J. Ecol. Field Biol. 31 (2): 107~113, 2008

Sexual Dimorphism in Morphometric Characteristics of Korean Chub *Zacco koreanus* (Pisces, Cyprinidae)

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ABSTRACT: We measured a set of 37 morphological characteristics in 97 specimens of adult Korean chub, *Zacco koreanus*, trapped in the Milyang River, Korea, in May and October of 2005. Twelve out of thirty-seven morphometric measurements were significantly different between the sexes. In particular, both the pectoral fin length and the direct distance between the insertion of the dorsal fin and the insertion of the anal fin were highly significant ($p < 0.001$). This sexual dimorphism may reflect the outcome of sexual selection in this species.

Key words: Morphometric characteristics, Sexual dimorphism, *Zacco koreanus*

INTRODUCTION

The dark chub, *Zacco temminckii* (Temminck and Schlegel 1846) is widely distributed in the rivers and lakes of Japan, Korea, and mainland China (Miyadi et al. 1976), and is well known as the most common species in fresh water in these areas (Kim et al. 2005). Since Jordan and Starks (1905) first reported *Z. temminckii* on the basis of several specimens from Korea, which differed somewhat from those of Japan, the dark chub has been known as the only single species.

However, several authors subsequently reported that geographic variation in dark chub morphological characters (Choi et al. 1990, Kim 1997, Hosoya 2002) and enzyme chemistry (Yang and Min 1987, 1989, Lee and Lee 1988). Accordingly, Korean chub, *Z. koreanus* was recently distinguished from dark chub based on several morphological characteristics (Kim et al. 2005) and differences in its nuptial color patterns (Chae and Yoon 2006). In general, changes in body color accompany sexual size differences in the spawning season. However, the extent of the size differences between the sexes in this species in the spawning season is unknown.

Sexual dimorphism occurs in many fishes. Females are usually larger than males of the same age. In some species, however, males are larger than females, e.g., Japanese minnow, *Pseudorasbora parva* (Nakamura 1963), gudgeon, *Gobio gobio* (Mann 1980), pumpkinseed, *Lepomis gibbous* (Deacon and Keast 1987), saddleback darter, *Percina vigil* (Heins and Baker 1989), and filefish, *Brachaluteres ulvarum* (Akagawa et al. 1995). The reason for the size difference is not clear (Katano 1998). Several authors reported that the evolution of larger body size in males likely results from male-male competition associated with a polygynous mating system (Trivers 1985, Andersson 1994, Katano 1998). Hence, exploring the nature and extent of sexual dimorphism can aid in understanding social structure and adaptation, as well as species identification.

Katano (1998) reported that the dark chub, which is closely related to Korean chub, does not display a significant sexual size difference when young (ages 3~5 years), but older males are larger than older females (ages 6~7 years). No sexual difference in growth rates was observed in the Kiyotaki River, Japan, except during the spawning period (Katano 1998). This result implies that there can be a possible sexual differences in morphometric characteristics during the spawning period and, at the same time, this size difference demonstrates the need to analyze the relationship of each morphometric variable with body size. Thus, this study is to examine the possible sexual dimorphism and the relative growth patterns of morphometric characteristics in Korean chub.

MATERIALS AND METHODS

In 2005, 97 specimens of the Korean chub were trapped in the Milyang River, Korea during the spawning (May) and non-spawning seasons (October). Thirty-eight different morphometric measurements were recorded from the freshly sampled individuals to the nearest 0.1 mm using Vernier calipers: standard length (LS), head depth (HD), head width (HW), eye diameter (ED), snout length (SNL), pectoral fin length (PECL), pelvic fin length (PELF), anal

