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# Sex Ratio, Spawning Period, and Sexual Group Maturity of the Largehead Hairtail *Trichiurus japonicus* (Teleostei: Trichiuridae) in Korean Waters

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**Abstract:** This study was performed to obtain information on the sex ratio, spawning period, and size at sexual maturity for fishery management of the largehead hairtail *Trichiurus japonicus* in Korean waters. The overall sex ratio (female, F; male, M) was 1:0.46 (n = 1274 females:589 males, 68.4% female) and as fish increased in length, the proportion of females increased. The oocyte development pattern was group-synchronous development, for which oocyte groups at different stages can be identified within the same ovary. The average gonadosomatic index (GSI) showed two peaks in June (3.03) and August (3.10) in females and in May (1.81) and September (2.24) in males. The median value of GSI showed two peaks in May (2.65F, 1.78M) and September (2.55F, 1.87M) for both females and males. As a result of analyzing the GSI and the monthly gonadal developmental stages, the main spawning season was estimated to be bi-annual (May–June and September–October). The anal length of fish at 50% sexual maturity was analyzed using a logistic regression model and was determined to be 16.38 cm (female) and 18.31 cm (male).

**Keywords:** *Trichiurus japonicus*; sex ratio; GSI; spawning period; sexual group maturity

**Key Contribution:** The spawning season of the largehead hairtail *Trichiurus japonicus* was estimated to be bi-annual (May–June and September–October) in Korean waters. The anal length of fish at 50% sexual maturity was 16.38 cm (female) and 18.30 cm (male).

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## 1. Introduction

The hairtail, *Trichiurus*, is a migratory teleost belonging to the family Trichiuridae of the order Scombriformes and is distributed in temperate and tropical zones around the world [1]. In Northeast Asia, the hairtail mainly migrates from the south of Hokkaido to the coastal waters of the East China Sea around Japan, the Korean Peninsula, and the Yellow and Bohai Seas [2].

*Trichiurus* sp., which is mainly caught in Republic of Korea, was previously reported as *Trichiurus lepturus*, but was later identified as *T. japonicus* as a result of molecular biological analysis [3,4]. In Korea, *Trichiurus* is an important fishery resource, with the average catch being 124,000 tons in the 1980s and approximately 68,000 tons in the early 2000s, though the average catch in the last five years has decreased to 55,000 tons [5]. The reasons for the continued decline in hairtail catch include the entry into force of The United Nations Convention on the Law of the Sea, which was signed in 1994, and the entry into force of

the agreement on fishing with Japan in 1999. As a result, many researchers continue to study the ecology, reproduction, and fishing of hairtail to find a way to manage the reduced fishing grounds [6–10].

The reproductive information, such as sex ratio, reproductive cycle, main spawning period, and maturity of the teleost, is critical in terms of the conservation and management of biological resources [8,11,12]. There have been many studies on the reproduction of the hairtail, including those on fishery biology [13]; migration in the East China Sea and Yellow Seas [14]; maturity and spawning in the Western Wakasa Bay [15]; stock assessment of the Indian waters [16]; maturation and spawning in Korean waters [6,7,17]; reproduction in the South China Sea [18]; reproduction in the southern Brazil subtropical convergence ecosystem [19]; age, growth, and reproduction in the southern East China Sea [20]; fishery, reproductive biology, and stock status on the south-west coast of India [21]; and reproductive biology in south-eastern Australia [22]. The results on the main spawning period and sexual maturity of *T. japonicus* migrating in Korean waters show differences among these studies [6,7,17].

Various methods, such as morphology, anatomy, histology, and molecular biology, are used to analyze biological indicators related to reproduction in teleosts. However, the results obtained via morphological and anatomical methods can lead to serious errors; in particular, when analyzing gonadal development and maturity using the histological method, many errors can occur in the interpretation of the results, so caution is needed regarding this [11,12,23]. In addition, immature individuals should be excluded from the analysis of the frequency of gonadal development stage and gonadosomatic index (GSI), which are essential parameters for main spawning period estimation. The sex ratio analysis differs according to the fishing methods, age of the sample, and size, so caution is required [7,18,19,24].

In this study, sex ratio, size at 50% sexual maturity, and main spawning period were analyzed and compared with existing data to provide information for the efficient fishery resource management of *T. japonicus* in Korea.

## 2. Materials and Methods

### 2.1. Sampling

Samples of *Trichiurus japonicus* were collected from January 2020 to December 2020 with a hairtail longline in Jeju Strait, Korea (Figure 1). About 150 specimens were collected every month and the sex ratio was analyzed with 1863 specimens (Tables 1 and 2). Among this group, a total of 549 specimens (total length (TL): 81.7 ± 11.3 cm; total weight (TW): 322.1 ± 185.8 g) were analyzed with histological analysis of the gonads (approximately 40–50 specimens every month) (Figure 2, Table 1). For the analysis of the gonadosomatic index (GSI), 531 specimens were used, excluding 18 immature specimens.

