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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.

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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; Apriliani *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 as1.15 million tons (FAO, 2020). Based on the Indonesianexport data, the fresh hairtail was exported to severalcountries such as China, Thailand, Taiwan, Malaysia,and South Korea. The increased demand for hairtailsexports has led to an increase in the catch of hairtailsin Indonesia. Currently, hairtail resources have reachedeconomic overfishing due to excessive fishing pressure(Panhwar *et al*., 2018). The hairtail is distributed widelyin the tropical and temperate waters worldwide (Bar-bosa *et al*., 2011; Cruz-Torres *et al*., 2014) and can befound in the Indian Ocean, the Atlantic Ocean, and thePacific Ocean. In the genus of *Trichiurus*, 17 speciesare recorded as members; however, only eleven speciesare considered as valid species i.e. *Trichiurus lepturus*,*Trichiurus auriga*, *Trichiurus australis* (Chakraborty,*et al*., 2005), *Trichiurus brevis*, *Trichiurus gangeticus*,*Trichiurus japonicus*, *Trichiurus russelli*, *Trichiurusnitens*, *Trichiurus margarites*, *Trichiurus nanhaiensis*,and *Trichiurus nickolensis* (Burhanuddin and Iwatsu-ki, 2003 ; Nakamura and Parin, 1993; Burhanuddin *etal*., 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. glossodon*, *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; Brraich and Akhter, 2015; Mwakiti *et al*., 2016), and to describe new species (Burhanuddin and Iwatsuki, 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 it 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 hairtails (*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), precaudal 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), postsupraoccipital 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), suborbital width (SW), 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).

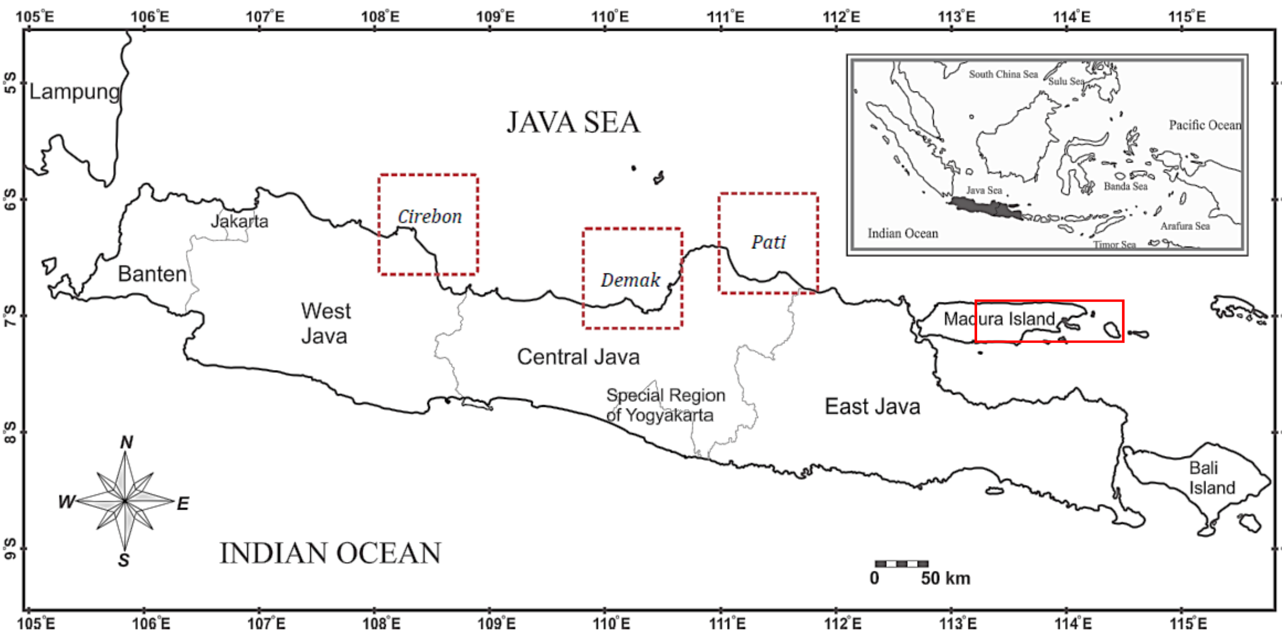

Figure 1. Sampling locations and predicted fishing ground.

