

Towards sustainable management of the Cunene horse mackerel (*Trachurus trecae*) in Guinea-Bissau waters

Diosnes Nonque^{1,2}, Matheus de Barros³ , Ana Martins^{1,4}  and Régis Santos^{1,4,5,*} 

¹ Department of Oceanography and Fisheries, Faculty of Sciences and Technology, University of the Azores, Horta, Azores, Portugal

² Instituto Nacional de Investigação das Pescas e Oceanografia - INIPO, Av. Amílcar Cabral, Rua 12 Bissau, CP 102-Bissau, Guinea-Bissau

³ School of Aquatic and Fishery Sciences, University of Washington, Seattle, United States

⁴ University of the Azores, Institute of Marine Sciences - OKEANOS, Rua Professor Doutor Frederico Machado 4, 9900-140 Horta, Portugal

⁵ CIBIO, Research Centre in Biodiversity and Genetic Resources, InBio Associate Laboratory, BIOPOLIS Program in Genomics, Biodiversity and Land Planning; UNESCO Chair – Land Within Sea: Biodiversity & Sustainability in Atlantic Islands, University of the Azores, Rua da Mãe de Deus, 9500-321 Ponta Delgada, Portugal

Received 13 December 2025 / Accepted 18 May 2026

Handling Editor: Nicolas Bez

Abstract – This study assessed the status of the Cunene horse mackerel (*Trachurus trecae*) stock in Guinea-Bissau (2018–2023) using fishery-dependent and independent data. Catches ranged from 29.1 kt (kilotones) in 2020 to 10.2 kt in 2023, dominated by Chinese (57.2%) and Guinean (22.6%) fleets. Fishing was concentrated between January and May, mainly in the 10–12°N and 16–18°W area, with demersal trawl accounting for 52.1% of catches. Biological parameters revealed negative allometry with $b = 2.80$ [2.75–2.84], $L_{50} = 20.0$ [19.6–20.3] cm for grouped sexes, L_{∞} of 48.8 [46.4–52.2] cm, K of 0.55 [0.34–0.74] yr⁻¹, and M of 0.67 [0.47–0.87] yr⁻¹, indicating a “fast” life history. Length-based indicators show reduced yields and loss of large spawners, suggesting current exploitation patterns might be unsustainable, but results were considerably sensitive to life history parameter values, particularly L_{∞} and L_{50} , which warrants continued data collection. These findings call for immediate science-based management, which might include seasonal closures, reduced fishing effort, improved gear selectivity, and enhanced monitoring. Enhanced institutional capacity and regional cooperation are critical to strengthening monitoring efforts.

Keywords: Horse mackerel / life history / stock assessment / sustainable fisheries management / West Africa

1 Introduction

Fishing plays a central role in the global economy and food security, providing livelihoods and supplying animal protein to over three billion people (Béné et al., 2015). In 2022, global production reached 91 Mt (megatonnes), corresponding to USD 157 billion, of which 80 Mt originated from marine fisheries and 11 Mt from inland fisheries (FAO, 2024). Since 1961, global fish consumption has grown at an average annual rate of 3%, exceeding the population growth rate of 1.6%, and reached 165 Mt in 2022 for human consumption, with a per capita average of 20.7 kg (FAO, 2024).

The persistent expansion of demand has placed significant pressure on fishery resources, resulting in a decline in the proportion of sustainably exploited stocks. In 1990, around 90% of global stocks were considered sustainable, decreasing to 62.3% in 2021 (FAO, 2024). The United Nations warns that

more than two-thirds of fishery resources are currently overexploited, posing a direct threat to food security (FAO, 2024). In addition to providing about 15% of the world's animal protein and 6% of total protein intake, aquatic foods contribute key nutrients such as omega-3 fatty acids, minerals, and vitamins and play a significant role in poverty reduction and improving living conditions (FAO, 2024).

In Guinea-Bissau, fishing is a key pillar of the national economy and local livelihoods, supported by the high productivity of its exclusive economic zone (EEZ). This area, considered one of the richest in West Africa, includes ecosystems such as mangroves and extensive fishing grounds that support both national and foreign fleets, providing income to thousands of families (Popoola and Olajuyigbe, 2023). The fisheries sector is strategic for Guinea-Bissau, with industrial landings valued at EUR 310 million per year, exceeding cashew exports (EUR 201 million/year) (IMF, 2023). However, the absence of an industrial port and European certification prevents formalization, resulting in annual losses equivalent to 20.8% of gross domestic product (IMF, 2023).

*Corresponding author: regis.vs.santos@uac.pt

This economic relevance is nevertheless embedded in a governance and operational context characterized by limited monitoring capacity, enforcement constraints, and infrastructural deficits that reduce value capture from landings and create conditions conducive to illegal, unreported, and unregulated fishing (CSR, 2014; Okafor-Yarwood, 2019; Dittel, 2022; IMF, 2023). Within this setting, *Trachurus trecae* is predominantly exploited by foreign industrial fleets operating under access agreements, consistent with broader regional dynamics in which distant-water fleets play a prominent role in West African fisheries (Intchama et al., 2018; Pauly et al., 2014).

These constraints translate into persistent pressures on sustainability and food security. Overfishing, driven by high demand for high-value species, has led to the overexploitation or depletion of several stocks, with impacts on biodiversity and the regenerative capacity of populations (Belhabib et al., 2018). Destructive practices such as bottom trawling degrade critical coastal ecosystems – including mangroves and benthic habitats – resulting in reduced productivity, particularly for demersal species (Polidoro et al., 2017; Virdin et al., 2019).

Global warming and ocean pollution are profoundly altering marine ecosystems, causing species to shift into new areas, disrupting reproductive cycles, and inducing physiological stress in sensitive organisms (Cheung et al., 2009; Poloczanska et al., 2016). These changes compromise the stability of resource abundance and distribution, create regional disparities in catch availability, and reduce the predictability of stocks (Pinsky et al., 2018; Free et al., 2019). Consequently, traditional management models have become insufficient, requiring adaptive strategies capable of responding to species redistribution and the increasing uncertainty associated with climate change (Goodman et al., 2025).

Limitations in scientific information represent an additional constraint. Accurate species identification at landings is hindered by high diversity and morphological similarities among species and subspecies, requiring specialized taxonomic expertise. The lack of advanced training among observers, outdated nomenclatures, and the use of local names for multiple species result in inconsistent records, affecting the quality of species-specific estimates and fishing effort data. As a result, the actual status of several populations remains uncertain, and reliance on aggregated assessments limits the development of robust models.

Among national fisheries, demersal resources are of economic and ecological relevance due to their association with shelf and slope habitats, exposure to bottom gears, and contribution to coastal community incomes. Survey data collected within Guinea-Bissau's EEZ have documented the diversity and composition of these communities. During a campaign conducted in November 2023, 423 species were recorded, including 287 fish species from 118 families, 85 crustacean species from 36 families, and 51 mollusc species from 27 families, at depths ranging from less than 50 to 1000 meters (Yraola et al., 2024). Fish dominated the biomass captured, accounting for approximately 95% of the total, followed by crustaceans (4%) and molluscs (1%). Although fish predominate in biomass, crustaceans and cephalopods remain among the most commercially valuable groups in the region (Yraola et al., 2024).

Among the demersal fish recorded during scientific surveys, the Cunene horse mackerel (*Trachurus trecae*) stands out, showing a consistent increase in its relative share of estimated demersal fish biomass, from 58% in 2018 to 66% in 2022 and 69% in 2023. This indicates high availability and spatial aggregation within the Guinea-Bissau EEZ (Yraola et al., 2019, 2023, 2024). Ecologically, the species occupies intermediate trophic levels, contributes to zooplankton regulation, and influences predator populations (Gushchin and Corten, 2017). Thus, biomass fluctuations driven by exploitation or environmental variability tend to affect the balance of the region's upwelling ecosystems (Cury et al., 2000). Economically, *T. trecae* is a commercially important resource, with a first-sale average price estimated at USD 3 per kg in 2024. It is in high demand on the domestic market and holds export significance, contributing substantially to the profitability of fishing operations and to the national fisheries economy (Barros et al., 2021). Despite its importance, the stock's status regarding sustainability remains unknown due to incomplete and poorly disaggregated landing and effort records, uncertainties in species identification, and non-standardized abundance indicators with irregular and insufficient temporal and spatial coverage to support consistent assessments.

This study aims to assess the stock status of *T. trecae* in Guinea-Bissau using recent available data and approaches appropriate for data-limited stocks. Specifically, we characterize the fishery, estimate key life history parameters required for assessment, and apply the length-based indicators (LBI) to assess stock status. LBI enables inferences on conservation, sustainability, yield optimization, and proximity to conditions compatible with maximum sustainable yield (MSY) without directly estimating MSY (Froese, 2004; ICES, 2015). Their use is further supported by simulation studies demonstrating that LBIs can reliably track trends in fishing mortality (F) and perform as well as, or better than, more complex methods when equilibrium assumptions are violated (e.g., changes in recruitment, gear selectivity, and measurement error), making them suitable for data- and capacity-limited contexts (Kell and Sharma, 2025). Interpretation of LBIs, however, assumes near-equilibrium conditions (e.g., roughly constant recruitment and mortality during the analysis period) and stable selectivity. Deviations from these assumptions, along with the quality and representativeness of the length data, influence diagnostic robustness (ICES, 2015). The analysis is based primarily on fishery-dependent data, complemented by fishery-independent data from scientific surveys. The aim is to provide scientific evidence to inform management decisions consistent with sustainability.

The present assessment is framed for the Guinea-Bissau EEZ, reflecting the spatial coverage of the fishery-dependent monitoring and the scientific surveys available for 2018–2023. Stock status is therefore inferred for this assessment area as an operational management unit. At the same time, biological stock limits for *T. trecae* in West Africa remain unresolved, and population genetic evidence from other parts of the species range indicates that spatial structuring at management-relevant scales is plausible, underscoring the need for caution when extrapolating results beyond the assessed domain (Sardinha and Nævdal, 2002; Mota et al., 2024).

Table 1. Macroscopic gonadal maturity scale used in this study (Maier, 1908), with stage codes and corresponding descriptions.

Stage	Description
I-Virgin	Sexual organs very small, situated close to vertebral column. Testis and ovary transparent, colourless or grey. Eggs not visible to naked eye.
II- Maturing virgin	Testis and ovary translucent, gray-red. Length of gonads 1/2, or slightly more, of length of ventral cavity. Individual eggs can be seen with magnifying glass.
III- Developing	Testis and ovary opaque, reddish with blood capillaries. Occupy about 1/2 of ventral cavity. Eggs visible to naked eye as whitish granular material.
IV- Developed	Testis reddish-white, no milt produced under pressure. Ovary orange-red. Eggs clearly discernible, opaque. Testis and ovary occupy about 2/3rds of ventral cavity.
V- Gravid	Sexual organs fill ventral cavity. Testis white. Drops of milt produced under pressure. Eggs completely round, some already translucent and ripe.
VI- Spawning	Roe and milt run under slight pressure. Most eggs translucent with few opaque eggs left in ovary.
VII- Spent	Not completely empty, no opaque eggs left in ovary.
VIII- Resting	Testis and ovary red and empty. A few eggs in state of resorption.