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fin length (AFL), direct distance between the most anterior extension of the head and the posterior end of the supraoccipital (MAEH-PES), direct distance between the posterior end of supraoccipital and the origin of the dorsal fin (PES-ODF), direct distance between the posterior end of the supraoccipital and the origin of the pelvic fin (PES-OPEF), direct distance between the posterior end of the supraoccipital and the origin of the pectoral fin (PES-OPCF), direct distance between the posterior end of the supraoccipital and the posterior end of the maxillary (PES-PEM), direct distance between the origin and the insertion of the dorsal fin (ODF-IDF), direct distance between the origin of the dorsal fin and the origin of the anal fin (ODF-OAF), direct distance between the origin of the dorsal fin and the origin of the pelvic fin (ODF-OPEF), direct distance between the origin of the dorsal fin and the origin of the pectoral fin (ODF-OPCF), direct distance between the insertion of the dorsal fin and the dorsal origin of the caudal fin (IDF-DOCF), direct distance between the insertion of the dorsal fin and the ventral origin of the caudal fin (IDF-VOCF), direct distance between the insertion of the dorsal fin and the insertion of the anal fin (IDF-IAF), direct distance between the insertion of the dorsal fin and the origin of the anal fin (IDF-OAF), direct distance between the insertion of the dorsal fin and the origin of the pelvic fin (IDF-OPEF), direct distance between the dorsal origin of the caudal fin and the ventral origin of the caudal fin (DOCF-VOCF), direct distance between the dorsal origin of the caudal fin and the insertion of the anal fin(DOCF-IAF), direct distance between the ventral origin of the caudal fin and the insertion of the anal fin (VOCF-IAF), direct distance between the insertion of the anal fin and the origin of the anal fin (IAF-OAF), direct distance between the origin of the anal fin and the origin of the pelvic fin (OAF-OPEF), direct distance between the origin of the pelvic fin and the origin of the pectoral fin (OPEF-OPCF), direct distance between the origin of the pectoral fin and the posterior end of the maxillary (OPCF-PEM), direct distance between the most anterior extension of the head and the origin of the dorsal fin (MAEH-ODF), direct distance between the most anterior extension of the head and the dorsal origin of the caudal fin (MAEH-DOCF), direct distance between the most anterior extension of the head and the origin of the anal fin (MAEH-OAF), direct distance between the most anterior extension of the head and the origin of the pelvic fin (MAEH-OPEF), direct distance between the most anterior extension of the head and the origin of the pectoral fin (MAEH-OPCF), direct distance between the most anterior extension of the head and the posterior end of the maxillary (MAEH-PEM), direct distance between the most anterior extension of the head and the most posterior aspect of operculum (MAEH-MPAO), direct distance between the insertion of the dorsal fin and the most posterior scale in the lateral line (IDF-MPSL) and direct distance between the most posterior scale in the lateral line and the insertion of the anal fin (MPSL-IAF) (Fig. 1). The sex and maturity of each individual were determined using external morphology, body