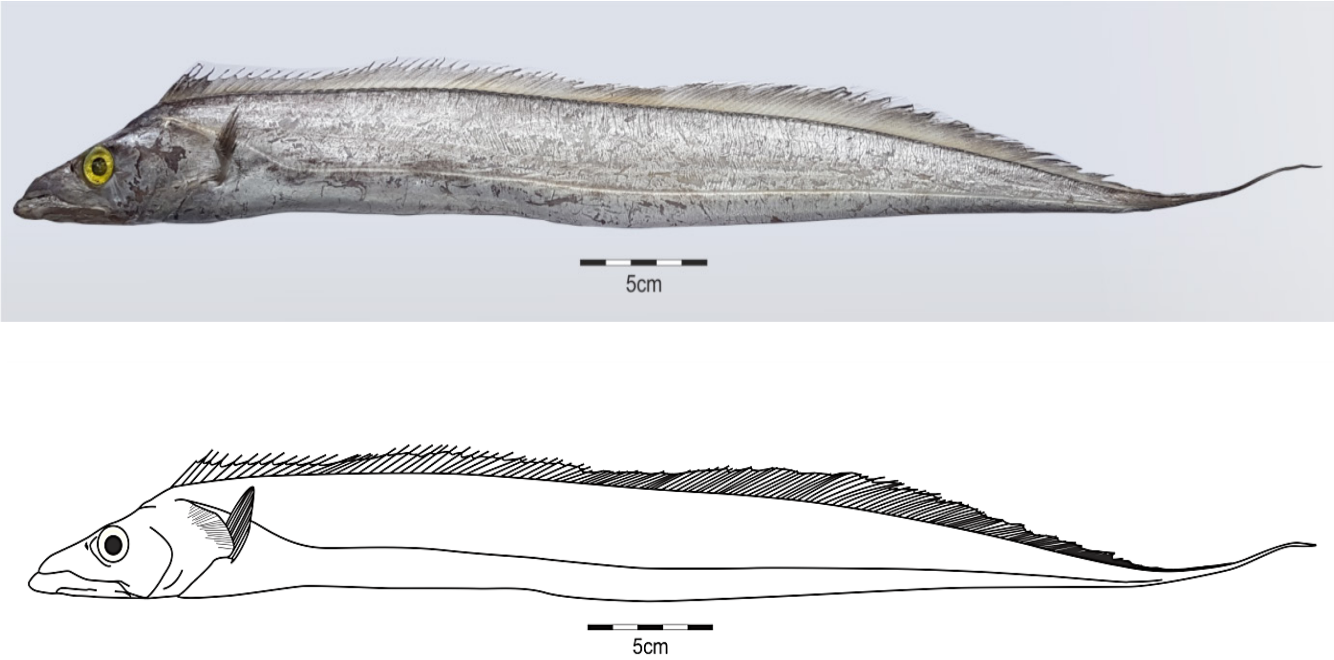

Figure 2. *T. lepturus* from the northern coast of Java

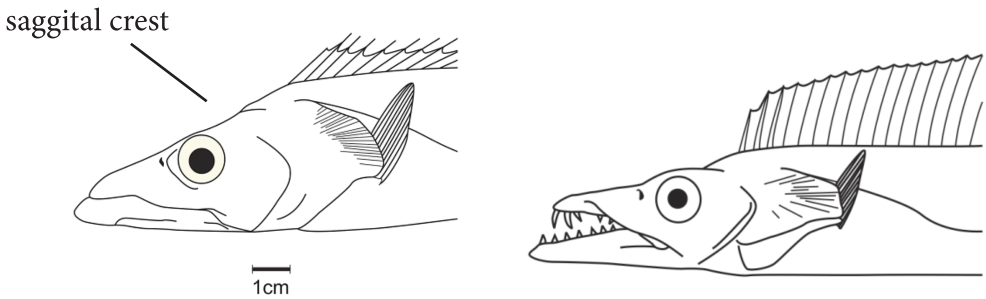

Figure 3. Head and *saggital crest* illustration on *T. lepturus* (left = this study, right = Nakamura and Parin, 1993).

