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Development of morphometric conversion equations for Blue Marlin (*Makaira mazara*) and Striped Marlin (*Kajikia audax*) using observer-collected photographs from Sri Lankan multiday fisheries

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Purpose, expectation and action intended (select one or more and include corresponding text)

Discussions (for information and open discussion):

[The paper is to inform meeting members that…, as set out in Section X]

This paper presents species-specific morphometric conversion equations for estimating lower jaw–fork length (LJFL) of Blue Marlin (*Makaira mazara*) and Striped Marlin (*Kajikia audax*) from alternative measurements obtained from observer-collected photographs. The paper is submitted for information and discussion by the Working Party on Billfish. The authors seek the Working Party's consideration of the applicability of the developed conversion equations to improve the consistency of billfish length data collected through biological data collection programmes and to support biological data reporting and stock assessment. Feedback from the Working Party on the applicability and potential use of these equations in IOTC data collection and reporting is welcomed.

Feedback (to collect input and suggestions)

[The paper is to request review and comments on…, as set out in Section X]

Conclusion (to record a concluded position or summary)

[The paper is to seek confirmation that…, as set out in Section X]

Recommendation (to ask the meeting to endorse a recommendation)

[The paper is to seek endorsement on…, as set out in Section X]

Decisions (to request formal approval of actions)

[The paper is to seek approval on…, as set out in Section X]

Abstract

Blue Marlin (*Makaira mazara*) and Striped Marlin (*Kajikia audax*) are important billfish species in Sri Lankan offshore fisheries. However, these species are frequently processed at sea before landing, resulting in the loss of morphological features required for standard length measurements, particularly lower jaw–fork length (LJFL), and creating gaps in biological data available for fisheries monitoring, stock assessment, and reporting to the Indian Ocean Tuna Commission (IOTC). This study developed species-specific morphometric conversion equations to estimate LJFL from alternative body measurements using whole-fish photographs collected through the National Observer Programme on Sri Lankan multiday fishing vessels operated during 2025/ 2026. A total of 66 Blue Marlin and 32 Striped Marlin specimens were analyzed. We measured lower jaw–fork length (LJFL), pectoral–second dorsal length (PDL), and pectoral–anus length (PAL) from standardized photographs and developed linear regression models to establish relationships among the three measurements. Strong linear relationships were observed for both species. For Striped Marlin, the strongest relationship was between LJFL and PDL ($R^2 = 0.94$), while the corresponding relationship for Blue Marlin was also strong ($R^2 = 0.92$). Relationships involving PAL produced R^2 values of 0.81 for Striped Marlin and 0.80 for Blue Marlin. The developed equations provide a practical means of reconstructing standard-length measurements when direct LJFL measurements are unavailable, thereby improving the consistency and compatibility of biological data collected under different sampling protocols. These results address an important gap in standardized billfish biological data and provide a useful tool for improving biological data reporting to the IOTC, fisheries monitoring, and stock assessment of Blue Marlin and Striped Marlin in the Indian Ocean.

Introduction

Billfishes are important components of pelagic marine ecosystems and are widely exploited by commercial and artisanal fisheries throughout the tropical and subtropical oceans. In the Indian Ocean, the Indian Ocean Tuna Commission (IOTC) is responsible for monitoring and assessing several billfish species, including Blue Marlin and Striped Marlin, which are frequently encountered in offshore fisheries. Reliable biological and fisheries-dependent data, particularly information on the size composition of catches, are essential for stock assessment and for developing effective fisheries management measures. The importance of improving the quality of such information is particularly evident for Indian Ocean billfishes, for which stock assessments rely on catch, catch-per-unit-effort (CPUE), and length-frequency information.