2 Methods

2.1 Study area

Guinea-Bissau is located on the West African coast, bordered to the north by Senegal, to the south and east by Guinea-Conakry, and to the west by the Atlantic Ocean. It lies between 10°59' and 12°20' N and near 13°40' W, covering a land area of approximately 36,125 km. The coastline is deeply indented, with numerous islands and islets. The maximum extent of the mainland is approximately 300 km from north to south and 270 km from east to west (FAO, 2025).

The straight baselines established in 1985 define the maritime boundaries of Guinea-Bissau, starting from the Bijagós Archipelago and the border with the Republic of Guinea. The maritime territory spans 107,301 km, of which 87,406 km correspond to the EEZ, 6184 km to territorial waters, and 13,711 km to internal waters, with a total volume of 208 billion m. About 60% of the marine area lies at depths shallower than 3000 meters (Pacheco, 2024).

2.2 Data sources

The data used in this study were provided by the Ministry of Fisheries of Guinea-Bissau through the National Institute for Monitoring and Control of Fisheries Activities (INFIS-CAP) and the National Institute for Fisheries and Oceanographic Research (INIPO), covering fishery-dependent records (onboard observation of commercial vessels) and fishery-independent records (scientific surveys in the EEZ).

2.2.1 Fishery-dependent data

The fishery-dependent component relied on the National Onboard Observer Program. The program includes nine primary certified observers (with designated alternates). Under Decree-Law No. 4/96 (August) and the conditions stipulated in vessel licenses, vessels engaged in fishing operations carried an onboard observer during the fishing season (typically 3–6 months), with observers deployed on a rotating basis across vessels. Observer coverage, defined as the number of licensed

vessels carrying an observer divided by the total number of licensed vessels, averaged 72% and ranged from 50% to 81% (Supplementary Tab. S1).

For each haul, operational and catch variables are recorded, including geographic coordinates, depth, fishing duration (hours), gear type, and species-specific catches in kilograms. These records are formalized (boarding certificate) and submitted monthly to INIPO, where statistical technicians validate and consolidate the data for the Fisheries Yearbooks. Data collected between 2018 and 2023 formed the basis for the spatiotemporal characterization of the fishery and for the catch and effort series by gear and fleet segment.

As part of the Scientific Observation Program, biological samples were also collected directly from the catches, totaling 732 samples over the study period. Measurements include, among others, total length (cm), sex, and gonad maturity stage. In this study, length data of *T. trecae* collected between 2021 and 2023 were used to describe population size structure and support growth parameter estimation and stock assessment.

2.2.2 Fishery-independent data

The fishery-independent component comprises scientific resource assessment surveys conducted in the EEZ, coordinated by INIPO's Marine Resources Division. These surveys use standardized bottom trawls with controlled duration and speed and stratified sampling by depth (Supplementary Fig. S1). These surveys lacked standardized spatial and temporal coverage, with irregular sampling in both space and time, data gaps across different observer programs, and inconsistencies across databases such as conflicting species naming. In addition, the species' schooling behavior further complicates the use of abundance surveys, as it implies time-varying catchability that is difficult to account for without high-resolution data (Sobrinho et al., 2022). Because of these uncertainties caused by irregular study design and data conflicts, we decided not to include relative abundance data in this study. For this study, 2025 survey data was only used to estimate the length-weight relationship and length at 50% maturity, as sampling during this year was considered reliable. Total length was measured to the nearest 0.1 cm using an

Table 2. Empirical methods used to estimate natural mortality (M) of *Trachurus trecae* in Guinea-Bissau.

Method	Equation
Alverson and Carney (1975)	$M = \frac{3K}{\exp(0.38 \cdot t_{\max} \cdot K) - 1}$
Hoening (1983)	$\ln(M) = 1.44 - 0.982 \cdot \ln(t_{\max})$ $\ln(M) = 1.46 - 1.01 \cdot \ln(t_{\max})$
Pauly (1980)	$\log_{10}(M) = -0.0066 - 0.279 \cdot \log_{10}(L_{\infty}) + 0.6543 \cdot \log_{10}(K) + 0.4634 \cdot \log_{10}(26)$
Then et al. (2015)	$M = 4.899 \cdot t_{\max}^{-0.916}$ $M = 4.118 \cdot K^{0.73} \cdot L_{\infty}^{-0.33}$

Table 3. Length-based indicators (LBI) used to assess the stock status of *Trachurus trecae* in Guinea-Bissau.

Indicator	calculation	Reference point	Indicator ratio	Expected value	Property
$L_{\max 5\%}$	Mean length of largest 5%	L_{∞}	$L_{\max 5\%} / L_{\infty}$	>0.8	Conservation
P_{mega}	Proportion of individuals above $L_{\text{opt}} + 10\%$	0.3–0.4	P_{mega}	>0.3	(large individuals)
$L_{25\%}$	25 th percentile of length distribution	L_{50}	$L_{25\%} / L_{50}$	>1	Conservation
L_c	Length at first catch (length at 50% of mode)	L_{50}	L_c / L_{50}	>1	(immatures)
L_{mean}	Mean length of individuals $>L_c$	$L_{\text{opt}} = \frac{3}{3+\frac{M}{K}} \times L$	$L_{\text{mean}} / L_{\text{opt}}$	≈ 1	Optimal yield
L_{mean}	Mean length of individuals $>L_c$	$L_F = M = (0.75L_c + 0.25L_{\infty})$	$L_{\text{mean}} / L_F = M$	≥ 1	MSY

ichthyometer and weight to the nearest 0.1 g using a balance. Gonads were macroscopically staged according to Maier's eight-point maturity key (Maier, 1908; Tab. 1), a typical and fairly satisfactory system for total spawners (Holden and Raitt, 1974). Maturity estimates were provided both separately and grouped by sex.

2.3 Data analysis

2.3.1 Fishery characterization

We derived descriptive indicators to support the spatio-temporal analysis of fishing activity: (i) annual catch of *T. trecae* (tonnes) by country, obtained by summing haul-level catches attributed to vessel flags; (ii) annual number of vessels with positive records of *T. trecae* by country, determined by counting unique vessel identifiers; (iii) annual spatial distribution of catches, mapped based on haul coordinates; (iv) monthly catch (tonnes) by gear type; and (v) monthly effort (fishing hours) by gear type. Fishing effort was defined as the total fishing hours per gear type combination, and vessel flag was used to assign national attribution in fleet-level aggregations.

2.3.2 Weight–length relationship

The weight–length relationship was estimated for combined sexes using biological data from the 2025 scientific survey. The exponential model $W = aL^b$ was fitted, where W is total weight (g), L is total length (cm), a is the scaling coefficient, and b is the allometric exponent (Froese, 2006). Natural logarithmic transformation was applied to linearize the model:

$$\ln(W) = \ln(a) + b \ln(L).$$

Parameters were estimated by ordinary least squares. Original-scale values were obtained by back-transformation: $a = \exp(\text{intercept})$, and b equals the slope. 95% confidence intervals (95% CI) were estimated for both parameters. The isometry hypothesis ($b = 3$) was tested using a t -test with $\alpha = 0.05$ (rejected when $P < 0.05$). Model fit quality was assessed using the coefficient of determination R^2 , interpreted as the proportion of variance in $\ln(W)$ explained by $\ln(a) + b \ln(L)$. Analyses were conducted in R (R Core Team, 2025), using the *stats* package.

2.3.3 Length structure

After filtering out implausible values, individuals were grouped into 1 cm classes defined by integer boundaries covering the full observed range. For each year, frequency distributions were constructed to describe the size composition of the catches.

To align these distributions with annual total landings, a raising procedure was applied. Mean weight per class was estimated using the weight–length relationship derived in this study, and annual raising factors were calculated such that the weighted sum of weights per class matched reported total landings. The resulting raised distributions represent the size composition of landings for each year.

2.3.4 Length at maturity

The length at maturity (L_{50}) was defined as the length at which an individual has a 50% probability of being mature. Estimates were obtained for pooled sexes and both males and females separately.

The data were collected during a research survey in Guinea-Bissau's EEZ. Although surveys can introduce seasonal bias when sampling is restricted to narrow time

Table 4. Length-based indicator status for *Trachurus trecae* in Guinea-Bissau, 2021–2023. Green cells indicate values within expected reference ranges (sustainable), while red cells indicate potential overexploitation.

Year	Conservation				Optimizing yield	Maximum sustainable yield (MSY)
	L_c/L_{50}	$L_{25\%}/L_{50}$	$L_{\max 5\%}/L_{\infty}$	P_{mega}	$L_{\text{mean}}/L_{\text{opt}}$	$L_{\text{mean}}/L_F = M$
2021	1.35	1.25	0.94	0.5	1.16	1.25
2022	0.85	1.25	0.92	0.33	1.00	1.30
2023	1.25	1.25	0.72	0.00	0.83	0.93

windows, in this case, the data covered February to April, coinciding with the species' main reproductive period (Ndjaula et al., 2013; Baião, 2015), ensuring that both mature and immature individuals were present – an essential condition for robust L_{50} estimation.

Individuals classified as stages I–II were considered immature, and those in stages IV–VII mature. Stage III, whose descriptive attributes indicate immaturity (Tab. 1), was excluded from the analysis because exploratory analyses showed its length distribution overlapped that of mature fish, increasing misclassification risk and degrading the model fit.

A logistic regression was fitted to the binary maturity classification (0 = immature, 1 = mature) using the model:

$$P_{\text{mature}} = \frac{1}{1 + e^{-(\beta_0 + \beta_1 L)}},$$

where L is total length (1-cm class interval), $\hat{\beta}_0$ is the intercept, and $\hat{\beta}_1$ is the slope. The length at 50% maturity was calculated as:

$$L_{50} = -\frac{\hat{\beta}_0}{\hat{\beta}_1}.$$

Estimation was performed in R using the *sizeMat* package (Torrejon-Magallanes, 2020). Uncertainty was quantified by implementing a non-parametric bootstrapping procedure with 999 iterations with a 95% CI reported for L_{50} . For each iteration, a random sample (n) was drawn with replacement equal to the total number of available data points for each group ($N_{\text{combined}} = 310$, $N_{\text{females}} = 141$, $N_{\text{males}} = 169$). All 999 iterations were retained.

2.3.5 Growth parameters

Growth parameters were estimated using the von Bertalanffy growth function (von Bertalanffy, 1938):

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

where L_t is the length at age t (years), L_{∞} is the asymptotic length (cm), i.e., the length that individuals would approach if growth continued indefinitely; K is the growth coefficient (yr^{-1}); and t_0 is the theoretical age at which length would be zero.