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).

Morphometic 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	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	2.00 - 4.00	2.76 ± 0.53	3.00 - 4.00	3.57 ± 0.51	2.50 - 4.00	3.02 ± 0.33	3.20 - 6.30	4.73 ± 0.57
Precaudal peduncle length	39.0 - 56.0	44.2 ± 3.77	52.5 - 63.5	59.5 ± 3.13	52.5 - 73.5	58.3 ± 4.59	52.60 - 93.00	68.18 ± 7.54
Preanal length	12.5 - 25.0	18.4 ± 1.99	18.0 - 28.0	24.5 ± 2.70	21.5 - 33.0	24.5 ± 2.54	22.40 - 35.30	27.68 ± 2.26
Caudal peduncle length	4.00 - 8.00	6.16 ± 0.91	8.50 - 12.5	10.2 ± 1.07	7.00 - 13.5	10.5 ± 1.17	5.90 - 19.80	10.49 ± 1.79
Postorbital length	2.70 - 4.50	3.45 ± 0.40	4.50 - 5.00	4.82 ± 0.25	4.00 - 6.00	4.57 ± 0.42	3.90 - 6.50	5.14 ± 0.43
Preopercle length	1.00 - 2.00	1.33 ± 0.26	2.00 - 2.00	2.00 ± 0.21	1.50 - 2.50	2.01 ± 0.16	1.90 - 4.90	3.08 ± 0.52
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	2.00 - 0.01	4.97 ± 0.51
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	III.128 - III.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	I.98 - 104	I.100 - 103	I.98 - 103	I.100 - 101	I.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	PC 2	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	0.012	-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	-0.134
		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).

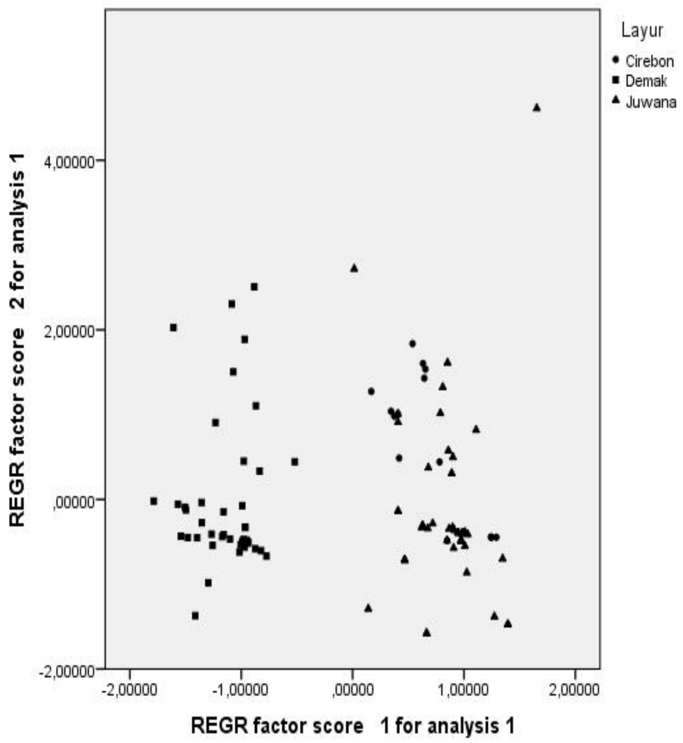

Figure 4. Scattergram plot between PC 1 and PC 2 morphometric character *T. lepturus* specimens from Northern Coast of Java.

