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Quantitative assessment reveals widespread depletion of demersal fisheries in the Brazilian meridional margin, SW Atlantic

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ABSTRACT

The Brazilian meridional margin has supported industrial and artisanal demersal fisheries for over six decades, yet a comprehensive, standardized assessment of stock status across species remains lacking. This study analyzed available data on historical catch, effort, and life history for 36 demersal fish stocks using three stock assessment models, according to data availability. Of these, 22 stocks had sufficient data to support quantitative assessments (Stock Synthesis and JABBA), providing biomass-based reference points, while for the remaining 14 stocks, only the productivity dimension was estimated (CMSY++). Among the 22 stocks with stock status estimates, the results reveal widespread and chronic depletion across assessed stocks, with 86% classified as overfished and biomass levels averaging 61% of that required to achieve maximum sustainable yield by 2019. Current landings are less than half of the estimated sustainable potential harvest, indicating significant productivity losses. These findings underscore the ecological and economic consequences of prolonged unmanaged exploitation and highlight the urgent need for strengthened monitoring, adaptive management, and regional cooperation to restore fishery productivity and resilience in the Southwestern Atlantic.

1. Introduction

The Brazilian meridional margin, extending from the southeastern coast (~20°S) to southern Brazil (~36°S) (Alberoni et al., 2020), encompasses the South Brazilian Shelf Large Marine Ecosystem (Sherman, 2005), a region characterized by complex oceanographic interactions that enhance marine productivity and support diverse and economically important fishery resources. The convergence of major currents, together with nutrient inputs from continental discharges such as the La Plata River and the Patos Lagoon, contributes to the high biological productivity that supports important demersal and pelagic assemblages (Defeo et al., 2025). Although small-scale fisheries were already present in southern Brazil in the late nineteenth century (Odebrecht, 2003), larger-scale demersal fisheries developed during the twentieth century second half, initially operated by pair trawlers based in São Paulo and otter trawlers based in Rio Grande (Yesaki and Bager, 1975). From the 1960s onward, these fisheries expanded rapidly due to technological developments, increases in fleet size, and fiscal incentives that promoted the exploration of new fishing grounds (Haimovici et al., 2014). Today, the region's demersal fisheries remain largely dominated by bottom trawl and bottom gillnet fleets (Valentini and Pezzuto, 2006; Pio et al., 2016; Haimovici and Cardoso, 2017).

Throughout the period of demersal fishery development, the substantial growth in fleet capacity was not matched by the establishment of an effective, science-based management system capable of monitoring stock status or implementing timely restrictions for the recovery of reduced stocks (Perez et al., 2024). Management measures were often reactive, fragmented, and influenced by specific sectorial interests. They seldom limited fishing pressure, but instead focused on protecting life-history traits (e.g., fishing bans during spawning seasons, minimum catch sizes, and others) of a few abundant target species amidst largely multispecies catches produced by trawlers and gillnetters. Fishers often reacted to these restrictions by expanding and redirecting fishing effort towards those 'uncontrolled' species, which were then progressively

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exploited on *quasi* open-access regimes (Perez et al., 2024). This lack of effective governance and enforcement has led to the overexploitation and, in several cases, the collapse of key fisheries often supported by such management-neglected demersal species. This is the case of the red porgy (*Pagrus pagrus*), the first documented collapse in Brazilian industrial fisheries, which occurred shortly after its discovery on the outer shelf (Haimovici et al., 2020). Red porgy landings peaked at 5000 t in 1973, halved the following year, and declined to only a few hundred tons thereafter. A similar pattern occurred in bottom longline fisheries targeting wreckfish (*Polyprion americanus*) and tilefish (*Lopholatilus villarii*), where the adoption of wire lines increased efficiency and profits, leading to a huge increase in the landings before the fishery collapse, prompting a *moratorium* in 2005 (Haimovici and Peres, 2005, Ávila-da-Silva and Haimovici, 2005). Even the more productive and commercially valuable demersal species, such as whitemouth croaker (*Micropogonias furnieri*), Argentine croaker (*Umbrina canosai*), striped weakfish (*Cynoscion guatucupa*), and southern king weakfish (*Macrodon atricauda*), have suffered major declines in abundance, truncation of age and size structure and shifts in life-history traits over recent decades (Vasconcellos and Haimovici, 2006; Cardoso and Haimovici, 2015; Haimovici et al., 2021; 2022).

Other notable cases of overexploitation include the catfishes (*Genidens barbus* and *G. planifrons*) and the black drum (*Pogonias courbina*) (Haimovici and Cardoso, 2017). These species undertake seasonal migrations to the Patos Lagoon estuary, where they are intensively harvested by artisanal fishers, while also being vulnerable to industrial fishing offshore. Similar patterns of decline have affected numerous elasmobranchs, including angel sharks (*Squatina guggenheim*, *S. occulta*, *S. argentina*), guitarfish (*Pseudobatos horkelii*), hammerhead sharks (*Sphyrna lewini*, *S. zygaena*), the striped smooth-hound (*Mustelus fasciatus*), and the sand tiger shark (*Carcharias taurus*), all categorized as critically endangered (Vooren and Klippel, 2005; Brazil, 2022).

Official landing data collection has historically been intermittent and fragmented among multiple governmental institutions (Freire et al., 2021). The last species-specific national landing statistics were published in 2007 (IBAMA, 2007), and since then consistent data have only been available for a few states, including Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, and Rio de Janeiro. In these states the academic institutions have played a key role in generating knowledge on Brazilian demersal fisheries through long-term independent monitoring programs that partially compensated for discontinuities in the official fisheries statistics. These programs typically involved systematic port-sampling surveys, biological sampling of commercial catches, and the reconstruction of landing and effort time series from local monitoring initiatives, allowing the maintenance of continuous datasets even during periods when national statistical systems were inactive. The Federal University of Rio Grande (FURG) has maintained systematic monitoring since 1976, collecting biological, size-composition, and effort data (Haimovici, 1987; FURG/SEMA, 2020). The University of Vale do Itajaí (UNIVALI) has conducted intensive biological and landing surveys since 2000 in one of Brazil's main fishing ports (UNIVALI/LEMA, 2023), while the Fisheries Institute of São Paulo (IP-SP) has gathered landings and effort data since the 1960s (Richardson and Moraes, 1960), albeit with intermittent biological sampling (Braga, 1962).

Although several individual stocks from southern and southeastern Brazil have been examined in previous studies, these analyses are typically species-specific and often rely on different methodological approaches. Consequently, a standardized regional synthesis of the status and productive capacity of the main demersal resources remains lacking. This limitation makes it difficult to situate the observed declines in individual species within the broader context of ecosystem-level changes and fishery productivity on the southwestern Atlantic shelf. To address this gap, the present study compiles available demographic and fisheries information for the main stocks exploited along the southern Brazilian shelf and continental slope. The study proposes a decision framework inspired by the stock assessment continuum idea proposed by Cope (2024) to assign stocks to the most appropriate assessment model based on data availability. By integrating evidence from multiple stocks, the study aims to provide a regional assessment of the current status of the main demersal resources and to quantify the magnitude of lost fishery productivity associated with long-term depletion. This is an effort to establish an assessment of multiple species affected by demersal fisheries, and to reconcile them to a renewed ecosystem-based management regime in the region (e.g., Perez et al., 2024).

2. Material and methods

2.1. Data sources

The life-history parameters used in the present assessments were mostly those compiled and described by Haimovici et al. (2025) for demersal and benthic species occurring along the Brazilian Meridional Margin (21°S–34°S). That study provided a comprehensive synthesis of available information on age, growth, reproduction, and natural mortality for 166 species of fishes, crustaceans, cephalopods, and other invertebrates, representing the most extensive reference currently available for the region. Accordingly, the parameters applied in the present analyses were selected from those reported by Haimovici et al. (2025), ensuring methodological consistency and comparability of results across the assessed stocks within the same biogeographic domain of the Southwestern Atlantic.

For each species, time series of landings, length compositions, and abundance indices available in the databases of the main academic and fisheries research institutions in southeastern and southern Brazil were compiled (Supplementary material #1). The data were consolidated, normalized, and structured to form a single and uniform database capable of supporting all analyses presented here, as well as potential future studies.

Catch and effort data for industrial trawling fleets operating in the main fishing harbors of São Paulo, Santa Catarina, and Rio Grande do Sul were obtained from long-term monitoring programs that documented fishing operations conducted by different fleet segments, including pair trawlers, otter-board trawlers, and double-rig trawlers (Perez et al., 1998; Perez and Pezzuto, 2006; UNIVALI/LEMA, 2023; FURG/SEMA, 2020). These monitoring programs were primarily based on systematic port-sampling surveys conducted at landing sites, where trained technicians recorded catch composition, fishing effort (e.g., fishing days), fishing grounds, and vessel characteristics through direct observation of landings and structured interviews with vessel captains and crews.

