KOREAN JOURNAL OF ICHTHYOLOGY, Vol. 31, No. 3, 141-149, September 2019
ISSN: 1225-8598 (Print), 2288-3371 (Online). DOI: https://doi.org/10.35399/ISK.31.3.3

Received: June 19, 2019
Revised: July 11, 2019
Accepted: July 17, 2019

Spawning Season, and Factors Influencing Allometric Growth Pattern and Body Condition of Walleye Pollock *Gadus chalcogrammus* in the Middle East Sea, Korea

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ABSTRACT **This study presents data on spawning season, weight-length relationships (WLRs) and condition factor of *Gadus chalcogrammus* inhabiting the middle East Sea, Korea. Monthly changes in the gonadosomatic index (GSI) revealed that the spawning period was from December to March. Overall value of the exponent *b*, estimated by nonlinear least squares from weight and length data was 2.806, ranging from 2.778 for female fishes to 2.985 for immature group. The *b* values were similar between spawning and non-spawning, and between female and male fishes, but it was significantly higher for immature than mature fishes. The condition factors were significantly higher for immature than mature groups, and during non-spawning than spawning periods, but it was not significant between male and female fishes.**

Key words: *Gadus chalcogrammus*, GSI, weight-length relationship, condition factor, East Sea

INTRODUCTION

Measuring body morphometric of fishes is a basic procedure in fishery sciences, because fishery species can identify and/or compare specific species, populations and stocks via morphometric relationships (King, 1995; Froese, 1998). In fisheries studies, the allometric growth parameter (*b*) and form factor (*a*) of weight-length relationships (WLRs) have been applied in assessing fish stocks and populations (Ricker, 1968; Hilborn and Walters, 2001). For example, WLRs are useful to predict the average weight at a given length or age group and then convert length data into weights to provide a measure of biomass (or vice versa) (Froese, 2006; Froese *et al*., 2011), because stock assessment models and management for fisheries require information about body weight for estimation and regulation of catches (Froese *et al*., 2014) and weight-at-age (Petrakis and Stergiou, 1995). Fulton's condition factor is widely used to measure the health of marine organisms (i.e. fish well-being) and seasonal body condition of individual fish (Le Cren, 1951; Froese, 2006). This factor is based on the hypothesis that for a given length, heavier fishes are in better condition than lighter fishes, and thus fatness is used as a measure of fish health (Bagenal and Tesch, 1978).

Walleye pollock (or Alaska pollock) *Gadus chalcogrammus* (Pallas, 1814) is a member of the family Gadidae and widely distributed in North Pacific Ocean (Froese and Pauly, 2019). The species is demersal and lives between depths of 50～500 m in eastern Korean waters (Kim *et al*., 2004), and mainly consumed various semi-benthic fishes and invertebrates (e.g. Dwyer *et al*., 1987; Yamamura *et al*., 2002; Adams *et al*., 2007). In the East Sea, *G. chalcogrammus* showed a spring and summer migration from spawning grounds to foraging area, and a winter migration returning to spawning grounds, with water temperature mainly affecting the distributions and movements of pollock (Kotwicki *et al*., 2005), but the evidence for this pattern of migration is sparse in the eastern sea of Korea. In addition, *G. chalcogrammus* constituted among the most