Length frequency data from individuals sampled between 2021 and 2023 under the Scientific Observation Program were aggregated into 2 cm classes. The growth function was fitted using the Electronic Length Frequency Analysis (ELEFAN)

method, optimized with a genetic algorithm via the R package *TropFishR* (Taylor and Mildenberger, 2017). Uncertainty was quantified by bootstrap ($n = 200$) with replacement using the *fishboot* package (Schwamborn et al., 2019), yielding empirical distributions and 95% CI for L_{∞} and K .

A plus group was defined at 46.5 cm, grouping all individuals ≥ 46.5 cm into the final length class. This was done to reduce instability in the distribution tails and prevent sparse counts from distorting the model fit.

2.3.6 Natural mortality

Natural mortality (M), defined as the mortality rate from causes other than fishing (e.g., predation, disease, senescence, and environmental variability), was estimated using empirical methods (Tab. 2), given the impracticality of direct measurement in the wild. Input parameters included the von Bertalanffy growth coefficients (L_{∞} , K) and maximum longevity (t_{max}), approximated as $t_{\text{max}} = 3/K$ (Pauly, 1983). To reduce the influence of outliers and obtain a more robust reference value, the final estimate of M was taken as the median of values obtained from the different equations.

2.3.7 Stock status assessment

Stock status was assessed using LBI with catch length frequency data (Scientific Observation Program, 2021–2023) and compared to predefined reference points. For each year, we used the length distributions (Sect. 2.3.3) along with the estimated life-history parameters: length at maturity (L_{50} , Sect. 2.3.4), von Bertalanffy growth parameters (L_{∞} and K , Sect. 2.3.5), and natural mortality (M , Sect. 2.3.6). Lengths were grouped into 2 cm classes. $L_{25\%}$, L_{mean} , and $L_{\max 5\%}$ were obtained directly from the annual length distributions. L_c , the length at first capture was inferred from the descending limb of the length distribution (Tab. 3; ICES, 2015). For these analyses, we used the length at maturity estimate for pooled sexes.

Indicator ratios were then compared with theoretical expectations associated with three objectives: conservation (“let them spawn” and “let the mega-spawners live”), yield optimization (“let them grow”), and proximity to MSY-compatible conditions (Tab. 3). Results were presented using a traffic-light scheme (green = meets objective, red = does not), following literature conventions (Caddy et al., 2005).

To determine how uncertainty in input parameters affects the length-based indicators, we performed sensitivity analyses by iteratively changing M/K , length at maturity, and L_{∞} values up and down 5%, 10%, 15%, 20%, and 25% from the default values, one at a time while keeping the others constant. For

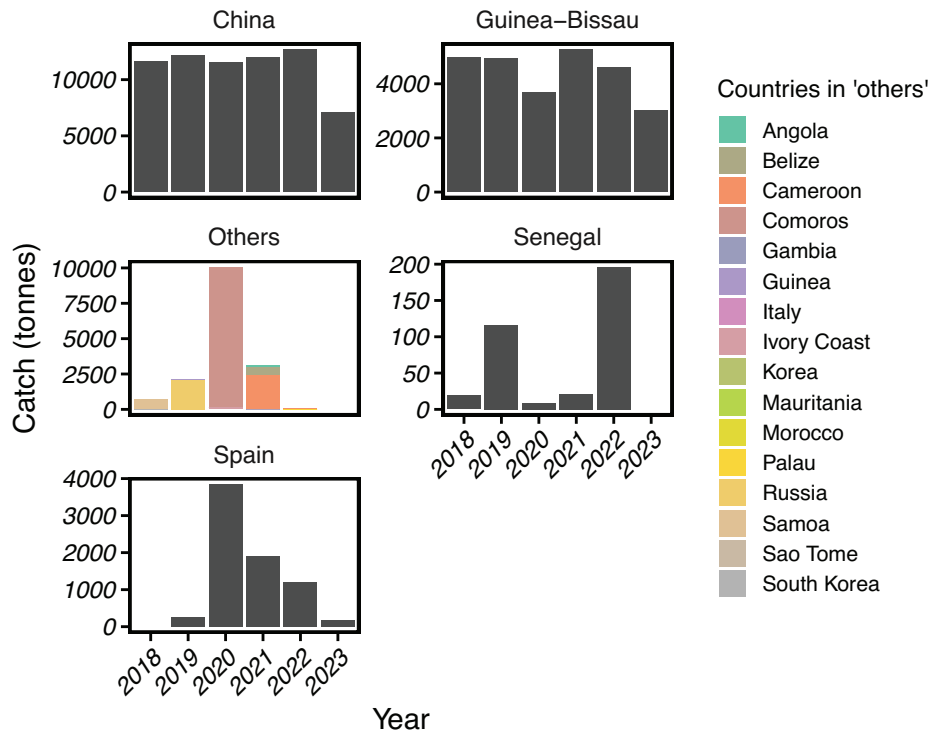


Fig. 1. Annual catch of *Trachurus trecae* (tonnes) by country in the coastal zone of Guinea-Bissau, 2018–2023.

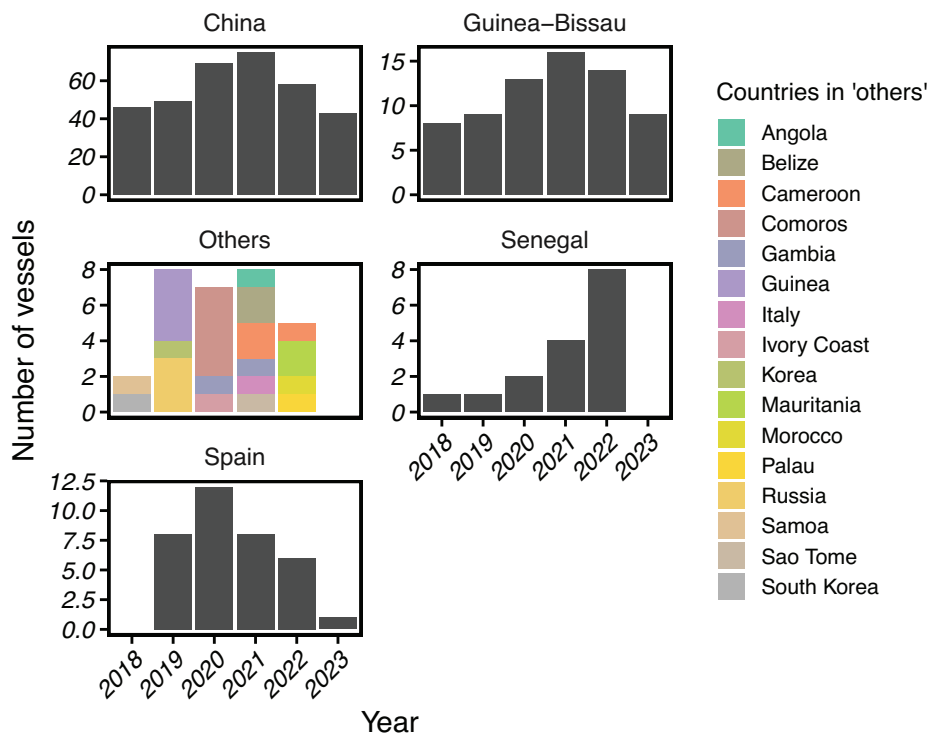


Fig. 2. Annual number of vessels by country landing *Trachurus trecae* in the coastal zone of Guinea-Bissau, 2018–2023.

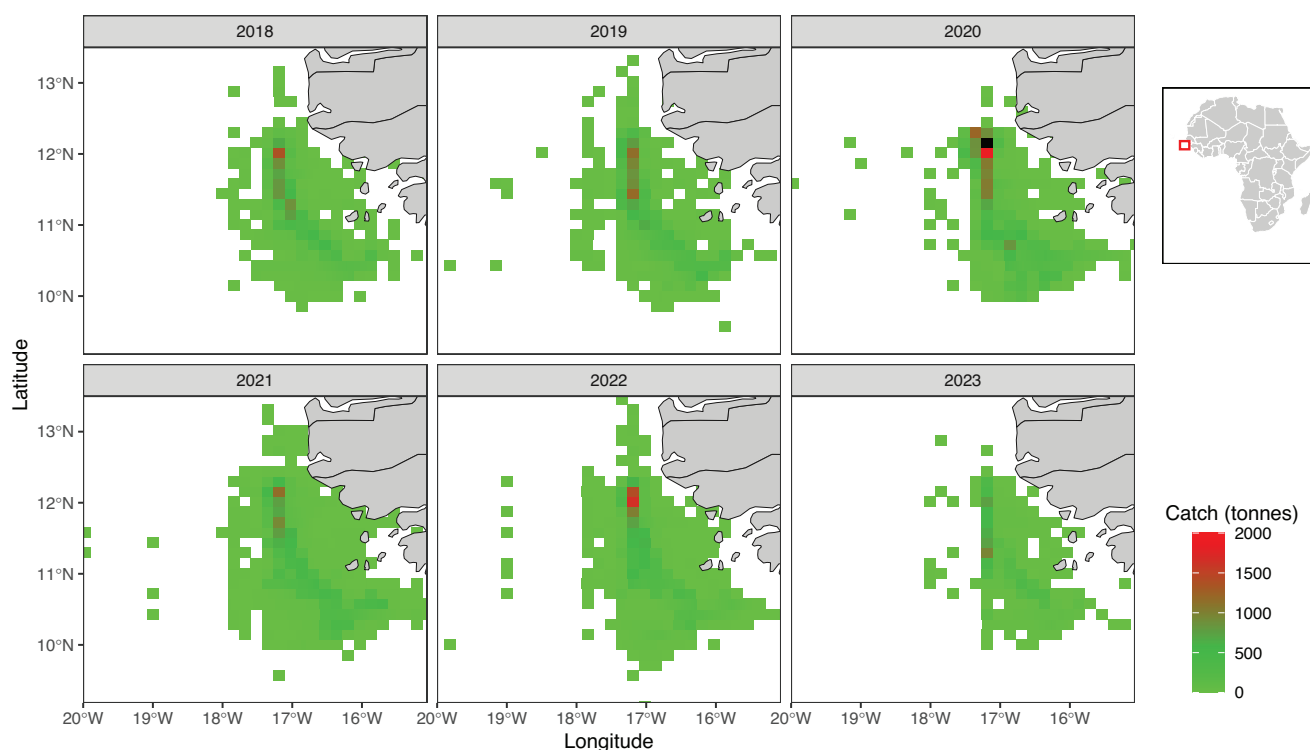


Fig. 3. Spatial distribution of annual *Trachurus trecae* catches (tonnes) in the coastal zone of Guinea-Bissau, 2018–2023. The black point in the 2020 panel represents an outlier where catches equaled 3285 tonnes.

each indicator, % deviations from the baseline scenario were calculated (Santos et al., 2026). We did not include the parameters of the length-weight relationship in the analyses, as changes in the exponent will not affect the relative contribution of each length class to the total numbers according to our raising procedure used to align the length compositions with reported landings.

2.3.8 Rules about the number of significant digits

Statistical software provides numbers with as many digits as allowed by the computational environment, which can imply a false level of precision relative to the natural variability common in biological data. To avoid reporting unrealistic levels of precision while preserving the mathematical correctness of our models, we report quantities expressed in kilotonnes (thousands of tonnes), for example, with a maximum of one decimal degree.

