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Length-weight, length-length relationships, and condition factors of black rockfish *Sebastes schlegelii* Hilgendorf, 1880 in Lidao Bay, China

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Abstract In this study, we analyzed the length-weight relationships (LWRs), total length (TL)—standard length (SL) relationships (LLRs), and Fulton's condition factor (K) of male and female black rockfish *Sebastes schlegelii* Hilgendorf, 1880 in Lidao Bay, Yellow Sea, China. Among the 729 *S. schlegelii* specimens sampled seasonally in February, May, August and November between 2011 and 2015, most were males (sex ratio = 1 male:0.79 female). The LWRs of each season were significant ($P < 0.05$), and all coefficients of determination (r^2) were higher than 0.95. The values of the slope (b) estimated for each LWR regression varied from 2.947 to 3.277 and were lower in spring than those in other seasons, especially in females. The LLRs calculated as the regression of TL on SL and vice versa were linear. The values of K ranged from 0.791 to 2.981 in males ($n = 407$) and from 0.752 to 2.681 in females ($n = 322$), and the highest value was found in spring. The present results provide baseline information on biological data of LWRs, LLRs, and K for *S. schlegelii* in this area, and will be useful in further studies on stock management of *S. schlegelii*.

Keywords *Sebastes schlegelii* Hilgendorf, 1880 · Lidao Bay · Length-weight relationships · Length-length relationships · Condition factor · Sex ratio

Introduction

The weight of fish varies in relation to its length. Length-weight relationships (LWRs) are the most important biological parameters for understanding fish survival, growth rate, reproduction stock biomass, and other aspects of population's dynamics (Martin-Smith 1996; Muchlisin et al. 2010). They enable us to follow seasonal variations in fish growth (Richter et al. 2000) and are useful for predicting fisheries yield (Garcia et al. 1998) and biomass (Martin-Smith 1996). In addition, LWRs can be used to

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Table 1 Seasonal variation in the number of male and female *Sebastes schlegelii* individuals and their sex ratio (male: female)

Season	N	M	F	Sex ratio M : F
Spring (May)	146	79	67	1 : 0.85
Summer (August)	276	170	106	1 : 0.62
Autumn (November)	204	115	89	1 : 0.77
Winter (February)	103	43	60	1 : 1.39
Overall	729	407	322	1 : 0.79

N number of individuals, *M* male, *F* female

perform morphological comparison among species or populations from different habitats or regions (King 1996). Relationships between different types of length measurements, such as total length-standard length relationships (LLRs), are also important in studies for comparing growth rates (Moutopoulos and Stergiou 2002). Therefore, determining LWRs and LLRs is very important for the management and conservation of natural populations.

Condition factor is a quantitative parameter of the condition state, fatness, or well-being of fish (Tesch 1968), based on the assumption that, for a given length, heavier fish are in better condition. Fulton's condition factor (*K*) is used for comparing seasonal changes in fish nutritional condition, and usually increases with sexual maturation.

Sex ratio, the proportion of males and females in a population, is a key demographic parameter and an indicator of the population's behavior and fecundity, and is a fundamental concept in evolutionary biology (Hardy 2002). Knowledge on a population's sex ratio across different seasons is essential for understanding the seasonal segregation of sexes and their differential growth. A bias in sex ratio might be due to environmental changes that interfere in the sex determination system, sex-biased mortality, divergent sexual behavior, growth