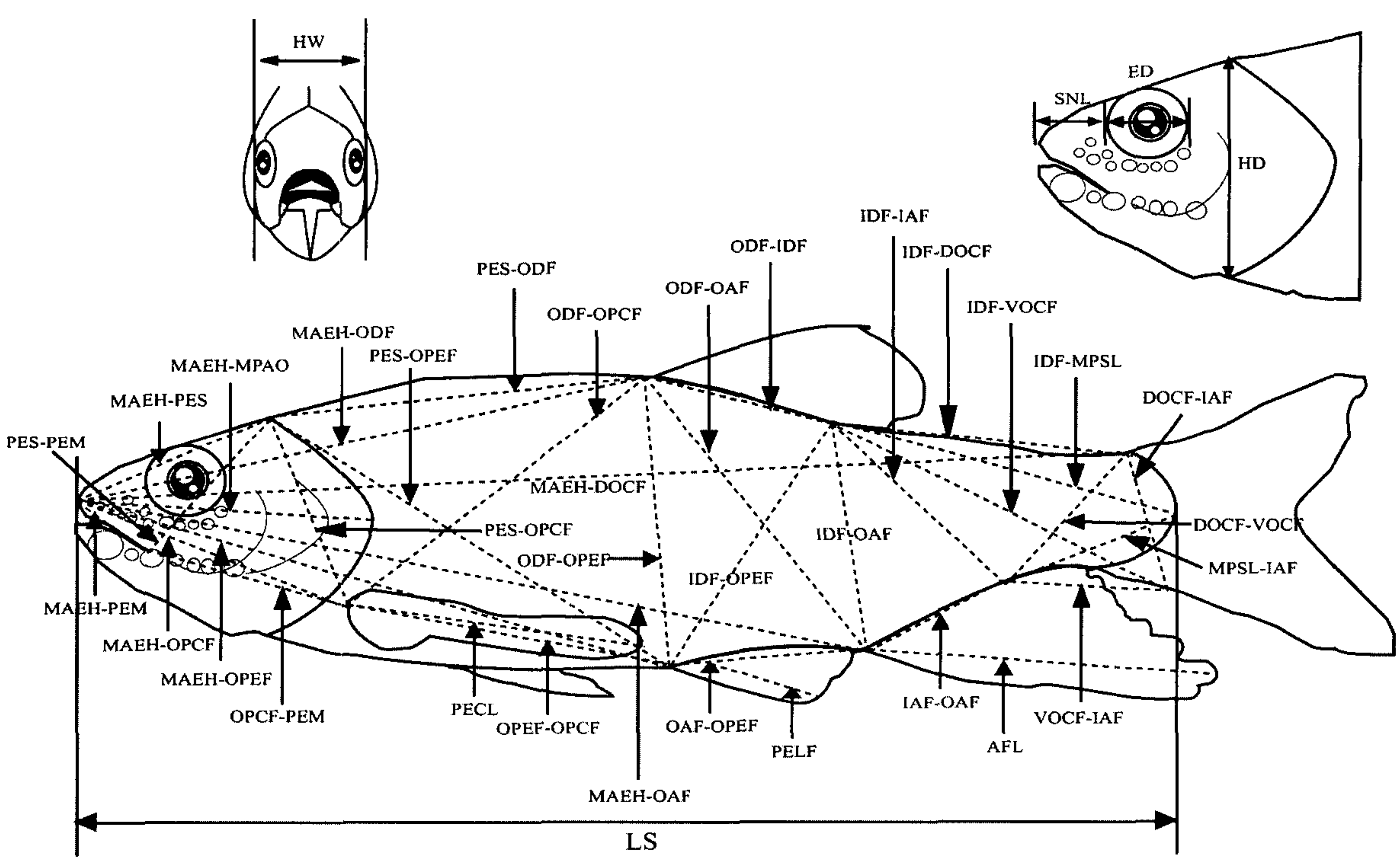

Fig. 1. Morphometric measurements of Korean chub used in this study. For abbreviations, see text.

color, internal gonad inspection, and gonad squash preparations as described by Kim et al. (2005). All of the measurements were standardized by dividing by the LS to compare the measurements by sex and were tested by the student's *t*-test. Each logarithmically transformed measurement was regressed on log LS by sex. Regression coefficients were compared between the sexes using ANCOVA (Zar 1984).

RESULTS

In the spawning season, 12 of the 37 morphometric measurements, PES-OPCF, ODF-IDF, IDF-IAF, DOCF-VOCF, DOCF-IAF, VOCF-IAF, IAF-OAF, MAEH-OPCF, MPSL-IAF, HD, SNL, and PECL, differed significantly between the sexes. In particular, the inter-sexual differences in the IDF-IAF and PECL were highly significant ($p < 0.001$). The ratio of PECL to LS was higher in males (0.213 ± 0.016) than in females (0.195 ± 0.017), but the ratio of IDF-IAF to LS was higher in females (0.263 ± 0.024) than in males (0.238 ± 0.017, Table 1). Males had significantly higher ratios than females for 10 characters of the 12 characters that differed, while females had higher ratios for IDF-IAF and SNL.

In the non-spawning season, only 3 of the 37 morphometric characteristics differed significantly between the sexes ($p < 0.05$; MAEH-DOCF, ED and PELF). The ratios of MAEH-DOCF and ED to LS were higher in females (0.999 ± 0.019, 0.088 ± 0.006, respectively) than in males (0.980 ± 0.019, 0.081 ± 0.010, respectively), whereas the ratio of PELF to LS was higher in males (0.154 ± 0.008) than in females (0.146 ± 0.011; Table 2).

