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# Length-weight relationships and length-frequency analysis varying with seasons for fish community in the Luanhe River Estuary, Bohai Sea, northern China

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**Abstract:** The Luanhe River Estuary in the Bohai Sea in northern China is an important nursery and good fishing grounds for many marine organisms, including fish. Length-weight relationship (LWR) of fish is an important indicator for the proper fishing and management of fish populations. This study was conducted to obtain LWRs for fish species distributed there. From December 2016 to August 2017 at one-month intervals and from July 2016 to November 2017 at two-month intervals, using crab pots, trawl nets and bottom trawl nets, a total of 7,593 individuals belonging to 32 species in 20 families were obtained and their length and weight were measured. The most abundant species was *Chaeturichthys stigmatias* (N = 2,487). Length-weight relationships ($W = a \times L^b$) were obtained for the 17 fish species for which sufficient individuals were available for statistical analysis. Linear regression of log-transformed data was highly significant for all analysed species ($p < 0.05$), with LWR slope b values ranging from 2.57 for *Synechogobius ommaturus* to 3.66 for *Engraulis japonicus*. The b values of 50% of the total species ranged between 2.95 and 3.30. The LWR information could be used to manage fish stocks not only in the Luanhe River Estuary but also in other estuarine fisheries.

***Keywords :*** *Luanhe river estuary, LWR, Bohai Sea, Xiangyun-wan*

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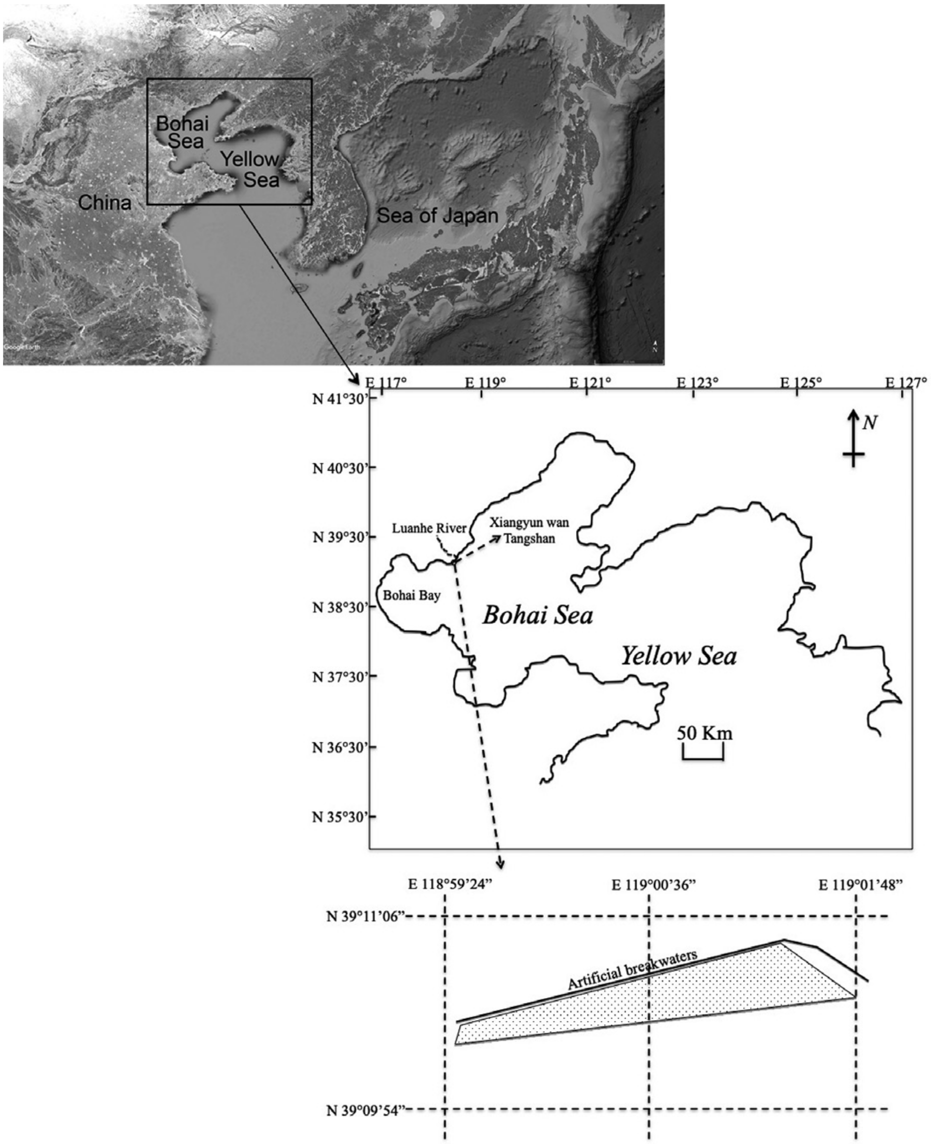


