneri

The GSIs for female *C. joyneri* were found to be higher in July and September (approx. 5) than in other months, whereas the values for males were typically low throughout the year, at less than 0.5.

Cynoglossus robustus

The GSIs of female *C. robustus* peaked in June and varied annually from 0 to 13, whereas for males, the GSIs fluctuated at values of less than 1 throughout the year.

Heteromycteris japonica

Females of *H. japonica* were characterized by clear seasonal changes in GSIs, with high values in May and June. Similarly, the GSIs of males were slightly higher around May compared with other months; however, the values did not exceed 1.

Our observations indicated apparent differences in the maximum size and age of male and female *C. abbreviations*, with females growing to a larger size than males. However, we were unable to discern any appreciable differences in longevity. For the other three species, we detected only slight differences in the TL of the different sexes. Previous studies have, however, obtained Von Bertalanffy growth equations for the males and females of this species, which are presented below.

Cynoglossus abbreviatus, $F = 256$, $P < 0.01$ (Katayama et al. 2010)

Male: $TL_t = 253\left(1 - \mathrm{e}^{-1.37(t-0.0767)}\right) + 13.3$

Female: $TL_t = 326\left(1 - \mathrm{e}^{-1.00(t-0.0767)}\right) + 13.3$

Cynoglossus joyneri, $F = 0.596$, $P > 0.05$ (Katayama et al. 2010)

Male: $TL_t = 222\left(1 - \mathrm{e}^{-1.16(t-0.0167)}\right) + 14.2$

Female: $TL_t = 225\left(1 - \mathrm{e}^{-1.09(t-0.0167)}\right) + 14.2$

Cynoglossus robustus, $F = 29.0$, $P < 0.05$ (Katayama and Yamamoto 2012)

Male: $TL_t = 324\left(1 - e^{-1.16t}\right) + 1.8$

Female: $TL_t = 351\left(1 - \mathrm{e}^{-1.05t}\right) + 1.8$

Heteromycteris japonica, $F = 47.3$, $P < 0.01$ (Yamamoto and Katayama 2013)

Male: $TL_t = 124\left(1 - \mathrm{e}^{-1.15(t+0.03)}\right)$

Female: $TL_t = 138\left(1 - \mathrm{e}^{-0.99(t+0.03)}\right)$

With regards to the growth patterns of Soleoidei fish, female *C. abbreviatus* grows faster and larger than males, whereas male and female *C. joyneri* showed similar growth trajectories, and the females of *C.*

robustus and H. japonica grew slightly larger than males. Therefore, among the four species examined, only *C. abbreviatus* appears to be characterized by sexual dimorphism. We also found that the sex ratio in *C. ababatus* showed a female bias. Previous studies on *Cynoglossus* species have reported that the sex ratios for *C. arel* and *C. lida* (Rajaguru 1992) and *C. robustus* (Baeck and Kim 2004) did not differ significantly from 1:1. Sex ratios are assumed to reflect the reproductive strategy throughout life history, associated with the life spans and growth patterns of males and females. We presume that the skewed sex ratio C. *ababatus* is an outcome of the marked differences in the growth performance of the two sexes.

Among the four Soleoidei fishes analyzed in this study, we detected substantial differences in gonad weights. The GSI values of mature testes in these species ranged from 0.5 to 1.5, and testes were approximately 10% of the weight of ovaries, after normalizing for body weight, which is consistent with the findings of Rajaguru (1992) and Park et al. (2013). Thus, it can be concluded that the pronounced lesser in gonad weight is a somatic characteristic of male Soleoidei fish. Furthermore, Rijnsdorp and Witthames (2005) noted that a lower surplus of accumulated energy in males may be due to reduced feeding. Accordingly, we can speculate that the lower GSIs of male Soleidae fish may be indicative of an effective energy allocation mechanism to female within populations.

Conflict of interest The authors declare no conflicts of interest.

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