In Sri Lanka, billfishes are captured mainly in offshore fisheries, including longline and gillnet fisheries, and contribute to both domestic consumption and export markets (Haputhantri and Maldeniya, 2011). However, collecting standard biological measurements from landed billfish is challenging because the fish are frequently cut into pieces and preserved at sea before landing (Haputhantri and Perera, 2014; Gunawardane et al., 2024). Such processing may involve the removal of morphological structures required to obtain conventional length measurements, particularly the lower jaw–fork length (LJFL). Consequently, the direct collection of standardized length data at landing sites is difficult, resulting in gaps or inconsistencies in the length-frequency information available for fisheries monitoring and stock assessment. Recent work undertaken in Sri Lanka has demonstrated the potential of length-conversion relationships based on alternative morphometric measurements to address such data limitations (Haputhantri and Perera, 2014; Gunawardane et al., 2024; Darsigan et al., 2025).

Morphometric conversion equations provide a practical approach for reconstructing standard length measurements when the preferred measurement cannot be obtained directly. By establishing statistically robust relationships between measurements that remain available on processed fish and standard reference lengths, biological information can be recovered from fish that would otherwise be excluded from length-based analyses. This approach is particularly valuable in fisheries where dressing practices vary among vessels and where measurements must be reconstructed from fish photographed or measured before processing. Recent research in Sri Lanka has shown strong relationships between lower jaw–fork length and alternative measurements such as pectoral–second dorsal length (PDL) and pectoral–anus length (PAL) for several billfish species. However, the strength of these relationships is not necessarily consistent across species, demonstrating the importance of developing and validating species-specific morphometric conversion equations.

Blue Marlin and Striped Marlin warrant particular attention because both species are important components of Indian Ocean billfish fisheries and are subject to stock assessment under the IOTC framework. The availability of reliable size data is especially important given the management concerns associated with these species. Recent IOTC assessments have identified substantial uncertainty and conservation concerns for both Blue Marlin and Striped Marlin in the Indian Ocean, reinforcing the need to improve the biological information available for assessment and management. The quality and consistency of length-frequency data are therefore important for improving the reliability of stock assessment inputs and strengthening the scientific basis for fisheries management.

Although morphometric relationships have been investigated for several billfish species, relatively little information is available on species-specific conversion relationships for Blue Marlin and Striped Marlin in Sri Lankan fisheries. Previous Sri Lankan investigations have focused on developing conversion factors for other billfish species. At the same time, recent image-based studies have also indicated that the strength of relationships between alternative body measurements and LJFL can vary considerably among species. In particular, the relationships identified for Blue Marlin have shown greater variability than those observed for some other billfish species, highlighting the need for additional species-specific observations and validation (Darsigan et al., 2025). This gap is particularly relevant for Striped Marlin, for which robust morphometric conversion relationships based on Sri Lankan fisheries observations remain limited.

The present study therefore focuses specifically on Blue Marlin and Striped Marlin, rather than repeating morphometric analyses already conducted for other billfish species. Biological measurements obtained from whole-fish photographs collected through onboard observer programmes on Sri Lankan multiday fishing vessels were used to investigate linear relationships among key morphometric measurements. Species-specific linear regression models were developed to establish conversion equations between alternative morphometric measurements and standard-length measurements, with model performance evaluated using the coefficient of determination (R^2). The resulting equations are expected to provide practical tools for estimating standard biological measurements from processed fish landed at Sri Lankan ports, thereby improving the availability, consistency, and utility of length data for fisheries monitoring, stock assessment, and reporting to the IOTC.

Materials and methods

Data collection

Morphometric data for Blue Marlin and Striped Marlin were collected through the National Observer Programme of the Department of Fisheries and Aquatic Resources (DFAR), Sri Lanka. Specimens were sampled from Sri Lankan offshore multiday fishing vessels operating in the Indian Ocean. Each fish was photographed before processing using a standardized protocol to ensure that key anatomical landmarks were clearly visible for subsequent measurements.