**Fig. 1** Schematic map showing the survey area (dotted area in the bottom panel) in the northernmost part of Bohai Bay (middle panel), the Bohai Sea (top and middle panels), northern China (39° 11'06"-39° 09'54" N, 118° 59'24"-119° 01'48" E).

## 1. Introduction

Estuarine areas are extremely important areas in the life cycle of some fish species. These ecosystems provide food, shelter, and spawning grounds for varieties of marine organisms. The Luanhe River is a sediment-laden water course on the northern shore of Bohai Sea, China (GAO, 1981). The estuary of the Luanhe River is recognised as important feeding and breeding grounds for marine organisms and migratory species and is a famous fishing ground within Bohai Bay (WU, 1980; CHENG *et al.*, 1982; HU and

ZHAN, 1983; XU *et al.*, 1986).

The rational utilization of estuarine fisheries resources is necessary to build a sustainable society. Length-weight regressions (LWRs) are an important tool for the proper exploitation and management of fish populations (ANENE, 2005) because length and weight data for fish are needed to estimate growth rates, age structure, and other population dynamics (KOLHER *et al.*, 1995). This information is also commonly used in the ecosystem modeling approach (CHRISTENSEN and WALTERS, 2004) to calculate the production to biomass ratio (P/B) of different functional groups. Modeling should utilise the values of LWR of fish in the area of interest for modeling in order to estimate more accurate weights. In addition, LWRs allow life history and morphological comparisons among different fish species, or between fish populations from different habitats and/or regions (GONÇALVES *et al.*, 1997). Biological scientists often estimate fish weight in the field using LWR (MOREY *et al.*, 2003).

Prior to this study there was no LWR data available for fish species in the Luanhe River Estuary. This study aimed to provide information of the first LWR references for 18 fish species that could be used for the management of the Luanhe River fishery ground. The LWR data will be made available through the Fishbase Database (FROESE and PAURY, 2010), which can be used by other researchers in any countries.

**Fig. 2** Photo of a fisherman deploying crab pots in the sea.

## 2. Materials and methods

This study was carried out in the Luanhe River Estuary between longitude 118°59'24"-119°01'48" E and latitude 39°11'06"-39°09'54" N (Fig. 1). The estuary is subject to irregular, semidiurnal tides. The current study was conducted in 2016–2017 as part of a series of studies to assess the biological sustainable capacity of this area. Samples were collected at monthly intervals from December 2016 to August 2017 and at bimonthly intervals from July 2016 to November 2017. The fishing gear used for sampling included a crab pot, trammel net of various inner mesh sizes, and a bottom trawl. Trammel nets (50 m long and 1.3 m high) with mesh sizes of 2.0 cm, 3.3 cm, 3.5 cm, and 4.0 cm and an outer net mesh of 17.0 cm were used. The trammel nets of the four mesh sizes were continuously connected together, giving a total length of 200 m. The crab pot was 8 m long consisting of rectangular column traps measuring 20 cm long, 15 cm high and 15 cm wide, with a 10 cm sized mouth opening at the top of the trap (Fig. 2). Five crab pots were continuously connected together at the survey station, giving a total length of 40 m. They were set up and retrieved from the fishing grounds overnight. Trawl net was a mouth length of 2.5–m and a net length of 16 m with a mesh size of 3.5 cm. Trawling was carried out at a speed of 2 knots for 30 minutes.

After sampling, fish samples were immediately transported to the laboratory in Hebei Provincial Research Institute for Engineering Technology of Coastal Ecology Rehabilitation. Specimens were identified to the species level.

