J.Natn.Sci.Foundation Sri Lanka 2025 53 (4): 447 - 457
DOI: http://dx.doi.org/10.4038/jnsfsr.v53i4.12519

RESEARCH ARTICLE

Fisheries Ecology

A multidimensional study on Spotted Sardinella: Biometric, ecological, and heavy metal perspectives from Negombo, Sri Lanka

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Submitted: 10 March 2025; Revised: 11 October 2025; Accepted: 26 November 2025

Abstract: Biometric parameters, feeding habits, heavy metal content, and fisheries aspects of *Amblygaster sirm* (Spotted sardinella) in the coastal waters off Negombo, Sri Lanka were studied from August 2022 to March 2023. Length-weight relationships for males, females, and the pooled data were W=0.0029 $TL^{3.3546}$, W=0.0035 $TL^{3.2819}$ and W=0.0030 $TL^{3.3459,}$ respectively showing positive allometric growth. Fulton's condition factors for males, females and pooled data were 0.9047 ± 0.1074, 0.94392 ± 0.08699, and 0.92331 ± 0.09995 respectively. Food mainly consisted of animal parts (77.56%) with crustacean larvae being the most abundant food item (25.51%). The gastro-somatic index showed the highest and lowest feeding intensities in the size classes of 17.5-18.5 cm and 12.5-13.5 cm respectively. Outboard fiberglass reinforced plastic boats and gillnets of mesh sizes 1¼ and 1½ inches are widely used for fishing. The results of the principal component analysis showed that variables such as total length, standard length, head length, body weight, gut length, and gut weight were positively associated with each other. The mean concentrations of Cr, Zn, Cu and Cd in the edible muscles of *A. sirm* were 10.067 ± 3.658 mg/kg, 7.878 ± 1.856 mg/kg, 5.3857 ± 0.0818 mg/kg and 0.5209 ± 0.0447 mg/kg respectively. These values did not exceed the permissible limits declared by FAO and WHO. Overall, the study found that the fishes were in good physical condition with safe levels of heavy metal content for human consumption.

Keywords: *Amblygaster sirm,* food, heavy metal content, length-weight relationship, stomach fullness.

INTRODUCTION

Sri Lanka is one of the major fishing countries situated to the south of the Indian subcontinent with a coastline spanning approximately 1739 km (Thivviyan & Jayakody, 2017). Sri Lanka, as a coastal nation, relies on fisheries resources for sustenance and economic prosperity, making them a crucial source of food and a significant contributor of protein to local communities (Suseno et al., 2014; Thivviyan & Jayakody, 2017; Bandaranayake et al., 2024). Fish are important for a balanced and healthy diet because they provide protein, long-chain omega-3 polyunsaturated fatty acids, micronutrients such as iodine and selenium, potassium, vitamins such as D and B. (Medeiros et al., 2012; Weichselbaum et al., 2013; Ali et al., 2020). Approximately 40% of the fish caught in Sri Lanka consist of small pelagics (Jayasuriya, 2007). Among the small pelagics, spotted sardinella (*Amblygaster sirm),* which belongs to the family Clupeidae of the order Clupeiformes, is characterized by a slender body with a series of 10 to 20 gold spots down the flank (Devi et al., 2018). It is a schooling fish and is also associated with reefs. It is recorded in depths ranging from 10-70 m (Devi et al., 2018; Osman et al., 2021). In Sri Lanka, coastal fishery is operated year-round using gillnets and 17-feet fiberglass reinforced plastic boats equipped with 30 HP

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outboard motors. Earlier studies have shown that *A. sirm* contributes for >40% of the small pelagic fish production of Sri Lanka (Karunasinghe & Wijeyaratne, 1995). Nets with mesh sizes of 20 mm and 38 mm are commonly used in this fishery (Karunasinghe &Wijeyaratne, 1991a; Jayasuriya, 2007).

The fisheries sector in Sri Lanka is facing multiple challenges, including overfishing, diminishing fish stocks, and ecosystem degradation due to habitat destruction, pollution and climate change. To ensure food security and meet the domestic demand for fish, it is crucial to implement sustainable fisheries management practices (World Bank, 2021; Bandaranayake et al., 2024). *A. sirm* fishery in the coastal waters off Negombo, Sri Lanka appears to be heavily overexploited and in order to exploit this fishery at the optimum level, it is recommended that gillnets with a mesh sizes of >25 mm should be used (Karunasinghe & Wijeyaratne (1995). It has also been shown that the best fishing season for this species in the coastal waters off Negombo is from April to November and the full moon period (Karunasinghe and Wijeyaratne, 1996).