Morphometric measurements

Morphometric measurements were obtained from digital photographs using image-analysis software. Lower jaw–fork length (LJFL), the standard-length measurement recommended by the Indian Ocean Tuna Commission (IOTC), was used as the reference variable. Alternative measurements, pectoral–second dorsal length (PDL) and pectoral–anus length (PAL), were evaluated as predictors of LJFL.

Statistical analysis

Separate linear regression models were developed for Blue Marlin and Striped Marlin to establish relationships between LJFL and each alternative morphometric measurement using the equation:

$$\mathrm{LJFL} = \mathrm{a} + \mathrm{b}X$$

where X represents the alternative morphometric measurement, and a and b are the regression intercept and slope, respectively. Before analysis, data were screened to remove incomplete observations and obvious measurement errors. Model performance was evaluated using the coefficient of determination (R^2). Regression assumptions were assessed by examining residual plots, and statistical significance was determined at $P < 0.05$. All analyses were performed using R statistical software (R Development Core Team, 2026).

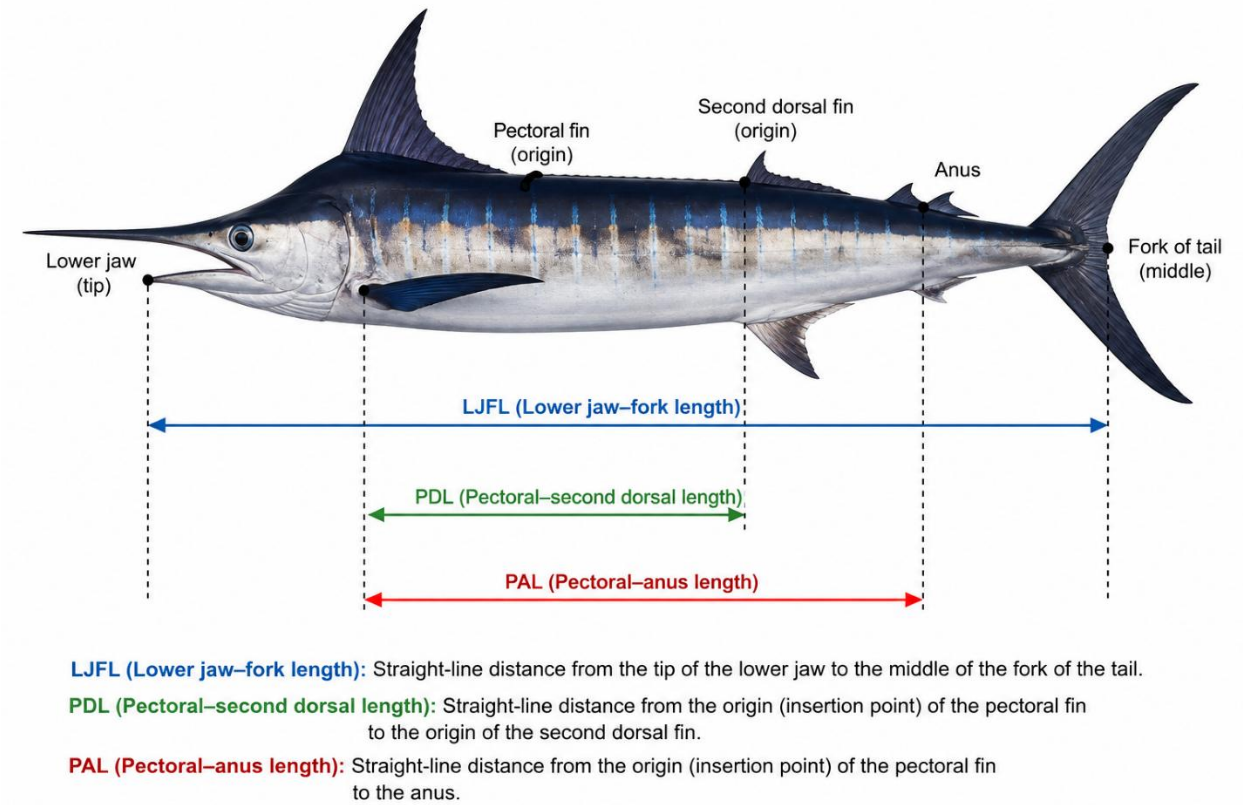

Figure 1. Illustration of different morphometric measurements of Marlin

Results and discussion

A total of 66 Blue Marlin and 32 Striped Marlin specimens were used to develop morphometric conversion equations based on pectoral–second dorsal length (PDL), pectoral–anus length (PAL), and lower jaw–fork length (LJFL). Blue Marlin exhibited a wider size range than Striped Marlin, reflected by the larger standard deviations of the measured lengths. The mean (±SD) PDL, PAL, and LJFL of Blue Marlin were 97.8 ± 33.5 cm, 63.1 ± 10.5 cm, and 178.3 ± 37.5 cm, respectively, whereas the corresponding values for Striped Marlin were 155.6 ± 13.8 cm, 61.0 ± 5.9 cm, and 216.0 ± 18.5 cm (Table 1).

Table 1. A summary of the length measurements used for development of morphometric conversion equations for Blue Marlin and Striped Marlin

Species	Sampling size	Mean length ±SD		
		PDL	PAL	LJFL
Blue marlin	66	97.8 ± 33.5	63.1 ± 10.5	178.3 ± 37.5
Striped marlin	32	155.6 ± 13.8	61.0 ± 5.9	216.0 ± 18.5