**Table 1.** Seasonal variations (spring, summer, autumn, winter) of the number (unit: inds) and body length range (unit: cm) for 32 fish species caught in study area.

| | Spring | | Summer | | Autumn | | Winter | |
|---|---|---|---|---|---|---|---|---|
| | *Number* | *Range* | *Number* | *Range* | *Number* | *Range* | *Number* | *Range* |
| *Synechogobius ommaturus* | 49 | 15.3–37.2 | 732 | 3.4–18.6 | 318 | 6.6–31.5 | 170 | 12.1–36.0 |
| *Tridentiger barbatus* | 20 | 3.0–10.8 | 20 | 4.2– 9.2 | | | 17 | 2.7–11.2 |
| *Tridentiger trigonocehalus* | 3 | 6.0– 8.7 | | | | | | |
| *Tridentiger bifasciatus* | 3 | 6.7– 7.8 | | | | | 5 | 4.6– 9.2 |
| *Chaeturichthys stigmatias* | 13 | 9.0–14.1 | 1,265 | 2.7–16.7 | 616 | 4.1–17.5 | 593 | 4.4–18.7 |
| *Paratrypauchen microcephalus* | | | 37 | 4.0–12.4 | 7 | 4.5–10.1 | 3 | 6.7–10.3 |
| *Acanthopagrus schlegelii* | | | 1 | 8.1 | 5 | 11.3–17 | | |
| *Zoarces elongatus* | 1 | 29.5 | | | | | | |
| *Chirolophis japonicus* | 3 | 17.9–18.8 | 1 | 18.4 | | | | |
| *Ernogrammus hexagrammus* | 4 | 10.0–12.6 | | | | | | |
| *Johnius belangerii* | | | 418 | 2.7–12.6 | | | | |
| *Lateolabrax maculatus* | | | 5 | 8.4–14.1 | | | 1 | 30.3 |
| *Hexagrammos agrammus* | 2 | 14.3–14.8 | 6 | 4 –10.5 | | | | |
| *Hexagrammos otakii* | 207 | 6.0–28.1 | 107 | 6.5–19.4 | 7 | 8.9–11.8 | 13 | 9.6–19 |
| *Sebastes schlegelii* | 791 | 5.3–23.5 | 796 | 2.7–21.6 | 43 | 4.2–19.5 | 105 | 5.0–20.3 |
| *Trachidermus fasciatus* | 1 | 11.4 | 1 | 5.9 | | | 7 | 10.2–12.2 |
| *Platycephalus indicus* | 2 | 20.9–24.4 | 46 | 4.9–28.1 | | | | |
| *Cociella crocodilus* | | | 14 | 5.0– 9.3 | 5 | 6.4– 7.4 | 3 | 6.4– 9.4 |
| *Cynoglossus joyneri* | 1 | 12.6 | 698 | 6.8–20 | 69 | 4.7–17.5 | 31 | 6.1–17.5 |
| *Kareius bicoloratus* | | | 6 | 7.0–13.9 | | | 1 | 16.2 |
| *Paralichthys olivaceus* | 3 | 12.2–16 | 4 | 15–22.5 | 15 | 9.2–21 | 4 | 9.5–16.6 |
| *Scophthalmus maximus* | | | 1 | 20 | | | | |
| *Thrissa kammalensis* | | | 63 | 4.5–11.5 | 3 | 5 – 6.8 | | |
| *Stolephorus indicus* | | | 3 | 8 – 9.6 | | | | |
| *Engraulis japonicus* | | | 14 | 3.6– 8.6 | | | | |
| *Sardinella zunasi* | | | 32 | 5.6–13.2 | | | | |

Scientific names for each species were checked with Fishbase (Froese and Paury, 2010). The standard length (L) of each specimen was measured to the nearest 0.1 cm using a 30-cm ruler. Fish body weight for all specimens was weighed to the nearest 0.01 g using an electric balance (CR-5000WP, Custom, Japan).