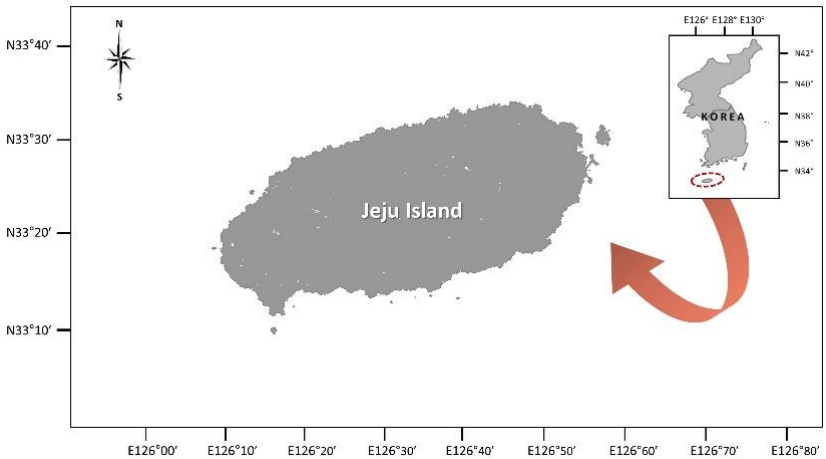


**Figure 1.** Sampling area of *Trichiurus japonicus*.

**Table 1.** Number of samples used in the analyses of the largehead hairtail *Trichiurus japonicus*.

| Months (2020) | Number of Samples (Total Length, TL; Total Weight, TW) | |
|---|---|---|
| | **Sex Ratio** | **Histological Analysis of the Gonads** |
| January | 30 (TL 85.5 ± 6.9 cm, TW 346.6 ± 128.0 g) | 30 (TL 85.5 ± 6.9 cm, TW 346.6 ± 128.0 g) |
| February | 30 (TL 77.1 ± 4.6 cm, TW 253.4 ± 57.1 g) | 30 (TL 77.1 ± 4.6 cm, TW 253.4 ± 57.1 g) |
| March | 70 (TL 83.8 ± 7.9 cm, TW 308.2 ± 126.8 g) | 32 (TL 85.0 ± 8.7 cm, TW 343.3 ± 145.5 g) |
| April | 185 (TL 79.1 ± 12.6 cm, TW 281.7 ± 204.1 g) | 62 (TL 79.0 ± 15.3 cm, TW 300.8 ± 258.2 g) |
| May | 95 (TL 78.3 ± 9.9 cm, TW 252.6 ± 130.1 g) | 60 (TL 74.8 ± 19.0 cm, TW 279.0 ± 195.5 g) |
| June | 108 (TL 80.3 ± 11.9 cm, TW 323.8 ± 172.8 g) | 25 (TL 90.2 ± 12.9 cm, TW 420.9 ± 188.3 g) |
| July | 70 (TL 78.8 ± 10.9 cm, TW 316.0 ± 179.2 g) | 62 (TL 78.7 ± 11.4 cm, TW 206.7 ± 43.0 g) |
| August | 228 (TL 79.6 ± 5.8 cm, TW 284.8 ± 92.4 g) | 64 (TL 79.6 ± 7.4 cm, TW 294.5 ± 102.6 g) |
| September | 209 (TL 83.1 ± 10.0 cm, TW 328.7 ± 163.8 g) | 64 (TL 81.7 ± 10.4 cm, TW 317.7 ± 150.9 g) |
| October | 272 (TL 84.9 ± 8.2 cm, TW 327.5 ± 159.7 g) | 60 (TL 87.6 ± 10.9 cm, TW 388.9 ± 225.6 g) |
| November | 286 (TL 83.6 ± 8.5 cm, TW 314.6 ± 197.4 g) | 30 (TL 84.2 ± 11.1 cm, TW 320.1 ± 188.0 g) |
| December | 280 (TL 83.7 ± 7.2 cm, TW 305.4 ± 120.5 g) | 30 (TL 84.6 ± 9.3 cm, TW 322.4 ± 138.4 g) |
| Total | 1863 | 549 |
| Average | TL 81.9 ± 9.2 cm, TW 303.2 ± 155.3 g | TL 81.7 ± 11.3 cm, TW 322.1 ± 185.8 g |

**Table 2.** Sex ratio with total length of largehead hairtail *Trichiurus japonicus*.

| Total Length (cm) | Number | | | Sex Ratio (F:M) | Female (%) |
|---|---|---|---|---|---|
| | **Total** | **Female** | **Male** | | |
| 50.1–55.0 | 3 | 2 | 1 | 1:0.50 | 66.7 |
| 55.1–60.0 | 4 | 3 | 1 | 1:0.33 | 75.0 |
| 60.1–65.0 | 32 | 13 | 19 | 1:1.46 | 40.6 |
| 65.1–70.0 | 77 | 46 | 31 | 1:0.67 | 59.7 |
| 70.1–75.0 | 262 | 153 | 109 | 1:0.71 | 58.4 |
| 75.1–80.0 | 496 | 293 | 203 | 1:0.69 | 59.1 |
| 80.1–85.0 | 456 | 311 | 145 | 1:0.47 | 68.2 |
| 85.1–90.0 | 222 | 177 | 45 | 1:0.25 | 79.7 |
| 90.1–95.0 | 117 | 102 | 15 | 1:0.15 | 87.2 |
| 95.1–100.0 | 113 | 102 | 11 | 1:0.11 | 90.3 |
| 100.1–105.0 | 55 | 48 | 7 | 1:0.15 | 87.3 |
| 105.1–110.0 | 14 | 12 | 2 | 1:0.17 | 85.7 |
| 110.1–115.0 | 7 | 7 | - | - | 100 |
| 115.1–120.0 | 5 | 5 | - | - | 100 |
| Total/Average | 1863 | 1274 | 589 | 1:0.46 | 68.4 |