PDL- Pectoral–second dorsal length; PAL: Pectoral–anus length; LJFL- Lower jaw–fork length

Linear regression analysis revealed strong morphometric relationships among the three length measurements in both species. In Striped Marlin, the strongest relationship was observed between LJFL and PDL ($R^2 = 0.93$) (Table 2). Relationships involving PAL showed comparatively lower, but still strong, coefficients of determination ($R^2 = 0.81$), indicating that PAL can also be used as a reliable predictor of the other length measurements.

Table 2. Morphometric relationships of Striped Marlin

Response <chr>	Predictor <chr>	Intercept <dbl>	Slope <dbl>	R2 <dbl>	n <int>
LJFL	PDL	14.2	1.30	0.94	32
LJFL	PAL	42.6	2.84	0.81	32
PDL	LJFL	-0.62	0.72	0.94	32
PDL	PAL	26.2	2.12	0.81	32
PAL	LJFL	-0.76	0.29	0.81	32
PAL	PDL	1.48	0.38	0.81	32

PDL- Pectoral–second dorsal length; PAL: Pectoral–anus length; LJFL- Lower jaw–fork length

Similarly, Blue Marlin exhibited strong linear relationships among all morphometric measurements. The relationship between LJFL and PDL explained 92% of the variation ($R^2 = 0.92$), whereas the relationship between PDL and PAL explained 85% of the variation ($R^2 = 0.85$) (Table 3). Regression models involving PAL and LJFL produced R^2 values of 0.80, demonstrating that all morphometric measurements were highly correlated and suitable for conversion between length types.

Table 3. Morphometric relationships of Blue Marlin

Response <chr>	Predictor <chr>	Intercept <dbl>	Slope <dbl>	R2 <dbl>	n <int>
LJFL	PDL	-2.45	1.85	0.92	66
LJFL	PAL	-14.6	3.06	0.80	66
PDL	LJFL	9.26	0.49	0.92	66
PDL	PAL	-5.00	1.63	0.85	66
PAL	LJFL	16.4	0.26	0.80	66
PAL	PDL	12.3	0.52	0.85	66

PDL- Pectoral–second dorsal length; PAL: Pectoral–anus length; LJFL- Lower jaw–fork length

The scatter plots presented in Figures 1 and 2 further illustrate the strong positive linear relationships among the morphometric measurements for both Striped Marlin and Blue Marlin. The data points are closely distributed around the fitted regression lines, indicating that linear models adequately describe the relationships between the measured body dimensions over the observed size ranges.