The regression coefficients of the logarithm of the 10 measurements that were significantly bigger in males than females to the logarithm of the LS of Korean chub were significantly different between the sexes during the spawning season ($p < 0.05$; Table 3). The regression coefficients of both the slopes and intercepts of the logarithm of ODF-IDF, DOCF-IAF, OAF-OPEF, and MAEH-PEM to the logarithm of LS were significantly different between the sexes (Table 3). The interceptions of the regression of IDF-IAF and PECL were highly significantly different between the sexes (Table 3; Fig. 2).

DISCUSSION

Sexual size dimorphism is one component of external morphological variation between the sexes, along with features such as the genital papilla, body pigmentation, fin shape, nuptial tubercles, and nuptial coloration (Kim and Kim 2001). Sexual size dimorphism is the most conspicuous difference between the sexes (Anderson 1994).

In the spawning season, Korean chub exhibited sexual size differences in PES-OPCF, ODF-IDF, IDF-IAF, DOCF-VOCF, DOCF-IAF, VOCF-IAF, IAF-OAF, MAEH-OPCF, MPSL-IAF, HD, SNL, and PECL. Most of these characters were larger in males than in females, but the IDF-IAF and SNL were larger in females. In particular, the PECL was much larger in males than in females, whereas the IDF-IAF was much larger in females than in males. Therefore, these external characteristics can be used to determine the sex of Korean chub in the spawning season. However, intersexual differences in these features were not observed in the non-spawning season.

In some species in which the males provide parental care, *Cottus amblystomopsis* (Berg 1932), *Cottus nozawae* (Nakamura 1963), *Cottus hangiongensis* (Goto 1984), and *Gymnogobius* spp. (Kim 2002), the pelvic and pectoral fin lengths and the mouth size are distinctly greater in males than in females. During the spawning season, males of these species attract females to spawn, and subsequently defend the nest from intruders and fan the eggs with their pectoral or pelvic fins. In contrast, male *Zacco* leave the nest after spawning (Wang et al. 1995) without providing parental care, and many satellites (both males and females) prey upon the eggs at the instant of spawning (Katano 1992). The pectoral and pelvic fins (including the anal fin) do not seem to play a functional role in the protection of eggs through fanning.

Wang et al. (1995) noted that the dark chub, which is closely related to the Korean chub, used behavioral tactics to succeed in mating competition. Several males chase one female at the beginning of courtship and display their fins to threaten competitors and fight aggressively. Only one winner succeeds in mating. Larger males may have an advantage in mating competition (Goto 1984, Oliveria and Almada 1995, Park et al. 2001, Kim 2002). Accordingly, the sex differences in several morphological characteristics in Korean chub may be related to sexual selection for male features that lead to greater male success in competition for access to females. However, we cannot explain why some morphological features (e.g., the direct distance between the insertion of the dorsal fin and the insertion of the anal fin: IDF-IAF) were larger in females than males in the spawning season.

In October when the temperature begins to drop, the fish generally hide in crevices under rocks and boulders and do not forage or engage in reproductive activity. Thus, while reproductive tactics may have an important influence on male and female Korean chub morphology in the spawning season, environmental factors such as low water temperature and food availability may have a stronger effect on morphological features than reproductive tactics in the non-spawning season (Wootton 1990, Katano 1998). Further study is required to clarify the relationships among sexual competition, ecology, and adult morphological characteristics in the Korean chub.

Table 1. Student *t*-tests for differences between the sexes in the ratio of 37 body measurements to standard length (LS) in Korean chub in the spawning season

Characteristic	Male (mean ± SD)	Female (mean ± SD)	*t*	Probability (*P*)	
MAEH-PES	0.203 ± 0.013	0.204 ± 0.013	−0.30	0.771	NS
MAEH- PEM	0.102 ± 0.007	0.104 ± 0.009	−1.14	0.265	NS
PES-ODF	0.334 ± 0.012	0.330 ± 0.021	0.88	0.388	NS
PES-OPEF	0.380 ± 0.015	0.376 ± 0.021	0.78	0.440	NS
PES-OPCF	0.187 ± 0.009	0.182 ± 0.009	2.23	0.030	*
PES-PEM	0.174 ± 0.009	0.176 ± 0.010	−0.78	0.443	NS
ODF-IDF	0.111 ± 0.009	0.105 ± 0.008	2.85	0.006	**
ODF-OAF	0.274 ± 0.010	0.273 ± 0.022	0.39	0.702	NS
ODF-OPEF	0.231 ± 0.014	0.223 ± 0.026	1.47	0.158	NS
ODF-OPCF	0.347 ± 0.024	0.353 ± 0.019	−1.08	0.293	NS
IDF-DOCF	0.359 ± 0.010	0.360 ± 0.021	−0.06	0.950	NS
IDF-VOCF	0.375 ± 0.016	0.381 ± 0.018	−1.37	0.181	NS
IDF-IAF	0.238 ± 0.017	0.263 ± 0.024	−4.73	0.001	***
IDF-OAF	0.196 ± 0.013	0.207 ± 0.024	−2.04	0.048	NS
IDF-OPEF	0.245 ± 0.016	0.242 ± 0.024	0.49	0.632	NS
DOCF-VOCF	0.105 ± 0.007	0.098 ± 0.012	2.67	0.010	*
DOCF-IAF	0.193 ± 0.013	0.183 ± 0.018	2.47	0.017	*
VOCF-IAF	0.168 ± 0.015	0.156 ± 0.018	2.60	0.012	*
IAF-OAF	0.144 ± 0.010	0.133 ± 0.016	2.98	0.005	**
OAF-OPEF	0.211 ± 0.015	0.213 ± 0.019	−0.52	0.602	NS
OPEF-OPCF	0.269 ± 0.014	0.274 ± 0.022	−1.04	0.301	NS
OPCF-PEM	0.172 ± 0.008	0.174 ± 0.014	−0.56	0.583	NS
MAEH-ODF	0.524 ± 0.011	0.532 ± 0.020	−1.86	0.069	NS
MAEH-DOCF	0.985 ± 0.018	0.985 ± 0.021	−0.02	0.981	NS
MAEH-OAF	0.699 ± 0.014	0.701 ± 0.036	−0.24	0.818	NS
MAEH-OPEF	0.510 ± 0.017	0.501 ± 0.027	1.46	0.153	NS
MAEH-OPCF	0.261 ± 0.013	0.249 ± 0.019	2.79	0.007	*
MAEH-MPAO	0.265 ± 0.010	0.263 ± 0.013	0.71	0.488	NS
IDF-MPSL	0.505 ± 0.023	0.497 ± 0.020	1.42	0.161	NS
MPSL-IAF	0.203 ± 0.013	0.191 ± 0.019	2.80	0.007	**
HD	0.182 ± 0.010	0.175 ± 0.009	2.66	0.010	*
HW	0.134 ± 0.006	0.133 ± 0.006	0.94	0.352	NS
ED	0.077 ± 0.009	0.081 ± 0.008	−1.85	0.070	NS
SNL	0.081 ± 0.006	0.085 ± 0.007	−2.14	0.037	*
PECL	0.213 ± 0.016	0.195 ± 0.017	4.04	0.001	***
PELF	0.169 ± 0.013	0.164 ± 0.014	1.46	0.158	NS
AFL	0.213 ± 0.035	0.205 ± 0.031	0.94	0.355	NS

The sample numbers of females and males are 30 and 30, respectively. For abbreviations, see text. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant.