The length-weight relationship (LWR) of fish is significant in the field of fisheries science as it serves multiple purposes including the extrapolation of total catch from length-frequency samples, estimation of biomass based on underwater length observations, and assessment of fish condition (Ceyhan et al., 2009). The LWR also helps to determine whether somatic growth follows an isometric or allometric pattern.

Fulton's condition factor (K) is an important measure used to assess the "condition" or physical health of a fish stock (Lizama & Ambrosio, 2002). It evaluates the plumpness or relative weight of individuals within a population (Osman et al., 2021). It provides insights into variation in the physiological status among fish and allows for comparison between populations living in different feeding, climatic, and environmental conditions (Devi et al., 2018). By assessing K, one can determine the feeding activity of a species and evaluate whether it is effectively utilizing the food sources (Lizama & Ambrosio, 2002). Fisheries scientists use this information to make management recommendations for fish stocks to ensure their well-being and sustainability (Osman et al., 2021).

The intensity of feeding of fish, which is based on the fullness of their stomach varies with the season, availability of preferred food items, maturity stage, and spawning season. It can be quantified using the gastro-somatic index (GaSI) (Khongngain et al., 2017).

Feeding habits of fish can be determined based on the predominant food items found in their stomachs (Hynes, 1950). Qualitative and quantitative analyses of gut contents are used to determine the composition of the diet of fish (Mahesh et al., 2018). The diet of *A. sirm* predominantly consists of copepods, nauplii and zoea larvae, bivalve larvae, gastropods, as well as dinoflagellates such as *Peridinium* and *Ceratium* (Whitehead, 1985).

Due to the ecological position of fish as prominent members of the aquatic food chain, they have the inherent ability to accumulate heavy metals derived from their diet, water, and sediment (El-Moselhy et al., 2014). The presence of toxic heavy metals in fish can cause adverse effects on human health (Castro-González & Méndez-Armenta, 2008), resulting in renal failure, liver damage, cardiovascular diseases, and even fatality (El-Moselhy et al., 2014). Therefore, it is important to analyze the heavy metal content in fish muscles also.

The objective of this study is to quantify the length-weight relationship, condition factor, relative gut length, gastro-somatic index, stomach contents, and heavy metal contents in the muscles of *A. sirm*. It is hypothesized that there is a significant difference between the length-weight relationship of males and females of *A. sirm* and the heavy metal content in their muscles is within the safe levels for human consumption.

MATERIALS AND METHODS

Monthly sampling of *A. sirm* specimens was conducted the at Sea Street landing site in Negombo, located on the west coast of Sri Lanka (7.2040°N and 79.8277°E) from August 2022 to March 2023. In each month, 25 specimens were randomly collected from five boats operating the gillnets of mesh sizes 1¼ and 1½ inches, and another 30 specimens were randomly collected for heavy metal analysis from October 2022 to March 2023. Samples were packed in ice and transported to the laboratory and stored at -20^{0}C for further analysis. Standard length (SL), total length (TL), fork length (FL), and head length (HL) were measured to the nearest 0.1 cm and the total body weight was measured to the nearest 0.1g.

Length-weight relationship and condition factor

The length-weight relationship of the fish, was calculated using the following equation proposed by Gulland (1969).

$W = aL^b$

W = Body weight of fish in g
L = Standard length of fish in cm
a = Antilogarithmic value of the intercept of the plot of log W against log L
b = Slope of the plot of log W against log L

Regression analysis was conducted on log weight (g) against log standard length (cm) to determine the length–weight relationship. To verify whether the slope 'b' significantly deviated from the expected value for isometric growth (b=3), a one-sample t-test was performed.

Fulton's Condition factor (K) was calculated using the following relationship proposed by Gulland (1969).

$K = 100W / L^3$

W = Body weight of fish in g
L = Standard length of fish in cm

Food and feeding

Each fish was dissected, the digestive tract was separated from the body and its length was measured. The relative gut length of the fish was calculated using the following formula proposed by Al-Hussaini (1949).

RGL = LG / TL

LG = Length of gut in cm
TL = Total length of fish in cm

Stomach fullness was visually assessed as full, three-fourths (3/4) full, half (1/2) full, one-fourth (1/4) full, and empty. Stomach contents of each fish were scooped out, weighed and gastro-somatic index (GaSI) was calculated using the following formula proposed by Hynes (1950).

GaSI = (Weight of stomach contents / Weight of fish) x 100

Stomach contents were identified to the lowest possible taxonomic level using a microscope and the frequency of occurrence of different food items was determined using the method proposed by Hynes (1950).