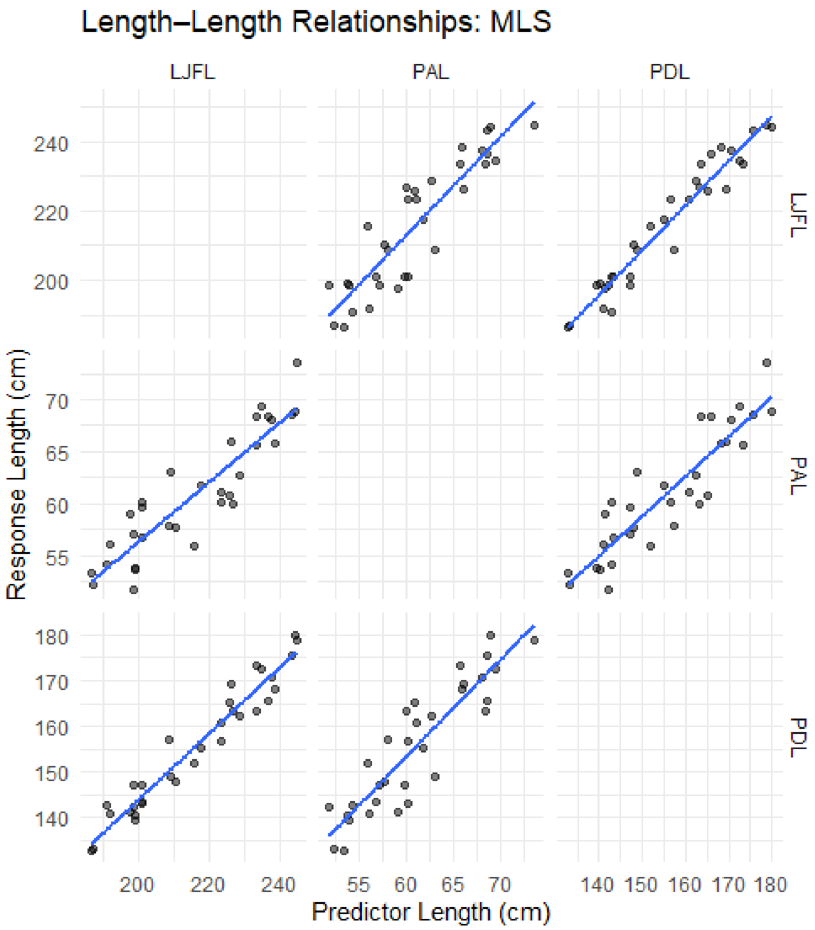

Figure 1. Length – Length relationships of Striped Marlin: PDL- Pectoral–second dorsal length; PAL: Pectoral–anus length; LJFL- Lower jaw–fork length