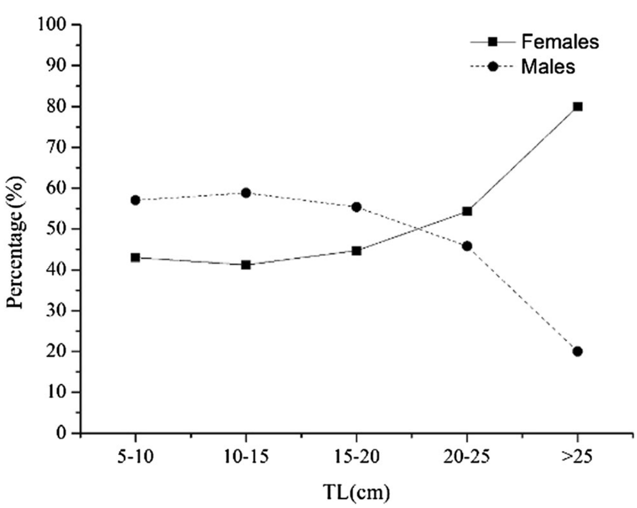

Fig. 1 Sex ratios calculated for the total length (TL) classes of *Sebastes schlegelii* from the Lidao Bay, China

rate, and longevity expectation (Conover and Kynard 1981; Schultz 1996).

The black rockfish, *Sebastes schlegelii* Hilgendorf, 1880 (Scorpaeniformes: Scorpaenidae: *Sebastes*), inhabits rocky reefs in the coastal waters of the North Pacific Ocean (Sasaki 2003). It is commercially important, and is an important cultured species for stock enhancement in Japan, Korea, and China (Yoshida et al. 2005; An et al. 2009; Liu et al. 2014). In Japan and Korea, artificially raised *S. schlegelii* juveniles have been released to enhance fisheries production since the 1980s and middle 1990s, respectively (Yoshida et al. 2005; An et al. 2009), and in China the *S. schlegelii* stock enhancement started in 1995. In 2010, 3.85 million *S. schlegelii* juveniles were released in the coastal region of Shandong Province, China (unpublished data), a number that decreased to approximately 1 million juveniles in 2012 (Lü et al. 2014). So far, most studies performed on *S. schlegelii* have focused on genetic diversity, immunity, growth, protein utilization, and gene function (Lee et al. 2000; Kim et al. 2014; Song et al. 2015). Although a few research papers have dealt with its biological characteristics, including LLRs, LWRs, and condition factor (Xue et al. 2011; Wang et al. 2013, 2016), the information is still incomplete and limited to the fish inhabiting a few areas within the Yellow Sea. Although it is known that biological characteristics may vary temporarily and spatially, there is a lack of comprehensive seasonal biological data for male and female *S. schlegelii*. Lidao Bay is a typical costal bay located in the northern coast of the Yellow Sea, Shandong Province, China. *S. schlegelii* is one of the commercially important dominant fish species in this area but there is no biological information about this species in Lidao Bay. Hence, the present study aimed to provide baseline biological data on LWRs, LLRs and condition factors of male and female *S. schlegelii* populations inhabiting Lidao Bay, which will be useful for the fishery and stock enhancement of this species.

Materials and methods

S. schlegelii specimens were sampled in the lower section of the Lidao Bay, central Yellow Sea, China (between 37°12′-37°24′ N and 122°33′-122°48′ E). Sampling was conducted seasonally in February, May, August and November at each location, from spring 2011 to spring 2015, using stake net. All captured fish were immediately placed on ice and transported to the laboratory for identification, according to Cheng and Zheng (1987), and measurement. All specimens were sexed by visual inspection of the gonads (Baba et al. 2005) and categorized into three groups: males, females, and combined sexes. Total length (TL) and standard length (SL) of each specimen were measured to the nearest 0.1 cm, and total weight (TW) was recorded to the nearest 0.01 g.

Table 2 Statistical description and length (cm) - weight (g) relationship (LWR) parameters in the samples of *Sebastes schlegelii* collected seasonally in Lidao Bay, China