Table 2. Student *t*-tests for differences between the sexes in the ratio of 37 body measurements to standard length (LS) in Korean chub in the spawning season

Characteristic	Male (mean ± SD)	Female (mean ± SD)	t	Probability (P)	
MAEH-PES	0.215 ± 0.016	0.212 ± 0.013	0.61	0.541	NS
MAEH- PEM	0.101 ± 0.007	0.102 ± 0.009	−0.47	0.640	NS
PES-ODF	0.342 ± 0.044	0.329 ± 0.014	1.15	0.263	NS
PES-OPEF	0.375 ± 0.058	0.366 ± 0.023	−0.09	0.931	NS
PES-OPCF	0.182 ± 0.020	0.179 ± 0.013	0.32	0.755	NS
PES-PEM	0.184 ± 0.012	0.186 ± 0.012	−0.53	0.600	NS
ODF-IDF	0.101 ± 0.010	0.103 ± 0.012	−0.58	0.561	NS
ODF-OAF	0.264 ± 0.015	0.272 ± 0.015	−1.72	0.095	NS
ODF-OPEF	0.211 ± 0.020	0.221 ± 0.020	−1.59	0.121	NS
ODF-OPCF	0.340 ± 0.018	0.345 ± 0.029	−0.79	0.445	NS
IDF-DOCF	0.363 ± 0.025	0.372 ± 0.028	−1.04	0.311	NS
IDF-VOCF	0.379 ± 0.025	0.388 ± 0.031	−1.03	0.311	NS
IDF-IAF	0.245 ± 0.018	0.252 ± 0.028	−1.00	0.330	NS
IDF-OAF	0.191 ± 0.013	0.200 ± 0.018	−1.66	0.111	NS
IDF-OPEF	0.229 ± 0.017	0.238 ± 0.020	−1.70	0.099	NS
DOCF-VOCF	0.100 ± 0.006	0.103 ± 0.009	−1.53	0.142	NS
DOCF-IAF	0.188 ± 0.021	0.189 ± 0.019	−0.01	0.955	NS
VOCF-IAF	0.153 ± 0.015	0.155 ± 0.016	−0.36	0.723	NS
IAF-OAF	0.132 ± 0.019	0.128 ± 0.010	0.45	0.651	NS
OAF-OPEF	0.200 ± 0.017	0.192 ± 0.013	1.77	0.086	NS
OPEF-OPCF	0.258 ± 0.018	0.267 ± 0.018	−1.61	0.121	NS
OPCF-PEM	0.168 ± 0.014	0.171 ± 0.015	−0.58	0.561	NS
MAEH-ODF	0.523 ± 0.019	0.524 ± 0.014	−0.50	0.621	NS
MAEH-DOCF	0.980 ± 0.019	0.999 ± 0.019	−2.16	0.038	*
MAEH-OAF	0.698 ± 0.021	0.702 ± 0.019	−0.85	0.398	NS
MAEH-OPEF	0.499 ± 0.020	0.510 ± 0.020	−1.85	0.074	NS
MAEH-OPCF	0.256 ± 0.012	0.255 ± 0.015	−0.28	0.784	NS
MAEH-MPAO	0.267 ± 0.014	0.265 ± 0.011	0.29	0.771	NS
IDF-MPSL	0.510 ± 0.018	0.510 ± 0.028	0.09	0.926	NS
MPSL-IAF	0.196 ± 0.020	0.197 ± 0.023	−0.07	0.953	NS
HD	0.181 ± 0.010	0.179 ± 0.008	0.63	0.538	NS
HW	0.133 ± 0.009	0.133 ± 0.006	−0.34	0.733	NS
ED	0.081 ± 0.010	0.088 ± 0.006	−2.85	0.008	*
SNL	0.083 ± 0.009	0.087 ± 0.008	−1.98	0.056	NS
PECL	0.193 ± 0.014	0.193 ± 0.013	−0.08	0.941	NS
PELF	0.154 ± 0.008	0.146 ± 0.011	2.41	0.022	*
AFL	0.171 ± 0.030	0.170 ± 0.029	0.10	0.922	NS

The sample numbers of females and males are 18 and 19, respectively. For abbreviations, see text. $^{*}p < 0.05$, NS: not significant.

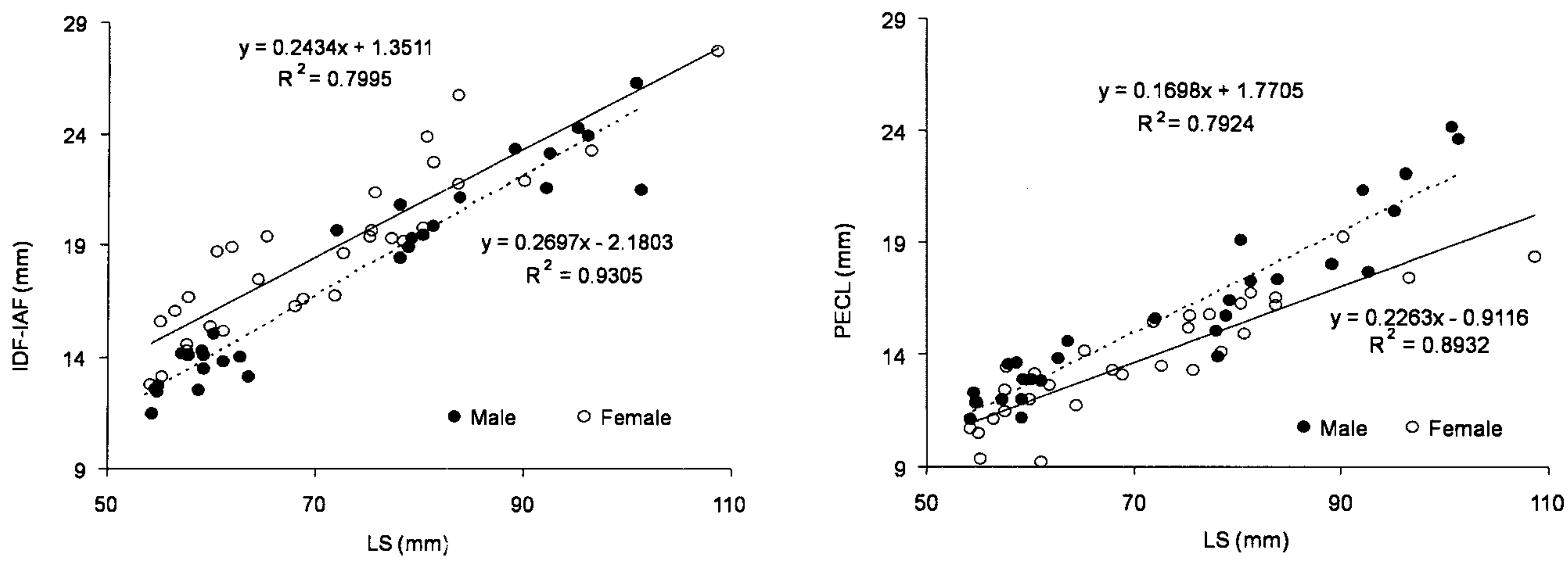

Fig. 2. The relationship between Standard length (LS) and (a) direct distance between the insertion of the dorsal fin and the insertion of the anal fin (IDF-IAF) and (b) pectoral fin length (PECL) for male (●) and female(○) Korean chub in the spawning season.

Table 3. Comparison of the test statistics from log-log regression of the morphometric characteristics to standard length for male and female Korean chub in the spawning season

Characteristic	n	Difference between slopes		Difference between intercepts	
		Student's *t*	*P*-level	Student's *t*	*P*-level
PES-OPEF	60	1.93	NS	5.02	*
ODF-IDF	60	4.37	*	8.02	**
IDF-OAF	60	3.82	NS	23.36	***
DOCF-IAF	60	6.38	*	7.47	**
VOCF-IAF	60	0.68	NS	6.06	*
IAF-OAF	60	0.43	NS	6.54	*
OAF-OPEF	60	8.95	**	10.71	**
MAEH-PEM	60	5.69	*	7.91	**
MPSL-IAF	60	0.41	NS	9.07	**
PECL	60	1.23	NS	15.56	***

For abbreviations, see text. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the technical staff at Pukyong National University and Korea Maritime University for their support. We also thank the anonymous referees for their constructive comments on the manuscript.

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(Received February 20, 2008; Accepted April 21, 2008)