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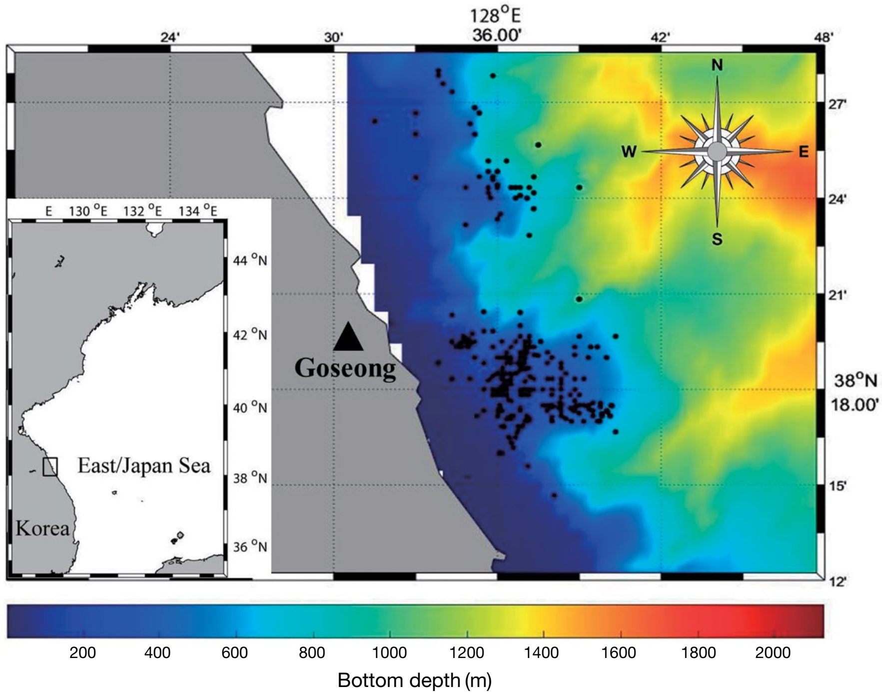

Fig. 1. Location of sampling area in the middle East Sea, Korea. Samples were collected along the shore lines within boxed area. The data of color depth contour were obtained from Korea Hydrographic and Oceanographic Agency (http://www.khoa.go.kr).

important fisheries species in Korean waters (Kim *et al*., 2004) as well as throughout North Pacific countries (Beamish and McFarlane, 1995). However, pollock fishery stock had dramatically decreased since 1980s due to overfishing and climate change induced oceanographic changes, or interplay of those influences. Studies on fisheries ecology including reproduction and growth are crucial in application to fisheries management and conservation (e.g. Britton and Pegg, 2011; Park *et al*., 2018), but a few is known regarding fishery ecology and biology for *G. chalcogrammus* inhabiting Korean waters. This paper provides data of fisheries characteristics including spawning season, WLR parameters and condition factors for *G. chalcogrammus* inhabiting East Sea, Korea.

MATERIALS AND METHODS

1. Field samplings

Fish specimens of 1,816 were collected in the middle East Sea, Korea at depths between 50～800 m (Fig. 1). Samplings were conducted monthly from August 2015 to January 2018, and fish samples were collected using primarily a bottom gillnet and occasionally demersal trawl (during summer season). Immediately after capture, individuals were snap frozen, taken to the laboratory, and kept

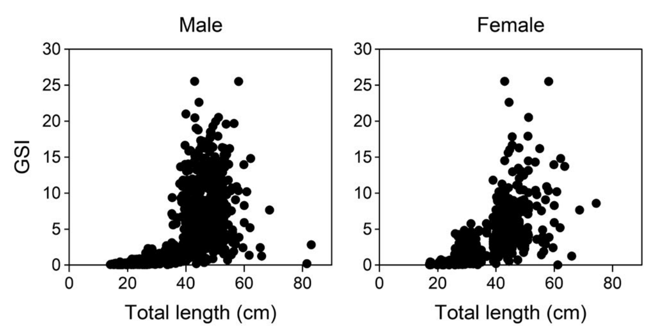

Fig. 2. The gonadosomatic index (GSI) and total length for male and female *Gadus chalcogrammus* inhabiting middle East Sea, Korea.