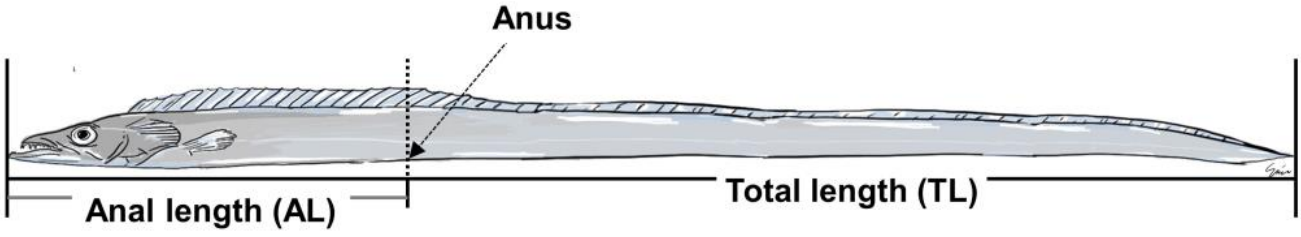


**Figure 2.** Morphometric characteristics of *Trichiurus japonicus*.

### *2.2. Environmental Conditions*

Monthly averages of water temperature profiles of the study area were calculated from daily measurements obtained from the Korea Hydrographic and Oceanographic Administration [25].

### *2.3. Histological Analysis*

After measuring morphometric characteristics (TL, TW, AL, gonad weight), gonads were prepared for examination under light microscopy. The samples were fixed in aqueous 10% neutral formalin for 24 h. The fixed sample was rinsed in running water for 48 h, dehydrated through a graded ethanol series (70–100%), and then embedded in paraplast (Leica, Wetzlar, Germany). Embedded tissues were serial-sectioned at a thickness of 4–6 µm using a microtome (RM2235, Leica, Wetzlar, Germany). Samples were stained with Mayer's hematoxylin—0.5% eosin (H–E) stain.

### *2.4. Sex Ratio*

The sex ratio (female:male) and percentage of females in the population were calculated with the following Equations (1)and (2):

$$\text{Sex ratio} = \text{Female (n)}:\text{Male (n)} \quad (1)$$

$$\text{Female frequency (\%)} = [\text{Female (n)}/\text{Female (n)} + \text{male (n)}] \times 100 \quad (2)$$

### *2.5. Gonadosomatic Index (GSI)*

The gonadosomatic index (GSI) was calculated with the following Equation (3) [8,24,26,27]:

$$\text{GSI } (\%) = \frac{\text{Gonad weight (g)}}{\text{Total weight (g)}} \times 100 \quad (3)$$

### *2.6. Gonadal Developmental Stage*

The oocytes were classified into six developmental stages: oogonium, previtellogenic, initial vitellogenic, active vitellogenic, mature, and ripe [28]. The male germ cells were classified into developmental stages of spermatogonium, spermatocyte, spermatid, and sperm [22]. Gonadal development was classified into growing, mature, ripe, and spent and degenerative stage for both males and females according to the degree of dominance of each developmental stage of germ cells [29].

### *2.7. Sexual Group Maturity*

In this study, the logistic regression model was used to estimate anal length at 50%, 75%, and 97.5% sexual maturity. Individuals were categorized based on their length into 2.0 cm class intervals. Afterwards, for each length group, we calculated 50%, 75%, and 97.5% group maturity levels based on the size of the individuals corresponding to the mature, ripe, and spent and degenerative stage. The mature individuals were evaluated based on whether their ovaries were dominated by active vitellogenic oocytes, mature oocytes of GVBD (germinal vesicle breakdown), or ripe oocytes, and only individuals that developed ovaries after spawning were considered.

## 3. Results

### *3.1. Sex Ratio*

The overall sex ratio (F:M) was 1:0.46. The female frequency was 68.4%, and as fish increased in length, the proportion of females increased (Table 2).

### *3.2. Monthly Change of Gonadosomatic Index (GSI)*

The average of the GSI showed two peaks in June (3.03) and August (3.10) for females and May (1.81) and September (2.24) for males. In females, after increasing from January to June, the GSI showed a rapid decrease in July. After showing a rapid increase again in August, it continued to decrease until November. In males, after reaching 1.8 in May, the GSI rapidly decreased in June, increased from July to September, and then decreased again until November (Figure 3).

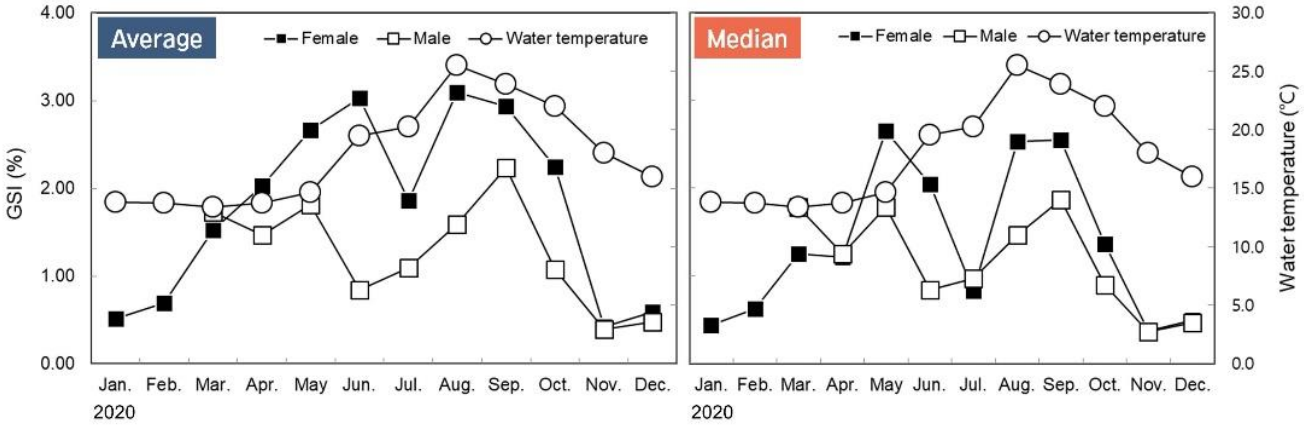


**Figure 3.** Monthly changes in gonadosomatic index (GSI) of largehead hairtail *Trichiurus japonicus* and water temperature.