Season	Sex	Total length (cm)		Body weight (g)		Parameters of the LWR		
		Min.	Max.	Min.	Max.	*a* (95% CL)	*b* (95% CL)	r^2
Spring (May)	M	6.9	23.6	6.38	222.70	0.0164 (0.0108–0.0249)	3.039 (2.082–3.196)	0.951
	F	7.4	34.3	7.00	550.00	0.0210 (0.0142–0.0311)	2.947 (2.804–3.090)	0.963
	B	6.9	34.3	6.38	550.00	0.0187 (0.0141–0.0247)	2.989 (2.886–3.093)	0.957
Summer (August)	M	5.6	24.4	1.91	237.00	0.0086 (0.0075–0.0100)	3.225 (3.164–3.286)	0.985
	F	5.7	26.0	2.61	339.50	0.0083 (0.0068–0.0102)	3.229 (3.146–3.311)	0.983
	B	5.6	26.0	1.91	339.50	0.0085 (0.0076–0.0096)	3.226 (3.177–3.275)	0.984
Autumn (November)	M	6.8	23.1	4.01	248.07	0.0074 (0.0063–0.0087)	3.277 (3.211–3.342)	0.989
	F	7.1	22.5	4.84	194.56	0.0090 (0.0077–0.0105)	3.204 (3.140–3.269)	0.991
	B	6.8	23.1	4.01	248.07	0.0081 (0.0073–0.0091)	3.242 (3.196–3.288)	0.990
Winter (February)	M	8.8	21.5	10.18	184.32	0.0106 (0.0069–0.0164)	3.120 (2.961–3.278)	0.974
	F	8.9	24.0	9.88	203.91	0.0089 (0.0063–0.0127)	3.195 (3.068–3.322)	0.977
	B	8.8	24.0	9.88	203.91	0.0097 (0.0074–0.0126)	3.163 (3.065–3.261)	0.976
Overall	M	5.6	24.4	1.91	248.07	0.0086 (0.0076–0.0096)	3.234 (3.188–3.281)	0.979
	F	5.7	34.3	2.61	550.00	0.0089 (0.0078–0.0100)	3.217 (3.168–3.266)	0.981
	B	5.6	34.3	1.91	550.00	0.0087 (0.0080–0.0094)	3.226 (3.192–3.259)	0.980

M male, *F* female, *B* both sex, *Max* maximum, *Min* minimum, *SD* standard deviation, *a* intercept of relationship, *b* slope of relationship, *CI* estimate ± 95% confidence limit, r^2 coefficient of determination

Length-weight relationships were calculated using the equation $W = aL^b$ (Ricker 1975), where W is the total weight of the fish in g, L is the total length of the fish in cm, *a* is the intercept, and *b* is the slope of the above linear regression. This equation was logarithmically transformed into $W = \log a + b \log L$, which fitted a least squares regression using W as the dependent variable. The parameters *a* and *b* were estimated by linear regression, after the logarithmic transformation of weight and length data. Slope *b* provides valuable information on fish growth, which is isometric when $b = 3$, positive allometric when $b > 3$, and negative allometric when $b < 3$ (Morey et al. 2003). Log-log plots of length-weight pairs were performed to exclude extreme outliers (Froese 2006) before regression analysis. Additionally, 95% confidence limits (CL) were estimated for *a* and *b*, along with the coefficient of determination (r^2) in LWRs. A similar linear regression was also used to determine LLRs. Fulton's condition factor was calculated according to $K = (W/L^3) \times 100$.

The three indices, LWRs, LLRs, and *K*, were calculated for each length class and season for males, females, separately, and for all specimens combined. A Chi-square test helped to identify the sex-ratio (male, M: female, F) using SPSS 16.0. All statistical analyses were considered significant for $P < 0.05$.

Results

Among the 729 specimens of *S. schlegelii* collected in Lidao Bay from 2011 to 2015, 407 were males (55.83%) and 322 were females (44.17%). The sex ratio of the total population was 1:0.79 (M:F), which was significantly different ($P < 0.05$). Sex ratio varied among seasons (1:0.62 to 1:1.39), showing a predominance of males in spring, summer, and autumn. A summary of the data is shown in Table 1. When individuals were classified according to TL (Fig. 1), males were more abundant than females in all TL classes between 5 and 20 cm, with sex ratios of 1:0.75 in the 5–10 cm class, 1:0.71 in the 10–15 cm class, and 1:0.81 in the 15–20 cm. Female proportion gradually increased with increasing length and for TL > 20 cm there were more females than males.

All the parameters estimated for the LWRs of *S. schlegelii* in Lidao Bay are shown in Table 2. All length-weight regressions were significant ($P < 0.05$), with r^2 values ranging from 0.951 to 0.991, and slopes (*b*) ranging from 2.947 to 3.277, with a mean value of 3.169. Thus, LWRs indicated a positive allometric growth in both males ($W = 0.0086\ L^{3.234}$, $r^2 = 0.979$) and females ($W = 0.0089\ L^{3.217}$, $r^2 = 0.981$) (Fig. 2). Seasonal evaluation of LWRs evidenced that *b* varied from 3.039 (spring) to 3.277 (autumn) in males, and from 2.947 (spring) to 3.229 (summer) in females.

The LLRs estimated for *S. schlegelii* in Lidao Bay, along with their estimated parameters and r^2 values, are given in Table 3. All LLRs were significant ($P < 0.05$), presenting r^2 values greater than 0.950 and *b* ranging from 0.797 to 0.885.

K values ranged from 0.791 to 2.981 in males ($n = 407$) and from 0.752 to 2.681 in females ($n = 322$). Within each season, there were no significant differences in *K* values between males and females. In males, the lowest average *K* was found in autumn ($K = 1.459$) and the highest in spring ($K = 1.846$); in females, the lowest average *K* was found in summer ($K = 1.463$) and the highest in spring ($K = 1.849$) (Fig. 3).

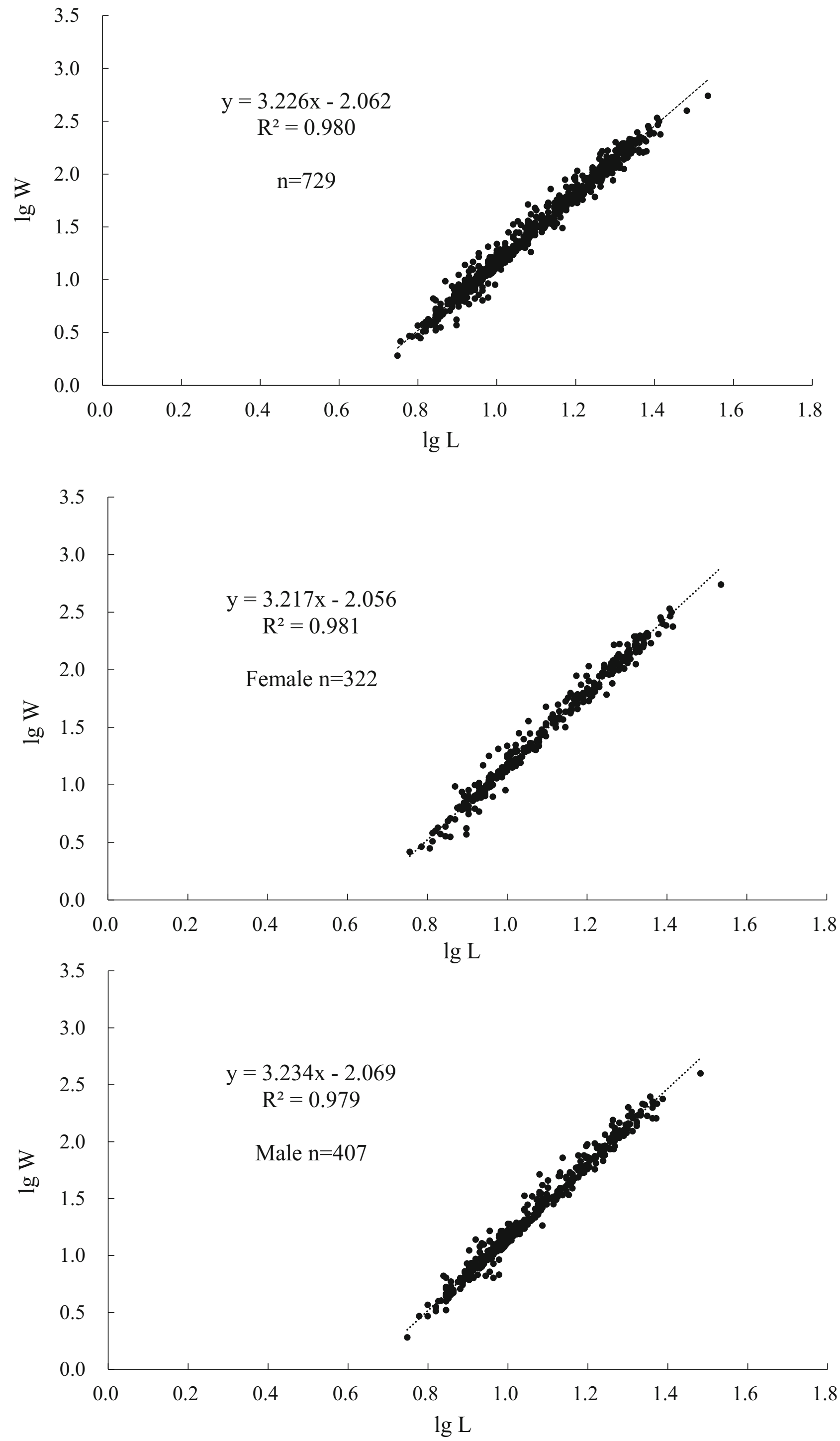

Fig. 2 Relationships between total length (cm) and body weight (g) on both sexes of *Sebastes schlegelii* from the Lidao Bay, China

Average *K* values in relation to size class are shown in Fig. 4 and, overall, males and females showed a similar trend. Values increased with increasing TL (5–25 cm TL) in both males and females, and maximum values were observed in the 20–25 cm TL. The lowest value was observed in the 5–10 cm TL class in both males and females and individuals of both sexes > 25 cm TL displayed a downward trend in *K*.

Discussion

Fish LWRs are affected by a series of factors including season, habitat, gonad maturity, diet, stomach fullness, and sex (Tesch 1971; Bagenal and Tesch 1978). Some fish species exhibit dimorphic growth according to sex, so their LWRs might be significantly different between sexes. In such cases, LWRs

Table 3 Parameters of the linear regressions performed for length measurements (TL and SL in cm) in *Sebastes schlegelii* samples from Lidao Bay, China

Season	Sex	*a*	*b*	r^2
Spring (May)	M	0.680	0.810	0.969
	F	0.700	0.797	0.975
	B	0.756	0.799	0.972
Summer (August)	M	−0.053	0.830	0.992
	F	0.021	0.823	0.992
	B	−0.020	0.827	0.992
Autumn (November)	M	0.111	0.802	0.991
	F	0.035	0.808	0.993
	B	0.085	0.804	0.992
Winter (February)	M	−0.149	0.838	0.980
	F	−0.856	0.885	0.985
	B	−0.500	0.862	0.982
Overall	M	−0.060	0.833	0.983
	F	−0.056	0.831	0.987
	B	−0.051	0.832	0.985

M male, *F* female, *B* both sex, *a* intercept of relationship, *b* slope of relationship, r^2 coefficient of determination

should be presented separately for males, females, and both sexes (Froese 2006). The value of *a* may vary daily, seasonally, or between habitats, but the value of *b* does not vary significantly throughout the year (Bagenal and Tesch 1978) generally ranging from 2.5 to 3.5 in LWRs (Froese 2006). In fact, the use of length-weight relationships should be strictly limited to the length ranges used in the linear regression. In the present study, all *b* values were within the expected normal range, so LWRs can be used to predict *S. schlegelii* weight in the length range 5–35 cm, which was the range of TLs sampled within this study. The values of *b* obtained in this study revealed a positive allometric growth for all sample categories

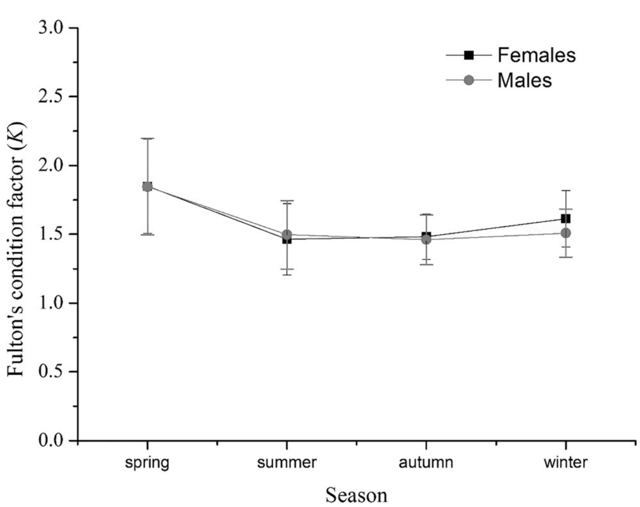

Fig. 3 Condition factor (*K*) values calculated for both sexes of *Sebastes schlegelii* from the Lidao Bay, China, according to season

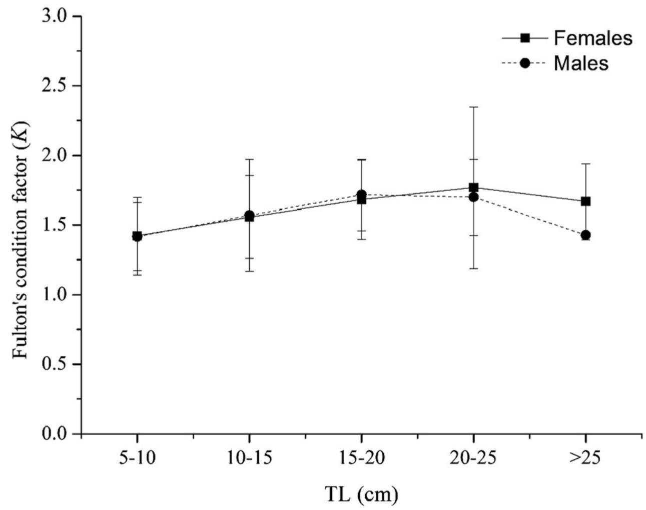

Fig. 4 Condition factor (*K*) values calculated for both sexes of *Sebastes schlegelii* from the Lidao Bay, China, according to total length classes

within each season, except for females in spring (Table 2), indicating an increasing in relative body thickness or plumpness. In this study, *b* was lower on spring than on other seasons, especially for females. These low values are probably related to black rockfish's viviparous reproduction in which gestation starts in April and parturition occurs in June (Mori et al. 2003). Thus, some spring specimens might be collected just after spawning season, which might be the reason why spring had lower *b* values than other seasons. Wang et al. (2013) and Xue et al. (2011) also reported a positive allometric growth for *S. schlegelii* in Haizhou Bay ($n = 334$) and Jiaozhou Bay ($n = 147$), which are located along the central coast of the Yellow Sea, China (Table 4). For *S. schlegelii* inhabiting Korea's south coast, the value of *b* was 3.01, considering all individuals ($n = 322$), and 2.98 for females and 3.02 for males ($n = 140$ and $n = 182$, respectively; Baeck et al. 2012).

Condition factor is a useful index for the monitoring of feeding intensity and growth rates in fish (Oni et al. 1983). It is strongly influenced by both biotic and abiotic conditions and can therefore be used as an index to assess the status of the aquatic ecosystem in which fish live (Anene 2005). The *K* values of all specimens were constant during summer, autumn, and winter, and increased in spring, possibly due to high food availability and increased water temperatures. While, females *K* decreased after parturition in June (early summer). Females tend to have larger and heavier gonads, which would increase their *K* in comparison to males of identical length, but average *K* values were not significantly different between sexes. The lack of seasonal data on prey availability prevents us from examining *K* variation relative to food-production cycles. As there are no other studies on *S. schlegelii K*, the data presented here constitute the baseline for future work regarding condition factors' variation in relation to biotic and abiotic variables.

Table 4 Parameters of LWRs for *Sebastes schlegelii*

Area	N	Sex	*a*	*b*	r^2	References
Jiaozhou Bay	147	B	0.0058	3.45	0.99	Xue et al. 2011
Haizhou Bay	334	B	0.00637	3.37	0.99	Wang et al. 2013
Roncheng Bay	812	B	0.0086	3.23	0.98	Wang et al. 2016
South coast of Korea	182	M	0.0142	3.02	0.98	Baeck et al. 2012
	140	F	0.0167	2.98	0.98	
	322	B	0.0148	3.01	0.98	
Lidao Bay	407	M	0.0086	3.23	0.98	This study
	322	F	0.0089	3.22	0.98	
	729	B	0.0087	3.23	0.98	

N number of individuals, *M* male, *F* female, *B* both sex, *a* intercept of LWRs relationship, *b* slope of LWRs relationship, r^2 coefficient of determination

Understanding variation in sex ratio is especially important, as it is a key parameter of population fecundity. Unbalanced sex ratios can drive sexual selection, affect mating system, and influence population persistence and conservation status, owing to the effect of sex ratio on effective population size (Emlen and Oring 1977; Clutton-Brock 2007). The overall sex ratio of *S. schlegelii* (1:0.79, M:F) significantly deviated different from the expected 1:1. Significant deviations were also found in other fish species of the genus *Sebastes,* but with no consistent trend. In southern Newfoundland waters, the overall M:F ratio in beaked rockfishes (*S. fasciatus* and *S. mentella*) was 1:0.94, and in the golden redfish *S. marinus* was 1:1.33 (Ni and Wilfred 1985). In the Gulf of Alaska, *S. polyspinis* M:F ratio was nearly 1:1, while females predominated in the Aleutian Islands (57 females to 43 males) (Clausen and Heifetz 2002). Seasonal and size class variations in sex ratio found in the present study indicated sexual segregation in *S. schlegelii* according to both variables. Males predominated in spring, summer, and autumn, and there was an increase in female abundance in winter, which might be due to vitellogenesis being completed in March (Mori et al. 2003).

Examining sex ratios across TL classes showed that female proportion gradually increased with increasing length, which was consistent with Baba et al. (2005) results. For *S. schlegelii* with TL ranging from 5 to 20 cm, there were more males than females, but for TL > 20 cm, female ratio increased. This increase in female ratio in relation to body size might be due to different longevity or growth rates between sexes (Schultz 1996). *S. schlegelii* females are known to grow faster than males, and their asymptotic mean length is also larger than that of males (Baba et al. 2005). Variations in sex ratio at different growth stages or ages were documented in other rockfishes, such as *S. melanops.* The representation of *S. melanops* females in age categories falls from about 50% to 10–20% from 10 to 20 years-old fish (Ralston and Dick 2003). Sex ratio bias could be caused by several mechanisms, such as offspring sex ratio, sex differences in mortality and migratory rates, and differ according to age at maturity (Donald 2007). Thus, in addition to hereditary factors, the sex ratio of *S. schlegelii* might be influenced by environmental factors including temperature and toxicants, which either affect sex determination or induce sex-biased mortality. In fish, both males and females might be the least represented sex (Székely et al. 2014). Increased male mortality is typically associated with mate search and courtship or with male-male competition for territories and mating opportunities (Le Boeuf 1974; Lodé et al. 2004). A recent meta-analysis concluded that reports on biased sex ratios may often be false due to small sample size or sampling bias (Wehi et al. 2011), which will erroneously make one sex appear more abundant than another. However, the lack of adequate information about *S. schlegelii* sex ratio in other populations restrains further considerations, indicating that more studies are required to confirm a sex ratio bias in this species.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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