2.1.1. CPUE standardization

Catch and effort datasets were used to derive standardized indices of relative abundance for each stock. Given the heterogeneity in fleet composition and fishing strategies, CPUE standardization was conducted to isolate temporal trends in abundance from confounding effects associated with fishing behavior and technological variability.

Fishing trips were first classified into distinct fishing strategies using multivariate clustering approaches based on catch composition, allowing the identification of groups with similar operational characteristics. This step enabled the explicit incorporation of targeting behavior into the modelling framework.

Standardization was performed within a Bayesian hierarchical modelling framework, implemented using Integrated Nested Laplace Approximation (INLA) (Rue et al., 2009; Lindgren et al., 2011). This approach allows the incorporation of multiple sources of variability through structured random effects, including temporal (year), seasonal (quarter), vessel-specific, and fishing strategy effects, thereby improving the separation between abundance signals and operational variability.

Alternative model structures were evaluated, including lognormal and delta-lognormal formulations, to account for the zero-inflated na of CPUE data. Model selection was based on multiple perfor- ance criteria, including Deviance Information Criterion (DIC) (Spiegelhalter. et al, 2002), Watanabe–Akaike Information Criterion (WAIC) (Watanabe, 2010), Conditional Predictive Ordinates (CPO) (Roos and Held, 2011), and Probability Integral Transform (PIT) diagnostics (Schrödle et al., 2011).

Standardized annual CPUE indices were derived from model-based predictions under fixed reference conditions for operational covariates, ensuring comparability across years. Resulting indices were scaled to represent relative abundance trends and were subsequently used as input for stock assessment models.

A full description of data preprocessing, clustering procedures, model formulation, prior specification, model selection, and diagnostic evaluation is provided in Supplementary Material #2.

2.2. Stock structuring and spatial delimitation

For each species, the potential for population structuring along the meridional Brazilian margin also followed the information presented in Haimovici et al. (2025). These studies included life-history traits, reproductive season, molecular analyses, parasitic fauna, otolith shape analysis, and morphometric and meristic characteristics. References of the stock identification studies for individual species are listed in the supplementary material in Haimovici et al. (2025).

Accordingly, stocks exhibiting evidence of differentiation or contrasting biological characteristics were divided into Northern and Southern stocks. The Northern stocks were defined as those distributed between latitudes 21°30'S and 28°53'S, encompassing the region between northern Rio de Janeiro and Cabo de Santa Marta Grande in Santa Catarina (Fig. 1). The Southern stocks were defined as those occurring between 28°53'S and 33°45'S, extending from Cabo de Santa Marta Grande to Chuí, in Rio Grande do Sul. For species lacking evidence of population structuring or presenting continuous distributions along the shelf, populations were treated as Single Stocks throughout the entire Brazilian Meridional Margin (Fig. 1). This spatial stratification approach ensures that the assessments reflect both ecological and biogeographical realities of the region while maintaining consistency with p us regional management and research frameworks.

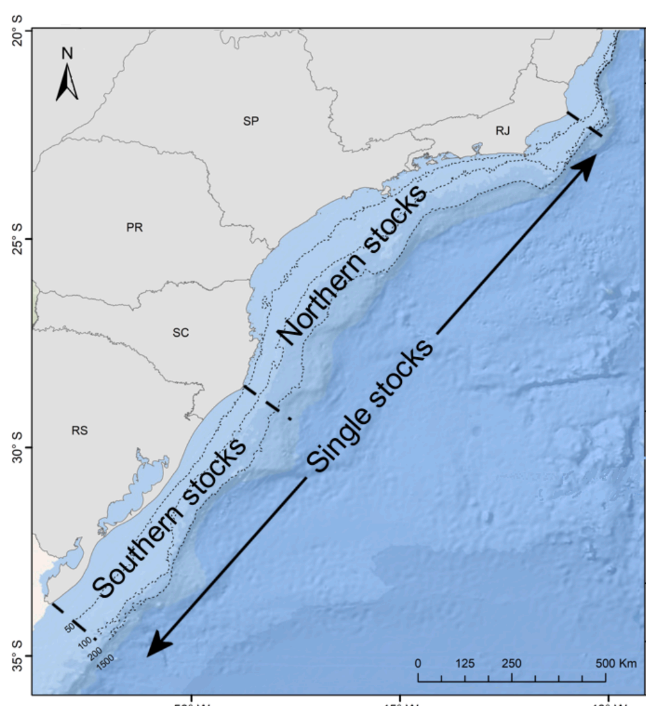

Fig. 1. Brazilian Meridional Margin and stock boundaries definitions for southern, northern and single stocks.

2.3. Decision framework for selecting the appropriate stock assessment model

The choice of the most appropriate stock assessment model for each stock followed a standardized decision framework (Fig. 2), developed to ensure methodological consistency across data types and levels of information.

The minimum requirement for assessment was the existence of basic life-history parameters (growth, natural mortality, maturity) and a continuous landings time series. If this information was not available, the stock was not assessed. The second criterion was the availability of catch and effort (CPUE) time series. Stocks for which no reliable CPUE data were available were assessed using the CMSY++ model (Froese et al., 2017), a Bayesian catch-only approach that estimates biomass dynamics from life-history traits and historical catches.

When CPUE were available, the next decision level considered the existence of size composition data. Stocks with catch and CPUE data but without size composition were assessed using the JABBA model (Just Another Bayesian Biomass Assessment) (Winker et al., 2018), a state-space surplus-production model suited for such intermediate data availability situations.

Finally, stocks for which detailed length composition data were available in addition to catches and CPUE indices, were assessed using the Stock Synthesis (SS) framework (Methot and Wetzel, 2013), an integrated age-structured population dynamics model capable of incorporating multiple data sources simultaneously and estimating recruitment, selectivity, and fishing mortality trajectories.

This hierarchical flow ensured that each stock was analyzed with the most informative and statistically robust model supported by its data structure, allowing the integration of the assessed stocks under a unified, transparent, and reproducible analytical framework.

2.4. Population dynamic modelling

The following three stock assessment models were used to assess each stock that filled the minimum data requirement.

2.4.1. CMSY++

For those stocks in which only life history and catch data were available, the stock was assessed using the CMSY++ method (Froese et al., 2017; https://github.com/SISTA16/cmsy), a Bayesian biomass dynamic model belonging to the available data-limited stock assessment methods.

This method requires a historical catch time series and prior distributions for the intrinsic population growth rate (r), carrying capacity (k), and stock depletion levels in the first (Bstart/k) and last (Bend/k) years of the time series. The CMSY++ priors are structured using plausible parameter ranges determined through expert knowledge or the guidelines provided by Froese et al. (2017). All analyses followed the CMSY++ framework, in which r, k, and MSY were assumed to follow lognormal prior distributions, while relative biomass (B/k) was modeled using beta distributions bounded between 0 and 1. Priors for terminal depletion were defined according to alternative scenarios representing moderate (0.3–0.7) and high (0.15–0.5) depletion levels, consistent with empirical ranges proposed by Froese et al. (2023). Detailed parameterization is provided for each stock in the Supplementary Material #1.

An essential input is the stock's resilience, expressed through the parameter r, which can be categorized as very low (0.015–0.1), low (0.05–0.5), medium (0.2–0.8), or high (0.6–1.5). These classifications were derived from life-history parameters presented in Haimovici et al. (2025).

CMSY++ assumes that the production function of the biomass dynamic model reaches its maximum when the stock biomass (B) is at half

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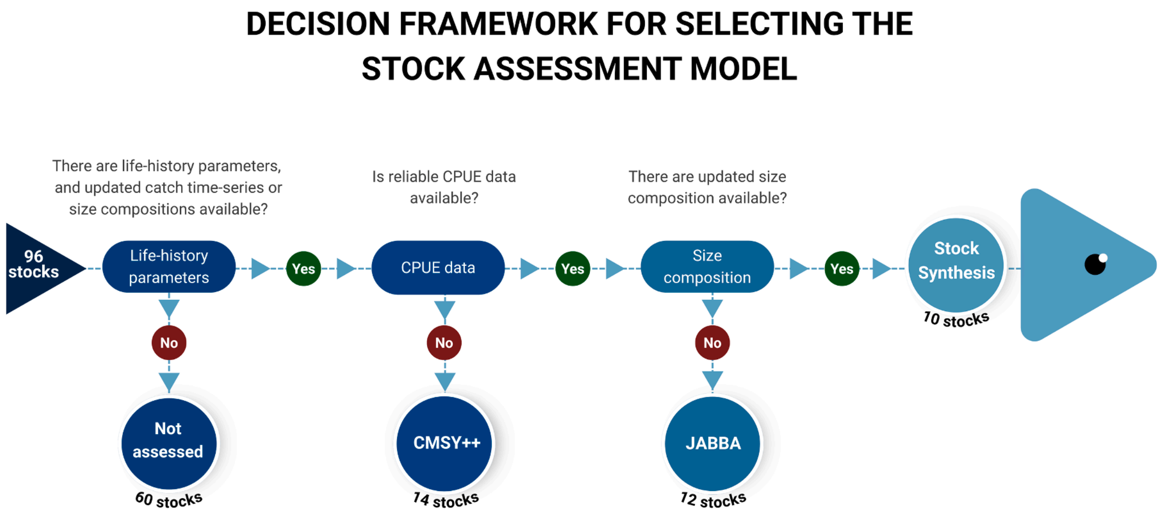

Fig. 2. Conceptual decision framework illustrating the flow chart followed to decide which stock assessment model/framework to use for each fish stock.

of k. Thus, the biomass level that produces the maximum surplus production (also known as the maximum sustainable yield) is described as BMSY/k = 0.50, aligning with the Schaefer biomass dynamic model (Schaefer, 1954) parameterization.

The CMSY++ model has a state-space structure and explicitly incorporates process error in the biomass dynamic equation. Additionally, the CMSY++ version used in this analysis differs from the version described in Froese et al. (2017) by fully incorporating the Bayesian approach through Markov Chain Monte Carlo (MCMC) simulation. Furthermore, random r-k pairs are drawn from a multivariate normal distribution, replacing the uniform distribution used in earlier versions (Martell and Froese, 2013; Froese et al., 2017).

After generating random r-k pairs, biomass trajectories that would lead to stock collapse, exceed the carrying capacity, or result in biomass levels inconsistent with assumed depletion levels are excluded from the simulations.

Further details on this methodology can be found in Froese et al. (2023).

2.4.2. *Just another Bayesian biomass assessment*

For stocks with available catch time series and standardized CPUE indices, the stock was assessed using the JABBA model (Just Another Bayesian Biomass Assessment; Winker et al., 2018). JABBA is a Bayesian state-space surplus production model designed for data-moderate stock assessments.

The model requires as input a time series of annual catch data, standardized CPUE indices with associated standard errors, and prior distributions for key population parameters, including the intrinsic rate of population growth (*r*), carrying capacity (*k*), and initial and final depletion levels. Priors for *r* were derived from scientific literature on species' life history, expert knowledge, or external sources such as FishBase, while priors for *k* and depletion levels can be set based on prior assessments or expert input. Details on these input parameters and its distribution are provided for each stock in the Supplementary Material #1.

JABBA explicitly incorporates process error in the biomass dynamics and observation error in the CPUE indices, implemented under a Bayesian framework using Markov Chain Monte Carlo (MCMC) methods to obtain posterior distributions for model parameters and reference points. The production function follows the Schaefer surplus production model (Schaefer, 1954), assuming maximum surplus production occurs at half of the carrying capacity ($B_{MSY}/k = 0.5$), allowing the estimation of key reference points such as maximum sustainable yield (MSY), biomass at MSY (BMSY), and fishing mortality at MSY (FMSY).

During the fitting process, JABBA estimates the biomass trajectory over time and evaluates its consistency with the CPUE indices while ensuring biological plausibility in the population dynamics. The model allows the use of multiple CPUE indices simultaneously, weighting them according to their variances, and providing a comprehensive approach to handling multiple data sources while quantifying uncertainty.

Diagnostic procedures, including trace plots, posterior density checks, fits to observed CPUE indices, and Kobe phase plots (B/BMSY *vs* F/FMSY), were used to evaluate the model's convergence and the adequacy of the fit. Retrospective analyses were also conducted to assess potential biases in the model estimates.

The outputs of the JABBA model include probabilistic estimates of current stock status relative to management reference points, such as B/BMSY and F/FMSY, with credible intervals, as well as time series of estimated biomass, fishing mortality, and reference point distributions. Further details on the methodology can be found in Winker et al. (2018).

2.4.3. *Stock synthesis*

For those stocks with available catch, size/age composition, and standardized CPUE indices, the stock was assessed using the Stock Synthesis (SS3) framework (Methot and Wetzel, 2013), an integrated statistical age-structured population dynamics model widely applied in stock assessments globally.

SS3 simultaneously incorporates key biological and fishery processes such as natural mortality, recruitment, growth, and selectivity, providing a coherent structure that links observed catch, size and age composition data, and CPUE indices within a unified estimation framework. This integrated approach ensures that potential correlations among different data sources are appropriately accounted for, enhancing the robustness of the assessment and allowing uncertainties in the input data to be propagated into model outputs (Methot and Wetzel, 2013).

Biological parameters, including growth, maturity, and natural mortality, were specified based on the best available life history information for each stock. Catch data and standardized CPUE indices with associated uncertainties were incorporated, along with size or age composition data, allowing the estimation of temporal trajectories of biomass, fishing mortality, and recruitment while explicitly separating process and observation error. Selectivity was modeled according to the fishing gear characteristics. For bottom trawl fisheries, selectivity was represented using a logistic function, while for gillnet fisheries a double-normal selectivity pattern was applied. In both cases, selectivity parameters were estimated freely by the model. In addition to selectivity, only the unfished recruitment parameter (R0) was estimated within the SS3 framework. All remaining life-history and population parameters (see Supplemental Material #1, Section 1.2.) were treated as fixed in[illegible] based on available biological information and previous studies.

A suite of diagnostics was selected to provide a complementary evaluation of model performance, encompassing goodness-of-fit to observed data, consistency of model assumptions, and robustness of parameter estimation, following commonly adopted practices in stock assessment modelling. For this, the final model configurations for each stock were evaluated following the Carvalho et al. (2021) diagnostic workflow (see Supplemental Material #1). The first diagnostic criterion assessed whether the Hessian matrix (the matrix of second derivatives of the likelihood function) inverted successfully, indicating a stable solution. The second criterion examined joint residual plots to ensure residuals were randomly distributed, indicating a good model fit. The third diagnostic involved retrospective analyses using five-year retrospective peels, evaluating potential retrospective patterns in biomass and fishing mortality estimates. The fourth diagnostic consisted of likelihood profiles for the unfished recruitment parameter (R0), which were used to evaluate how different data components supported the estimate of R0. No fixed quantitative thresholds were imposed to define model acceptability; instead, diagnostic results were evaluated jointly, following current best practices that emphasize a weight-of-evidence approach across multiple diagnostics.

This modeling approach allowed for a detailed and integrated assessment of stock status, providing probabilistic estimates of management reference points such as MSY, BMSY, and FMSY, as well as current stock status indicators (B/BMSY and FMSY). The biological reference points were derived from the equilibrium yield analysis implemented within the model framework. Maximum sustainable yield (MSY) was estimated based on the equilibrium fishing mortality rate (FMSY) that maximizes long-term yield under the fitted population dynamics, accounting for age structure, growth, recruitment, and selectivity patterns. The corresponding biomass reference point (BMSY) and fishing mortality reference point (FMSY) were obtained directly from the model outputs following the standard procedures implemented in the Stock Synthesis platform (Methot and Wetzel, 2013). The probabilities associated with current stock status indicators (B/BMSY and F/FMSY) were estimated using the delta-multivariate lognormal (MVLN) approximation implemented in the SSdeltaMVLN function of the ss3diags package (Carvalho et al., 2021), based on 50,000 simulations.

2.5. *Analytical steps for interpreting stock assessment results*

The presentation of results was organized to reflect three complementary analytical dimensions, stock status, scale and productivity. First, the overall stock status and its temporal trends were described exclusively for the stocks assessed using Stock Synthesis (SS3) and JABBA models, as these frameworks explicitly estimate fishing mortality (F), biomass (B), and their ratios to biological reference points (F/FMSY and B/BMSY). The stock status temporal trends were presented separately for coastal and deep water stocks. The coastal stocks were those fished within the coast and the inner shelf in depths lower than 100 meters, while the deep water stocks were those fished in the outer shelf and continental slope between 100 and 600 m deep. Second, changes in exploitable biomass over time were analyzed for these same stocks, allowing a historical reconstruction of depletion trajectories from 1960 to 2019 separating the stocks by coastal and deep water stocks and by model used to estimate the biomass trajectory. For those stocks with data beginning beyond 1960, the status and the exploitable biomass estimated for the first assessment year were back-projected to 1960, assuming it represented the same condition and biomass as at the beginning of the assessment period. Finally, fishery productivity was evaluated by comparing the estimated maximum sustainable yield (MSY) and the recent average landings for all assessed stocks, including those evaluated through the CMSY++ model.

While SS3 and JABBA provide the most reliable estimates of stock status and biomass dynamics, the CMSY++ model, being based solely on catch data and life history priors, is best suited to approxima[illegible]tainable yield levels rather than depletion status. This structure ens[illegible] a consistent interpretation of stock conditions, biomass trends, and potential productivity losses across the different data-rich and data-limited contexts represented in the demersal fisheries of the Brazilian Meridional Margin.

The stock assessment templates for individual stocks can be found in the supplementary material #1.

3. Results

3.1. *Assessed stocks*

Of the 96 stocks considered, only 36 met the minimum data requirements for assessment, while 60 did not (Supplementary material #1, Table S1). Fourteen stocks were assessed using the CMSY++ method, twelve using the JABBA method, and ten using age-structured models built within the Stock Synthesis framework (Fig. 2, Table 1).

The temporal coverage of the available data for these assessments varied across stocks and data types, ranging from 1960 to 2019 (Fig. 3). For the stocks assessed with SS3, landings, abundance index, and size data were split across different fleets (See supplemental material #1). For those assessed using JABBA, landing data were combined across fleets, while indices were kept by fleet. For the stocks assessed with CMSY++, landing data were combined across fleets.

3.2. *Stock status*

The overall stock status and temporal trends were described for the 22 stocks assessed using JABBA and Stock Synthesis. Among these, three (13.6%) were neither overfished nor subject to overfishing (green Kobe quadrant), fourteen (63.6%) were overfished but not currently subject to overfishing (yellow quadrant), and five (22.7%) were both overfished and undergoing overfishing (red quadrant).

Considering both coastal and deeper assessed stocks, 86.3% were estimated to be overfished in the last year considered in the assessments (2019). For the coastal and inner shelf stocks, the frequency of overfished stocks (red and yellow Kobe plot quadrants) showed a sustained increase beginning in the early 1970s, when the first stock, the southern *M. atricauda*, became overfished, and then continued through 2019 (Fig. 4). The proportion of overfished stocks that were also subject to overfishing increased over time, reaching a peak in 2011 when 55.6% of the stocks were in the red quadrant of the Kobe plot (Fig. 4). Since then, the number of stocks in red decreased and in 2019 some of these stocks have remained overfished but are no longer subject to overfishing.

For the outer shelf and continental slope stocks the first stock was estimated as overfished just in mid- 2000s, while some overfishing was occurring since the late 1990s (Fig. 4). The number of stocks overfished increased since mid- 2000's and in 2010's almost all stocks were overfished (Fig. 4).

The temporal trajectories of exploitable biomass showed consistent signs of depletion across both depth strata, although the magnitude and timing of these declines varied among stocks and assessment models (Fig. 5).

For coastal and inner shelf species (<100 m), both Stock Synthesis (SS3) and JABBA assessments indicated substantial long-term reductions in biomass. The SS3-assessed stocks exhibited a marked decline from the 1960s through the late 1980s, with total biomass falling below the aggregated BMSY level around 1990 and remaining at depleted levels thereafter despite a modest recovery during the 2000s. Similarly, the JABBA-assessed stocks showed a progressive decline throughout the time series, with biomass dropping below BMSY during the 2010s. By the end of the series, both model groups indicated biomass levels well below those associated with MSY reference points.

During the initial decades of the time series, landings represented only a small fraction of the available biomass, reflecting relatively high

Ta[illegible]
[illegible] of assessed stocks within the proposed framework (Fig. 2), stock structuring (Stock) within Brazilian Meridional Margin (Fig. 1), model used and the estimated [illegible] and reference points.

English and Brazilian common names	Scientific name	Stock	Model used	Estimated MSY (metric tons)	B/B_{MSY}	95% C.I. B/B_{MSY}	F/F_{MSY}	95% C.I. F/F_{MSY}
Striped weakfish, Maria-mole	*Cynoscion guatucupa*	Single	SS3	4863.7	1.147	(0.808–1.623)	0.856	(0.594–1.236)
Jamaica weakfish, Goete	*Cynoscion jamaicensis*	Single	SS3	2803.18	0.374	(0.279–0.468)	0.363	(0.251–0.475)
Blackfin goosefish, Sapo	*Lophius gastrophysus*	Single	SS3	896.1	1.018	(0.859–1.205)	0.211	(0.176–0.253)
Southern king weakfish, Pescadinha-real	*Macrodon atricauda*	South	SS3	3621.4	0.579	(0.292–1.135)	0.194	(0.100–0.380)
Whitemouth croaker, Corvina	*Micropogonias furnieri*	South	SS3	12,219.5	0.387	(0.267–0.559)	1.065	(0.772–1.472)
Brazilian flathead, Tira-vira	*Percophis brasiliensis*	South	SS3	150.9	0.525	(0.457–0.592)	1.404	(1.243–1.562)
Bluewing Searobin, Cabrinha	*Prionotus punctatus*	South	SS3	2260.9	0.625	(0.462–0.844)	1.318	(0.991–1.761)
Argentine croaker, Castanha	*Umbrina canosai*	South	SS3	8407.3	0.194	(0.145–0.26)	3.268	(2.396–4.463)
Brazilian codling, Abrótea-verdadeira	*Urophycis brasiliensis*	South	SS3	1409.8	1.165	(0.849–1.596)	0.090	(0.059–0.139)
Brazilian codling, Abrótea-de-profundidade	*Urophycis mystacea*	Single	SS3	1439.3	0.757	(0.561–1.02)	0.188	(0.126–0.27)
Gamefish, Batata	*Lopholatilus villari*	Single	JABBA	338.0	0.521	(0.271–1.497)	0.008	(0.001–0.012)
Southern king weakfish, Pescadinha-real	*Macrodon atricauda*	North	JABBA	1346.1	0.814	(0.282–1.619)	0.960	(0.327–3.082)
Kingfish, Papa-terra	*Menticirrhus spp*	Single	JABBA	1271.0	0.460	(0.275–0.747)	0.733	(0.440–1.129)
Argentine hake, Merluza	*Merluccius hubbsi*	Single	JABBA	1589.0	0.515	(0.390–0.832)	0.492	(0.185–0.715)
Whitemouth croaker, Corvina	*Micropogonias furnieri*	North	JABBA	6320.0	0.643	(0.348–1.083)	1.936	(0.892–3.629)
Octopus, Polvo comum	*Octopus americanus*	Single	JABBA	1688.0	0.610	(0.392–1.033)	0.265	(0.102–0.528)
Brazilian croaker, Maria-luiza	*Paralonchurus brasiliensis*	Single	JABBA	521.0	0.696	(0.242–2.281)	0.346	(0.048–1.040)
Harvestfish, Gordinho	*Peprilus paru*	Single	JABBA	364.0	0.568	(0.429–0.738)	0.597	(0.400–0.849)
Brazilian flathead, Tira-vira	*Percophis brasiliensis*	North	JABBA	296.0	0.777	(0.438–1.253)	0.143	(0.070–0.245)
Bluewing Searobin, Cabrinha	*Prionotus punctatus*	North	JABBA	884.7	0.820	(0.060–1.182)	0.690	(0.389–1.228)
Argentine croaker, Castanha	*Umbrina canosai*	North	JABBA	1069.0	0.700	(0.509–1.028)	0.021	(0.009–0.037)
Brazilian codling, Abrótea-verdadeira	*Urophycis brasiliensis*	North	JABBA	244.0	0.684	(0.475–0.894)	0.060	(0.026–0.093)
Longsnout striped shrimp, Camarão-cristalino	*Plesionika longirostris*	Single	$CMSY_{++}$	199.5				
Argentine stiletto shrimp, Camarão-ferrinho	*Artemesia longinaris*	Single	$CMSY_{++}$	3238.8				
Argentine red shrimp, Camarão-santana	*Pleoticus muelleri*	Single	$CMSY_{++}$	1330.8				
Atlantic seabob, Camarão-sete-barbas	*Xiphopenaeus kroyeri*	Single	$CMSY_{++}$	5330.9				
Pink shrimp, Camarões-rosa	*Farfantepenaeus spp*	Single	$CMSY_{++}$	4545.4				
Snowy grouper, Cherne-verdadeiro	*Hyporthodus niveatus*	Single	$CMSY_{++}$	157.5				
Brazilian pink cusk-eel, Congro-rosa	*Genypterus brasiliensis*	Single	$CMSY_{++}$	289.0				
Largehead hairtail, Espada	*Trichiurus lepturus*	Single	$CMSY_{++}$	682.6				
Uruguayan lobster, Lagostim	*Metanephrops rubellus*	Single	$CMSY_{++}$	62.7				
Sand flounder, Linguado	*Paralychthys spp.*	Single	$CMSY_{++}$	1918.1				
Inshore squid, Lula	*Doryteuthis spp*	Single	$CMSY_{++}$	1258.9				
Red porgy, Pargo-rosa	*Pagrus pagrus*	South	$CMSY_{++}$	1705.8				
Grey triggerfish, Peixe-porco	*Balistes capriscus*	Single	$CMSY_{++}$	2829.4				
Hooded slipper lobster, Sapateira	*Scyllarides deceptor*	Single	$CMSY_{++}$	30.6				

stock abundance and low exploitation intensity. As fisheries expanded, landings increased while biomass declined, resulting in progressively higher exploitation pressure relative to the available stock biomass.

For outer shelf and upper slope stocks (>100 and <600 m), the depletion process occurred later. SS3-assessed stocks displayed a gradual decline from the 1970s onwards, with biomass remaining close to the aggregated BMSY level by the end of the series. In contrast, the JABBA-assessed stocks remained relatively stable until the late 1990s, followed by a pronounced decline during the 2000s that reduced biomass to approximately half of the aggregated BMSY level. This delayed depletion pattern is consistent with the expansion of industrial fishing activities into deeper waters during recent decades.

Despite differences in the timing and magnitude of biomass declines among model groups, the overall pattern was remarkably consistent: both coastal and deeper-water assemblages experienced substantial reductions in exploitable biomass over the last five decades. These results highlight the broad spatial extent of fishing impacts across the South Brazilian shelf and slope ecosystem and suggest that biomass depletion has occurred across multiple species, and habitats.

Fig. 6 compares the estimated current biomass with the biomass required to achieve maximum sustainable yield (BMSY) for the stocks assessed using JABBA and Stock Synthesis. The largest biomass deficits are observed for both stocks of *M. furnieri* and for the southern stock of *U. canosai*. Relative to the other stocks, these three cases exhibit substantially greater rebuilding requirements to reach the BMSY reference point.

3.3. Fishery harvest

The combined maximum sustainable yield (MSY) estimated for the 36 assessed stocks reached 77,398.9 metric tons, whereas the combined average landings during the last three years of assessment (2017–2019) corresponded to only about 50% of this potential, totaling 39,249 metric tons.

As illustrated in Fig. 7, most demersal stocks currently display average landings considerably below their estimated MSY, demonstrating that current production remains substantially below its sustainable potential across the region. The red bars in the figure represent this difference between potential MSY and recent average landings, evidencing the substantial portion of yield that could be sustainably harvested if severely depleted stocks were rebuilt to healthy biomass levels.

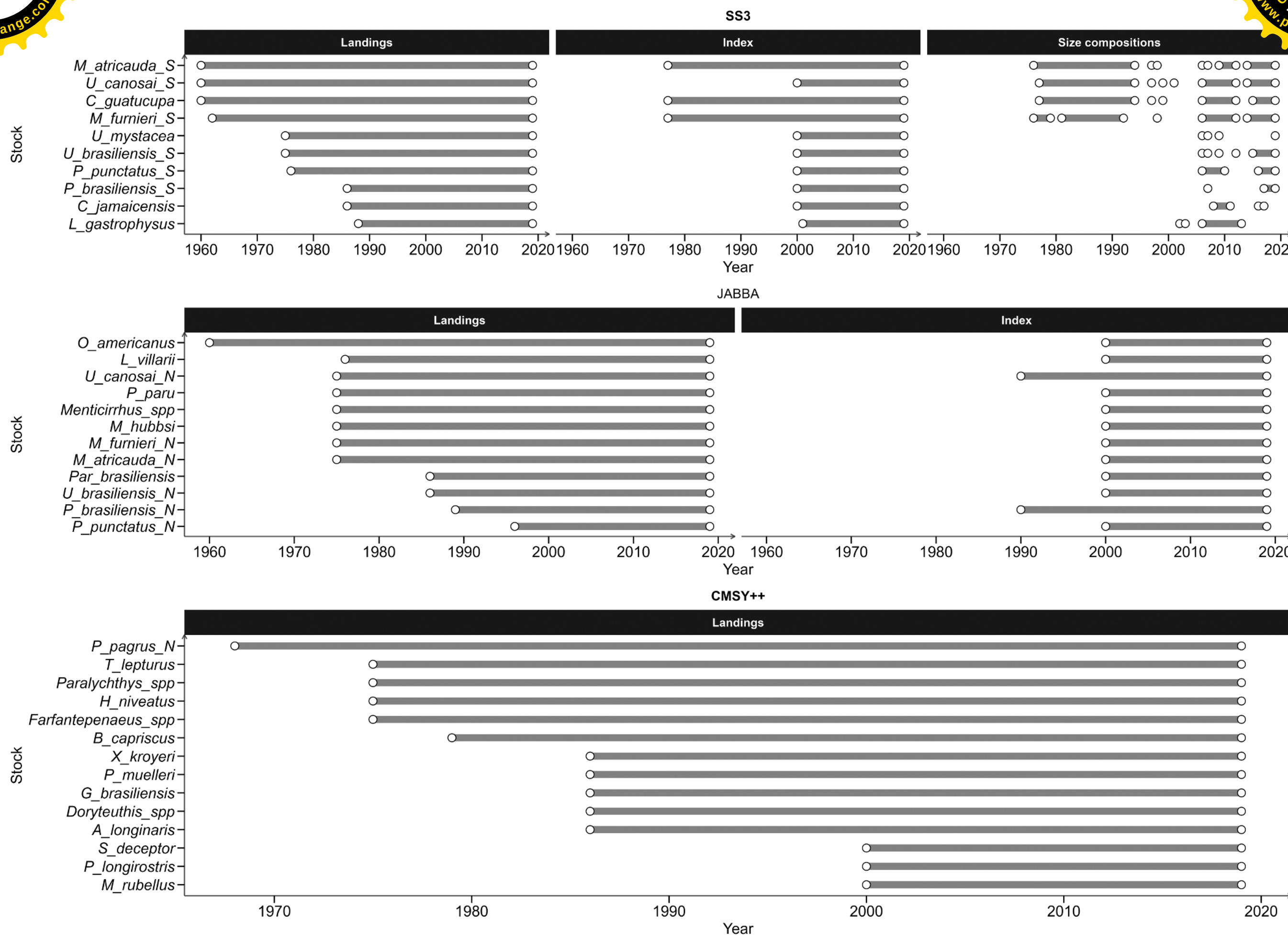

Fig. 3. Temporal coverage of each data type for the assessed stocks with the three models. _N – northern stock, _S - southern stock of each species.

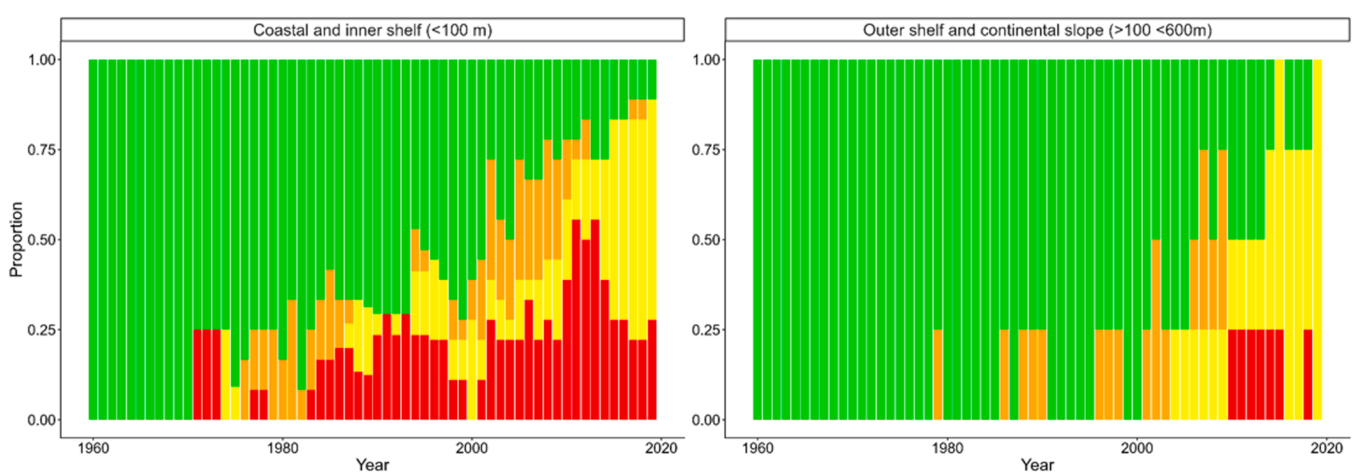

Fig. 4. Proportion of the 22 stocks assessed with Jabba and Stock Synthesis at each Kobe plot quadrant by year for the coastal and inner shelf stocks (< 100 m deep, left panel) and the Outer shelf and continental slope stocks (>100 < 600 m deep, right panel) from 1960 to 2019.

Only two stocks, the northern stock of *M. furnieri* and the southern stock of *Urophycis brasiliensis*, presented current catches slightly exceeding their MSY estimates. For most other species, however, the gap between current and potential catches underscores a historic depletion of biomass that has curtailed production capacity.

4. Discussion

This study provides robust evidence of a pervasive and long-term depletion of demersal fish stocks along the Brazilian Meridional Margin, in the Southwestern Atlantic, resulting from more than six decades of largely unmanaged exploitation (Perez et al., 2024). The assessed stocks represent more than 80% of the total demersal fish

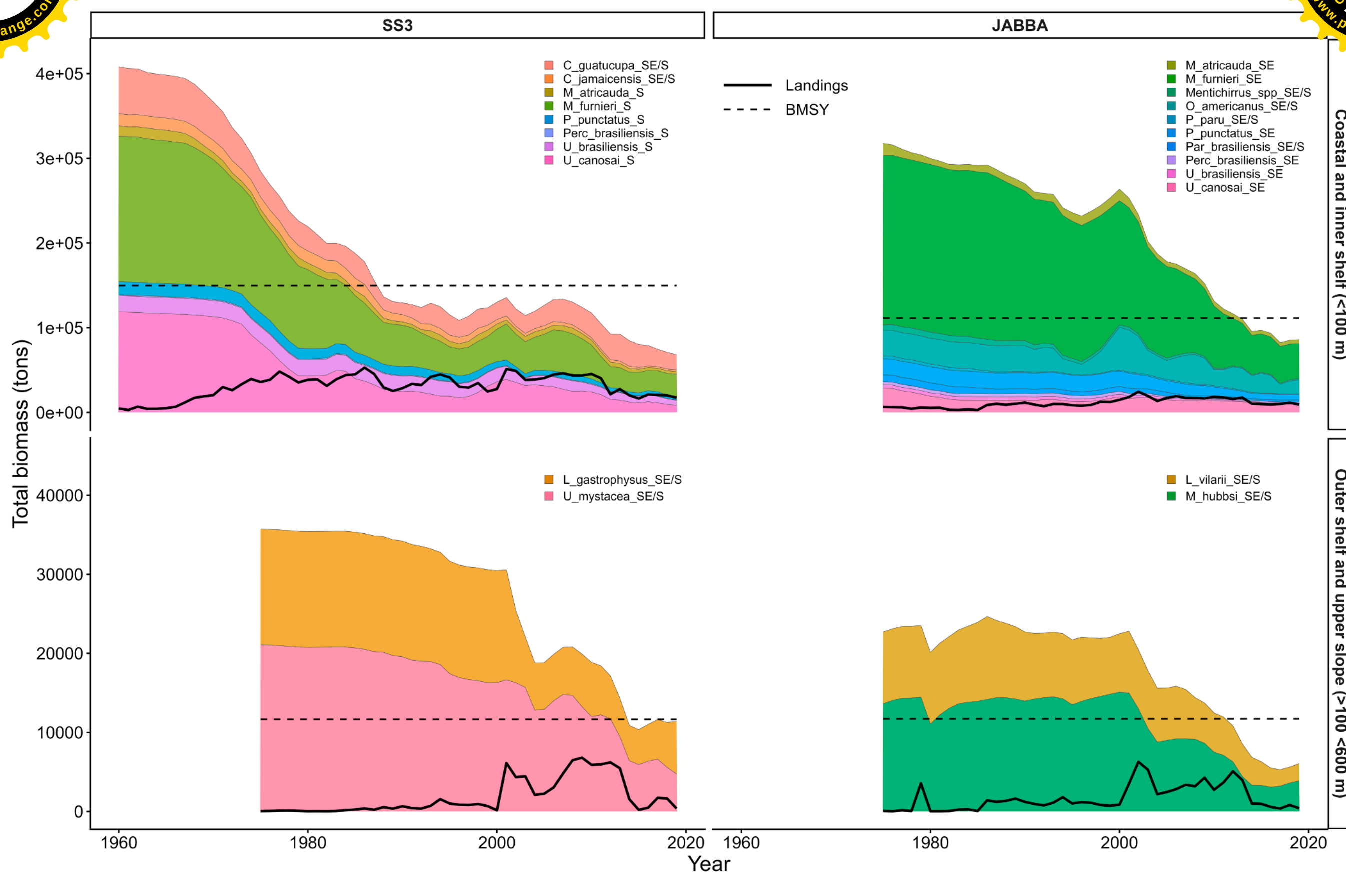

Fig. 5. Temporal trends in the estimated exploitable biomass (stacked colored areas by stock) by the SS3 and JABBA model for the coastal and inner shelf stocks (< 100 m deep, upper panel) and the Outer shelf and continental slope stocks (>100 < 600 m deep, lower panel) from 1960 to 2019. The continuous black line represents the total landings for the represented stocks while the dashed horizontal line represent the combined estimated B_{MSY}.

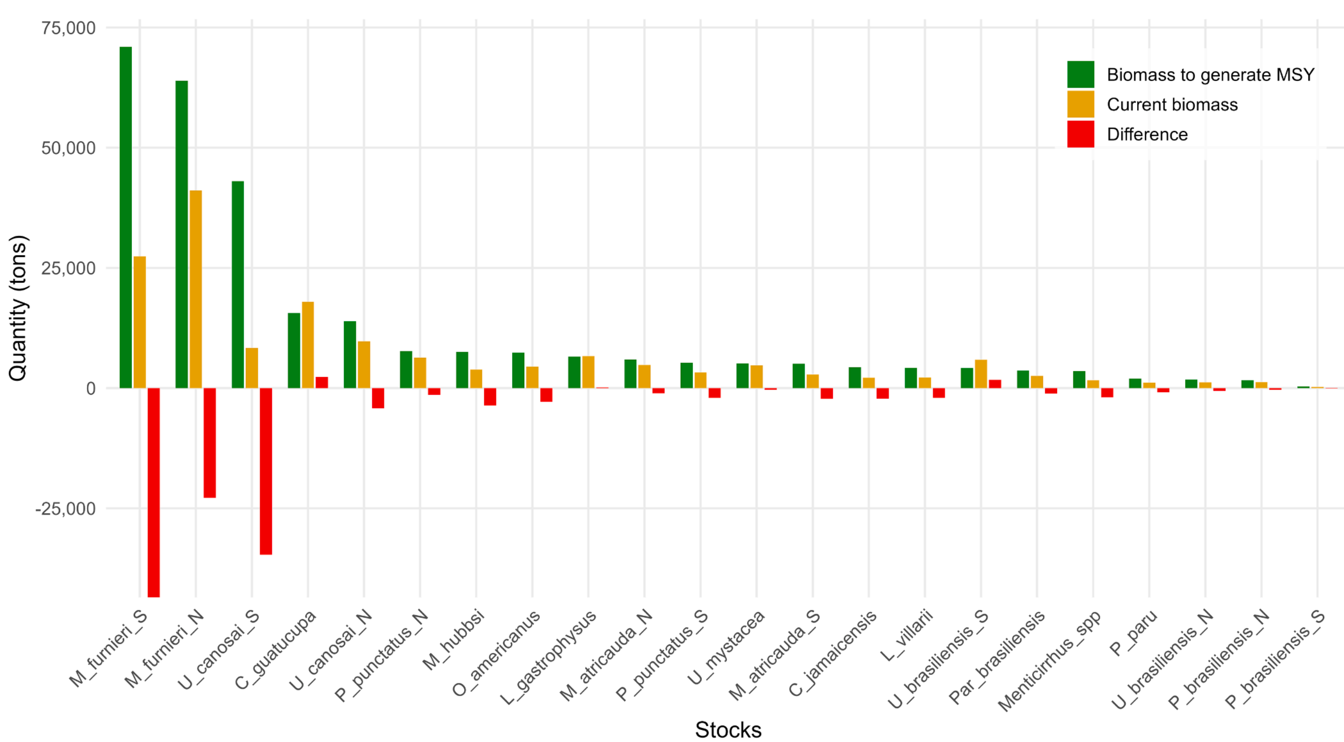

Fig. 6. Biomass that would generate the maximum sustainable yield (green), current biomass in 2019 (gold) and the difference (red) for the stocks assessed with JABBA and Stock Synthesis.

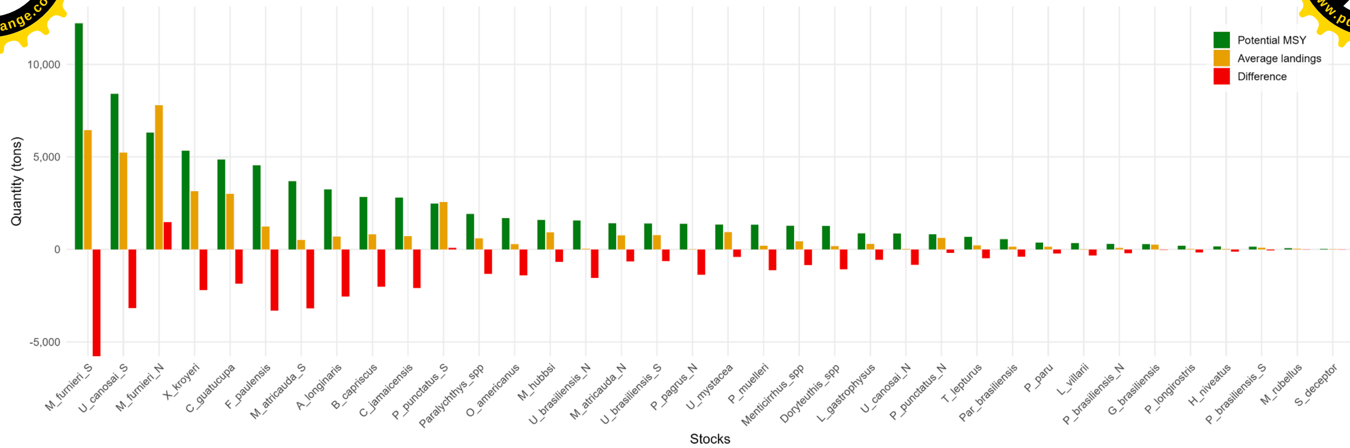

Fig. 7. Potential Maximum Sustainable Yield (Green), 2017–2019 average landings (gold), difference between MSY and Average landings (red) for the assessed stocks.

landings in 2023 and 2024 (MPA, 2025), suggesting that the assessed status may be indicative of the overall status of the demersal stocks in the region. The majority of the assessed stocks (86.3%) were found to be overfished, with nearly one-fifth still undergoing overfishing (Fig. 4). This widespread depletion across both coastal and outer shelf–slope assemblages demonstrates that the impacts of excessive fishing effort have extended throughout the entire depth gradient of the region's demersal ecosystem. The high proportion of stocks in the overfished categories of the Kobe plot, particularly since the 1980s, underscores the chronic nature of overexploitation and the absence of effective recovery measures.

The temporal trajectories of exploitable biomass highlight a dramatic reduction in the productive capacity of these resources. Coastal and inner shelf stocks, which historically supported the bulk of demersal landings (e.g., *M. furnieri, U. canosai, and C. guatucupa*), experienced a continuous decline from the 1960s through the mid-1990s, stabilizing thereafter at roughly 60% of the biomass required to sustain yields comparable to those associated with the MSY reference point. In deeper areas, where industrial fishing expanded more recently, a steep decline in biomass has occurred since the 2000s, indicating that the process of depletion propagated sequentially from shallow to deeper ecosystems as fleets expanded their spatial reach. Together, these patterns indicate that both shelf and slope assemblages are currently below the biomass levels corresponding to the MSY reference point (BMSY). Several studies have demonstrated a long-term truncation of the size and age structures for some important stocks of the region that contribute significantly to total landings, including the southern stock of *M. furnieri* (Haimovici et al., 2021), *U. canosai* (Haimovici et al., 2022), *C. guatucupa* (Miranda and Haimovici, 2007), and *M. atricauda* (Cardoso and Haimovici, 2015). The loss of larger and older individuals may negatively affect recruitment dynamics because large, older fish typically exhibit disproportionately higher fecundity, produce larger and higher-quality eggs, and often spawn over longer periods, increasing the probability of successful larval survival under variable environmental conditions (Berkeley et al., 2004; Hixon et al., 2014). The truncation of age structure may therefore reduce reproductive potential and diminish the resilience of stocks, imposing additional challenges for rebuilding depleted stocks.

The loss of biomass has translated directly into a substantial decline in fishery productivity. The combined maximum sustainable yield (MSY) estimated for the assessed stocks (≈78,500 t) is nearly double the average landings observed in the final years of the time series (≈39,000 t). This indicates that current landings represent only about half of the potential yield that could be sustainably harvested if depleted stocks were rebuilt to healthier biomass levels. Therefore, low catches should not necessarily be interpreted as evidence of sustainable exploitation, but rather as the outcome of long-term overfishing and biomass depletion. Rebuilding depleted stocks toward levels consistent with MSY-based reference points has the potential to substantially increase long-term yields and improve the sustainability of fisheries systems. A growing body of literature shows that rebuilding strategies can lead to higher and more stable catches over time, while also enhancing ecosystem resilience and supporting food security and socio-economic benefits in fishing-dependent regions (Costello et al., 2016; Hilborn et al., 2020). However, achieving these long-term gains may require short-term reductions in fishing mortality, which can result in temporary declines in catches and associated socio-economic impacts for fishing communities. The stock-specific comparisons (Fig. 6) and B/BMSY estimates (Table 1) help identify the most depleted stocks and reduce the potential masking effect of aggregated indicators. In this context, rebuilding efforts should prioritize both stocks of *Micropogonias furnieri* and the southern stock of *Umbrina canosai*, as they exhibit the largest biomass deficits (Fig. 6). From an ecosystem perspective, rebuilding these key stocks may also contribute to the recovery of other associated resources. At the same time, these stocks account for a substantial proportion of total catches, highlighting their socio-economic importance. This underscores the need for carefully designed rebuilding strategies that balance short-term costs with long-term benefits, including the use of adaptive management approaches, phased implementation of harvest controls, and complementary social and economic support measures.

An important consideration when interpreting the results presented here is that, although the assessment framework adopted in this study attempted to match model complexity to data availability, the biological reference points were derived from different stock assessment approaches (CMSY++, JABBA, and Stock Synthesis) with intrinsic different inferential strengths and uncertainties. The used models rely on different representations of population dynamics and may therefore produce somewhat different estimates of quantities such as MSY, B/BMSY and F/FMSY. Integrated age-structured models such as Stock Synthesis can provide detailed population dynamics estimates when sufficiently informative data are available, but their performance may become more sensitive to model assumptions when composition data are sparse or abundance indices present weaker diagnostic support. Conversely, surplus production models such as JABBA generally require fewer data inputs but provide lower biological resolution. Therefore, the biological reference points estimates presented here should not be interpreted as having equivalent levels of certainty across all stocks and assessment approaches.

Additionally, MSY should not be viewed as a fixed property of a stock, but rather as a context-dependent quantity that may vary according to factors such as gear selectivity, population structure, environmental conditions, and model assumptions, thereby contributing to differences among assessment outputs (Pauly and Froese, 2021). However, the objective of the present study was neither to conduct a methodological comparison among assessment models nor to provide formal management advice, but rather to apply assessment approaches compatible with the available information for each stock and to synthesize broad regional patterns of stock status and fishery productivity. In this context, MSY-based reference points were used primarily as standardized comparative benchmarks, particularly because formal biological reference points have not yet been officially established for the demersal stocks in Brazil. Nevertheless, MSY-based indicators should be interpreted cautiously, since its interpretation as a direct management target may increase the risk of overexploitation, especially under uncertainty and environmental variability. For this reason, many fisheries management systems adopt precautionary approaches, including biomass targets above BMSY, fishing mortality targets below FMSY, and harvest control rules that explicitly incorporate uncertainty (Pauly and Froese, 2021). Therefore, the MSY-related indicators presented here should be interpreted only as comparative regional reference points rather than prescriptive management targets.

Another important limitation of the present study is the reliance on fishery-dependent abundance indices for the stocks assessed with JABBA and Stock Synthesis. Although standardized CPUE series are widely used in fisheries assessments, they may be influenced by changes in fishing strategies, technological developments, targeting behavior, spatial distribution of fishing effort, and market dynamics through time (Maunder and Punt, 2004). These factors can affect the proportionality between CPUE and stock abundance and may introduce additional uncertainty into stock status estimates. In this study, standardized indices were developed using statistical approaches designed to account for important operational and spatial effects, and diagnostic procedures were applied to evaluate model performance. Nevertheless, these procedures may reduce, but not fully eliminate, the uncertainties inherent to fishery-dependent data sources.

Another important technical aspect to consider is that while the modelling frameworks applied here have been evaluated and applied in previous studies (e.g., Winker et al., 2018), and tested through simulation frameworks in the case of Stock Synthesis (Anderson et al., 2014), the specific multi-stock integration and data-limited application developed in this study would benefit from dedicated simulation testing. Simulation-based approaches could be used to evaluate the robustness of the framework under varying assumptions about data quality and model specification, as well as to assess the propagation of uncertainty in a regional multi-stock context. Future work should therefore focus on developing simulation frameworks tailored to the Southwestern Atlantic, enabling systematic evaluation of model performance and the reliability of derived management indicators under realistic scenarios.

Furthermore, although the last year of data included in the present assessments was 2019, this represents the most recent year for which consistent and comparable datasets were available across all assessed stocks. More recent data exist for some individual stocks, but were not incorporated to preserve comparability in the multi-stock synthesis. Despite this, the general conclusions regarding the depletion status of demersal stocks remain valid in 2025. Since then, there is no evidence of major changes in management policies, fishing effort regulation, or monitoring coverage that could have significantly altered the exploitation patterns described here. Therefore, it is reasonable to assume that the overall condition of most demersal resources has not substantially improved. In recent years, one relevant local policy development was the approval of the Sustainable Fisheries State Policy Act in 2018 (Rio Grande do Sul State Law 15,223/2018), which banned all motor-powered bottom trawling up to 12 miles from the study region's southernmost 570 km marine coastline. According to Cardoso et al. (2021), this regulation has the potential to promote the gradual rebuilding of several coastal southern stocks such as the whitemouth croaker (*M. furnieri*), the king weakfish (*M. atricauda*), the striped weakfish (*C. guatucupa*), and the Argentine croaker (*U. canosai*). The Brazilian Federal Decree No. 12,868 established a new spatial closure through the creation of a 10,000 km^2 marine protected area in the southern part of the study region, locally known as Albardão. The effectiveness of this measure may depend on how well the protected boundaries capture the highly dynamic oceanographic processes that structure demersal assemblages along the southern Brazilian shelf. In particular, seasonal mesoscale shifts in fish assemblages associated with oceanographic fronts and temperature gradients may cause fish to move across protected boundaries (Martins and Haimovici, 2016). Nonetheless, at the national scale, the broader governance and management framework for demersal fisheries in southern Brazil remains largely unchanged, suggesting that the patterns of biomass depletion and lost productivity identified in this study may continue to represent the current state of the fisheries.

The broad results presented in this paper mirror global patterns observed in data and resource limited fisheries (Cope, 2024) where institutional and monitoring gaps have prevented effective management interventions (Hilborn et al., 2020). The Brazilian case epitomizes this "assessment gap," where management systems have not evolved in parallel with industrial development. Although major investments were made in fleet expansion between the 1960s and 1980s, scientific and regulatory capacity remained weak, resulting in fragmented and reactive governance (Haimovici et al., 2014; Perez et al., 2024). This inertia has perpetuated an almost open-access regime in which overexploitation could proceed unchecked. Establishing a continuous, science-based monitoring system, integrating long-term academic datasets such as those from FURG, UNIVALI, and IP-SP is essential for transitioning toward evidence-based management and regular stock assessments.

The findings also emphasize the urgent need for regional cooperation. Many demersal teleost fish stocks and several elasmobranch species are transboundary resources shared among Brazil, Uruguay, and Argentina. Fragmented national management undermines sustainability, particularly in the face of climate-driven distributional shifts and changes in productivity (Defeo et al., 2025). Collaborative institutions such as the Argentina–Uruguay Joint Technical Commission (CTMFM) provide useful precedents for coordinated management. Expanding similar frameworks to include Brazil would promote shared reference points, harmonized assessment methodologies, and regional data-sharing agreements.

Another challenge involves species currently listed as threatened or critically endangered in Brazil (Brasil, 2022), for which scientific monitoring has become nearly impossible due to landing bans and limited observer coverage. Developing complementary approaches, such as market-sampling programs, genetic or eDNA-based monitoring, remote electronic observation systems, and research cruises would allow for the evaluation of conservation outcomes and the design of adaptive evidence-based recovery strategies.

This multi-stock assessment represents the most comprehensive quantitative evaluation ever conducted for demersal resources along the Brazilian Meridional Margin, providing a benchmark for future rebuilding strategies. The modelling framework adopted here also offers an operational foundation for future Management Strategy Evaluation (MSE) processes (Punt et al., 2014; Carruthers et al., 2016), an increasingly popular tool to test alternative management procedures under uncertainty. In particular, the assessment outputs generated for multiple stocks under different data conditions could support the development of operating models appropriate to different levels of information availability, ranging from data-limited MSE approaches based on biomass dynamics to more complex age-structured simulations for data-rich stocks. To our knowledge, formal MSE applications have not yet been conducted for most demersal stocks in the Brazilian Meridional Margin. Nevertheless, the standardized assessment framework developed here provides a consistent basis for implementing future MSE analyses and testing alternative harvest strategies within a regional governance context.

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Finally, given the accelerating environmental variability and projected tropicalization of the Southwestern Atlantic (Gianelli et al., 2023, Perez and Sant'Ana, 2022, Franco et al., 2020), the transition toward adaptive and ecosystem-based management becomes urgent. Integrating biological, oceanographic, and socio-economic monitoring within a data-driven governance system will be key to restoring the productivity, resilience, and long-term sustainability of demersal fisheries and the industry and coastal communities that depend on them.

CRediT authorship contribution statement

Perez José Angel Alvarez: Writing – original draft, Validation, Project administration, Funding acquisition, Data curation, Conceptualization. **Kikuchi Eidi Santos:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Mourato Bruno Leite:** Writing – original draft, Methodology, Formal analysis, Data curation. **Manuel Haimovici:** Writing – original draft, Validation, Data curation. **Antonio Olinto Avila-da-Silva:** Writing – original draft, Validation, Data curation. **Cardoso Luis Gustavo:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Rodrigo Sant'Ana:** Writing – original draft, Methodology, Formal analysis, Data curation.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT (OpenAI) in order to support English editing and text refinement. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2026.107805.

Data availability

Data will be made available on request.

References

Ávila-da-Silva, A.O., Haimovici, M., 2005. Lopholatilus villarii Miranda Ribeiro, 1915. In: Cergole, M.C., Ávila-da-Silva, A.O., Wongtschowski, C.L.D.B.R. (Eds.), Análise das principais pescarias comerciais da região Sudeste-Sul do Brasil: dinâmica populacional das espécies em exploração. Série Documentos REVIZEE–Score Sul, Instituto Oceanográfico da USP, São Paulo, pp. 74–80.

Vooren, C.M., Klippel, S. (Eds.), 2005. Ações para a conservação de tubarões e raias no sul do Brasil. Igaré, Porto Alegre.

Alberoni, A.A.L., Jeck, I.K., Silva, C.G., Torres, L.C., 2020. The new digital terrain model (DTM) of the Brazilian continental margin: detailed morphology and revised undersea feature names. Geo-Mar. Lett. 40, 949–964. https://doi.org/10.1007/s00367-019-00606-x.

Anderson, S.C., Monnahan, C.C., Johnson, K.F., Ono, K., Valero, J.L., Cunningham, C.J., 2014. ss3sim: An R package for fisheries stock assessment simulation with Stock Synthesis. PLoS. ONE 9 (4), e92725. https://doi.org/10.1371/journal.pone.0092725.

Berkeley, S.A., Chapman, C., Sogard, S.M., 2004. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85 (5), 1258–1264.

Braga, A.S., 1962. Métodos de compilação e computação de dados estatísticos de desembarque de pescado no porto de Santos. Bol. do Inst. Oceanogr. áfico 12, 39–64.

Brazil, Ministry of the Environment, 2022. Ordinance MMA No. 148, of June 7, 2022. Diário Oficial da União, Section 1, p. 10, June 8, 2022.

Cardoso, L.G., Haimovici, M., 2015. Long-term changes in the age structure, mortality and biomass of the king weakfish Macrodon atricauda (Günther, 1880) in southern Brazil: is it resilient enough to avoid collapse? Fish. Res. 167, 174–179. https://doi.org/10.1016/j.fishres.2015.02.007.

Cardoso, L.G., Haimovici, M., Abdallah, P.R., Secchi, E.R., Kinas, P.G., 2021. Prevent bottom trawling in southern Brazil. Science 372, 138. https://doi.org/10.1126/science.abg7494.

Carruthers, T.R., Kell, L.T., Butterworth, D.S., Maunder, M.N., Geromont, H.F., Walters, C., et al., 2016. Performance review of simple management procedures. ICES J. Mar. Sci. 73 (2), 464–482. https://doi.org/10.1093/icesjms/fsv212.

Carvalho, F., Winker, H., Courtney, D., Kapur, M., Kell, L., Cardinale, M., Methot, R.D., 2021. A cookbook for using model diagnostics in integrated stock assessments. Fish. Res. 240, 105959. https://doi.org/10.1016/j.fishres.2021.105959.

Cope, J.M., 2024. Reconciling trade-offs between data and assumptions in stock assessment. Fish. Res. 267, 106783. https://doi.org/10.1016/j.fishres.2023.106783.

Costello, C., Ovando, D., Clavelle, T., Strauss, C.K., Hilborn, R., Melnychuk, M.C., Branch, T.A., Gaines, S.D., Szuwalski, C.S., Cabral, R.B., Rader, D.N., Leland, A., 2016. Global fishery prospects under contrasting management regimes. Proc. Natl. Acad. Sci. 113 (18), 5125–5129. https://doi.org/10.1073/pnas.1520420113.

Defeo, O., Franco, B.C., Piola, A.R., Buratti, C.C., Cardoso, L.G., Cortés, F., et al., 2025. Facing oceanographic, fisheries, and governance hotspots: scientific evidence and policy implications from the southwest South Atlantic Ocean. Mar. Policy 173, 106584. https://doi.org/10.1016/j.marpol.2024.106584.

Franco, B.C., Combes, V., González Carman, V., 2020. Subsurface ocean warming hotspots and potential impacts on marine species: the southwest South Atlantic Ocean case study. Front. Mar. Sci. 7, 563394. https://doi.org/10.3389/fmars.2020.563394.

Freire, K.M.F., Almeida, Z.S., Amador, J.R.E.T., Aragão, J.A., Araújo, A.R.R., Ávila-da-Silva, A.O., et al., 2021. Reconstruction of marine commercial landings for the Brazilian industrial and artisanal fisheries from 1950 to 2015. Front. Mar. Sci. 8, 659110. https://doi.org/10.3389/fmars.2021.659110.

Froese, R., Demirel, N., Coro, G., Kleisner, K.M., Winker, H., 2017. Estimating fisheries reference points from catch and resilience. Fish Fish 18 (3), 506–526. https://doi.org/10.1111/faf.12190.

Froese, R., Winker, H., Coro, G., Palomares, M.L.D., Tsikliras, A.C., Dimarchopoulou, D., Touloumis, K., Demirel, N., Vianna, G.M.S., Scarcella, G., Schijns, R., Liang, C., