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UPDATED SEX-SPECIFIC GROWTH PARAMETERS FOR SWORDFISH (*XIPHIAS GLADIUS*) IN THE TROPICAL INDIAN OCEAN FOR THE 2026 IOTC STOCK ASSESSMENT

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Discussions: The paper is to inform meeting members of updated sex-specific swordfish growth parameters for potential use in the 2026 stock assessment, as set out in Sections 2–3.

Feedback: The paper is to request review and comments on the reference MF growth scenario and its use in assessment sensitivity analyses, as set out in Section 3.

Conclusion: The paper is to seek confirmation that the MF estimates provide a documented, sex-specific Indian Ocean growth option with explicit uncertainty, as set out in Section 3.

Recommendation: The paper is to seek endorsement of using the MF growth parameters as a sensitivity scenario in the 2026 swordfish stock assessment, as set out in Section 3.

Decisions: No formal approval of actions is requested in this paper.

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Content:

Abstract

Updated sex-specific growth parameters are provided for Indian Ocean swordfish for consideration in the 2026 IOTC stock assessment. The analysis is based on 834 anal-fin ray specimens and 181 otolith specimens collected by Taiwanese scientific observers from major tropical Indian Ocean longline fishing grounds between May 2007 and April 2008. Four back-calculation formulations were evaluated in the full analysis, but this working paper focuses on the simplified modified Fry-type formulation (MF) as the reference scenario for assessment use. Otolith daily increment information was used as a complementary population-level constraint on early growth, and uncertainty was quantified through 1000 fish-level bootstrap iterations. Reference MF estimates were L_∞ = 274.31 cm, K = 0.136 yr^{-1}, and t_0 = -1.904 yr for females and L_∞ = 243.01 cm, K = 0.156 yr^{-1}, and t_0 = -1.992 yr for males. MF produced the lowest median RMSE for both sexes, although its fit did not differ significantly from the biological-intercept formulation. These historical data represent a regional tropical Indian Ocean growth scenario rather than a contemporary basin-wide growth curve, but they provide a documented sex-specific growth option with explicit uncertainty for stock assessment sensitivity analyses.

1. Introduction

Reliable sex-specific growth information is an important input to age-structured stock assessment of swordfish because females and males follow different growth trajectories and attain different maximum sizes. Current Indian Ocean swordfish assessment models are sex-explicit and age-structured, so growth assumptions directly influence the interpretation of length-composition data, age structure, selectivity, stock productivity, and estimated stock status (Fu, 2023; IOTC, 2025).

Indian Ocean-specific hard-part age and growth information remains limited. Wang et al. (2010) estimated sex-specific growth from anal-fin ray samples collected by the Taiwanese scientific observer program across the tropical Indian Ocean, and those estimates have continued to be considered as an Indian Ocean growth option in IOTC assessment work (Fu, 2023). More recent otolith work from the western Indian Ocean has provided important age information but has also highlighted the difficulty of obtaining sufficient large, sexed specimens for robust sex-specific growth estimation (Farley et al., 2021).

The present analysis revisits the same broad observer-based biological archive used by Wang et al. (2010) with additional otolith-derived early-life information, alternative back-calculation formulations, and fish-level bootstrap uncertainty. Four formulations were evaluated in the full analysis: allometric proportional (AP), biological intercept (BI), allometric biological-intercept (ABI), and simplified modified Fry-type (MF). Because the immediate purpose of this working paper is to provide growth inputs for the 2026 IOTC swordfish stock assessment, only the MF reference scenario is described in detail here.

2. Materials and methods

2.1. Biological samples

Swordfish were sampled by onboard scientific observers from Taiwanese pelagic longline vessels operating in the tropical Indian Ocean from May 2007 to April 2008. Sampling locations extended across approximately 35°E to 95°E and 15°S to 10°N and covered major longline fishing grounds (Fig. 1). A total of 834 anal-fin ray specimens were retained for growth analysis, comprising 461 females and 373 males with lower jaw fork lengths (LJFL) from 61 to 252 cm. Sagittal otoliths were obtained from a separate set of 181 fish. Of these, 152 had unambiguous sex assignments, including 64 females and 88 males with LJFL from 43 to 110 cm. Anal-fin rays and otoliths were collected from different individual fish and are therefore treated as independent data sources.

2.2. Age information and back-calculation

The second ray of the first anal fin was sectioned and interpreted using established swordfish aging procedures (Berkeley and Houde, 1983; Sun et al., 2002). Annuli were identified from alternating opaque and translucent bands, and monthly marginal increment patterns were consistent with annual annulus deposition, although the samples covered only one annual cycle. Otolith daily increments were used as complementary early-life age information rather than as specimen-level validation of fin-ray ages.

Back-calculated length at age was examined using four formulations in the full analysis: AP, BI, ABI, and MF (Campana, 1990; Ehrhardt, 1992; Francis, 1990; Vigliola et al., 2000; Vigliola and Meekan, 2009). For the intercept-based formulations, the empirical reference length L_0 was defined as the fifth percentile of otolith-derived fish lengths within each sex. L_0 was 61 cm for females and 66 cm for males, and the corresponding anal-fin ray radii derived from the sex-specific length-radius relationships were S_0 = 766 μm and 835 μm. For MF, the empirical lower-length offset a' was set to 0.75L0, giving 45.75 cm for females and 49.50 cm for males. These values are numerical early-life reference parameters and are not interpreted as length or radius at hatching.

The MF formulation follows the logarithmic structure of the modified Fry approach of Vigliola et al. (2000) as presented by Vigliola and Meekan (2009):

$$L_i = a' + e^{ln(L_0 - a') + \frac{(ln(S_i) - ln(S_0)) \cdot (ln(L - a') - ln(L_0 - a'))}{ln(S) - ln(S_0)}}$$

where L_i is the back-calculated fish length at annulus *i*, L is fish length at capture, S_i is the anal-fin ray radius at annulus *i*, S is the total anal-fin ray radius at capture, and L_0, S_0, and a' are the empirical early-life reference parameters defined above.

2.3. Growth estimation and uncertainty

Sex-specific growth was described with the von Bertalanffy growth function (VBGF):

$$L_t = L_\infty \cdot \left(1 - e^{-K(t-t_0)}\right)$$

where L_t is predicted LJFL at age t, L_∞ is asymptotic length, K is the growth coefficient, and t_0 is the theoretical age at zero length. For each sex, the fitting dataset combined MF back-calculated anal-fin ray lengths at age with otolith fish lengths and fractional ages derived from daily increment counts. Otolith observations therefore provided a population-level constraint on the early portion of the growth trajectory.

Parameter uncertainty was quantified using 1000 fish-level bootstrap iterations. Anal-fin ray and otolith specimens were resampled independently at the individual-fish level, and the complete analytical sequence was repeated in every iteration, including the length-radius relationship, empirical early-life reference values, back-calculation, and VBGF fitting. Bootstrap medians and 95% percentile intervals are reported below.

3. Results and discussion

3.1. Reference MF growth parameters

The four back-calculation formulations produced similar broad growth patterns but differed most strongly at young ages, where assumptions about the somatic to hard-part relationship have the greatest influence. MF yielded the lowest median VBGF RMSE for both females and males and was therefore retained as the reference formulation for presentation and assessment use. Its RMSE advantage over AP was significant for both sexes, but MF and BI did not differ significantly. Accordingly, the use of MF as the reference scenario should not be interpreted as evidence that it is biologically superior to BI or to the other structural alternatives.

Under MF, the female VBGF parameters were L_∞ = 274.31 cm, K = 0.136 yr^{-1}, and t_0 = -1.904 yr, whereas the male estimates were L_∞ = 243.01 cm, K = 0.156 yr^{-1}, and t_0 = -1.992 yr (Table 1). The corresponding median RMSE values were 12.09 cm for females and 12.45 cm for males. Female and male mean growth trajectories began to diverge visibly from approximately age 4 onward, with females attaining progressively larger sizes (Fig. 2).

3.3. Interpretation and limitations

The samples were collected in 2007 to 2008 and therefore represent a historical point-in-time growth scenario. They also cover major tropical longline fishing grounds rather than the full IOTC convention area, so the resulting curves should not be interpreted as contemporary basin-wide growth relationships. Temporal or geographic changes in growth cannot be excluded under changing population structure, selectivity, exploitation history, or environmental conditions (Lorenzen, 2016).

Despite these limitations, the broad tropical spatial coverage, sex-specific hard-part information, complementary otolith observations, and explicit uncertainty make this archive relevant for current assessment sensitivity analyses.

Contemporary paired sampling of anal-fin rays and otoliths across a wider size range, multiple years, and both tropical and higher-latitude areas remains a priority for future work.

A full methodological analysis of these data, including detailed comparisons among all four back-calculation formulations and associated uncertainty, has been submitted separately for peer-reviewed publication. The present working paper was prepared specifically to provide a concise and transparent set of growth inputs for the 2026 IOTC swordfish stock assessment.

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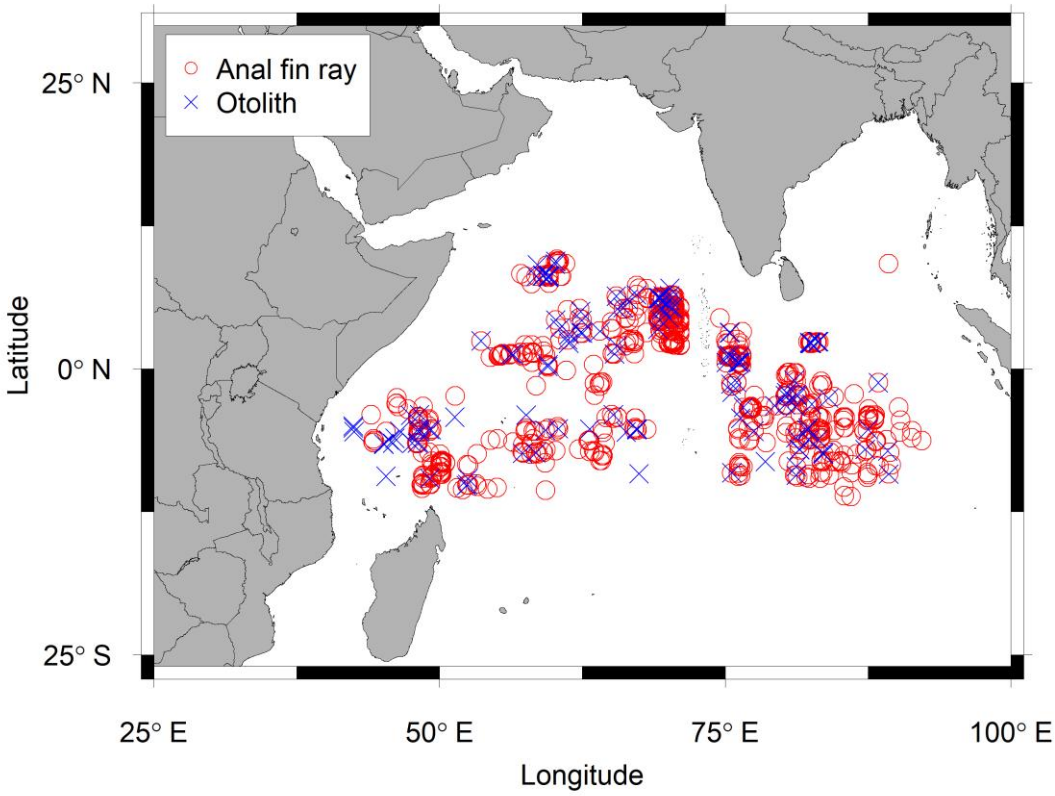

Fig. 1. Sampling locations of swordfish specimens collected by Taiwanese pelagic longline vessels in the tropical Indian Ocean between May 2007 and April 2008. Circles indicate anal-fin ray specimens and crosses indicate otolith specimens. Anal-fin ray and otolith specimens were obtained from different individual fish.

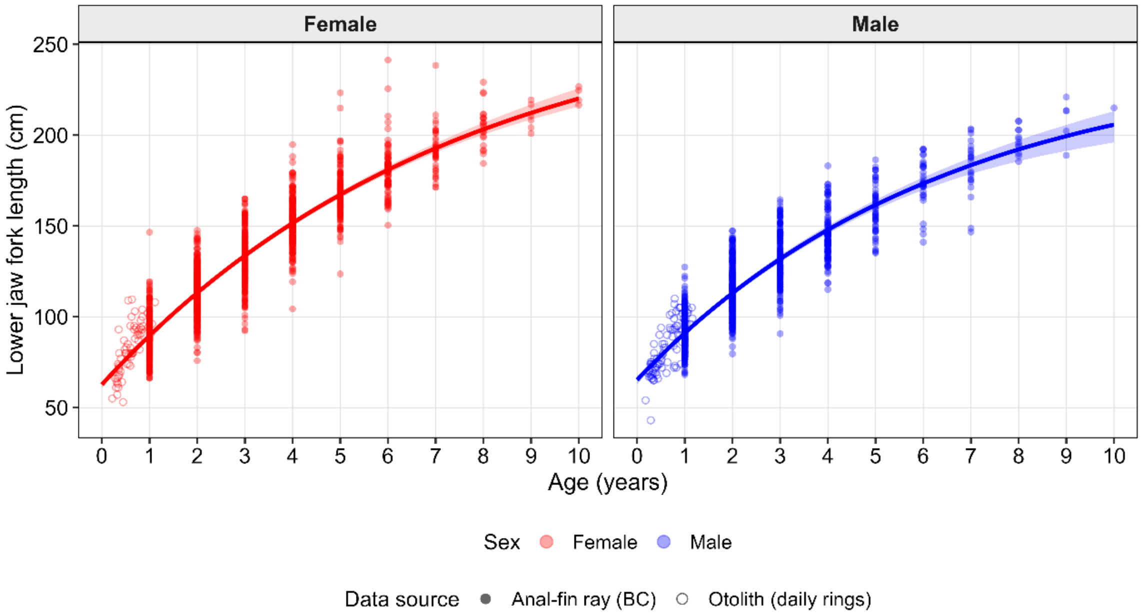

Fig. 2. Length-at-age observations and fitted sex-specific von Bertalanffy growth curves under the reference simplified modified Fry-type formulation. Pale points show individual anal-fin ray back-calculated observations and otolith-derived fractional-age observations. Colored points and vertical bars show mean length at age and bootstrap 95% intervals, solid curves show fitted VBGF trajectories, and shaded bands show bootstrap uncertainty around the curves. Anal-fin ray and otolith specimens were obtained from different individual fish.

Table 1. Sex-specific VBGF parameters and RMSE under the reference simplified modified Fry-type formulation. Values are bootstrap medians with 95% percentile intervals in parentheses.

Sex	L_∞ (cm)	K (yr^{-1})	t_0 (yr)	RMSE (cm)
Female	274.31 (257.82, 297.78)	0.136 (0.118, 0.155)	-1.904 (-2.105, -1.738)	12.09 (11.27, 12.98)
Male	243.01 (217.38, 270.21)	0.156 (0.126, 0.201)	-1.992 (-2.287, -1.705)	12.45 (11.74, 13.17)