The median value of the GSI showed two peaks in May (2.65F, 1.78M) and September (2.55F, 1.87M) for both males and females. Both males and females showed an increase from January to May, followed by a rapid decrease in June and July. After showing a rapid increase again in September, the GSI continued to decrease until November (Figure 3).

### *3.3. Histological Change with Gonadal Developmental Stage*

#### 3.3.1. Ovary

The oocyte development pattern was of the group-synchronous type, for which oocyte populations of various stages can be identified within the same ovary [30]. The spawning pattern showed a multiple spawning histology in which growing oocytes developed after spawning within the same ovary (Figure 4).

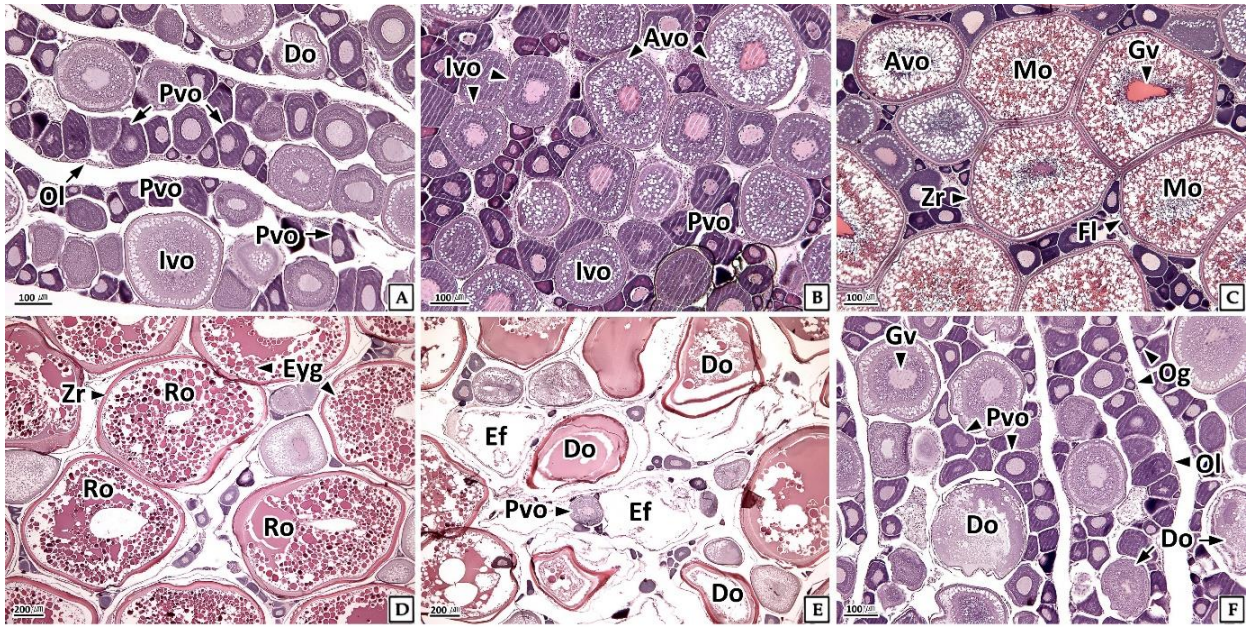


**Figure 4.** Ovarian developmental stage of the largehead hairtail *Trichiurus japonicus*. H–E stain. (**A**,**B**) growing stage, (**C**) mature stage, (**D**) ripe stage, (**E**,**F**) spent and degenerative stage. Avo: active vitellogenic oocyte, Do: degenerative oocyte, Ef: empty follicle, Eyg: eosinophilic yolk granule, Fl: follicular layer, Gv: germinal vesicle, Ivo: initial vitellogenic oocyte, Mo: mature oocyte, Og: oogonia, Ol: ovarian lobule, Pvo: previtellogenic oocytes, Ro: ripe oocyte, Zr: zona radiata.

In the growing stage of the ovary, the spent and degeneration of oocytes was not observed. In the early growing stage, the ovary was filled with oogonia and previtellogenic oocytes (Figure 4A), and initial vitellogenic oocytes and active vitellogenic oocytes were mainly observed in the late growing stage (Figure 4B). Some active vitellogenic oocytes were seen in the mature stage, but these were mainly mature oocytes with GVBD (germinal vesicle breakdown) (Figure 4C). At the ripe stage, ripe oocytes with a diameter of approximately 350 μm and eosinophilic stain were mainly observed (Figure 4D). At the spent and degenerative stage, the evidence for the release of ripe oocytes and the degeneration of undischarged oocytes, as well as the relocation of early oocytes, was confirmed (Figure 4E,F).

#### 3.3.2. Testis

The testicular development pattern was group synchronous, as multiple stages of germ cell populations within the same gonad were identified simultaneously (Figure 5). In the early growing stage, spermatocytes and spermatids were mainly observed (Figure 5A), and in the late growing stage, spermatocytes with condensed nucleoplasm and cytoplasm were mainly observed, compared to spermatogonia along with some spermatids (Figure 5B). In the mature stage, basophilic spermatids in the H–E stain were mainly identified (Figure 5C), and testis in the ripe stage were filled with sperm of basophilic in the H–E stain (Figure 5D). In the spent and degenerative stage, degeneration and resorption of the remaining sperm after being spent were observed in the medulla of the testis, but spermatogonia and spermatocytes were rearranged in the cortex (Figure 5E,F).

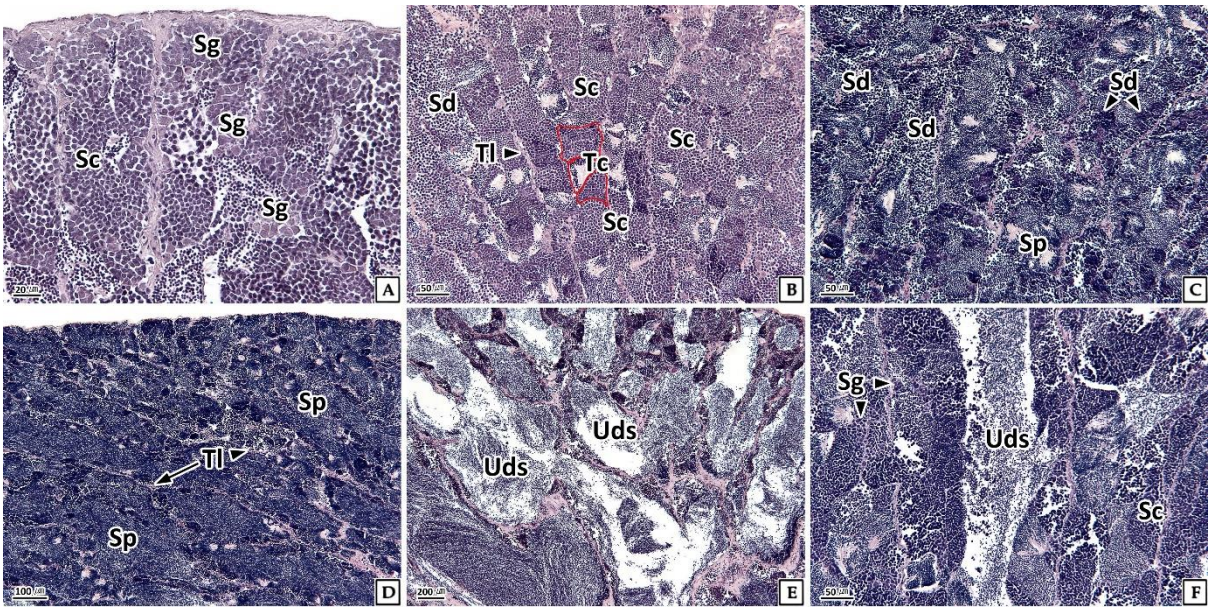


**Figure 5.** Testicular developmental stage of the largehead hairtail *Trichiurus japonicus*. H–E stain. (**A**,**B**) growing stage, (**C**) mature stage, (**D**) ripe stage, (**E**,**F**) spent and degenerative stage. Sc: spermatocytes, Sd: spermatids, Sg: spermatogonia, Sp: sperm, Tc: testicular cyst, Tl: testicular lobule, Uds: undischarged sperm.

### *3.4. Monthly Change of Gonadal Developmental Stage*

#### 3.4.1. Ovary

The annual frequencies (January 2020–December 2020) of the ovarian developmental stages were 31.3% for the growing stage, 11.9% for the mature stage, 19.5% for the ripe stage, and 37.5% for the spent and degenerative stage (Figure 6). The monthly frequencies of the spent and degenerative stage (48.0%) and the growing stage (40.0%) dominated in January, and the growing stage had a frequency of 92.0% in February. In March, the growing stage decreased to a 55.6% frequency, but the mature stage increased to 33.3%. The

ripe stage was dominant in April at 29.7% frequency and in May at 54.8%. In June, the ripe stage had a 54.2% frequency and the spent and degenerative stage had a frequency of 29.2%. The ripe stage was not observed in July, and the spent and degenerative stage reached 82.1% frequency. In August, the mature and ripe stages had a frequency of 36.6% and 17.1%, respectively. In September, when the water temperature dropped, the frequency of the ripe stage was 32.4% and that of the spent and degenerative stage was 51.4%. The spent and degenerative stage (93.6%) dominated in October and the growing stage dominated in November and December (Figure 7).