frozen at −20°C until processing, which occurred immediately after thawing in the laboratory. Total length (TL) and whole-body weight (BW) were measured to the nearest millimeter and nearest gram, respectively using Vernier calipers and electronic valance (Mettler Toledo ME204, USA). The peritoneum of each fish specimen was excised, and the gonads were removed and weighed to the nearest 0.001 g (GW). Sex was determined macro- or microscopically by examining gonads via binocular microscope (Kern OZP-5, Germany). Fish maturity was estimated by plotting gonadosomatic index (GSI) values of male and female against their TL (Fig. 2). The TL with a dramatic increase in GSI was considered to be the minimum maturity size (Tuuli *et al*., 2011), i.e. criteria to divide between juvenile (immature) and adult (mature). Immature groups had TL of 14.1~35.2 cm for males and 13.0~38.9 cm for females. Mature groups had TL of 35.3~83.0 cm for males and 39.0~74.4 cm for females. Such a sexual difference of maturity size was also reported in other walleye pollock population inhabiting northern Japan sea (Hamatsu and Yabuki, 2007).

2. Data analysis

The GSI was calculated as follows: GSI = (GW/BW) × 100, where GW is gonad weight (g) and BW is body weight (g). One-way analysis of variance (ANOVA) followed by Tukey's post-hoc comparisons were used to assess whether there were significant differences of GSIs among months.

For each species, the weight-length function, BW = $a\mathrm{TL}^b$, was fitted to the data using linear regressions of $\log_{10}$-transformed data, where BW represents body weight (g), TL is total length (cm), and a and b are the intercept and allometric coefficient, respectively. Extreme outliers were removed before fitting the regression because the data were increased measurement errors (Froese *et al*., 2011). The standard error (SE) of parameters a and b, and the statistical significance level of r^2 were estimated. The b values were compared using a t-test at the 0.05 significance level to verify whether the linear regressions were significantly different from the isometric value of 3 (Sokal and Rohlf, 1987). The comparison between obtained values of t-test and the respective tabled critical values allowed for their inclusion in the isometric [I] range ($b = 3$) or allometric ranges (negative allometry [A −]: $b < 3$ or positive allometry [A +]: $b > 3$). In the present study, the WLR parameters were summarized in each sex (female and male), season (spawning and non-spawning), maturi-