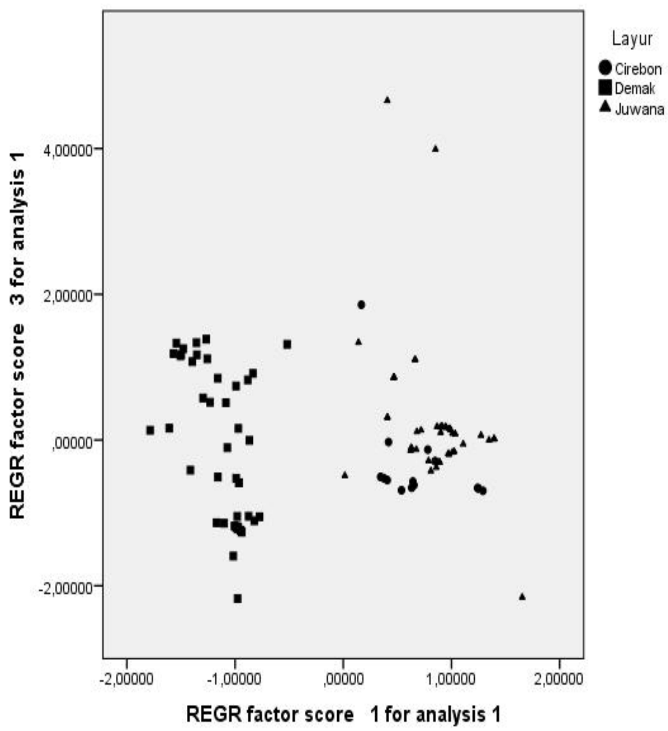

Figure 5. Scattergram plot between PC 1 and PC 3 morphometric character of *T. lepturus* specimens from Northern Coast of Java.

Table 7. The value of principal component analysis of morphometric characters ratio of *T. lepturus* speciemens 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 PC3 by13.53%. 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).

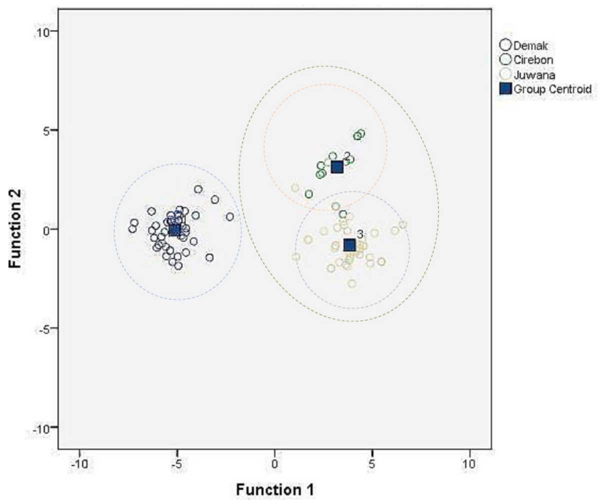

Figure 6. Diagram of canonical discriminant functions analysis of *T. lepturus* specimens from Northern Coast of Java

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

Morphometric Character	Function	
	DF 1	DF 2
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)	0393*	0.050
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*

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 9. Classification result for discrimination function analysis of *T. lepturus* specimens here examined

Types	Population	Cirebon	Demak	Pati	Total
Original Data	Cirebon	0 (0%)	12 (85.7%)	2 (14.3%)	14
	Demak	46 (100%)	0 (0%)	0 (0%)	46
	Pati	0 (0%)	2 (4%)	48 (96%)	50
Cross Validated	Cirebon	0 (0%)	12 (85.7%)	2 (14.3%)	14
	Demak	46 (100%)	0 (0%)	0 (0%)	46
	Pati	0 (0%)	3 (6%)	47 (94%)	50

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. russelli*, 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 Fagbuaro *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 Fagbuaro, 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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