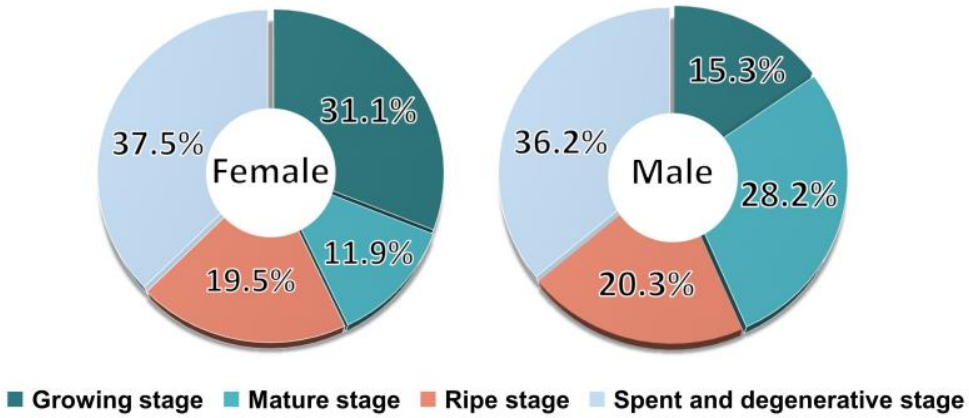


**Figure 6.** Annual frequency of gonadal developmental stage in the largehead hairtail *Trichiurus japonicus*.

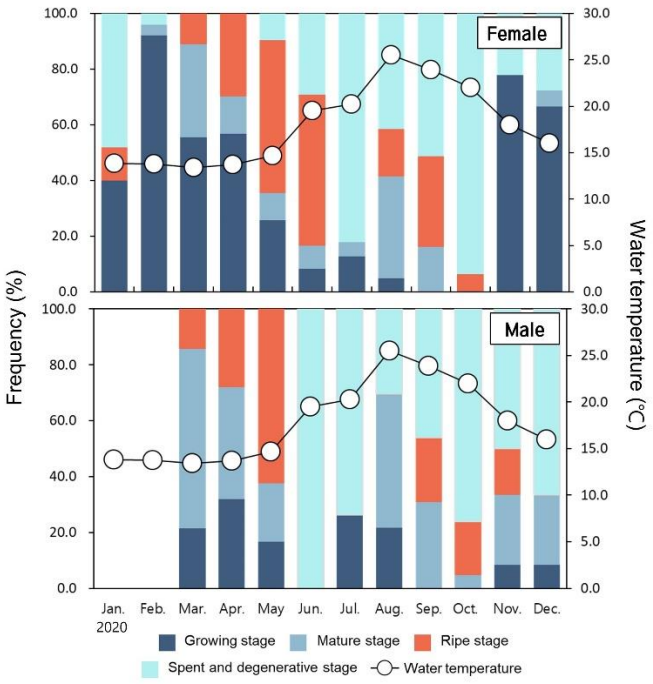


**Figure 7.** Monthly change in frequency of gonadal developmental stage in the largehead hairtail *Trichiurus japonicus* and water temperature.

3.4.2. Testis

The annual frequencies (March 2020–December 2020) of the testicular developmental stages were 15.3% for the growing stage, 28.2% for the mature stage, 20.3% for the ripe stage, and 36.2% for the spent and degenerative stage (Figure 6). The monthly frequencies of the testicular developmental stages, the ratios of the growing, mature, and ripe stages, were 21.4%, 64.3%, and 14.3% in March, respectively. In April, the mature stage reached a

40.0% frequency and the ripe stage reached 28.0%. In May, the mature stage and ripe stage dominated at 20.8% and 62.5%, respectively. In June, the spent and degenerative stage was at 100%. In July, the mature stage and ripe stage were not confirmed, and the spent and degenerative stage was at 73.7%. In August, the growing stage showed 21.7% frequency and the mature stage 47.8%. In September, the mature stage was at 30.8% and the ripe stage was at 23.1%. From October to December, the spent and degenerative stage was dominant (Figure 7).

### *3.5. Sexual Group Maturity*

The histologically analyzed female (n = 368) and male (n = 181) maturities were 96.2% and 80.7%, respectively (Table 3). In females, anal length (AL) at 50% maturity was 16.38 cm, and at 75% and 97.5% maturity, 19.39 cm and 26.42 cm, respectively. In males, AL at 50% maturity was 18.31 cm, and at 75% and 97.5% maturity, 23.91 cm and 36.97 cm, respectively (Figure 8).

**Table 3.** Sexual group maturity with anal length of largehead hairtail *Trichiurus japonicus*.

| Anal Length (cm) | Female | | | Male | | |
|---|---|---|---|---|---|---|
| | Examined Individuals | Mature Individuals | Maturity (%) | Examined Individuals | Mature Individuals | Maturity (%) |
| 18.1–20.0 | 5 | 5 | 100 | 7 | 3 | 42.9 |
| 20.1–22.0 | 37 | 32 | 86.6 | 25 | 16 | 64.0 |
| 22.1–24.0 | 68 | 66 | 97.1 | 51 | 43 | 84.3 |
| 24.1–26.0 | 72 | 69 | 95.8 | 44 | 38 | 86.4 |
| 26.1–28.0 | 74 | 70 | 94.6 | 29 | 22 | 75.9 |
| 28.1–30.0 | 23 | 23 | 100 | 7 | 7 | 100 |
| 30.1–32.0 | 28 | 28 | 100 | 1 | 1 | 100 |
| 32.1–34.0 | 34 | 34 | 100 | 12 | 12 | 100 |
| 34.1–36.0 | 14 | 14 | 100 | 3 | 2 | 66.7 |
| 36.1–38.0 | 6 | 6 | 100 | 2 | 2 | 100 |
| 38.1–40.0 | 2 | 2 | 100 | - | - | - |
| 40.1–42.0 | 3 | 3 | 100 | - | - | - |
| 42.1–44.0 | 2 | 2 | 100 | - | - | - |
| Total | 368 | 354 | 96.2 | 181 | 146 | 80.7 |

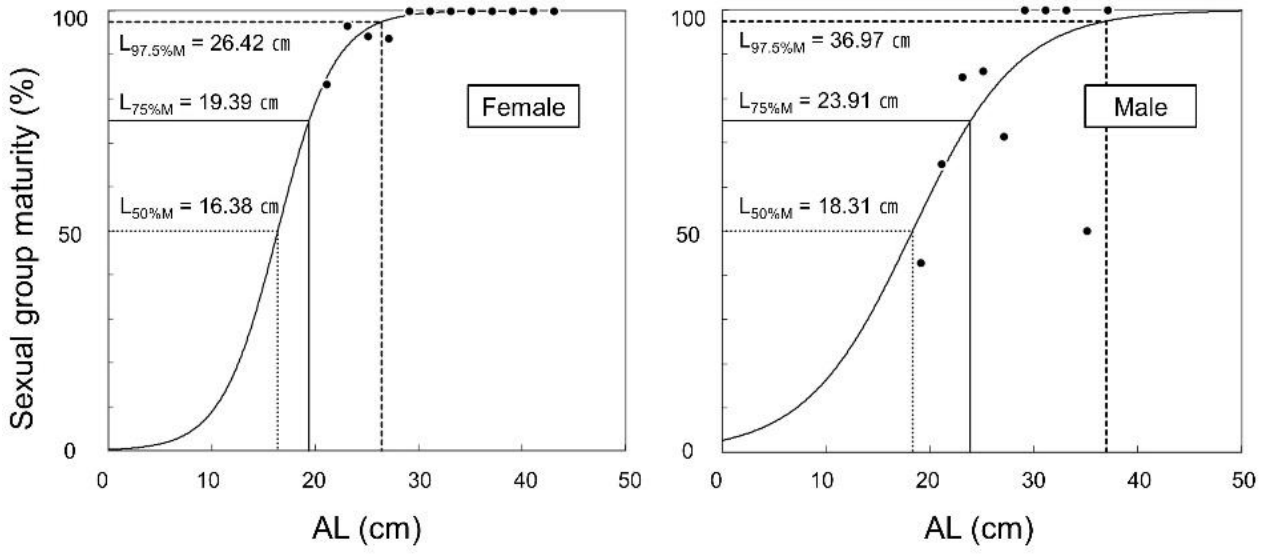


**Figure 8.** Relationship between anal length (AL) and sexual group maturity of largehead hairtail *Trichiurus japonicus*.

## 4. Discussion

The sex ratio of *Trichiurus* has been reported to be 1:1 or a high female ratio, but as shown in Table 3, it showed differences depending on the region and researcher. These discrepancies are thought to be due to differences in sample size according to the sampling period and sampling method [19]. Therefore, for sex ratio analysis, analyzing the same number of individuals in the same group size can reduce differences in the interpretation of the results. The sex ratio of *Trichiurus* is generally high for males in small groups and tends to increase for females with increasing size [19]. In the group collected from the East China Sea, females were longer and heavier than males. These biological differences between males and females are due to the difference in growth rate and lifespan, because females, after two years of age, have a faster growth rate than males, and females live more than four years longer than males [7,8].

In many studies on *Trichiurus*, even at the same stage of gonadal development, the GSI differed among researchers. The average GSI peak in females in previous studies was approximately 4.0 [6], 5.42 [7], and 3.5 [22,26], while in this study, it was 3.10. These differences in the GSI are believed to be due to variations in nutritional status according to habitat and food [19,30,31], anatomical errors in the process of gonadal extraction, and macroscopical classification of gonadal developmental stages [11,12,23].

Usually, the analysis of the GSI includes immature individuals and uses the average value. The GSI may be underestimated when immature individuals are included. In the GSI analysis, if the number of samples is small, a large difference in the average value may occur due to some individuals having a very low or high GSI. Therefore, when a small number of samples is used, it is recommended that the median value be used rather than the average. In this study, the GSI analysis excluded immature individuals and showed some differences when comparing the average and median values. When averages were used, two peaks were observed in June and August for females and in May and September for males. However, when the median value was applied, both males and females showed two peaks in May and September.

Anatomical and histological methods are important in the analysis of the gonadal developmental patterns, main spawning period, and sexual group maturity of teleosts. The anatomical method has advantages over the histological method in terms of time and cost, but has the disadvantage of low accuracy. Macroscopic staging for the ovarian developmental stage of *Trichiurus* showed approximately 85% accuracy compared to microscopic staging [18]. Care should be taken in microscopic interpretation for ovarian tissue specimens from the ripe or spawning period of teleosts. In particular, care must be taken in the interpretation of skipped spawning and the incidence of high-intensity atresia, because these histological features can be interpreted as normal spawning objects [32–34].

Oocyte development patterns can be classified into synchronous, group-synchronous, and asynchronous types according to the distribution patterns of dominant oocytes in the ovary [35]. The group-synchronous pattern is the one in which at least two populations of oocytes are distinct at the same time, and is a type mainly seen in teleosts, including *Leiognathus nuchalis* [29,36].

Previous reports on oocyte developmental patterns have also reported that *Trichiurus* are group synchronous and spawn more than twice during the spawning season once a year [6,7,17,18]. In this study, the oocyte developmental pattern was also confirmed as a group-synchronous type. However, in this study, the spawning season was observed twice a year, in May–June and September–October, and it was different from the April–October [6], June–November [7], and June–October [17] spawning seasons reported in the same region.