3 Results

3.1 Fishery characterization

3.1.1 Annual catches

Between 2018 and 2023, *T. trecae* catches within Guinea-Bissau's EEZ totalled 117 kt, with annual values of 17, 19, 29, 22, 19, and 10 kt. Catch distribution by country was highly concentrated, with China accounting for 57.2% of the total and Guinea-Bissau for 22.6% (Fig. 1).

China maintained consistently high catch volumes between 2018 and 2022 (11.6–12.7 kt/yr), followed by a reduction to 7 kt in 2023, representing a –38.7% decrease compared to

2020. Guinea-Bissau recorded between 3 and 5.3 kt/yr with a declining trend at the end of the series. The third-highest contribution came from Comoros, due to a single large event in 2020 (10 kt). Spain ranked fourth overall, peaking in 2020 with 3.8 kt. Additional records included Cameroon (2.3 kt in 2021) and Russia (2 kt in 2019), along with several minor contributors such as Senegal. Other countries – Angola, Ivory Coast, Gambia, Guinea, South Korea, Italy, Mauritania, Morocco, Palau, Samoa, and São Tome – were recorded in isolated years with low catch volumes.

3.1.2 Number of vessels

From 2018 to 2023, 179 distinct vessels were identified as active in the *T. trecae* fishery. Of these, China accounted for 100 (54.3%), Guinea-Bissau 25 (13.6%), Senegal 15 (8.2%), and Spain 14 (7.6%). Other countries included Comoros (5 vessels); Guinea (4); Cameroon and Russia (3 each); Belize, Gambia, and Mauritania (2 each); and Angola, Italy, Ivory Coast, South Korea, Morocco, Palau, Samoa, and São Tome (1 each). Annually, China maintained the largest fleet presence, with 46, 49, 69, 75, 58, and 43 vessels from 2018 to 2023, respectively (Fig. 2). Guinea-Bissau registered 8–16 vessels per year. Spain participated from 2019 to 2023, with declining numbers over time. Senegal increased its presence until 2022 but was absent in 2023. Other countries were present only sporadically.

3.1.3 Catch areas

Annual catch maps (2018–2023) revealed a consistent spatial pattern, with catches concentrated between 10–12°N

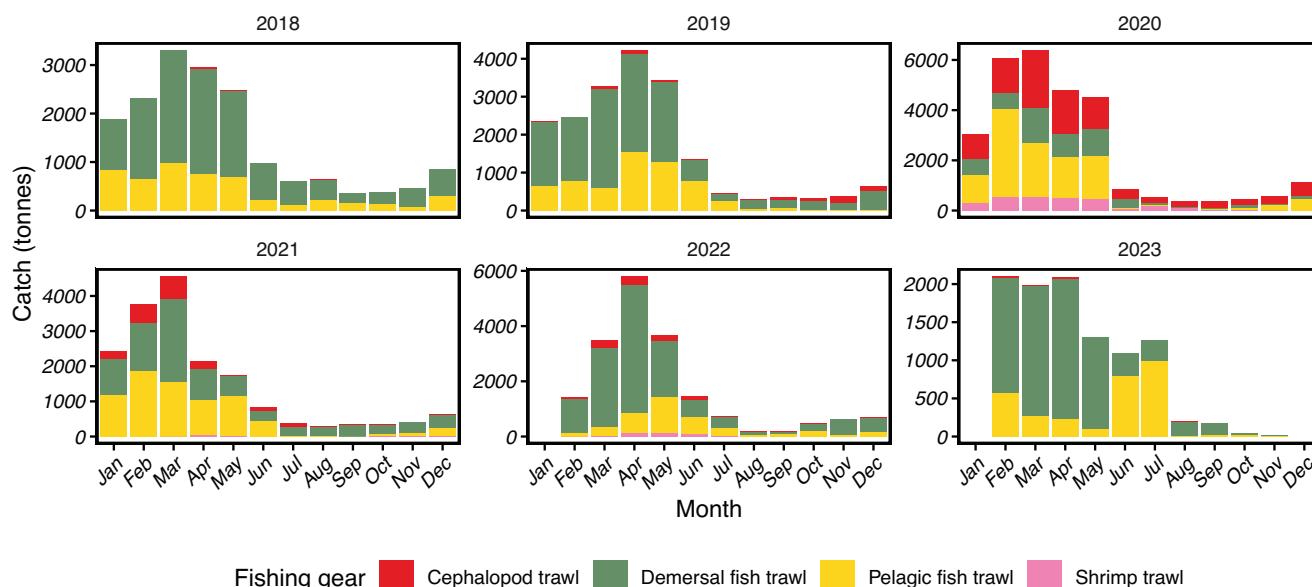


Fig. 4. Monthly catch of *Trachurus trecae* (tonnes) by gear type in the coastal zone of Guinea-Bissau, 2018–2023.

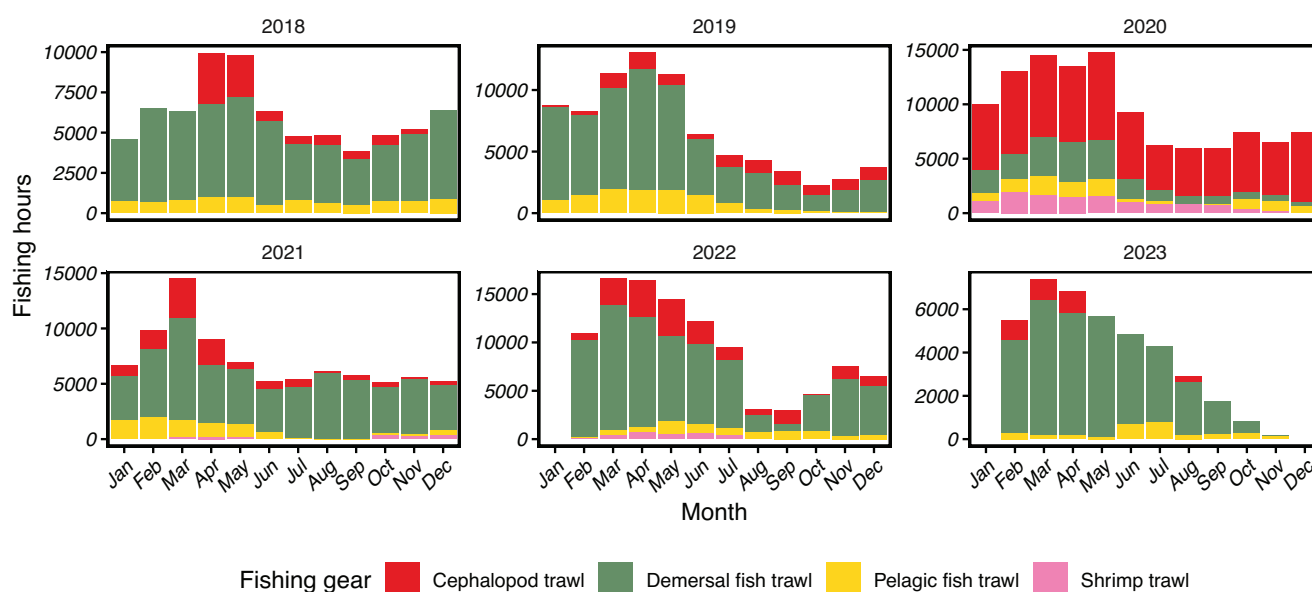


Fig. 5. Monthly fishing effort directed at *Trachurus trecae* (hours) by gear type in the coastal zone of Guinea-Bissau, 2018–2023.

and 16–18°W, roughly aligned with the 17°W meridian (Fig. 3). In 2020, a notable peak occurred in the northern portion of this core area ($\approx 12^\circ\text{N}$). In other years, the distribution remained centered within this band, with lower catch levels and no major spatial shifts. Peripheral areas were observed intermittently, varying in extent and intensity.

3.1.4 Fishing gears

Trachurus trecae was captured using four main gear types between 2018 and 2023. Demersal trawls contributed the largest share, with 58.7 kt (52.1% of total *T. trecae* catch) and 307,691 h of effort (61.7%). Pelagic trawls accounted for 36.7 kt (32.6%) and 49,232 h (9.9%); cephalopod trawls for

14.1 kt (12.6%) and 126,659 h (25.4%); and shrimp trawls for 3 kt (2.7%) and 15,420 h (3.1%).

Annual peak catches of *T. trecae* by gear type occurred in 2022 for demersal trawls (13.2 kt) and in 2020 for pelagic (10.9 kt), cephalopod (10 kt), and shrimp trawls (2.6 kt). Maximum fishing effort followed similar patterns: demersal trawls in 2022 (75,396 h), cephalopod and shrimp trawls in 2020 (72,149 and 11,521 h, respectively), and pelagic trawls in 2019 (11,179 h).

Monthly catch and effort patterns showed higher values between January and May, followed by a marked decline from June onward (Figs. 4 and 5). Demersal trawls reached peak catches in March (13.2 kt) and April (13 kt), with the highest effort in the same months. Pelagic trawl catches peaked in

