Morphometric and Meristic Characterization of Hairtails Trichiurus lepturus Linnaeus, 1758 (Scombriformes: Trichiuridae) from the Northern Coast of Java, Indonesia

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Abstract

Hairtails (*Trichiurus* spp.) are economically important fisheries resources and have become an export commodity. In Indonesia, there are several hairtail species; however, each species distribution is not yet certainly known. This study aimed to identify and determine the morphometric and meristic character of the hairtail from the northern coast of Java, Indonesia. Fish specimens were obtained from fishermen catches in the north coast of Pati and Demak (Central Java) and the northern coast Cirebon (West Java), which captures the fish in less than one-week fishing operation. Fish samples were grouped based on morphological similarities identified in previously published works. After that, 22 morphometric and four meristic characters were measured and counted. Principal Component Analysis and Discriminant Analysis were used to analyze morphometric data, while the meristic data were compared to the available published works. The hairtail caught at the northern coast of Java was long, flat, silvery in color, and had a sagittal crest, with the fin formula being D.III.125-134, P.I.10, and A.I.98-104. According to the morphological and meristic characters, the hairtail caught at Java’s northern coast was identified as *Trichiurus lepturus*. The most significant morphological variation was the snout length and caudal peduncle. The PCA and scattergram analyses showed that *T. lepturus* from the coast of Pati and Cirebon have a high morphometric character resemblance and possibly are members of the same population. *T. lepturus* in Demak waters formed a separate population group from *T. lepturus* from the coast of Pati and Cirebon, however still in the same species.
1. Introduction

Hairtails (Trichiurus Linnaeus, 1758 and other genera like Lepturacanthus) are widely caught economically important fishes and have become trade commodities (Meriem et al., 2011; Apriliiani et al., 2018; Hashemi et al., 2020; Jeong et al., 2021; Liao et al., 2021). Food and Agriculture Organization recorded the total production of largehead hairtail worldwide as much as 1.15 million tons (FAO, 2020). Based on the Indonesian export data, the fresh hairtail was exported to several countries such as China, Thailand, Taiwan, Malaysia, and South Korea. The increased demand for hairtail exports has led to an increase in the catch of hairtails in Indonesia. Currently, hairtail resources have reached economic overfishing due to excessive fishing pressure (Panhwar et al., 2018). The hairtail is distributed widely in the tropical and temperate waters worldwide (Bar-bosa et al., 2011; Cruz-Torres et al., 2014) and can be found in the Indian Ocean, the Atlantic Ocean, and the Pacific Ocean. In the genus of Trichiurus, 17 species are recorded as members; however, only eleven species are considered as valid species i.e. Trichiurus lepturus, Trichiurus auriga, Trichiurus australis (Chakraborty et al., 2005), Trichiurus brevis, Trichiurus gangeticus, Trichiurus japonicus, Trichiurus russelli, Trichiurus nitens, Trichiurus margarites, Trichiurus nanhaiensis, and Trichiurus nickolensis (Burhanuddin and Iwatsu-ki, 2003; Nakamura and Parin, 1993; Burhanuddin et al., 2002; Hsu et al., 2009; Fricke et al., 2022). Hair-tail species have different geographic distributions; for example, the T. gangeticus and Trichiurus auriga have restricted geographic distribution. Trichiurus auriga is distributed and commonly found in the Indian Ocean, Red Sea, and Timor, while T. gangeticus is limited to the east coast of India (Nakamura and Parin, 1993). In Indonesia, hairtail occurs along the east coast of Sumatra, the northern and southern coasts of Java, the coast of Kalimantan Island, the waters of South and North Sulawesi, the waters of Nusa Tenggara, the seas of Maluku, the Banda Sea, and the Arafura Sea (Carpenter and Niem, 2001). Carpenter and Niem (2001) stated that six species of hairtails could be found in Indonesia, namely Trichiurus lepturus, T. haumela, T. muticus, T. glassodon, T. auriga, and L. savala Cuvier, 1829. Recently, T. brevis was also reported found in East Java Indonesia (Firawati et al., 2017).