This difference is believed to be due to the method of analysis used to determine the maturity of the gonads. Cha and Lee [6] and Kim et al. [7] evaluated the spawning period by means of the GSI and gonadal developmental stages by gonadal appearance. In this study, the GSI increased again after the first spawning. In addition, as a result of the histological analysis of the gonads, the degeneration of residual oocytes and the

reappearance of early oocytes appeared simultaneously after the first spawning, and the development of early oocytes was confirmed up to the second spawning period.

Histological evidence of ovarian maturation should be considered when evaluating the maturity of females. In particular, in many studies on group-synchronous type fish, mistakes are made in judging ovarian histological maturity due to the difficulty of distinguishing between the germ cell development and the ovarian developmental stage. Oocytes of teleosts are laid in the primary oocyte stage of the first meiotic division. Therefore, from the histological view, the oocyte developmental stage of the teleost is based on morphological criteria including cell size, degree of yolk accumulation, and nuclear changes from the oogonium to the primary oocyte that can be identified in the ovary [28]. Germ cell development is the differentiation and development process of germ cells, but the ovarian developmental stage is classified based on the dominant germ cells in the gonads. Therefore, determination of ovarian maturity in group-synchronous type fish should be based on ovarian maturity, not in the developmental stage of germ cells.

The size at 50% sexual group maturity in *Trichiurus* has been reported differently by researchers, as shown in Table 3, and these differences are believed to be due to differences in the growth rate and analysis methods used. In the population collected from a sea area similar to this study, the anal length (AL) at 50% sexual group maturity was 25.5 cm [19], 26.0 cm [6], 26.4 cm [20], and 25.0 cm [7]. These results are different from the 16.38 cm AL found in this study. This difference is believed to be due to the difference in standards and evaluation methods used for mature individuals (Table 4).

**Table 4.** Sex ratio and size of 50% sexual group maturity ($L_{50}$) in *Trichiurus* sp.

| Region | Species | Sampling Area | Sex Ratio (F:M) | Size (cm) | Citation |
|---|---|---|---|---|---|
| Tropical to subtropical | *T. lepturus* | Visakhapatnam Waters, India | - | TL 42.5 | Reuben et al., 1997 [37] |
| | | All-India | - | TL 60 | Thiagarajan et al., 1992 [16] |
| | | Karnataka Coast, India | 1:0.85 | TL 55.4 | Rajesh et al., 2015 [21] |
| | | Arabian Sea, Oman | 1:0.12 | TL 79 | Al-Nahdi et al., 2009 [24] |
| | | Northern Arabian Sea | 1:0.75 | TL 61.2 | Ghosh et al., 2014 [27] |
| | | Northern Bay of Bengal | 1:0.81 | TL 52.9 | |
| | | South-eastern Brazil | - | TL 39 | Bellini, 1980 [38] |
| | | Gulf of Mexico | - | TL 35 | Sheridan et al., 1984 [39] |
| | | Southern Brazil | 1:1 | TL 69.3 | Martins and Haimovici, 2000 [19] |
| Temperate | *T. nanhaiensis* | South China Sea | 1:1 | AL 28.2 | Kwok and Ni, 1999 [18] |
| | *T. lepturus* | South China Sea | 1:1 | AL 25.5 | |
| | | South-eastern Australia | 1:0.4 | TL 108.0 | Clain et al., 2023 [22] |
| | | Jeju Island, Korea | - | AL 26.0 | Cha and Lee, 2004 [6] |
| | *T. japonicus* | Southern East China Sea | 1:1 | PL 26.4 | Shih et al., 2011 [20] |
| | | Jeju Island, Korea | 1:0.38 | AL 25.0 | Kim et al., 2020 [7] |
| | | Jeju Island, Korea | 1:0.46 | AL 16.4 | Present study |

AL: anal length, PL: preanal length, TL: total length.

In the report of Cha and Lee [6], four stages of ovary development were macroscopically classified as immature, maturing, mature, and spent, based on the size and color of the gonad, and the size and transparency of the egg. After the maturing stage, a fish was classified as a mature individual. Kim et al. [7] classified five stages, immature, developing, mature, spawning, and resting, under the same criteria as Cha and Lee [6], and considered a fish to be a mature individual after the mature stage. Kwok and Ni [18] and Shih et al. [20] classification methods seemed to be based on the oocyte developmental stage, not the ovarian developmental stage (Table 4).

The information on the main spawning season (May–June and September–October) and size at 50% group sexual maturity (AL 16.38 cm) obtained in this study can be considered for the establishment of prohibited fishing size and seasons for resource management of the *T. japonicus* in Korean waters.

## 5. Conclusions

This study was performed to obtain information on the exact reproductive ecology for fishery management of the largehead hairtail *Trichiurus japonicus* in Korea. The overall sex ratio (female:male) was 1:0.46 (n = 1274:589, 68.4% female) and the percentage of females in the population tended to increase with length. The sex ratio was different from that found in previous studies [15–17,34], and one of the methods employed to minimize this difference was to use the same number of individuals in the same group size from the same population. As a result of using the average and median values in the GSI analysis, both peaks appeared twice, but there was a temporal difference (average: F, June and August, M, May and September; median value: F and M, May and September). From these results, it is also recommended that the median together with the average be used in the analysis of the GSI. The spawning season was estimated to occur twice a year (May–June and September–October), and the anal length at 50% sexual group maturity was 16.38 cm for males and 18.31 cm for females. These results are different from those of previous studies, and thus differences in maturity standards and interpretations should be considered. The data on the main spawning season and size at 50% sexual group maturity can be considered for the establishment of prohibited fishing size and seasons for resource management of the *Trichiurus japonicus* in Korean waters.

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