% Oi = (Ni/ N) x 100

% Oi = Frequency of occurrence of food item i
Ni = Number of stomachs containing the food item i
N = Total number of stomachs with food

Heavy metal analysis

The body weight and length of fish were measured and the edible portions of the fish muscle were separated and labeled for further analyses. These muscles were homogenized using a mortar and pestle. From each fish, 1.00 g of homogenized muscle tissue was digested using 10 mL of 70% nitric acid and 1 mL of hydrogen peroxide in closed Teflon tubes using a microwave digester at a temperature of 45^0C for 3 hours. Blanks containing the digestion medium were also digested concurrently. At the end of the digestion process, the samples were cooled to room temperature, filtered using filter papers and diluted to 20 mL using deionized water (Milli-Q ultrapure water). Samples were then transferred to acid-washed labeled polypropylene bottles. All reagents used were of analytical grade The glassware was pre-soaked in 10% nitric acid and later rinsed with distilled water to avoid metal contamination as described by El-Moselhy et al. (2014). The concentrations of Cr, Zn, Cu, and Cd in the digested solutions were determined in triplicate using an atomic absorption spectrophotometer (Analytik Jena Model Nova 400 P). Standard solutions of each metal were prepared from commercial standard calibration solutions. The limit of quantification values were obtained for each heavy metal and the results were expressed as mg/kg of wet weight.

RESULTS AND DISCUSSION

Length frequency distribution

Length frequency distribution of *A. sirm* caught in gill nets operated in the coastal waters off Negombo is shown in Table 1. The mid-length (cm) of the group that showed the highest and the lowest frequencies were 18 cm and 23 cm.

Length-weight relationship, condition factor (K), and sex ratio

The length–weight relationship plots of log W against vs log SL are shown in Figure 1.

The length-weight relationships of males, females and for pooled data are given in Table 2.

The b value of the length weight relationship was significantly different from 3 ($P < 0.05$) indicating positive allometric growth. Devi et al. (2018) observed positive allometric growths for *A. sirm* in the Andaman coast. Abdussamad et al. (2010) have observed that the

Table 1: Lenth frequency distribution of *A. sirm* in the gillnet catches operated in the coastal waters off Negombo

Standard length size class (cm)	Frequency
12.5-13.4	6
13.5-14.4	18
14.5-15.4	16
15.5-16.4	31
16.5-17.4	29
17.5-18.4	39
18.5-19.4	36
19.5-20.4	18
20.5-21.4	4
21.5-22.4	2
22.5-23.4	1
Grand total	200

Table 2: Length-weight relationships (LWR) of *A. sirm*

	N	LWR	r^2
Pooled	200	$W= 0.0030\ TL^{3.3459}$	0.9376
Male	105	$W=0.0029TL^{3.3546}$	0.9230
Female	95	$W=0.0035\ TL^{3.2819}$	0.9497

b = 3.207 for the pooled *A. sirm* in the Gulf of Mannar, which is similar to the b value obtained in the current study (3.345). However, in a study conducted in the the Bay of Bengal off Bangladesh, *A. sirm* showed an overall negative allometric growth (Rahman et al., 2025).

The mean values for total length, weight, and condition factor (K) for *A. sirm* (pooled, male, and female values) are shown in Table 3.

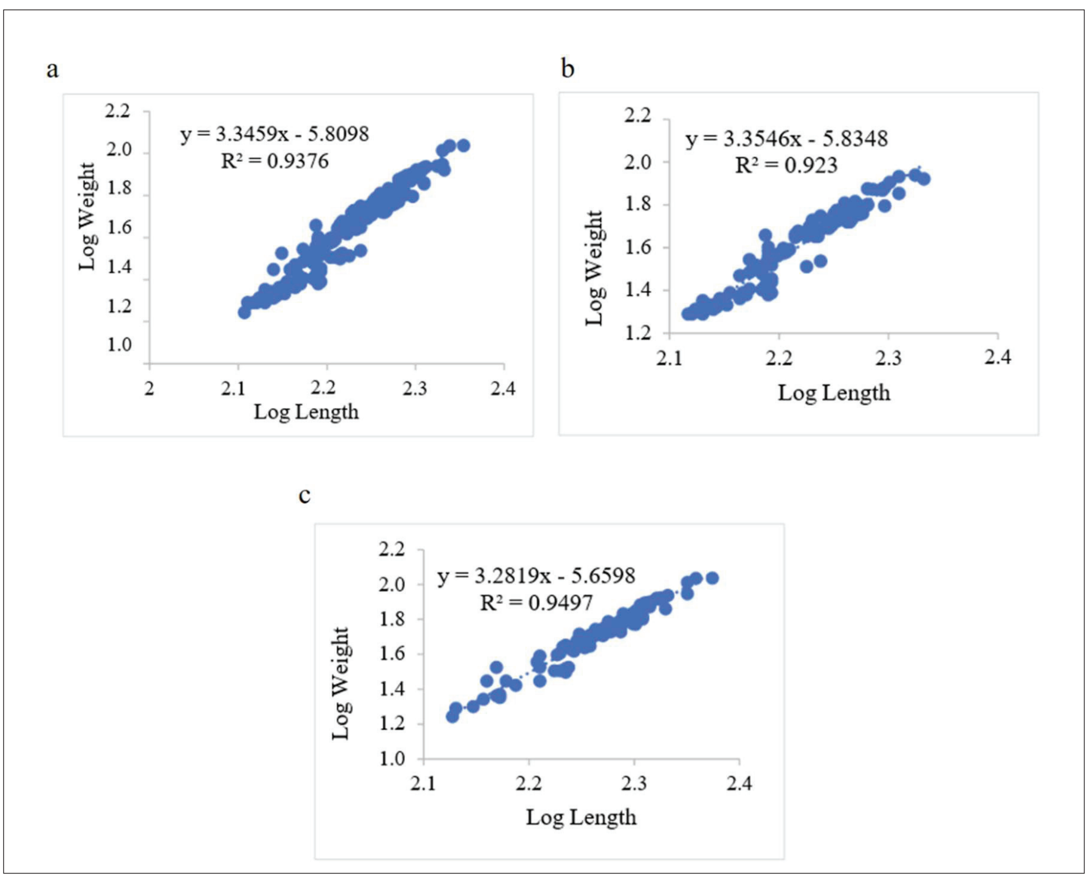

Figure 1: The plots of log weight (g) vs standard length (mm) of *A. sirm*: (a) pooled data, (b) males, and (c) females

Table 3: The mean values for total length, weight and condition factor (K) for *A. sirm*

	TL (cm)		Weight (g)		K
	Min - Max	Mean ± SD	Min - Max	Mean ± SD	Mean ± SD
Pooled	12.8 - 22.6	17.231 ± 2.037	17.5 -09.0	49.81±19.12	0.92331±0.09995
Male	13.1 - 21.5	16.809 ± 1.976	19.5-87.0	45.27±17.48	0.9047±0.1074
Female	12.8 - 22.6	17.697 ± 2.011	17.5-109.0	54.83±19.68	0.94392±0.08699

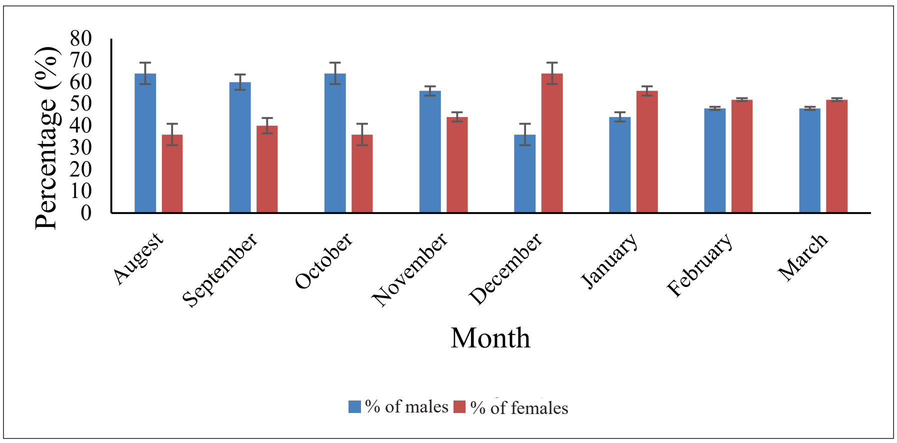

Figure 2: The percentage of males and females of *A. sirm* during August 2022 - March 2023

The Maximum length and the maximum weight of *A.sirm* recorded by Rahman et al. (2025) in the coastal waters of Bay of Bengal off Bangladesh were 30.5 cm and 142.56 g respectively. The asymptotic length of *A sirm* in the western coastal waters of Sri Lanka has been estimated to be 25.23 cm (Karunasinghe & Wijeyaratne, 1991b). Hence, the maximum length of *A. sirm* caught in the coastal waters of Bay of Bengal off Bangladesh is higher than the asymptotic length of this species in the western coastal waters of Sri Lanka. Different factors, such as sex, habitat, stomach fullness, gonadal maturity stage and ontogenetic development stage can make differences in the length weight relationship parameters of fishes.

The variation of the percentages of males and females of the *A. sirm* during the study period is shown in Figure 2. From August to November, the males were more abundant while the vice-versa was observed from December to March.

Earlier studies have shown that from January to April in 1984, May 1985 and in April, May and October in 1986, females were more abundant in the gillnet catches of the coastal fishery off Negombo, Sri Lanka (Karunasinghe & Wijeyaratne (1998). Nevertheless, statistical analysis has shown that it is not significantly different from 1:1 (Karunasinghe & Wijeyaratne (1998). Dayaratne (1984) reported that *A. sirm* in the western coastal waters off Sri Lanka breeds twice a year.

The condition factor can be used to get an idea about the physical and biological environment conditions, health, food reserves, feeding intensity, growth, and reproductive cycle of fish. Condition factor is affected by several factors, inclusing feeding intensity and gonad development (Jayakumar et al., 2022). In the present study, the mean condition factor ± SD for the males, females and for the pooled data were 0.9047±0.1074, 0.94392±0.08699 and 0.92331±0.09995 respectively. The mean condition factor of females was significantly higher than that of the males ($p<0.05$). Similar results have been recorded for *A. sirm* in the Andaman coastal waters in India (Devi et al., 2018). Results of the present study indicate that *A. sirm* stock in the coastal waters off Negombo is in good physical condition.

Stomach content analysis

Feeding is a major concern in the daily life of fish, and they use a large portion of their energy searching for food (Purusothaman et al., 2014). The number of fish and percentages for each category of stomach fullness are given in Table 4. Out of the 200 fish examined, 5% had a full stomach, 27.5% had three-quarter fullness, 12.5% had half fullness and 15% had quarter fullness while 40% had empty stomachs.

Table 4: The distribution of stomach fullness of *A. sirm* from the coastal waters off Negombo during the study period

Stomach fullness	Number of fish
Full	10
Three-fourth (3/4) full	55
Half (1/2) full	25
One-fourth (1/4) full	30
Empty	80
Total	200

Feeding intensity refers to the degree of feeding as indicated by the relative fullness of the stomach. It varies with seasonal changes, availability of preferred food items, maturity stage of the fish, and spawning season of the species (Khongngain et al., 2017). Stomach fullness indices and empty stomachs are important in assessing feeding intensity, which is negatively related to empty stomachs (Purusothaman et al., 2014).

The frequency of occurrence (%) for each food item is given in Table 5. The major food was crustaceans and their larvae (copepods, zoea larvae, nauplii) accounting for 25.51% followed by plankton accounting for 14.29%.

Synthetic fibers and unknown particles were also present in 2.6% and 4.1% of the stomachs analyzed respectively, which is evident for contamination of marine ecosystems by human-made materials. This can have detrimental effects on their physiology, growth, reproduction, and overall survival. Furthermore, synthetic materials can act as carriers of toxic substances, potentially magnifying the harmful effects on fish and other organisms in the food chain. The ingestion of these synthetic materials by fish poses a threat not only to their health but also to the overall ecological balance of marine habitats.

Table 5: Frequency of occurrence (%) of different food items consumed by *A. sirm*.

Prey item	Frequency of occurrence(%)
Plankton	14.29
Algae	1.53
Mollusk larvae	11.22
Crustacean larvae	25.51
Gastropod larvae	12.76
Fish eggs	15.31
Appendages	12.76
Synthetic fibers	2.55
Unknown particles	4.08

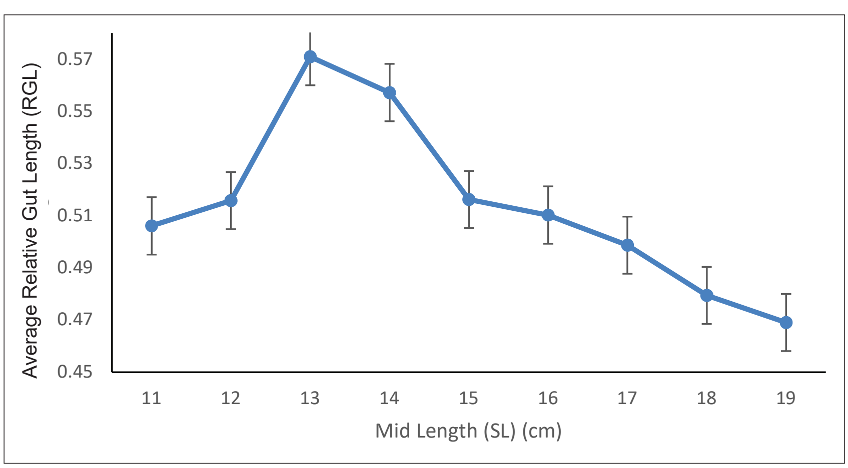

Figure 3: Variation of mean relative gut Length of different size classes (SL) (cm) of *A. sirm*

Relative gut length (RGL) and gastro somatic index (GaSI)

Variations of RGL and mean GaSI of different size classes are shown in Figures 3 and 4 respectively. The ranges of RGL and GaSI were 0.469-0.571 and 1.898-2.571 while their mean±SD values were 0.5137 ± 0.0110 and 2.2103 ± 0.0587 respectively.

RGL is used for classifying fish as carnivores, herbivores, and omnivores. These values are closely related to the presence of vegetable matter and animal matter in the diet. It increases with more vegetable matter and decrease with more animal matter in the diet (Dasgupta, 2004). In this study, the range of RGL was 0.469-0.571, with a mean ± SD of 0.5137 ± 0.0110. According to Karachle & Stergiou (2010), the RGL values are <1 when the fish are carnivorous, 1-3 when they are omnivorous and >3 when they are vegetarian. According to this criterion, *A. sirm* is a carnivore.

The GaSI is used to examine the feeding intensity of fish (Hynes 1950). The range of GaSI in this study was 1.898-2.571 with a mean ± SD value of 2.2103 ± 0.0587. The highest and the lowest feeding intensities were recorded the size classes of 17.5-18.5 cm and 12.5-13.5 cm respectively.

Heavy metal analysis of fish muscles of *A. sirm*

Mean concentrations (mg/Kg wet weight) of Cr, Zn, Cu, and Cd in the edible muscles of *A sirm* collected from Negombo coastal water are given in Table 6.

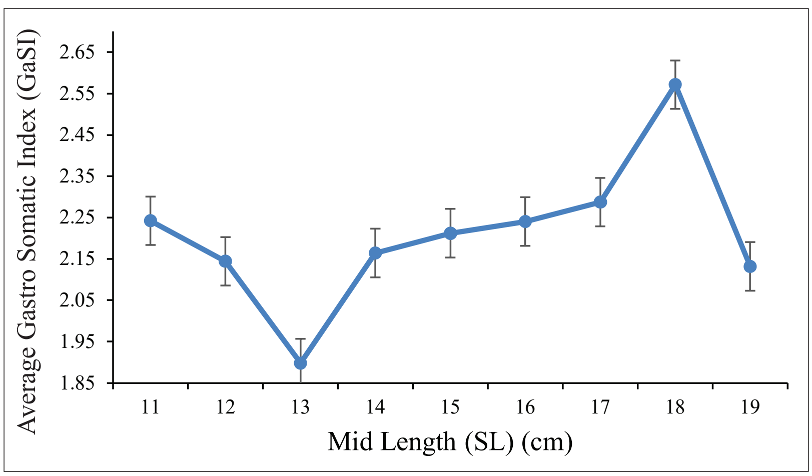

Figure 4: Variation of the mean gastro somatic index (GaSI) in different size classes (SL) (cm) of *A. sirm*

Table 6: Concentrations of heavy metals (mg/Kg wet weight) in *A. sirm*

Heavy metal	Mean ±SD (mg/Kg wetweight)	Minimum (mg/ Kg wet weight)	Maximum (mg/ Kg wetweight)	Maximum permissible level
Cr	10.07 ± 3.66	2.73	14.56	50
Zn	7.88 ±1.86	4.61	10.59	40
Cu	5.39 ± 0.08	5.29	5.57	30
Cd	0.52 ± 0.04	0.40	0.55	0.5

Table 7: Eigen analysis of the correlation matrix

Component	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7	PC_8
Eigenvalue	5.003	1.4141	0.9914	0.4895	0.0788	0.0122	0.0100	0.0016
Proportion	0.625	0.177	0.124	0.061	0.010	0.002	0.001	0.000
Cumulative	0.625	0.802	0.926	0.987	0.997	0.999	1.000	1.000

Table 8: Eigen vectors (coefficient in the linear combinations of variables making up PCs)

Variable	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7	PC_8
Total Length	0.440	0.043	0.031	-0.176	0.348	-0.329	0.262	0.689
Standard Length	0.438	0.050	0.041	-0.177	0.366	0.711	-0.362	-0.037
Head Length	0.318	0.065	0.320	0.890	-0.004	0.003	-0.003	0.011
Body Weight	0.433	0.043	0.119	-0.203	-0.514	-0.367	-0.597	-0.026
Gut Length	0.348	0.463	-0.285	-0.045	0.265	-0.296	0.225	-0.610
Weight of stomach contents	0.414	-0.209	-0.223	-0.054	-0.569	0.329	0.548	-0.019
RGL	-0.153	0.661	-0.497	0.178	-0.232	0.183	-0.153	0.388
Ga. SI	0.098	-0.543	-0.709	0.259	0.183	-0.146	-0.266	0.009

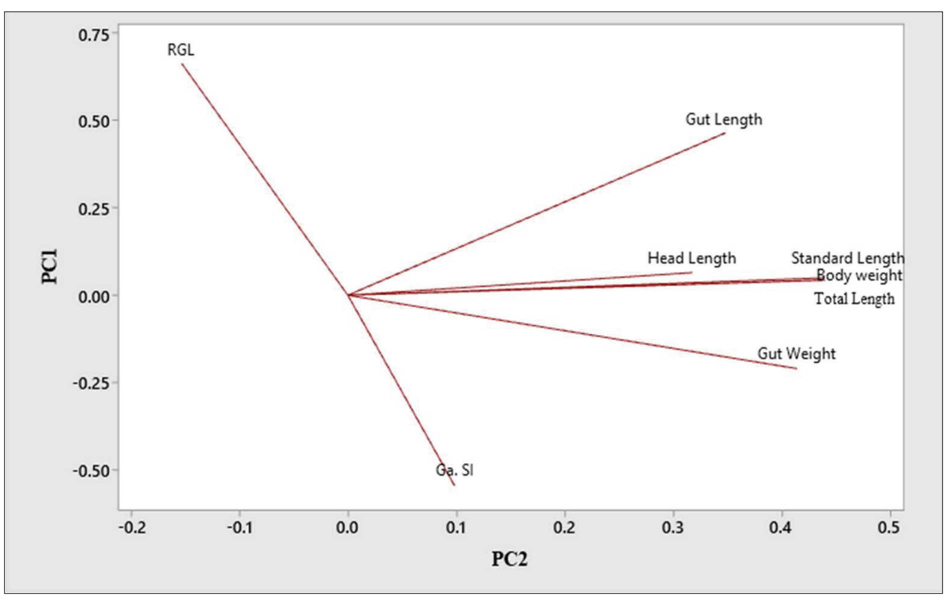

Figure 5: Loading plot of gut length, standard length, head length, total length, body weight, weight of stomach contents, gastro-somatic Index (GaSI), and relative gut length (RGL).

Principal component analysis (PCA) of various biometric traits

In the eigen analysis of the correlation matrix, only two eigen values were >1 (Table 7), which is a Kaiser criterion. Therefore, since most of the variables are captured in these two components, they are considered to be sufficient for further analysis.

The loadings of various variables on principal components (PCs), which provide insights into how each variable contributes to the underlying structure captured by these components, are given in Table 8. Loadings represent the correlation between variables and PCs, with higher absolute values indicating a stronger association. In this analysis, the total length, standard length, head length, body weight, gut length, and weight of stomach contents showed high positive loadings on PC1. This suggests that they are closely aligned with the structure represented by PC1 and are positively correlated with each other. Conversely, RGL is negatively loaded on PC1.

A loading plot of the 1st and 2nd PCs illustrates the relationship between the original variables and these two components. In this plot, each variable is represented as a vector, and the direction and length of the vector indicate the variable's contribution and direction of influence on the PCs. Figure 5 gives the coordinates and the intensity of each component based on the standardized PC scores and the first two components. As Figure 5 suggests, the variables of standard length, total length, gut length, head length, body weight, and weight of stomach contents are closer to each other than RGL and GaSI.

The biplot given in Figure 6 provides coordinates of each observation and variable based on the rotation (loading) of the first two components. The shorter distance between the two observations of standard length, total length, gut length, head length, body weight, and weight of stomach contents indicates higher similarities between them.