In general, fish can be identified based on their morphological features such as morphometric and meristic characteristics. Morphometric and meristic characters have several advantages such as can be used to distinguish several fish species (Yokogawa and Seki, 1995), distinguish the same species but from different localities (Yokogawa et al., 1997; Burhanuddin et al., 2002; Simon et al., 2010; Braich and Akhter, 2015; Mwakiti et al., 2016), and to describe new species (Burhanuddin and Iwatsu, 2003; Chakraborty et al., 2005). Currently, molecular approaches have also been widely used to support the morphological method in fish identification (Milana et al., 2011). Based on morphology and molecular analysis, Firawati et al. (2017) noted that only two species occur in the southern coast of East Java: Trichiurus lepturus and Trichiurus brevis. The most frequently studied species of hairtail is T. lepturus due to its extensive distribution and its importance both economically and ecologically, in China’s four great seas, especially in the East China Sea (Hou et al., 2021; Liao et al., 2021). The similarity in the shape and body color shared between the species results in inaccurate and imprecise species identifications of the genus.

Researches aiming the identification and morphological characters of hairtail from Indonesia are still scarce and mainly conducted in southern coast of Java. Firawati et al. (2017) examined the morphological and molecular characters of hairtail originated from the south coast of East Java. Based on morphological characters, two hairtail species inhabited the southern coast of East Java: T. lepturus and T. brevis. In a similar study conducted by Lestari et al. (2020) noted the presence of only T. lepturus found in Pangandaran waters (West Java). Trichiurus lepturus has a wide geographic distribution, occurring in tropical, subtropical, and temperate waters worldwide. Trichiurus taxonomy remains poorly known due to its similarity in body shape and coloration between species (Burhanuddin et al., 2002) and the lack of recent taxonomic revisions. Thus, further research on the species identification and characters variation of hairtails aiming to fill the information gaps of hairtail diversity in Indonesia should be conducted. This study aims to identify the species of hairtail from the northern coast of Java, based on morphometric and meristic characters.

2. Materials and Methods

2.1. Collection and Fish Identification

Specimens were collected in three different locations at the northern coast of Java, namely Pati (Juwana), Demak, and Cirebon (Figure 1). In total, 110 fishes were collected, with 50 specimens from Pati, 46 specimens from Demak, and 14 specimens from Cirebon. The specimens were brought to the laboratory using a cooler box filled with ice cubes, then stored in the freezer for further process. The identification of hair-
tails (*Trichiurus* spp.) were based on morphological differences according to Nakamura and Parin (1993) and Burhanuddin et al. (2002). Hairtails were identified and then separated based on their species to measure their morphometric and meristic characters.

2.2. Morphometric and Meristic of Hairtail

The morphometric and meristic data followed Burhanuddin and Iwatsuki (2003) with modifications, using twenty-two morphometric and four meristic characters based on fish morphology, i.e., dorsal fin rays, and dorsal fin soft rays opposite the first anal spine, anal fin rays, and pectoral fin rays. The measurements taken in this study were: total length (TL), head length (HL), snout length (SL), dorsal fin based length (DFBL), pre-caudal peduncle length (PPL), preanal length (PAL), predorsal length (PDL), longest pectoral fin ray length (LOPL), last pectoral fin ray length (LPL), caudal peduncle length (CPL), postorbital length (POL), preopercle length (PEL), upper jaw length (UJL), postsupra-occipital length (PSL), body depth at pectoral fin base (BDP), body depth at the anal (BDA), body width at pectoral fin base (BWP), body width at the anal (BWA), bony interorbital width (BIW), membranous interorbital width (MIW), dermal eye opening (DEO), dorsal fin rays (DFR), dorsal fin soft rays of position first anal spine (DFS), pectoral fin rays (PFR), and anal fin rays (AFR). In addition, seven ratios between morphometric characters were also measured to ensure the accuracy of the species identification. The hairtail species identification was based on Nakamura and Parin (1993).

2.3. Data Analysis

Principal Components Analysis (PCA) was used to classify correlated data into several independent groups (Cadrin, 2000). This analysis is used to know the variation of sizes and shapes between hairtail populations based on morphometric characters or their comparisons. The results were presented in a scattergram to plot and determine the number of groupings simply (Landau and Everitt, 2004). Discriminant Function Analysis (DFA) was used to classify, compare, and show differences between populations characterized by some quantitative variables. PCA and DFA were carried out using SPSS version 26 software. The meristic calculation characters were then analyzed and compared to a reference book such as FAO Species Catalogue Volume15: Snake Mackerels and Cutlassfishes of The World (Families Gempylidae and Trichiuridae) (Nakamura and Parin, 1993) and previous studies (Firawati et al., 2017; Lestari et al., 2020).