LWRs (Ricker, 1973) were calculated using the equation $W = a \times L^b$. The relationship between the length and weight of the specimens per species was calculated by the least-square linear regression applied to logarithmic transformed data combined as the following equation (Stergiou and Moutopoulos, 2001):

$$\log W = \log a + b \log L,$$

where $W$ is fish body weight (g), $L$ is fish

**Table 2.** Descriptive statistics and estimated parameters of LWR for 17 fish species caught in the study area.

| Family | Species | N | Length range (cm) | Weight range (g) | $a$ | $b$ | 95%$CI$ | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| **Gobiidae** | *Chaeturichthys stigmatias* | 2,487 | 2.7–18.7 | 0.1– 51.6 | 0.0115 | 2.95 | 0.250 | 0.957 |
| | *Tridentiger barbatus* | 57 | 2.7–11.2 | 0.3– 43.1 | 0.0133 | 3.33 | 0.171 | 0.984 |
| | *Synechogobius ommaturus* | 1,269 | 3.4–37.2 | 0.7–264.8 | 0.0312 | 2.57 | 0.130 | 0.967 |
| | *Paratrypauchen microcephalus* | 47 | 4.0–12.4 | 0.2– 5.9 | 0.0047 | 2.90 | 0.225 | 0.942 |
| **Sciaenidae** | *Johnius belangerii* | 418 | 2.7–12.6 | 0.5– 36.5 | 0.0127 | 3.04 | 0.460 | 0.919 |
| **Hexagrammidae** | *Hexagrammos otakii* | 334 | 6.0–28.1 | 3.6–318.1 | 0.0146 | 3.05 | 0.117 | 0.961 |
| **Sebastidae** | *Sebastes schlegelii* | 1,735 | 2.7–23.5 | 0.4–395.6 | 0.0185 | 3.16 | 0.177 | 0.989 |
| **Platycephalidae** | *Platycephalus indicus* | 48 | 4.9–28.1 | 0.6–177.6 | 0.0044 | 3.11 | 0.261 | 0.956 |
| | *Cociella crocodilus* | 22 | 5.0– 9.4 | 1.5– 7.5 | 0.0093 | 2.94 | 0.165 | 0.895 |
| **Cynoglossidae** | *Cynoglossus joyneri* | 799 | 4.7–20 | 0.5– 52.5 | 0.0034 | 3.16 | 0.145 | 0.942 |
| **Paralichthyidae** | *Paralichthys olivaceus* | 26 | 9.2–22.5 | 8.8–182.7 | 0.0067 | 3.29 | 0.079 | 0.985 |
| **Engraulidae** | *Thrissa kammalensis* | 66 | 4.5–11.5 | 1.1– 18.8 | 0.0074 | 3.21 | 0.169 | 0.963 |
| | *Engraulis japonicus* | 14 | 3.6– 8.6 | 0.4– 9.4 | 0.0042 | 3.66 | 0.169 | 0.989 |
| **Clupeidae** | *Sardinella zunasi* | 32 | 5.6–13.2 | 2.2– 39.9 | 0.0048 | 3.49 | 0.068 | 0.976 |
| | *Konosirus punctatus* | 39 | 12.9–19.3 | 25.5– 95.7 | 0.0366 | 2.65 | 0.062 | 0.941 |
| **Syngnathidae** | *Syngnathus acus* | 14 | 12.5–22.7 | 0.3– 3.3 | 0.0000 | 3.62 | 0.144 | 0.904 |
| **Mugilidae** | *Mugil cephalus* | 113 | 5.1–51 | 2.95–1974.4 | 0.0123 | 3.07 | 0.095 | 0.998 |

Note: N is the number of samples, length range (cm), weight range (g), $a$ and $b$ are parameters of the LWR, 95% × $CI$ ($b$) is the 95% confidence interval of $b$, and $R^2$ is the coefficient of determination.

standard length (cm), $a$ is the initial growth coefficient and $b$ is the growth coefficient. The statistical significance level of $R^2$ was estimated in LWR fitted by least-squares regression. Only extreme outliers attributed to errors in data collection were omitted from the analyses. Pearson's correlation coefficient analysis was applied to determine the relationships between fish standard length (cm) and fish body weight (g). A $p$ value $< 0.05$ was considered significant.

The application of these regressions should be limited to the observed length ranges. These estimated parameters can be treated as mean annual values for the species in our study.

The 95% confidence interval ($CI$) of b was computed using the following equation:

$$CI = b \pm (1.96 \times SE),$$

where $SE$ is the standard error of $b$.