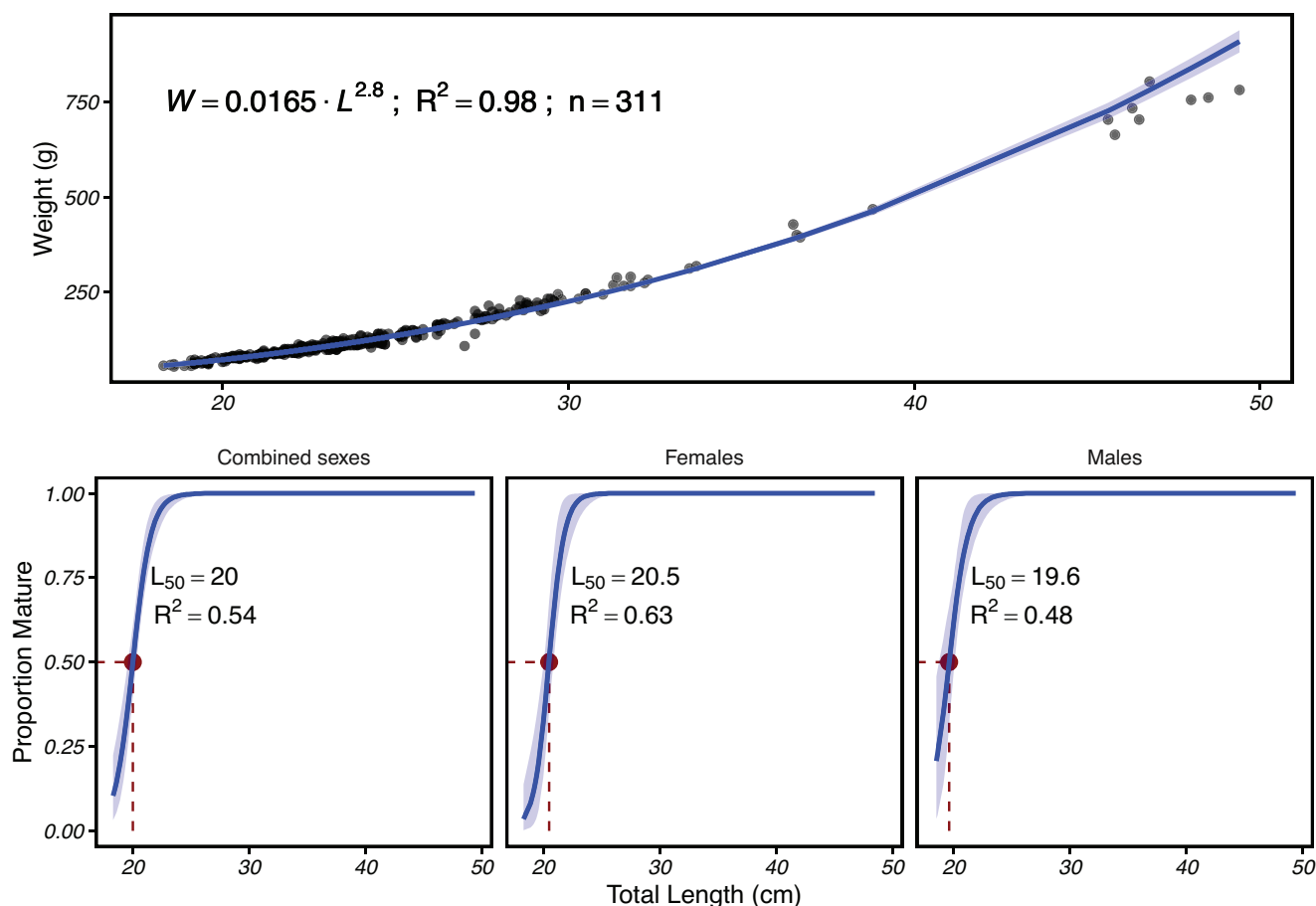


Fig. 6. Length-weight relationship (top) and maturity ogives (bottom) for *Trachurus trecae* were estimated from specimens collected during the 2025 scientific survey off the coast of Guinea-Bissau. Lines represent the expected value, while shaded areas are the 95% confidence intervals for the mean predicted weight at a given length.

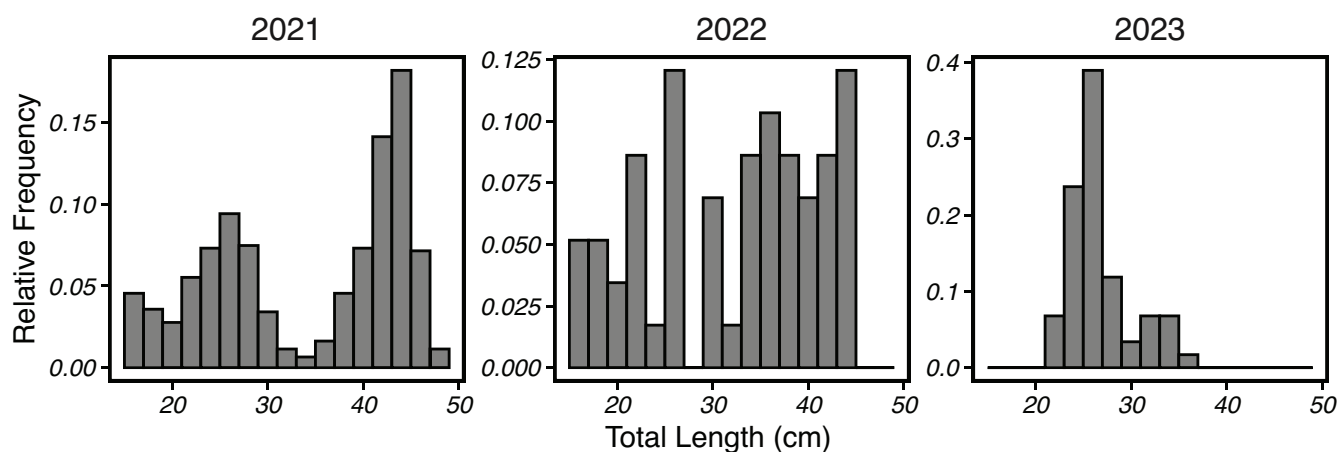


Fig. 7. Length-frequency distribution (2-cm class interval) of *Trachurus trecae* in the coastal zone of Guinea-Bissau, 2021–2023.

February (7.5 kt) and May (6.2 kt), with effort concentrated in May and March. Cephalopod trawls recorded peak *T. trecae* catches in March (3.3 kt) and April (2.4 kt), with the highest effort in April (18,838 h) and March (16,072 h). Shrimp trawls contributed mainly in 2020, with peak catches in April (638 t) and May (595 t).

3.2 Weight-length relationship

The weight-length relationship of *T. trecae* (Fig. 6) was described by the model $W = aL^b$, with $a = 0.016$ (95% CI: 0.014–0.019) and $b = 2.8$ (95% CI: 2.75–2.84). The exponent b was significantly less than 3 ($t = -9.129$; $P < 0.001$),

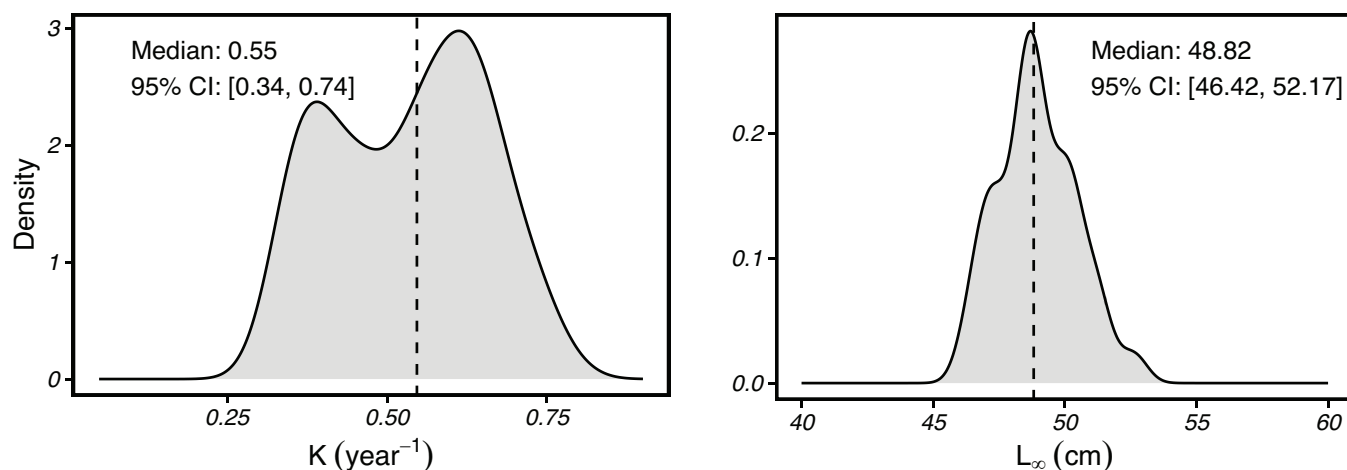


Fig. 8. Estimated density distributions for von Bertalanffy growth parameters of *Trachurus trecae* obtained by bootstrap resampling ($n = 200$) using the ELEFAN method. Black dashed lines represent the median estimate.

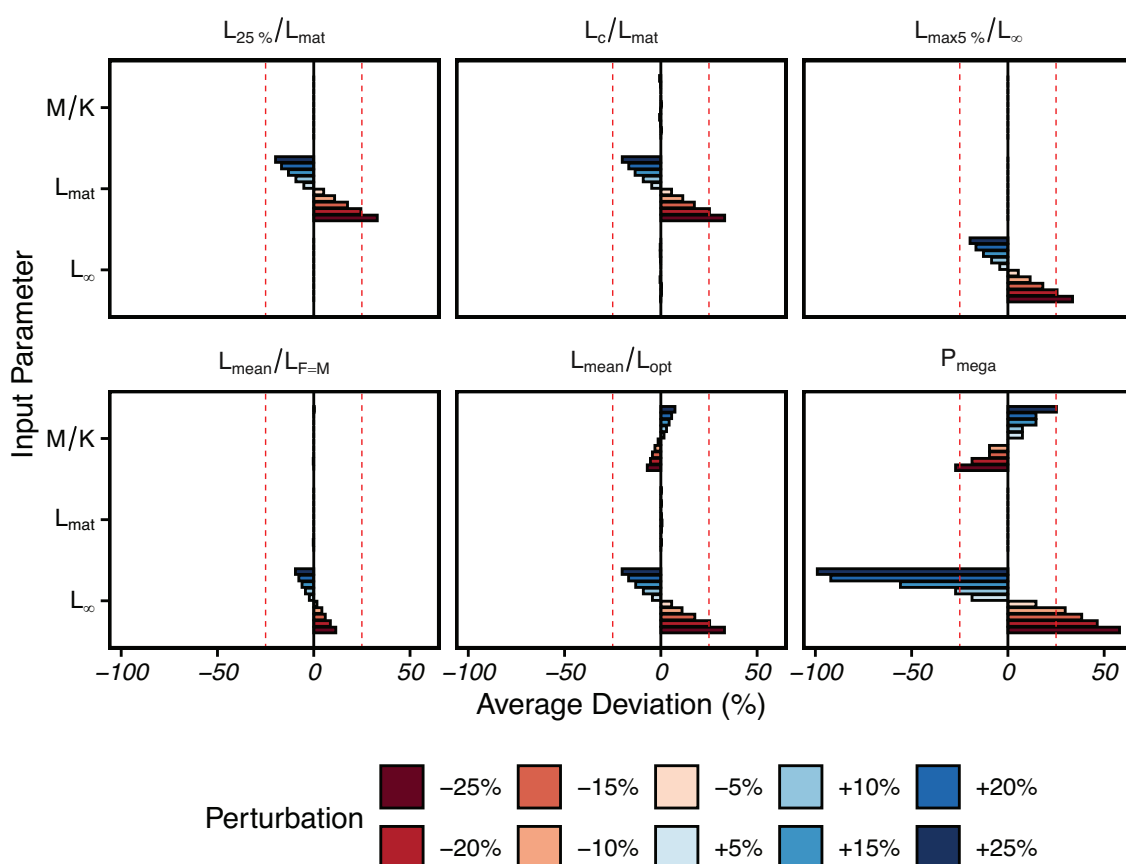


Fig. 9. Sensitivity of LBI indicators to input parameter variability. The x-axis represents the percentage deviation from the baseline scenario following iterative changes of -25 , -20 , -15 , -10 , -5 , $+5$, $+10$, $+15$, $+20$, and $+25\%$ in M/K , length at maturity, and L_{∞} , applied one at a time while keeping the remaining parameters constant.

indicating negative allometry. The model showed high explanatory power ($R^2 = 0.98$, $n = 311$).