3. Results and Discussion

3.1 Result

3.1.1 Hairtails species identification

Hairtail found at the northern coast of Java has a long and flat body shape like a ribbon, a silvery body color, and a bulge on the top of the head (sagittal crest). Based on morphological characters, all of the specimens in this study were identified as *Trichiurus lepturus* (Figure 2).
The total length of *T. lepturus* here reported ranged from 44.5-87.0 cm TL. Specimens from Pati ranged from 60.0–87.0 cm, specimens of Demak ranged from 44.5–64.0 cm, and specimens of Cirebon ranged from 65.0 to 74.5 cm. The total length average of hairtail from Cirebon has the most extended size (69.3 cm TL), compared to those from Pati (68.7 cm TL) and Demak (50.8 cm TL) (Table 1). The ratio of several morphometric characters of *T. lepturus* shows a variation (Table 2).

There are similarities in the meristic features of *T. lepturus* specimens from all locations and compared to previously published work (Table 3). The dorsal fin ray character is D.III.125–134, while the dorsal fin soft ray character opposite the first anal spine is 36–40. The anal fin rays are A.I.98–104, and the pectoral fin rays are P.I.10. On the anal fin, rays grow imperfectly, rendering detailed observation more difficult.

### 3.1.2 Morphometric character analysis

#### 3.1.2.1 Principal component analysis (PCA)

The principal component analysis of morphometric character generated three positive and negative main components. PCA results are depicted in a scattergram (Figure 6). PCA of hairtail morphometric characters produced three main components: PC 1, PC 2, and PC 3, with the total variant of the morphometric character of hairtails of 88.96% (Table 4). The first principal component (PC 1) explains the proportion of variance by 78.60%, the second main component (PC 2) explains 7.64%, and 2.71% was described by the third main component (PC 3).
Table 1. Morphometric characters of *T. lepturus* specimens from the Coast of Java compared to Firawati *et al.* (2017).