## 3. Results and discussion

A total of 7,593 individuals belonging to 32 species (20 families) were recorded in this study (Table 1). The total number (unit: ind) and body length range (unit: cm) varying with seasons for 32 fish species caught in study area are described in Table 1. The species, family, sample size (N), length range (cm) and weight range (g), length-weight relationship parameters $a$ and $b$, 95% $CI$ for $b$, the coefficient of determination ($R^2$) are presented in Table 2. We analyzed length-category (mm) frequency with seasonal variations for fish species *Synechogobius ommaturus*, *Hexagrammos otakii* and *Chaeturichthys stigmatias* (Fig. 2). Linear regressions of log transformed data were significant ($P < 0.05$) for all analyzed species. The most abundant species sampled was *Chaeturichthys stigmatias* (N = 2,487). The best represented family was Gobiidae with 4 species recorded.

**Table 3.** Seasonal variations (spring, summer, autumn, winter) of estimated parameters of LWR for *Synechogobius ommaturus, Chaeturichthys stigmatias, Sebastes schlegelii* and *Cynoglossus joyneri* caught in the study area.

| | Season | *a* | *b* | $R^2$ |
|---|---|---|---|---|
| *Synechogobius ommaturus* | Spring | 0.0001 | 2.46 | 0.936 |
| | Summer | 0.00002 | 2.90 | 0.912 |
| | Autumn | 0.000033 | 2.77 | 0.974 |
| | Winter | 0.00007 | 2.59 | 0.954 |
| *Chaeturichthys stigmatias* | Summer | 0.00001 | 3.10 | 0.910 |
| | Autumn | 0.000004 | 3.17 | 0.981 |
| | Winter | 0.000008 | 3.04 | 0.974 |
| *Sebastes schlegelii* | Spring | 0.00001 | 3.17 | 0.982 |
| | Summer | 0.00001 | 3.18 | 0.972 |
| | Autumn | 0.000011 | 3.19 | 0.993 |
| | Winter | 0.000012 | 3.16 | 0.996 |
| *Cynoglossus joyneri* | Summer | 0.000003 | 3.08 | 0.916 |
| | Autumn | 0.000004 | 3.05 | 0.977 |
| | Winter | 0.000001 | 3.23 | 0.966 |

The coefficients of determination ($R^2$) ranged from 0.95 to 1.00 for *Mugil cephalus, Sebastes schlegelii, Engraulis japonicus, Paralichthys olivaceus, Tridentiger barbatus, Sardinella zunasi, Synechogobius ommaturus, Thrissa kammalensis, Hexagrammos otakii, Chaeturichthys stigmatias, Platycephalus indicus*. On the other hand, $R^2$ values ranged from 0.90 to 0.95 for *Cynoglossus joyneri, Konosirus punctatus, Johnius belangerii, Syngnathus acus, Cociella crocodilus*, corresponding to a mean value of 0.957 (±0.03).

LWR slope ($b$) values ranged from 2.57 for *Synechogobius ommaturus* to 3.66 for *Engraulis japonicus*. The median value was 3.11 for *Platycephalus indicus*, although 50% of the values ranged from 2.95 to 3.30 for the complete data set. When $b = 3$, weight growth is isometric, and when the value of $b$ differs from 3 ($b \neq 3$), weight growth is allometric. In terms of growth type, these results revealed that 3 species showed negative allometries ($b < 3$), 9 showed positive allometries ($b > 3$) and 5 showed isometric growth ($b = 3$). Most of the species generally presented positive allometric growth. *C. crocodilus* ($b = 2.94$), *C. stigmatias* ($b = 2.90$), *J. belangerii* ($b = 3.04$), *H. otakii* ($b = 3.05$), *M. cephalus* ($b = 3.07$) all displayed isometric growth. Various factors may be responsible for differences in parameters of LWR such as temperature, salinity, food (quantity, quality and size), sex, time of year and stage of maturity.

## 4. Conclusions

The data collected during this study represents an important contribution of base line data on the LWR of a number of fish species that were previously unavailable. It is important to point out that these LWR should be strictly limited to the length ranges used in the estimation of

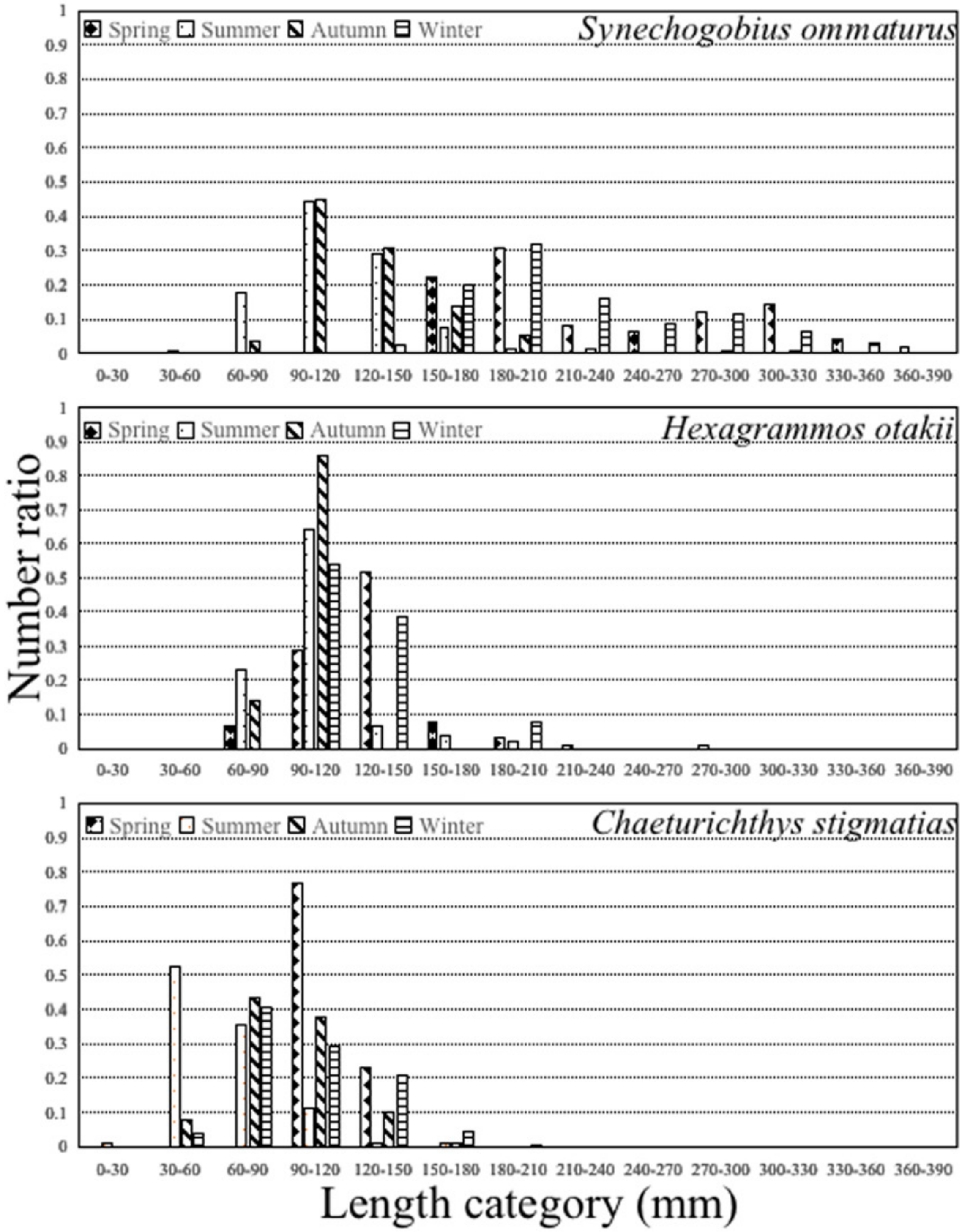


**Fig. 3** Length-frequency with seasonal variations for fish species *Synechogobius ommaturus*, *Hexagrammos otakii* and *Chaeturichthys stigmatias*.

the linear regression parameters (PETRAKIS and STERGIOU, 1995). The results obtained in the current study will contribute to the knowledge of important fish populations in the Luanhe River Estuary and also assist fisheries scientists and managers in the future.

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