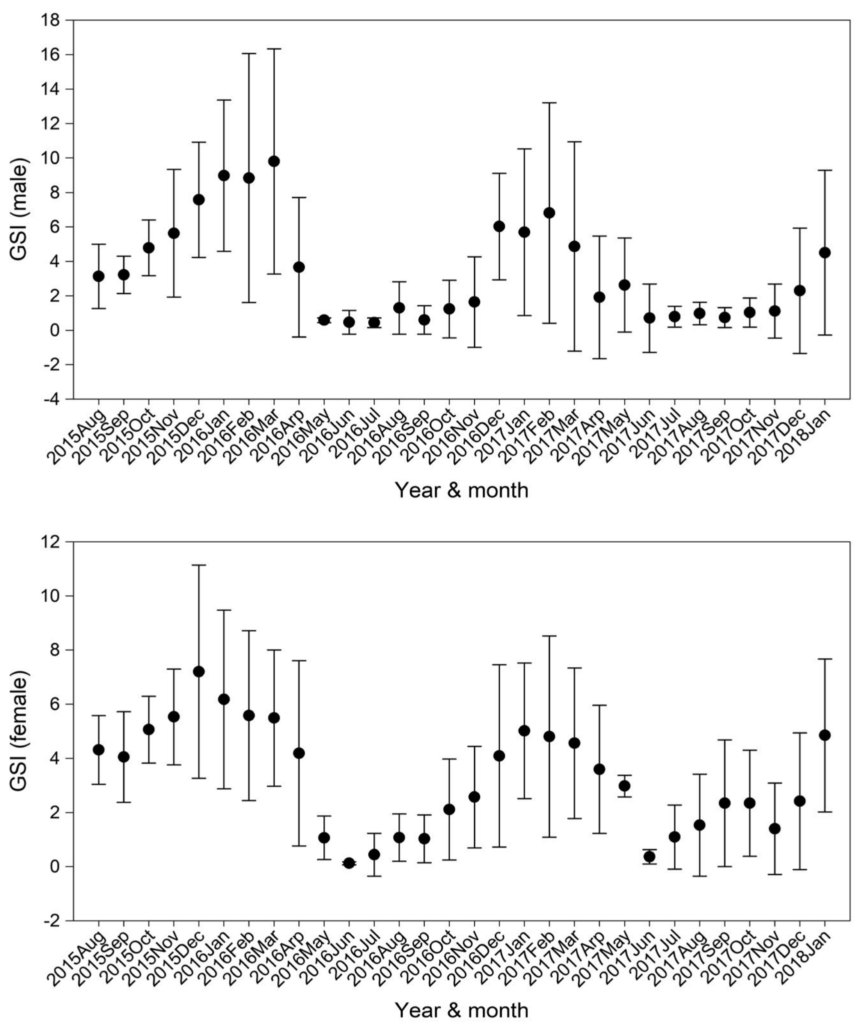

Fig. 3. Monthly changes in GSIs of male and female *Gadus chalcogrammus* inhabiting middle East Sea, Korea. Vertical bars indicate standard deviation.

ty (immature and mature), and all specimens combined. Analyses of covariance (ANCOVA) was used to test the effect of the categorical factors of sex, season and maturity in the relationships between body weight and total length. The relationships between BW and TL, and interactions between categorical factors and covariates on these relationships were investigated by ANCOVA.

The Fulton's condition factor (K) was calculated for each specimen according to the equation $K = 100 \times BW/TL^3$ (Pauly, 1984; Froese, 2006). Differences in condition factors were examined with respect to sex, season and maturity. The assumptions of normality and homoscedasticity were met for the species ($P > 0.05$); three-way analysis of variances (ANOVAs) was used to assess whether there were significant influences on condition factor by season, maturity and sex as well as their two-way and three-way interactions. All statistical analyses were performed using SYSTAT software (Systat version 18.0, SPSS Inc., Chicago, IL, USA). An assumed significance level of 0.05 was used in all statistical analyses.

RESULTS

Monthly GSI values showed similar trends between male and female, with increasing from November, reaching the highest level between December and March, and decreasing thereafter (Fig. 3). ANOVA results showed that GSI values were significantly different among months, with the highest value in January and February, followed by December and March (ANOVA post-hoc test, $P < 0.05$).

Condition factors (K) were shown collective trends with

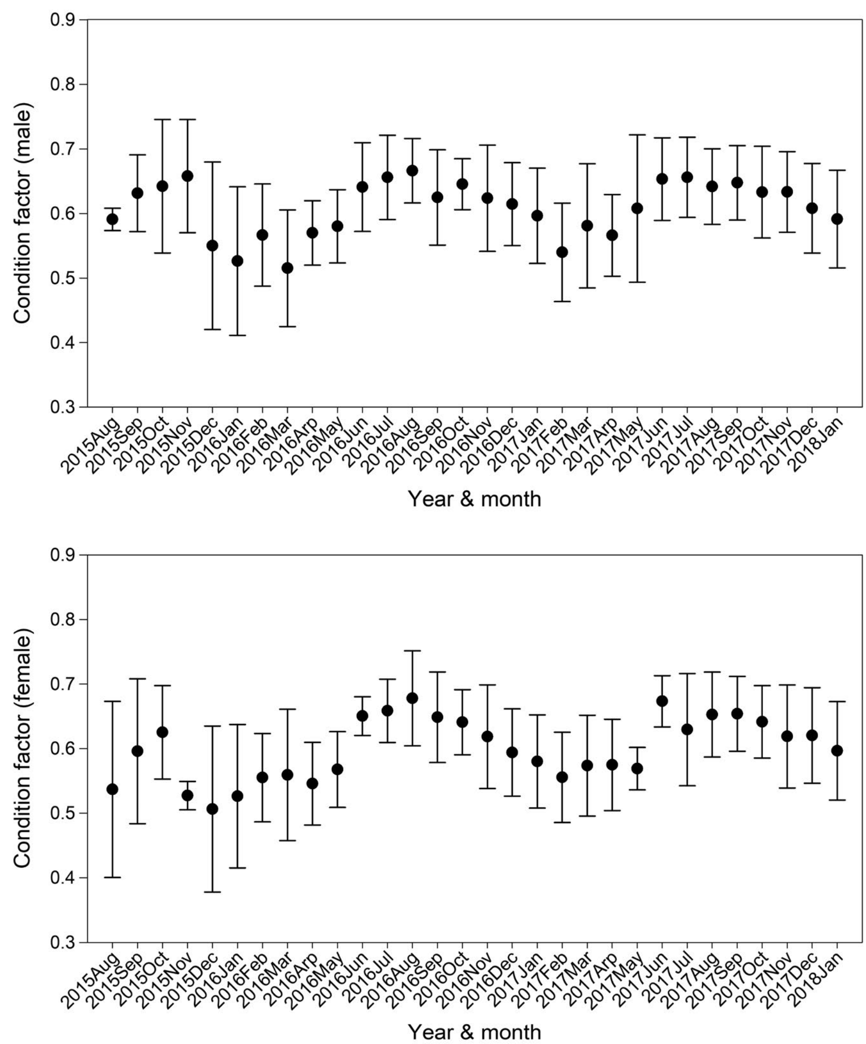

Fig. 4. Monthly changes in condition factors of male and female *Gadus chalcogrammus* inhabiting middle East Sea, Korea. Vertical bars indicate standard deviation.

changing months between male and female (Fig. 4). The *K* values were increasing from late spring to summer, peaking during autumn and decreasing in winter. The GSI and condition factor showed opposite trends, with condition factor exhibiting higher values according to decrease GSIs during summer and autumn (Figs. 3 and 4).

Weight-length regressions (WLRs) were applied to 1,816 specimens of *G. chalcogrammus*. The estimated parameters of WLR, and descriptive statistics by sex, season, maturity and all fishes, are provided in Table 1. All WLRs were highly significant ($P<0.05$), with r^2 values >0.888. The r^2 values ranged from 0.888 for mature group to 0.968 for individuals during the non-spawning period. ANCOVA results revealed that the slope (*b*-value) of the WLR did not differ significantly between non-spawning and spawning season, and between sexes, but it was significant between immature and mature groups, with higher value for immature fishes than mature group ($P<0.001$).

The mean values of condition factors were between 0.625 for immature *G. chalcogrammus* and 0.587 for mature *G. chalcogrammus*, showing significantly higher value for immature fishes ($P<0.05$). The values were also significantly higher during non-spawning season than spawning season ($P<0.05$). While there were no significant influences of sex as well as their two- and three-way interactions among three categorical factors on condition fac-

Table 1. Weight-length relationship (WLR) parameters of *Gadus chalcogrammus* with respect to inhabiting middle East Sea, Korea. Bold letter indicates statistical significance at $P\leq0.05$

Factors	N	TL (cm)	BW (g)	$W=aL^b$						G
				a	SE	b	SE	r^2	ANCOVA	
Sex										
Male	1,046	14.1~83.0	17.6~2,736.1	0.0111	0.025	2.818	0.016	0.968	0.061	A−
Female	770	13.0~74.4	12.9~2,620.1	0.0126	0.035	2.778	0.022	0.953		A−
Spawning season										
Non-spawning	822	14.1~81.5	17.6~2,677.9	0.0095	0.027	2.871	0.018	0.968	0.272	A−
Spawning	994	13.0~83.0	12.9~2,736.1	0.0098	0.033	2.842	0.021	0.950		A−
Maturity										
Immature (male)	875	14.1~35.2	17.6~329.5	0.0065	0.038	2.985	0.026	0.939	**<0.001**	I
(female)		13.0~38.9	12.9~392.3							
Mature (male)	941	35.3~83.0	258.0~2,736.1	0.0114	0.078	2.806	0.047	0.888		A−
(female)		39.0~74.4	246.7~2,620.1							
Total	1,816	13.0~83.0	12.9~2,736.1	0.0115	0.020	2.806	0.013	0.990		

N = number of individuals, TL = total length, BW = wet body weight, a = intercept, b = slope, r^2 = coefficient of determination, SE = standard error, G = growth type, A− = negative allometry, I = isometry

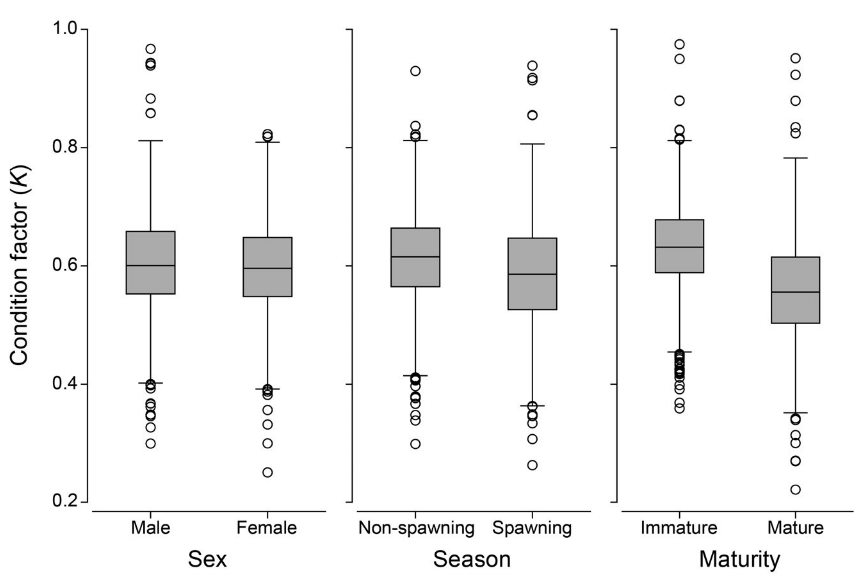

Fig. 5. Box plots of condition factors for *Gadus chalcogrammus* in relation to sex, spawning season and maturity. Open cycles represent outliers.

Table 2. Results of three-way ANOVAs testing the effects of sex, season, maturity and interactions of the three factors on condition factor of *Gadus chalcogrammus*. Bold letters indicate statistical significance at $P \leq 0.05$

Source	df	MS	F	P
Sex	1	0.001	0.057	0.811
Season	1	0.037	5.061	**0.025**
Maturity	1	0.402	55.144	**<0.001**
Sex × Season	1	0.008	1.053	0.305
Sex × Maturity	1	0.001	0.012	0.913
Season × Maturity	1	0.003	0.442	0.506
Sex × Season × Maturity	1	0.024	3.229	0.073
Residuals	1808	0.007		

tor (three-way ANOVAs; Table 2, Fig. 5).

DISCUSSION

Based on monthly GSI values, gonadal development begins from November, and the spawning period of *G. chalcogrammus* is estimated from December to March (Fig. 3). The breeding season of *G. chalcogrammus* appeared to correspond to the decrease in water temperature. This spawning season coincides with the results reported for other co-occurring fish species in middle East Sea, Korea, including Pacific cod *Gadus macerocephalus* and *Gymnocanthus herzensteini* (Lee *et al*., 2005; Park *et al*., 2007), as well as *G. chalcogrammus* inhabiting other regions of North Pacific (e.g. Smith, 1979; Maeda, 1986; Hinckley, 1987).

The weight-length regressions for many fish species have been listed in FishBase which is a global biological database on fishes (Froese and Pauly, 2019). Our result provides the first quantitative WLR estimates for *G. chalcogrammus* inhabiting the East Sea. The estimated *b* values from this study fell within the standard range of 2.5∼3.5 which indicate for the majority of fish species (Froese, 2006). Overall *b* values were the lower end of the expected range, indicating towards negative allometry, but that of immature group was shown isometry. Especially, *G. chalcogrammus* showed ontogenetic changes in growth types allowing mature individuals to grow longer in size during a shorter period of time. While smaller specimens (immature group) have shown isometric growth pattern which occurs at the same rate for all parts of individuals so that its shape is consistent throughout development. Generally, the allometric coefficient of the mass-length relationship is mainly influenced by the quantity and quality of the ingested food (Fu *et al*., 2016; Phillips *et al*., 2018). The digestive tracts of immature individuals may be well adapted to efficiently exploit the food ingested (i.e. abundant semi-pelagic invertebrate; Park *et al*., 2018), while the negative allometry observed in mature individuals is implying allocation of more energy to axial growth rather than biomass (Wootton, 1990).

In this study, the condition factors were significantly different between non-spawning and spawning, and between immature and mature fishes, but not between sexes. Because there were no significant interactions among those factors, variations of condition factor of this species were attributed to seasonal or ontogenetic changes in body condition in relation to spawning behavior and/or food intakes. Seasonal and ontogenetic changes in body condition were related with variations in energy reserves (protein, lipid, glycogen and total energy) which are usually driven by food availability, environmental conditions, and reproductive status (Weatherley and Gill, 1987; Chellappa *et al*., 1995), consequently, changes in food reserves throughout the year (Hossain, 2010; Lavergne *et al*., 2013). Yamamura *et al*. (2002) reported that *G. chalcogrammus* condition fell during winter and then recovered rapidly during spring and summer, due to the expenditure of energy reserves under reduced food availability, but the transformation of energy to gonad maturation during breeding season. Such a decrease of condition during winter also has been frequently reported in several high latitude fishes (e.g. Griffiths and Kirkwood, 1995; Paul and Paul 1998). While ontogenetic change in body condition may be related feeding behavior, because smaller fish need to ingest food more frequently than large fish, supporting their metabolic demand (Paul *et al*., 1998). Thus, such higher condition factor and isometric growth pattern of smaller fishes are advantageous for their development during younger period.

This study provides data on the spawning season, WLR parameters, and seasonal condition factors of *G. chalcogrammus* captured from the coastal waters of middle East Sea, Korea. These results contribute towards future conservation studies of the species, and be useful for fishery biologists and managers in Korea.

ACKNOWLEDGMENTS

We would like to thank to members of Fisheries Oceanography Laboratory at Ganeneung-Wonju National University for their assistances in the sample collections and measurements of the fishes. This research was parts of the project entitled “Walleye Pollock stock management based on Marine Information & Communication Technology” funded by the Ministry of Oceans and Fisheries, Korea.

This research was supported by the Korea Institute of Ocean Science & Technology project (PE99713).

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동해 중부 연안에 출현하는 명태(*Gadus chalcogrammus*)의 산란기 및 성장패턴(allometric growth pattern)과 비만도(body condition) 변화에 영향을 미치는 요인

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요 약 : 본 연구는 동해 중부 연안에 출현하는 명태(*Gadus chalcogrammus*)의 산란기, 체장-체중 관계(weight-length relationships, WLRs), 비만도(condition factor)를 조사하였다. 생식소숙도지수(gonadosomatic index, GSI))의 월변화를 통하여 추정한 명태의 산란기는 12월에서 3월이었다. 전반적인 체장-체중 관계식의 지수값 *b*는 2.806이었고, 2.778 (암컷)에서 2.980 (미성숙 그룹)의 범위를 나타냈다. *b*값은 암수 사이에서 유사하였으나, 미성숙 그룹과 비산란기 동안 성숙 그룹 또는 산란기 보다 유의하게 높은 값을 나타냈다. 비만도는 미성숙 그룹에서 성숙 그룹보다 유의하게 높았으나, 산란기와 비산란기, 암컷과 수컷 사이에서는 유의한 차이가 없었다.

찾아보기 낱말 : 명태, GSI, WLR, 비만도, 동해