| Morphometric Character | Demak (N = 46) (This study) | Cirebon (N = 14) (This study) | Pati (N = 50) (This study) | Muncar (N=170) (Firawati *et al.*, 2017) |
|------------------------|-----------------------------|-------------------------------|-----------------------------|------------------------------------------|
|                        | Range (cm)                  | Mean ± SD                     | Range (cm)                  | Mean ± SD                                | Range (cm) | Mean ± SD                                |
| Total length           | 44.5 - 64.0                 | 50.8 ± 4.55                   | 65.0 - 74.5                 | 69.3 ± 2.84                             | 60.0 - 87.0 | 68.7 ± 4.99                              | 63.0 - 93.70 | 76.58 ± 5.54                             |
| Dorsal fin based length| 35.0 - 50.0                 | 39.9 ± 3.36                   | 47.0 - 57.0                 | 53.4 ± 3.37                             | 47.0 - 69.5 | 52.3 ± 3.88                              | 49.70 - 71.20 | 59.02 ± 4.25                             |
| Head length            | 5.50 - 9.70                 | 6.65 ± 0.84                   | 9.00 - 10.5                 | 9.68 ± 0.58                             | 8.00 - 13.0 | 9.47 ± 0.87                              | 9.10 - 13.40 | 10.59 ± 0.81                             |
| Snout length           | 3.00 - 5.00                 | 3.57 ± 0.51                   | 3.50 - 4.00                 | 3.76 ± 0.37                             | 2.50 - 4.00 | 3.02 ± 0.33                              | 2.30 - 6.30  | 4.73 ± 0.57                              |
| Premaxillary length    | 49.70 - 71.20               | 59.02 ± 4.25                  | 3.50 - 4.00                 | 3.76 ± 0.37                             | 2.50 - 4.00 | 3.02 ± 0.33                              | 2.30 - 6.30  | 4.73 ± 0.57                              |
| Preopercle length      | 1.00 - 2.00                 | 2.01 ± 0.16                   | 1.50 - 2.50                 | 2.01 ± 0.16                             | 1.70 - 2.00 | 1.93 ± 0.18                              | 2.00 - 2.10  | 1.54 ± 0.22                              |
| Upper jaw length       | 2.00 - 4.00                 | 2.84 ± 0.48                   | 3.00 - 4.00                 | 3.75 ± 0.33                             | 3.00 - 5.00 | 3.24 ± 0.45                              | 3.80 - 5.80  | 4.60 ± 0.41                              |
| Body depth at pectoral fin base | 3.00 - 5.50 | 3.85 ± 0.50 | 4.00 - 5.00 | 4.54 ± 0.41 | 4.00 - 6.00 | 4.56 ± 0.47 | 5.50 - 0.03 | 5.15 ± 0.50 |
| Body depth at anus      | 3.00 - 5.00                 | 3.81 ± 0.42                   | 4.00 - 5.00                 | 4.54 ± 0.41                             | 4.00 - 6.00 | 4.56 ± 0.47                              | 5.50 - 0.03 | 5.15 ± 0.50                             |
| Body width at pectoral fin base | 1.00 - 1.70 | 1.10 ± 0.16 | 1.10 - 1.50 | 1.26 ± 0.13 | 1.00 - 2.00 | 1.22 ± 0.19 | 0.70 - 2.80 | 1.27 ± 1.41 |
| Body width at anus      | 1.00 - 1.60                 | 1.07 ± 0.12                   | 1.00 - 1.50                 | 1.19 ± 0.11                             | 1.00 - 1.80 | 1.11 ± 0.15                              | 0.60 - 2.80  | 1.27 ± 0.24                             |
| Predorsal length       | 4.00 - 6.50                 | 4.83 ± 0.78                   | 6.00 - 7.00                 | 69.3 ± 0.33                             | 6.00 - 9.00 | 6.76 ± 0.72                              | 5.00 - 9.70  | 7.11 ± 0.71                             |
| Longest pectoral fin ray length | 1.80 - 3.00 | 2.18 ± 0.33 | 3.00 - 3.50 | 3.04 ± 0.13 | 3.00 - 4.00 | 3.07 ± 0.25 | 2.00 - 4.10 | 3.06 ± 0.34 |
| Last pectoral fin ray length | 0.50 - 1.50 | 1.06 ± 0.19 | 1.50 - 2.00 | 1.54 ± 0.12 | 1.50 - 2.00 | 1.53 ± 0.12 | 1.10 - 2.10 | 1.54 ± 0.22 |
| Membranous interorbital width | 0.60 - 1.20 | 1.00 ± 0.09 | 1.20 - 1.30 | 1.26 ± 0.08 | 1.00 - 1.70 | 1.23 ± 0.12 | 1.40 - 3.00 | 1.96 ± 0.26 |
| Bony interorbital width | 0.80 - 1.50                 | 1.12 ± 0.10                   | 1.40 - 1.60                 | 1.53 ± 0.09                             | 1.40 - 2.40 | 1.51 ± 0.17                              | 1.10 - 2.20  | 1.43 ± 0.19                             |
| Dermal eye opening     | 0.80 - 1.40                 | 1.02 ± 0.09                   | 1.50 - 1.50                 | 1.50 ± 0.15                             | 1.00 - 2.00 | 1.46 ± 0.20                              | 0.90 - 2.90  | 1.68 ± 0.24                             |
| Suborbital width       | 0.50 - 1.00                 | 0.59 ± 0.15                   | 1.00 - 1.00                 | 1.00 ± 0.11                             | 0.50 - 1.50 | 0.95 ± 0.18                              | 0.80 - 1.90  | 1.09 ± 0.21                             |
### Table 2. Morphometric character Ratio of *T. lepturus* specimens from Northern Coast of Java compared to Firawati et al. (2017) and Lestari et al. (2020)

| Morphometric Character Ratio (%) | *T. lepturus* Demak (N=46) (This study) | *T. lepturus* Cirebon (N=14) (This study) | *T. lepturus* Pati (N=50) (This study) | *T. lepturus* Muncar (Firawati et al., 2017) | *T. lepturus* Pangandaran (Lestari et al., 2020) |
|---------------------------------|---------------------------------------|----------------------------------------|-----------------------------------|---------------------------------|----------------------------------|
| DFBL/TL                         | 79.6                                  | 77.0                                   | 76.1                              | 80                              | 79                               |
| CPL/TL                          | 12.1                                  | 14.7                                   | 15.3                              | 9                               | 12                               |
| CPL/HL                          | 93.8                                  | 105.6                                  | 112                               | 57                              | 81                               |
| SL/HL                           | 41.4                                  | 36.8                                   | 31.9                              | 43                              | 36                               |
| POL/HL                          | 19.8                                  | 20.7                                   | 21.2                              | 27                              | 20                               |
| PDL/HL                          | 72.3                                  | 65.6                                   | 71.4                              | 69                              | 68                               |
| DEO/HL                          | 15.3                                  | 15.5                                   | 15.4                              | 17                              | 18                               |