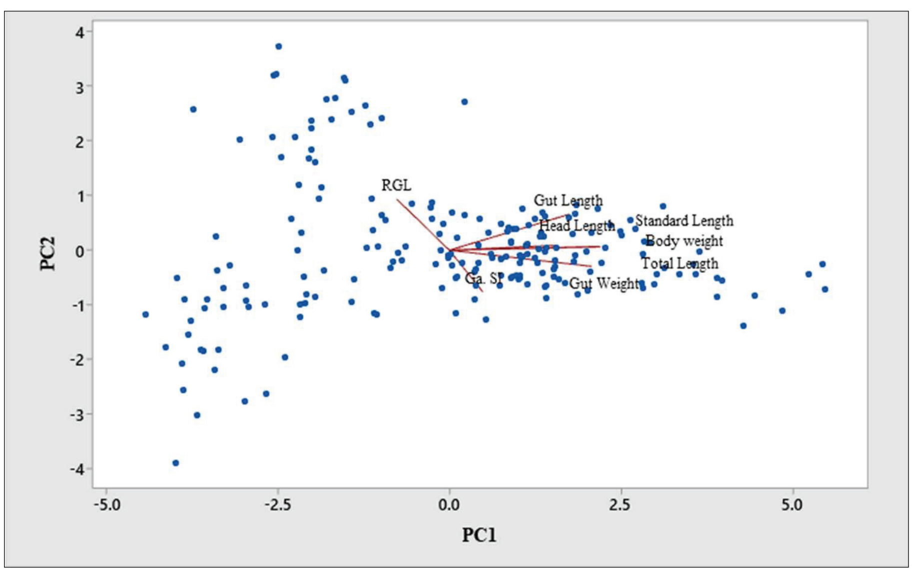

Figure 6: Biplot of gut length, standard length, head length, total length, body weight, weight of stomach contents, gastro-somatic index (GaSI) and relative gut length (RGL).

According to the PCA, variables such as total length, standard length, head length, body weight, gut length, and weight of the stoch contents were positively associated with each other.

The presence of toxic heavy metals in fish muscles can diminish the advantageous properties with adverse effects on human health (Castro-Gonzales & Mendez-Armenta, 2008). Heavy metals include both biologically essential (e.g. Cu and Zn) and not essential metals (e.g. Cd) (Kennish, 1998). According to this study, the mean concentrations of Cr, Zn, Cu and Cd (mg/kg wet weight) in edible muscles of *A. sirm,* are 10.07 ± 3.66, 7.88 ± 1.86, 5.39 ± 0.08 and 0.52 ± 0.04 respectively. These values did not exceed the maximum permissible limits recommended by the FAO and WHO (FAO, 1983;

FAO/WHO 2009). Therefore, these fish are suitable for human consumption.

CONCLUSION

The *A. sirm* stock in the western coastal waters of Sri Lanka has been found to be overharvested and it has been suggested to use the gillnets of >25 mm mesh size (Karunasinghe and Wijeyaratne (1995). During the present study, it was found that the mesh size of the gillnets used in this fishery is 1¼ inches (31.8 mm) and 1½ inches (38.1 mm), which are >25 mm of mesh size. This shows that the recommendations made through scientific studies are very important to maintain the sustainable utilization of the resources.

A. sirm stock in the coastal waters off Negombo showed a positive allometric growth, with fish being in good physical condition. The mean condition factor of females (0.9439 ± 0.8699) was higher than that of males (0.9047 ± 0.1074).

The most preferred food item was crustacean larvae. The frequency of occurrence of synthetic material in stomach contents was 2.55%. This can affect their physiology, growth, reproduction, and overall survival. The RGL of the fish was <1, indicating that this species is carnivorous. The GaSI showed the different feeding intensities in different length classes.

The Cr concentration was observed to range from 2.73 mg/Kg to 14.56 mg/Kg with a mean value of 10.07 ± 3.66 mg/Kg. According to WHO (1989), the maximum permissible limit (MPL) for Cr is 50.0 mg/Kg. The mean Zn concentration was observed to be 7.88±1.86 mg/Kg, with a range of 4.61-10.59 mg/Kg. According to FAO/WHO (2009), MPL of Zn is 40 mg/Kg. The mean Cu concentration was observed to be 5.39 ± 0.08 mg/Kg with a range of 5.29-5.57 mg/Kg. According to the FAO/WHO (2009), MPL of Cu is 30 mg/Kg. The mean Cd concentration was observed to be 0.52 ± 0.04 mg/Kg, with a range of 0.40-0.55 mg/Kg. According to FAO/WHO (2009), the MPL of Cd is 0.5 mg/Kg Therefore the present study indicates that the concentration of Cr, Zn, Cu and Cd in the edible parts of the fish indicated safe levels for human consumption (WHO, 1989; FAO/WHO, 2009).

Acknowledgement

The authors gratefully acknowledge the Department of Zoology and Environmental Management, University of Kelaniya for providing research facilities and the fishermen in the Negombo Sea Street landing site for providing fish samples.

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