3.3 Length at maturity

The logistic models showed reasonable fits to the maturity data for grouped sexes ($R^2 = 0.54$), females ($R^2 = 0.63$), and males ($R^2 = 0.48$). The estimated length at first maturity for *T. trecae* was 20.0 cm for grouped sexes (95% CI: 19.6–20.3 cm), 20.5 for females (95% CI: 20–20.9 cm), and 19.6 for males (95% CI: 18.7–20.1 cm) (Fig. 6).

3.4 Length composition

Length–frequency distributions varied across years (Fig. 7). In 2021, lengths of *T. trecae* ranged from 15–49 cm, showing a multimodal pattern with high frequencies in the 25–35 cm range and the presence of larger individuals (≥ 40 cm). In 2022, the range was 16–45 cm, with a wide but irregular distribution. In 2023, lengths ranged from 22 to 36 cm, with most individuals between 24 and 28 cm and limited occurrence of larger sizes.

3.5 Growth parameters

Based on aggregated length–frequency data from 2021 to 2023, von Bertalanffy growth parameters for *T. trecae* were estimated as $L_\infty = 48.8$ cm (95% CI: 46.4–52.2 cm) and $K = 0.55$ yr⁻¹ (95% CI: 0.34–0.74 yr⁻¹) (Fig. 8). The distribution of estimates showed a well-defined peak for L_∞ and greater dispersion for K , indicating more uncertainty in the latter.

3.6 Natural mortality

Estimated values for natural mortality (M , yr⁻¹) were: 0.46 (Alverson and Carney, 1975); 0.60 and 0.58 (Hoenig, 1983); 1.02 (Pauly, 1980); 0.79 and 0.74 (Then et al., 2015). The median value was 0.67.

3.7 Stock status

LBFI for *T. trecae* in 2021–2023 highlight three main points. For immature conservation, both 2021 and 2023 met reference points, with L_c/L_{50} and $L_{25\%}/L_{50}$ above the threshold. In 2022, L_c/L_{50} fell below the reference (0.85), although $L_{25\%}/L_{50}$ remained at 1.25. For the conservation of large spawners, 2021 met both criteria ($L_{max5\%}/L_\infty$; P_{mega}). In 2022, only $L_{max5\%}/L_\infty$ was met (0.92), while P_{mega} was very close to the threshold. In 2023, neither criterion was met. For yield and MSY compatibility, L_{mean}/L_{opt} was above the target in 2021 (1.16) and at the target in 2022 (1), falling below in 2023 (0.93). $L_{mean}/L_F = M$ indicated MSY-compatible levels in 2021 and 2022 (1.25–1.30) but fell below the threshold in 2023 (0.93). Thus, 2021 met all reference points. In 2022, indicators failed for immature conservation and large spawner preservation, while yield was suboptimal though still compatible with MSY. In 2023, indicators for large spawners and yield fell below expected values (Tab. 4).

Sensitivity analyses on the length-based indicators showed moderate-high deviations from the baseline scenario, with increased divergences as input parameters further deviate from the default. P_{mega} was the most sensitive indicator, with close to 40% deviation from the base scenario when L_∞ is varied by 10%, up to 100% deviation with 25% change. Effects of varying L_∞ on P_{mega} were asymmetrical, with a higher impact from positive biases. Varying M/K also had a large but symmetrical impact on P_{mega} , with up to 50% deviations from baseline when M/K is negatively or positively biased by 25%. The remaining indicators were also moderately sensitive to changes in the length at maturity and L_∞ , but not M/K (Fig. 9).

Sensitivity analyses on the length-based indicators showed moderate-high deviations from the baseline scenario, with increased divergences as input parameters further deviate from the default. P_{mega} was the most sensitive indicator, with close to 40% deviation from the base scenario when L_∞ is varied by 10%, up to 100% deviation with 25% change. Effects of varying L_∞ on P_{mega} were asymmetrical, with a higher impact from positive biases. Varying M/K also had a large but symmetrical impact on P_{mega} , with up to 50% deviations from baseline when M/K is negatively or positively biased by 25%. The remaining indicators were also moderately sensitive to changes in the length at maturity and L_∞ , but not M/K (Fig. 9).

4 Discussion

This study assesses exploitation patterns and stock status of *T. trecae* in the EEZ of Guinea-Bissau from 2018 to 2023. Spatially, fishing activity was concentrated between 10–12°N and 18–16°W, an area characterized by high coastal productivity due to nutrient-rich upwelling, freshwater inputs, and estuarine exchange (Barri, 2008; Yraola et al., 2025). These environmental features support feeding, growth, and reproduction but also attract concentrated fishing effort, particularly between February and April, coinciding with the reproductive peak. This temporal overlap exacerbates the risk of recruitment overfishing (Cury and Roy, 1989; de Mitcheson et al., 2008).

Biologically, *T. trecae* is a benthopelagic carangid distributed from Morocco to Angola (Bianchi et al., 1999; Smith-Vaniz et al., 2015), typically occurring between 47 and 340 m depth, with occasional records near 900 m (Yraola et al., 2025). Although specific studies on *T. trecae* are lacking, closely related species such as *T. trachurus* and *T. mediterraneus* show clear ontogenetic shifts in habitat, with juveniles inhabiting shallower coastal waters and adults moving to deeper offshore zones (Abaunza et al., 2003; Rodríguez, 2016). Due to the taxonomic proximity to these species, juveniles of *T. trecae* might also be more likely to inhabit coastal areas before migrating to the deep. This age-related spatial segregation increases the vulnerability of juveniles to fishing pressure, particularly given that fishing activity in this study was concentrated in coastal areas where juveniles are likely to occur, raising concerns about the potential for growth and recruitment overfishing. Functionally, the species occupies an intermediate trophic level, facilitating energy transfer between lower and higher trophic levels; therefore, fluctuations in its abundance can have cascading effects throughout the food web, with implications for both

ecosystem dynamics and fisheries productivity (Cury et al., 2000).

The species' strong schooling behavior adds complexity to assessment efforts, as aggregation influences catchability and can distort abundance estimates derived from fishery-dependent data (Hilborn and Walters, 1992). Catch per unit effort (CPUE) is often used as a proxy for abundance; however, its reliability is contingent on appropriate standardization. Without accounting for factors such as gear type, fishing area, seasonality, and fleet composition, CPUE may reflect changes in fishing efficiency rather than true biomass trends. Standardized indices using generalized linear or additive models are therefore recommended to isolate effort-related variability and provide more robust abundance indicators (Hoyle et al., 2024). However, due to severe sampling inconsistencies in the fishery-independent data, we were unable to use it to derive stock status. As sampling programs aiming to provide estimates of relative abundance are underway, future years with standardized sampling effort will become increasingly available to provide information on stock status as data conflicts are resolved and potential flaws in study design are addressed. We recommend this abundance data should be used in conjunction with other available information to build an ensemble of integrated models that vary in assumptions and data requirements to provide a more comprehensive assessment of stock status and its associated uncertainty. Gear-specific dynamics revealed substantial differences in effort allocation, catch volume, and selectivity. Demersal trawls contributed the majority of *T. trecae* catches (52.1%) and accounted for 61.7% of total effort, indicating their dominant role in exploitation but also a lower catch efficiency relative to pelagic gears. Pelagic trawls, though responsible for a smaller share of catches (32.6%), operated with significantly less effort (9.9%), suggesting higher efficiency per unit of effort when targeting midwater aggregations. Cephalopod and shrimp trawls, responsible for 12.6% and 2.7% of catches, respectively, also recorded notable *T. trecae* bycatch, especially given their targeting of other species. These patterns highlight the importance of gear-specific management approaches that address both directed and incidental catch and account for differences in efficiency, selectivity, and ecological impact.

Temporal trends in length composition revealed a progressive truncation of the size distribution between 2021 and 2023, with more noticeable differences in 2023. While the 2021 distribution still encompassed a broad size range, including adults, modal structure weakened in 2022, and by 2023, catches were dominated by individuals near the length at maturity. The absence of larger individuals and the decline of P_{mega} (proportion of mega-spawners) suggest reduced reproductive capacity that could lead to recruitment overfishing. The species' life-history traits – fast growth ($K = 0.55 \text{ yr}^{-1}$), moderate/small asymptotic length ($L_{\infty} = 48.82$), high fecundity, and short lifespan (as per the high natural mortality) – are characteristic of r-strategists, which generally display high turnover and higher resilience under moderate fishing pressure (Quetglas et al., 2016). However, such resilience is contingent on maintaining a sufficient spawning biomass and avoiding persistent removal of mature individuals, particularly during peak reproductive periods (King and McFarlane, 2003).

Natural mortality ($M = 0.668 \text{ year}^{-1}$) falls within expected ranges for small tropical pelagics (Pauly, 1980; Then et al., 2015) and implies lower standing biomass and high turnover. Yet, the high population productivity does not ensure sustainability in the absence of management, particularly given the loss of large spawners and the seasonal targeting of reproductive aggregations. LBI show a clear downward trend: values in 2021 were consistent with sustainable exploitation, but those from 2022 and 2023 indicate overfishing could have occurred during these years, with declining $L_{\text{mean}}/L_{\text{opt}}$ and $L_{\text{mean}}/L_F = M$ ratios and P_{mega} reaching zero by 2023. These findings align with earlier assessments of *T. trecae* in Guinea-Bissau, which reported fluctuations in catch levels, seasonal pulses in availability, and signs of overfishing. For instance, biomass estimates in 2020 from a surplus production model using fishery-dependent CPUE placed the stock slightly above B_{MSY} (biomass at maximum sustainable yield), while fishing mortality (F) exceeded F_{MSY} by approximately 46%, suggesting overexploitation (Sobrinho et al., 2022). As shown by the sensitivity analysis, the high uncertainty in life history traits considerably affects LBI outputs and therefore stock status, warranting a precautionary approach to management going forward and increased data collection to further refine life history parameters. Our results agree with previous literature showing length-based models are highly sensitive to input parameters (Santos et al., 2026; Medeiros-Leal et al., 2023).

A similar overfishing status has been reported in other regions of West Africa, particularly in an assessment covering the area from the southern border of Senegal to the northern Atlantic border of Morocco, including the Canary Islands (FAO, 2020). However, these findings contrast with an evaluation focused specifically on Senegalese waters, which reported stocks in good condition (Baldé et al., 2022). This discrepancy likely reflects differences in geographic coverage, species migratory behavior, and assessment methodologies. While the FAO (2020) used the Schaefer Dynamic Production Model, the study by Baldé et al. (2022) applied the Length-based Bayesian Biomass (LBB) model (Froese et al., 2018), which has been increasingly questioned due to its assumptions and sensitivity in data-limited and spatially dynamic fisheries (Pons et al., 2020; Wang et al., 2025).

In Guinea-Bissau, the interpretation of both the present study and the assessment by Sobrinho et al. (2022) must consider methodological limitations. Earlier studies were affected by effort aggregation across fleets, assumptions of constant catchability (q), and limited standardization of fishery-dependent abundance indices – each of which can distort reference point estimates. Similarly, length-based methods are sensitive to the choice of life-history parameters, particularly L_{∞} and the M/K ratio. The present study estimated L_{∞} at 48.82 cm and K at 0.55 yr^{-1} , values higher than those reported for Mauritania, Senegal, and Angola (Ba et al., 1990; Baião, 2015; Baldé et al., 2022), yet biologically plausible for the region.

Recent findings by Medeiros-Leal et al. (2023) highlight the susceptibility of certain LBIs – especially P_{mega} and $L_{\text{max}5\%}/L_{\infty}$ – to bias in the initial selection of L_{∞} and M/K , whereas indicators of immature individual protection (e.g., $L_{\infty}/L_{\text{mat}}$, $L_{25\%}/L_{\text{mat}}$) are less affected. In particular, P_{mega} was shown to be the most sensitive indicator to growth input uncertainty, while MSY-related metrics were comparatively

robust. Given these insights, the declining trend in P_{mega} observed here should be interpreted cautiously, although the consistency with multiple complementary indicators (including $L_{\text{mean}}/L_{\text{opt}}$ and $L_{\text{mean}}/L_F = M$) strengthens the overall conclusion of increasing exploitation pressure. Future work should incorporate uncertainty analysis or Bayesian frameworks to quantify the impact of input variation and enhance reliability in length-based stock assessments.

Management of *T. trecae* in Guinea-Bissau occurs within a legal-administrative national framework oriented toward sustainable use. Key instruments include the General Fisheries Law (Decree-Law No. 10/2011; Republic of Guinea-Bissau, 2011), specific regulations for industrial and artisanal fleets, minimum landing sizes, and seasonal closures introduced in 2022. Total allowable catches (TACs) and quotas are defined by fleet category and supported by the National Institute for Fisheries and Oceanographic Research (INIPO), which contributes scientific and statistical inputs (Republic of Guinea-Bissau, 2022). Satellite-based vessel monitoring systems (VMS), electronic reporting (ERS), and traceability requirements have also been implemented under international agreements such as the Sustainable Fisheries Partnership Protocol with the European Union (Council of the European Union, 2007; EU, 2024). Guinea-Bissau is further engaged in regional and international mechanisms, including the Sub-Regional Fisheries Commission (CSRP), which promotes harmonized legislation and regional cooperation, and the United Nations Convention on the Law of the Sea (UNCLOS), which outlines sovereign and shared responsibilities for the conservation of marine resources within the EEZ (UN, 1982; CSRP, 2014). Despite these advances, effective implementation remains limited by persistent structural challenges, such as insufficient institutional capacity, weak enforcement, and gaps in data transparency.

Interpretation of the length-based results should be restricted to the Guinea-Bissau assessment area represented by the available data. Because biological stock boundaries are not estimated in this study, connectivity with adjacent waters or within-area spatial structure cannot be excluded and may influence local size composition through movement and availability. In such circumstances, pooled length indicators may mask spatially structured depletion or overstate local trends if availability changes independently of underlying biomass. Evidence of non-panmixia reported elsewhere for *T. trecae* supports treating the present inference as area-specific and motivates future stock identification work in the region to strengthen management advice (Sardinha and Nævdal, 2002; Mota et al., 2024).

Within this assessment area, the exploited component of *T. trecae* within Guinea-Bissau's EEZ shows clear signs of overexploitation. Progressive truncation of the size structure and the decline in length-based indicators, together with the predominance of immature individuals, indicate increasing fishing pressure and reduced reproductive capacity. Despite life-history traits associated with relatively high turnover, sustained removals during peak reproductive periods, combined with weak enforcement and limited management effectiveness, are likely to undermine sustainability. Reversing this trend will require effective implementation of science-based management measures such as fishery closures, effort controls, and improved gear selectivity. Strengthened moni-

toring relies on enhanced institutional capacity and regional cooperation, critical to securing the long-term viability of this economically and ecologically important resource.

Acknowledgments

The authors thank all who participated in data collection in the fisheries sector and during the scientific surveys. They also thank Dr. Iça Barri from INIPO – Instituto Nacional de Investigação, Pesquisa e Oceanografia of Guinea-Bissau for his collaboration. OKEANOS research unit received national funds through the FCT - Fundação para a Ciência e Tecnologia, I.P. by project reference UID/05634/2025 (DOI: 10.54499/UID/05634/2025), and from the Regional Directorate for Science, Innovation and Development of the Azores Government through the PROSCIENTIA Incentive System under project M1.1.A/FUNC.UI&D/014/2025. Work supported by National Funds through FCT-Fundação para a Ciência e a Tecnologia in the scope of the project UID/50027/2025-Rede de Investigação em Biodiversidade e Biologia Evolutiva and Azorean regional funds through DRCID (M1.1.A/FUNC.UI&D/015/2025/RTF/001/Apoio UI&D).

Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics approval

No ethical approval was required as this study is non-experimental.

Supplementary material

Table S1. Annual coverage of licensed vessels by the onboard observer program from 2018 to 2023. Values are the number of vessels monitored with onboard observers and the total number of licensed vessels operating in each year.

Fig. S1. Sampling stations of the Scientific Resource Assessment Survey in Guinea-Bissau's EEZ, coordinated by INIPO (Fisheries Resources Service).

The Supplementary Material is available at <https://www.alr-journal.org/10.1051/alr/2026009/olm>

References

- Abaunza P, Gordo L, Karlou-Riga C, Murta A, Eltink ATGW, Garcia Santamaría MT, Zimmermann C, Hammer C, Lucio P, Iversen SA, Molloy J, Gallo E. 2003. Growth and reproduction of horse mackerel, *Trachurus trachurus* (Carangidae). *Rev. Fish Biol. Fish.* 13: 27–61.
- Alverson DL, Carney MJ. 1975. A graphic review of the growth and decay of population cohorts. *J. Cons. Int. Explor. Mer.* 36: 133–143.

- Ba I, Mylnikov N, Djigo Y. 1990. Détermination de l'âge des chinchards (*Trachurus trachurus* et *Trachurus trecae*) de la ZEE mauritanienne par otolithométrie. *Bull. Sci. CNROP*. 21: 7–14.
- Baião NF. 2015. Crescimento, ecologia alimentar e reprodução de *Trachurus trecae* (Cadenat, 1949), na costa sul de Angola–Namibe. Master thesis, Universidade do Algarve.
- Baldé BS, Brehmer P, Diaw PD. 2022. Length-based assessment of five small pelagic fishes in the Senegalese artisanal fisheries. *PLOS One*. 17: e0279768.
- Barri I. 2008. Recursos pesqueiros, estuarinos e marinhos da Guiné-Bissau. Dissertação de mestrado, Universidade de Aveiro.
- Barros M de (Ed.), Carvalho F, Menut A. 2021. Diagnosis of the fisheries situation in Guinea-Bissau. Ministry of Fisheries, Republic of Guinea-Bissau.
- Belhabib D, Greer K, Pauly D. 2018. Trends in industrial and artisanal catch per effort in West African fisheries. *Conserv. Lett.* 11: e12360.
- Belhabib D, Sumaila UR, Pauly D. 2015. Feeding the poor: Contribution of West African fisheries to employment and food security. *Ocean Coast. Manag.* 111: 72–81.
- Béné C, Barange M, Subasinghe R, Pinstup-Andersen P, Merino G, Hemre G-I, Williams M. 2015. Feeding 9 billion by 2050—Putting fish back on the menu. *Food Secur.* 7: 261–274.
- Bianchi G, Carpenter KE, Roux J-P, Molloy FJ, Boyer D, Boyer HJ. 1999. FAO species identification guide for fishery purposes: Field guide to the living marine resources of Namibia. Rome, FAO.
- Caddy JF, Wade E, Surette T, Hebert M, Moriyasu M. 2005. Using an empirical traffic light procedure for monitoring and forecasting in the Gulf of St. Lawrence fishery for the snow crab, *Chionoecetes opilio*. *Fish. Res.* 76: 123–145.
- Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Pauly D. 2009. Projecting global marine biodiversity impacts under climate change scenarios. *Fish Fish.* 10: 235–251.
- Council of the European Union. 2007. Council Decision of 4 December 2007 concerning the conclusion of the Agreement in the form of an Exchange of Letters on the provisional application of the Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Republic of Guinea-Bissau for the period 16 June 2007 to 15 June 2011 (2007/854/EC). *Off. J. Eur. Union L* 342: 1–2.
- CSRP. 2014. Strategy to combat IUU fishing in the CSRP zone. Sub-Regional Fisheries Commission, Department of Monitoring and Control of Fisheries Management (DSCSA), Banjul, Gambia.
- Cury PM, Bakun A, Crawford RJM, Jarre A, Quiñones RA, Shannon LJ, Verheye HM. 2000. Small pelagics in upwelling systems: Patterns of interaction and structural changes in “wasp-waist” ecosystems. *ICES J. Mar. Sci.* 57: 603–618.
- Cury P, Roy C. 1989. Optimal environmental window and pelagic fish recruitment success in upwelling areas. *Can. J. Fish. Aquat. Sci.* 46: 670–680.
- De Mitcheson YS, Cornish A, Domeier M, Colin PL, Russell M, Lindeman KC. 2008. A global baseline for spawning aggregations of reef fishes. *Conserv. Biol.* 22: 1233–1244.
- Dittel ML. 2022. Fishy business: How the sustainable fishery partnership agreement between the European Union and Guinea-Bissau delays fulfillment of human rights obligations. Undergraduate thesis, Columbia University, Institute for the Study of Human Rights.
- EU. 2024. Protocol on the implementation of the Fisheries Partnership Agreement between the European Community and the Republic of Guinea-Bissau (2024–2029). *Off. J. Eur. Union L* 2589: 1–42.
- FAO. 2020. Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa, Banjul, the Gambia, 26 June–1 July 2018. FAO Fish. Aquac. Rep. R1247, Rome, FAO.
- FAO. 2025. Fishery and Aquaculture Country Profiles: Guinea-Bissau (2018). Fisheries and Aquaculture Division, Rome, FAO.
- FAO. 2024. The state of world fisheries and aquaculture 2024: Blue transformation in action. Rome, FAO.
- Free CM, Thorson JT, Pinsky ML, Oken KL, Wiedenmann J, Jensen OP. 2019. Impacts of historical warming on marine fisheries productivity. *Science*. 363: 979–983.
- Froese R. 2004. Keep it simple: Three indicators to deal with overfishing. *Fish Fish.* 5: 86–91.
- Froese R. 2006. Cube law, condition factor and weight–length relationships: History, meta-analysis and recommendations. *J. Appl. Ichthyol.* 22: 241–253.
- Froese R, Winker H, Coro G, Demirel N, Tsikliras AC, Dimarchopoulou D, Scarcella G, Probst WN, Dureuil M, Pauly D. 2018. A new approach for estimating stock status from length-frequency data. *ICES J. Mar. Sci.* 75: 2004–2015.
- Goodman MC, Reum JCP, Barnes CL. 2025. Climate covariate choice and uncertainty in projecting species range shifts: A case study in the Eastern Bering Sea. *Fish Fish.* 26: 389–403.
- Gushchin AV, Corten A. 2017. Feeding of pelagic fish in waters of Mauritania: 3–Atlantic chub mackerel (*Scomber colias*), Atlantic horse mackerel (*Trachurus trachurus*), Cune horse mackerel (*Trachurus trecae*). *J. Ichthyol.* 57: 410–423.
- Hilborn R, Walters CJ. 1992. *Quantitative fisheries stock assessment: choice, dynamics and uncertainty*. New York, Springer.
- Hoenig JM. 1983. Empirical use of longevity data to estimate mortality rates. *Fish. Bull.* 82: 898–903.
- Holden MJ, Raitt DFS (Eds.). 1974. *Manual of fisheries science. Part 2—Methods of resource investigation and their application*. Rome, FAO.
- Hoyle SD, Campbell RA, Ducharme-Barth ND, Grüss A, Moore BR, Thorson JT, Tremblay-Boyer L, Winker H, Zhou S, Maunder MN. 2024. Catch per unit effort modelling for stock assessment: A summary of good practices. *Fish. Res.* 269: 106860.
- ICES. 2015. Report of the Fifth Workshop on the Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE V), 5–9 October 2015, Lisbon, Portugal. ICES CM 2015/ACOM:56, 157 pp., Copenhagen, ICES.
- IMF. 2023. Guinea-Bissau: Request for a three-year arrangement under the Extended Credit Facility – Press release and staff report. IMF Staff Country Rep. 2023/087, Washington DC, IMF.
- Intchama JF, Belhabib D, Tomás Jumpe RJ. 2018. Assessing Guinea-Bissau's legal and illegal unreported and unregulated fisheries and the surveillance efforts to tackle them. *Front. Mar. Sci.* 5: 79.
- Jones S. 1992. Guinea-Bissau. In: Sayer JA, Harcourt CS, Collins NM (Eds.), *The conservation atlas of tropical forests: Africa*. London, Palgrave Macmillan, pp. 240–247.
- Kell LT, Sharma R. 2025. An evaluation of the robustness of length-based stock assessment approaches for sustainable fisheries management in data and capacity limited situations. *Sustainability*. 17: 4791.
- King JR, McFarlane GA. 2003. Marine fish life history strategies: Applications to fishery management. *Fish. Manag. Ecol.* 10: 249–264.

- Maier HN. 1908. Beiträge zur Altersbestimmung der Fische. I. Allgemeines. Die Altersbestimmung nach Otolithen bei Scholle und Kabeljau. *Arb. Dtsch. Wiss. Komm. Meeresforsch.* 5: 57–115.
- Medeiros-Leal W, Santos R, Peixoto UI, Casal-Ribeiro M, Novoa-Pabon A, Sigler MF, Pinho M. 2023. Performance of length-based assessment in predicting small-scale multispecies fishery sustainability. *Rev. Fish Biol. Fish.* 33: 819–852.
- Mota KG, Perazza CA, Vaz Velho F, Sardinha M L, Morais L, Vaini JO, Hallerman E, Hilsdorf AWS. 2024. Population genetic diversity of Cunene horse mackerel *Trachurus trecae* on the Angolan coast. Implications for management and conservation. *Fish. Res.* 277: 107069.
- Ndjaula H, Krakstad JO, Kjesbu O. 2013. Reproductive biology of horse mackerel *Trachurus capensis* and *Trachurus trecae* in Namibia and Angola. *Afr. J. Mar. Sci.* 35: 141–150.
- Okafor-Yarwood I. 2019. Illegal, unreported and unregulated fishing, and the complexities of the sustainable development goals (SDGs) for countries in the Gulf of Guinea. *Mar. Policy.* 100: 124–132.
- Pacheco MB. 2024. *Medidas da terra e do mar da CPLP: Apontamento*. 1 ed., Lisboa, Edições da Marinha & Instituto Hidrográfico.
- Pauly D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. Int. Explor. Mer.* 39: 175–192.
- Pauly D. 1983. Some simple methods for the assessment of tropical fish stocks. *FAO Fish. Tech. Pap.* 234, Rome, FAO.
- Pauly D, Belhabib D, Blomeyer R, Cheung WWL, Cisneros-Montemayor AM, Copeland D, Harper S, Lam VWY, Mai Y, Le Manach F, Österblom H, Mok KM, van der Meer L, Sanz A, Shon S, Sumaila UR, Swartz W, Watson R, Zhai Y, Zeller D. 2014. China's distant-water fisheries in the 21st century. *Fish Fish.* 15: 474–488.
- Pinsky ML, Reygondeau G, Caddell R, Palacios-Abrantes J, Spijkers J, Cheung WWL. 2018. Preparing ocean governance for species on the move. *Science.* 360: 1189–1191.
- Polidoro BA, Ralph GM, Strongin K, Harvey M. 2017. The status of marine biodiversity in the Eastern Central Atlantic (West and Central Africa). *Aquat. Conserv. Mar. Freshw. Ecosyst.* 27(S1): 106–120.
- Poloczanska ES, Burrows MT, Brown CJ, García Molinos J, Halpern BS, Hoegh-Guldberg O, Kappel CV, Moore PJ, Richardson AJ, Schoeman DS, Sydeman WJ. 2016. Responses of marine organisms to climate change across oceans. *Front. Mar. Sci.* 3: 62.
- Pons M, Cope JM, Kell LT. 2020. Comparing performance of catch-based and length-based stock assessment methods in data-limited fisheries. *Can. J. Fish. Aquat. Sci.* 77: 1026–1037.
- Popoola OO, Olajuyigbe AE. 2023. Operationalizing the blue economy in the Gulf of Guinea, Africa. *Front. Polit. Sci.* 5: 1070508.
- Quetglas A, Rueda L, Alvarez-Berastegui D, Guijarro B, Massuti E. 2016. Contrasting responses to harvesting and environmental drivers of fast and slow life history species. *PLOS ONE.* 11: e0148770.
- R Core Team. 2025. *R: A language and environment for statistical computing*. Vienna, R Foundation for Statistical Computing.
- Republic of Guinea-Bissau. 2011. Decree-Law No. 10/2011 approving the General Fisheries Law. *Suppl. Bol. Of. Repub. Guiné-Bissau* No. 23.
- Republic of Guinea-Bissau. 2022. Decree No. 21/2022 creating the National Institute for Fisheries and Oceanography Research (INIPO). *Suppl. Bol. Of. Repub. Guiné-Bissau* No. 48 (4th Suppl.), Part I: 1–13.
- Rodríguez JAC. 2016. *Life history traits and spatial patterns of five mid-size pelagic fish species of the Gulf of Cadiz*. Master's thesis, Universidad de Cádiz.
- Santos R, de Barros M, Medeiros-Leal W. 2026. Advancing stock assessment in the Azores through an ensemble approach based on length-based models. *Reg. Stud. Mar. Sci.* 96: 104859.
- Sardinha MI, Nævdal G. 2002. Population genetic studies of horse mackerel *Trachurus trecae* and *Trachurus trachurus capensis* off Angola. *S. Afr. J. Mar. Sci.* 24: 49–56.
- Schwamborn R, Mildenerberger TK, Taylor MH. 2019. Assessing sources of uncertainty in length-based estimates of body growth in populations of fishes and macroinvertebrates with bootstrapped ELEFAN. *Ecol. Model.* 393: 37–51.
- Smith-Vaniz WF, Monteiro V, Camara K, Sidibe A, Sylla M. 2015. *Trachurus trecae*. The IUCN Red List of Threatened Species 2015: e.T21113110A43157620.
- Sobrinho I, Intchama J, Lino PG. 2022. Relatório da 8 Reunião do Comité Científico Conjunto sobre o Acordo de Parceria para Pesca Sustentável entre a República da Guiné-Bissau e a União Europeia. Centro de Investigação Pesqueira Aplicada (CIPA), Bissau, Guiné-Bissau.
- Taylor MH, Mildenerberger TK. 2017. Extending electronic length frequency analysis in R. *Fish. Manag. Ecol.* 24: 230–238.
- Temudo MP, Cabral AI. 2017. The social dynamics of mangrove forests in Guinea-Bissau, West Africa. *Hum. Ecol.* 45: 307–320.
- Then AY, Hoenig JM, Hall NG, Hewitt DA. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES J. Mar. Sci.* 72: 82–92.
- Torrejon-Magallanes J. 2020. *sizeMat: An R package to estimate size at sexual maturity*. Vienna, R Foundation for Statistical Computing.
- UN. 1982. *United Nations Convention on the Law of the Sea*. Montego Bay, Jamaica, United Nations.
- Virdin J, Kobayashi M, Akester S, Vegh T. 2019. West Africa's coastal bottom trawl fishery: Initial examination of a trade in fishing services. *Mar. Policy.* 108: 103632.
- von Bertalanffy L. 1938. A quantitative theory of organic growth (Inquiries on growth laws. II). *Hum. Biol.* 10: 181–213.
- Wang K, Zhang C, Ji Y, Xu B, Xue Y, Ren Y. 2025. Navigating life-history parameter uncertainty in data-limited fisheries: A comparative analysis of length-based stock assessment methods. *Rev. Fish Biol. Fish.* 35: 1711–1733.
- Yraola IS, Barri I, Cantos CB, Gomes JP, Dafé CS. 2023. Relatório da campanha de avaliação dos stocks demersais na Zona Económica Exclusiva da Guiné-Bissau. Ministério das Pescas – Centro de Investigação Pesqueira Aplicada (CIPA), Bissau, Guiné-Bissau.
- Yraola IS, Barri I, Jumpe RJT, N'bunde MA, Cantos CB, Dafé C, Jaló D, Trindade NL, Intchama JF. 2024. Relatório da campanha de avaliação dos stocks demersais na Zona Económica Exclusiva da Bissau 1123. Ministério das Pescas e Economia Marítima – Instituto Nacional de Investigação das Pescas e Oceanografia (INIPO), Cádiz, Espanha.
- Yraola IS, Barri I, N'Bundé MA, Jimenez JG, Cantos CB. 2019. Relatório da campanha de avaliação dos stocks demersais na Zona

Económica Exclusiva da Guiné-Bissau. Ministério das Pescas – Centro de Investigação Pesqueira Aplicada (CIPA), Cádiz, Espanha. Yraola IS, Barri I, Nbundé MA, Cantos CB, Intchama JF, Gomes JP, Burgos MC. 2025. Relatório da campanha de avaliação dos

stocks demersais na Zona Económica Exclusiva da Guiné-Bissau. Ministério das Pescas e Economia Marítima – Instituto Nacional de Investigação das Pescas e Oceanografia (INIPO), Bissau, Guiné-Bissau.

Cite this article as: Nonque D, de Barros M, Martins A, Santos R. 2026. Towards sustainable management of the Cunene horse mackerel (*Trachurus trecae*) in Guinea-Bissau waters. *Aquat. Living Resour.* 39: 16. <https://doi.org/10.1051/alr/2026009>