### Table 3. Meristic character of *T. lepturus* specimens from Northern Coast of Java compared to Firawati et al. (2017) and Nakamura and Parin (1993)

| Morphometry Character           | Demak (This study) | Cirebon (This study) | Pati (This study) | *T. lepturus* (Firawati et al., 2017) | *T. lepturus* (Nakamura and Parin, 1993) |
|---------------------------------|--------------------|----------------------|-------------------|--------------------------------------|------------------------------------------|
| Dorsal fin rays                 | III.125 - III.132  | III.128 - III.132    | I.I.128 - I.I.134 | III.136 - III.137                    | III.130 - III.135                        |
| Dorsal fin rays opposite first anal spine | 36 - 39            | 36 - 39              | 36 - 40           | 36-37                                | 39-41                                    |
| Pectoral fin rays               | I.10               | I.10                 | I.10              | I.10                                 | I.11-13                                  |
| Anal fin rays                   | 1.98 - 104         | 1.100 - 103          | 1.98 - 103        | 1.100 - 101                          | 1.100 - 105                             |
Table 4. The principal component analysis of morphometric characters of *T. lepturus* specimens from Northern Coast of Java

| Morphometric Character                          | Principal Component PC 1 | Principal Component PC 2 | Principal Component PC 3 |
|------------------------------------------------|--------------------------|--------------------------|--------------------------|
| Total Length                                   | 0.975                    | -0.159                   | -0.043                   |
| Dorsal fin based length                        | 0.972                    | -0.109                   | -0.054                   |
| Precaudal peduncle length                      | 0.970                    | -0.122                   | -0.047                   |
| Preanal length                                 | 0.913                    | -0.093                   | -0.121                   |
| Caudal peduncle length                         | 0.857                    | -0.373                   | -0.054                   |
| Head length                                    | 0.982                    | -0.085                   | -0.064                   |
| Snout length                                   | 0.650                    | 0.479                    | -0.169                   |
| Postorbital length                             | 0.948                    | -0.082                   | -0.022                   |
| Preopercle length                              | 0.929                    | -0.189                   | 0.040                    |
| Upper jaw length                               | 0.817                    | 0.359                    | 0.009                    |
| Body depth at pectoral fin base                | 0.912                    | 0.280                    | 0.159                    |
| Body depth at anus                             | 0.921                    | 0.216                    | 0.164                    |
| Body width at pectoral fin base                | 0.768                    | 0.559                    | -0.039                   |
| Body width at anus                             | 0.632                    | 0.664                    | -0.024                   |
| Predorsal length                               | 0.931                    | -0.129                   | 0.113                    |
| Longest pectoral fin ray length                | 0.961                    | -0.134                   | 0.059                    |
| Last pectoral fin ray length                   | 0.941                    | -0.143                   | 0.026                    |
| Membranous interorbital width                  | 0.913                    | 0.020                    | -0.165                   |
| Bony interorbital width                        | 0.936                    | -0.051                   | -0.185                   |
| Dermal eye opening                             | 0.825                    | -0.359                   | 0.077                    |
| Suborbital width                               | 0.866                    | -0.099                   | -0.215                   |
| Postsupraoccipital length                      | 0.767                    | 0.018                    | 0.593                    |
| Eigenvalue                                     | 17.294                   | 1.682                    | 0.597                    |
| The proportion of variance (%)                 | 78.609                   | 7.647                    | 2.711                    |
| Cumulative variance (%)                        | 78.609                   | 86.256                   | 88.967                   |

The values of the second principal component (PC 2) and the third principal component (PC 3) show positive results (Table 5 and Table 6).

The main second component (PC 2) and third main component (PC 3) showed a positive and negative value, indicating a variation of shapes in the observed fish sample. In PC 2, most of the positive values are on the head and around the body; this indicates that the characters located around the head can be used as distinguishing characters between populations of hairtail. For PC 3, negative values were also found around the head character. Based on PCA results, almost all the characters around the head and body can be used to distinguish between populations of hairtails.