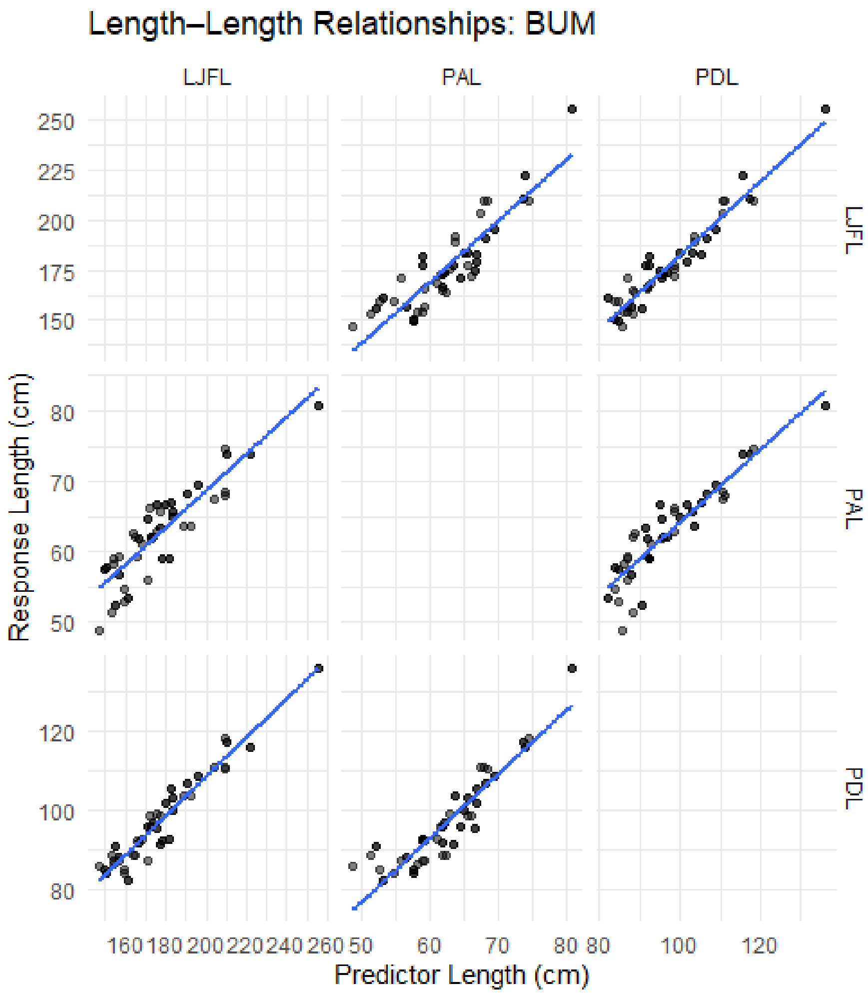

Figure 2. Length – Length relationships of Blue Marlin: PDL- Pectoral–second dorsal length; PAL: Pectoral–anus length; LJFL- Lower jaw–fork length

The consistently high coefficients of determination obtained in this study suggest that PDL, PAL, and LJFL are highly interchangeable for estimating missing morphometric measurements in both species. Among the evaluated relationships, PDL and LJFL provided the highest predictive accuracy for both Blue Marlin and Striped Marlin, making these equations particularly useful when one of these measurements is unavailable. Such conversion equations are valuable for fisheries observer programmes, port sampling, and historical datasets where different length measurements have been recorded. Standardizing measurements through reliable conversion equations improves the compatibility of datasets collected under different sampling protocols and enhances the quality of biological analyses, including length-frequency analysis, growth studies, stock assessments, and regional comparisons.

Although all regression models were statistically strong, relationships involving PAL showed slightly lower coefficients of determination than those involving PDL and LJFL. This may reflect greater variability in locating the anatomical landmarks used to measure PAL, resulting in slightly lower prediction accuracy than for PDL and LJFL. Nevertheless, the observed R^2 values (0.80–0.85) indicate that PAL remains an appropriate predictor for morphometric conversions when other measurements are unavailable.

Overall, the developed morphometric equations provide a practical tool for converting among commonly used length measurements for Blue Marlin and Striped Marlin in the Indian Ocean. Their application will facilitate harmonization of biological data collected from different fisheries monitoring programmes and contribute to improved fisheries research and stock assessment.

Conclusion

This study developed reliable morphometric conversion equations among LJFL, PDL, and PAL for Blue Marlin and Striped Marlin in the Indian Ocean. The strong relationships observed provide a practical basis for converting length measurements collected under different sampling protocols, improving the consistency and integration of billfish biological data. Importantly, the study addresses a much-needed gap in the availability and reporting of standardized billfish biological data to the Indian Ocean Tuna Commission (IOTC), thereby supporting improved data quality, fisheries monitoring, and stock assessment of these important species.

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