Table 5. Values of second principal component value (PC 2)

| Positive Morphometric Character | PC 2 | Negative Morphometric Character | PC 2 |
|--------------------------------|------|---------------------------------|------|
| Snout length                   | 0.479| Total Length                    | -0.159|
| Upper jaw length               | 0.359| Dorsal fin based length         | -0.109|
| Body depth at pectoral fin base| 0.280| Precaudal peduncle length       | -0.122|
| Body depth at anus             | 0.216| Caudal peduncle length          | -0.373|
| Body width at pectoral fin base| 0.559| Preopercle length               | -0.189|
| Body width at anus             | 0.664| Predorsal length                | -0.129|
| Longest pectoral fin ray length|       | Last pectoral fin ray length    | -0.143|
| Dermal eye opening             |       |                                 | -0.359|

Table 6. Value third principal component value (PC 3)

| Positive Morphometric Character | PC 3 | Negative Morphometric Character | PC 3 |
|--------------------------------|------|---------------------------------|------|
| Body depth at pectoral fin base | 0.159| Preanal length                  | -0.121|
| Body depth at anus              | 0.164| Snout length                    | -0.169|
| Predorsal length                | 0.113| Postorbital length              | -0.022|
| Postsupraoccipital length       | 0.593| Body width at pectoral fin base | -0.039|
|                                 |      | Body width at anus              | -0.024|
|                                 |      | Membranous interorbital width   | -0.165|
|                                 |      | Bony interorbital width         | -0.185|
|                                 |      | Suborbital width                | -0.215|

Based on the scattergram, the hairtail populations formed separate groups indicated by the distance of each other group (Figure 4). The scattergram of PC 1 and PC 3 also shows similar results, but the populations of *T. lepturus* from Cirebon and Pati overlap that forms as one population, while *T. lepturus* from Demak formed a separate population (Figure 5).
Figure 4. Scattergram plot between PC 1 and PC 2 morphometric character T. lepturus specimens from Northern Coast of Java.

Figure 5. Scattergram plot between PC 1 and PC 3 morphometric character of T. lepturus specimens from Northern Coast of Java.

Figure 6. Diagram of canonical discriminant functions analysis of T. lepturus specimens from Northern Coast of Java.

Table 7. The value of principal component analysis of morphometric characters ratio of T. lepturus specimens from Northern Coast of Java

| Morphometric Character Ratio | Principal Component |
|-----------------------------|---------------------|
|                            | PC 1    | PC 2    | PC 3    |
| DFBL/TL                    | -0.887  | 0.137   | -0.001  |
| CPL/TL                     | 0.952   | -0.067  | -0.092  |
| CPL/HL                     | 0.926   | 0.059   | -0.037  |
| SL/HL                      | -0.667  | -0.153  | 0.045   |
| POL/HL                     | 0.552   | -0.170  | 0.416   |
| PDL/HL                     | 0.008   | 0.692   | 0.689   |
| DEO/HL                     | 0.156   | 0.751   | -0.537  |

Eigenvalue                  3.324   1.123   0.947
Proportion of Diversity (%) 47.492   16.039  13.533
Cumulative Diversity (%)    47.492   63.531  77.063

The analyses of ratios of morphometric character produce PC 1, PC 2, and PC 3. The first principal component (PC 1) shows the proportion of variance by 47.49%, the PC 2 by 16.03%, and the PC 3 by 13.53%. The value of PC 1, PC 2, and PC 3 consisted of positive and negative, which indicates a variation of shapes from the sample fish.

3.1.2.2 Discriminant function analysis (DFA)

The combination of PC and discriminant analysis was used to separate the population group and define the morphometric characters differentiated between hairtail populations. The discriminant analysis produces two discriminant functions (DF). Based on the morphometric characters, even though all three groups are in the same species, the hairtail from Cirebon and Pati is closer than from Demak (Figure 6).
The correlation of the morphometric characters and the discriminant function was indicated by an asterisk (*). The highest value of the discriminant function in the first column is 0.465, while in the second column is 0.327 (Table 8). The caudal peduncle length and snout length are morphometric characters that can be used to differentiate the populations. Cross validated between populations was used to ensure the classification results of the discriminant analysis of the original data. The discriminant model of the initial data classifies 96.4% of the sample, while the cross-validated data can classify the population of 95.5% of the sample (Table 9).

### Table 8. Correlation between morphometric characters and discriminant function (DF) of *T. lepturus* specimens from Northern Coast of Java

| Morphometric Character | Function |
|------------------------|----------|
| Caudal peduncle length (CPL) | 0.465* -0.019 |
| Total length (TL) | 0.430* 0.124 |
| Last pectoral fin ray length (LPL) | 0.397* 0.034 |
| Dorsal fin based length (DFBL) | 0.395* 0.141 |
| Preopercle length (PEL) | 0.086 0.192 |
| Longest pectoral fin ray length (LOPL) | 0.384* 0.089 |
| Precaudal peduncle length (PPL) | 0.371* 0.160 |
| Dermal eye opening (DEO) | 0.349* 0.126 |
| Bony interorbital width (BIW) | 0.337* 0.090 |
| Head length (HL) | 0.318* 0.146 |
| Suborbital width (SW) | 0.304* 0.110 |
| Membranous interorbital width (MIW) | 0.294* 0.209 |
| Predorsal length (PDL) | 0.294* -0.136 |
| Preanal length (PAL) | 0.288* 0.215 |
| Postorbital length (POL) | 0.287* 0.126 |
| Postsupra occipital length (PSL) | 0.242* -0.048 |
| Body depth at anus (BDA) | 0.192* 0.010 |
| Body depth at pectoral fin base (BDP) | 0.170* 0.014 |
| Body width at pectoral fin base (BWP) | 0.086* 0.086 |
| Snout length (SL) | 0.092 0.327* |
| Upper jaw length (UJL) | 0.125 0.307* |
| Body width at anus (BWA) | 0.044 0.60* |

3.2 Discussion

The *Trichiurus lepturus* found at the Northern Coast of Java has similar morphological appearance as *T. ruselli*, *T. brevis* and *L. savala*, namely silvery body color, long and flat body like a ribbon. Morphological character differences between *T. lepturus* and *L. savala* can be seen in a sagittal crest or protrusion on the head and eye width. The eye width of *L. savala* is smaller than *T. lepturus*, and *T. lepturus* species has a protrusion on the top of the head (sagittal crest) (Nakamura and Parin, 1993). Morphological character differences were also found between *Trichiurus ruselli* and *T. lepturus*. The main difference between these two species is the position of the tip of the supraoccipital crest on the head. The end of the supraoccipital crest of *T. lepturus* lies slightly behind the eye circle, while *T. ruselli* lies just behind the eye circle. Firawati et al. (2017) also reported another difference between *T. lepturus* and *T. ruselli*, namely on dorsal fin base and caudal peduncle. *Trichiurus ruselli* has a longer dorsal fin base than *T. lepturus* but has a shorter caudal peduncle. *Trichiurus russelli* and *T. brevis* are clearly distinguished from *T. lepturus* in having lower numbers of total vertebrae, longer dorsal fin bases, shorter caudal peduncle lengths, and snout lengths (Burhanuddin et al., 2002). In this study, the dorsal fin color is slightly different, i.e., silvery-yellow dorsal fin for the population from Cirebon and silvery-white dorsal fin for populations from Demak and Pati. Still, they were identified as the same species.

According to Nakamura and Parin (1993), the...
total length of this species can reach up to 120 cm, but the hairtail which is commonly caught was 50-100 cm in size. The total length of *T. lepturus* from Pati, Demak, and Cirebon ranged from 44.5 to 87.0 cm, with the smallest specimen in this study being 44.5 cm, but can be classified as an adult fish, able to produce eggs for breeding (Nakamura and Parin, 1993). Lee and Kim (2014) mentioned that the adult stage *T. lepturus* from Korea can be achieved reaching a total length of 29 cm. The variation in the size might be due to the differences of age groups (cohorts) of the hairtails specimens inhabiting the Java Sea. The morphometric character of particular species hairtail may show variations for each region. According to Chakraborty and Iwatsuki (2006) stated *T. lepturus* originating from West Africa has a longer snout length, pectoral fin, predorsal length, and shorter caudal peduncle compared to *T. lepturus* originating from the West Atlantic and the Indo-Pacific region. In addition, a degree of geographical isolation can also result in marked morphometric, meristic, and genetic differences between populations within the same species due to the absence of gene flow between these populations (Turan et al., 2004).

The average ratio between dorsal fin base length and total length (DFBL/TL) in Demak population was larger than the other two locations (79% vs. 76.1-77.0% TL). A larger average ratio was also shown between snout length and head length (SL/HL) (41.4% vs. 31.9-36.8% HL). However, the ratio between caudal peduncle length and total length (CPL/TL) and caudal peduncle length to head length (CPL/HL) shows a smaller average ratio than other locations i.e., 12.1% vs. 14.7-15.3% (CPL/TL) and 93.8 vs. 105.6-112.0% (CPL/HL), respectively (Table 2). The average ratio of other morphometric characters indicates almost the same value. However, these ratio measurements are not much different from the research conducted by Firawati et al. (2017) and Lestari et al. (2020). Apart from morphometric characters, meristic characters can also support the differences between hairtails species, especially in the dorsal fin and the location of the first anal fin based on the order of the dorsal fin. *Trichiurus lepturus* from all locations showed a similar fin formula. The fin formula of *T. lepturus* was D.III.125-134, P.I.10, and A.I.98-104. The meristic characteristics of *T. lepturus* originated from Pati, Demak, and Cirebon are almost the same as those described by Nakamura and Parin (1993), D.III.130-135, P.I.11-13, and A.I.100-105. This meristic character was also similar to *T. lepturus* from the southern coast of East Java has the key of determination D.III.136-137, P.I.10, and A.I.100-101 (Firawati et al., 2017).

The combination between principal component analysis and discriminant analysis was used to separate the population groups and define the specific distinguishing characteristics of the hairtail population. The PCA showed high morphometric character resemblance, closely related and possible as one population between *T. lepturus* from Cirebon and Pati. In contrast, the *T. lepturus* from Demak is separate from the other two populations (Figure 6), although, Demak is located between Pati and Cirebon. The separation of the hairtail population shows the differences in morphometric characters among the locations. This fact supposed that besides the genetic factors, environmental factors might also influence fish morphology. According to Fagbuaaro et al. (2015), morphometric characters can describe the ability of fish to adapt to different environmental conditions, such as food abundance and temperature. Furthermore, the uniqueness of features and morphometric variation in each species can also be related to the habits and habitats of the species (Akindele and Fagbuaaro, 2022). Principal Component Analysis showed that the characters around the head and tail can be used to distinguish between populations. Principal component analysis based on the ratio of morphometric characters is more accurate compared to using solely morphometric characters. Furthermore, the discriminant analysis showed that the specific distinguishing character between populations of hairtail can be determined from the caudal peduncle length and snout length. The discriminant function’s cross-validated were relatively high, namely the initial data of 96.4% and cross data validated by 95.5%.

Based on differences in pectoral fin morphology and tooth patterns, only three species of hairtail are recognized as valid species belonging to the genus *Trichiurus*, i.e., *T. lepturus*, *T. auriga* and *T. gangeticus* (Nakamura and Parin, 1993). According to Fricke et al. (2022), the latest opinion is that as many as 17 species of hairtail belonging to the genus *Trichiurus* have been reported, but only eleven species are considered valid species. Species belonging to the genus *Trichiurus* are divided into two groups: the short-tailed hairtail, *Trichiurus russelli* complex, and the long-tailed hairtail, *T. lepturus* complex (Nakamura and Parin, 1993; Burhanuddin et al., 2002). According to Chakraborty et al. (2005), *Trichiurus* found in Atlantic waters is known as *T. lepturus*, while the population found in Indo-Pacific waters are known as *T. haumela* Forsskal, 1775. However, Bailly (2013) stated that *T. haumela* is not a valid species, but it is a synonym for *T. lepturus*. *Trichiurus lepturus* has been more widely studied than the other species due to their wide distribution, covering tropical
to subtropical waters. The accuracy of species identification and the determination of the distribution areas are essential for sustainable fisheries management. Errors in recognizing fish species can result in critical errors in managing and exploiting fish stocks (Carvalho and Hauser, 1994). Therefore, further research is necessary to identify the members of the genus Trichiurus by morphological and molecular approaches and distribution in other Indonesian waters.

4. Conclusion

Based on the morphological identification, this study found only Trichiurus lepturus at the northern coast of Java, although they have slightly different morphometric and meristic characters. Differences in habitat conditions might cause morphological variation in the hairtail population. Identification of the species accurately is essential for fish stock management. Further, determining the members of the genus Trichiurus along the coastal water of Java using morphological and molecular approaches and analyzing their genetic population is necessary.

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Authors’ Contributions

AFA collecting data and analysis, MUR analysed the data and wrote the manuscript, ES designed the research, wrote the manuscript and supervised all the process. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that there is no competing interests.

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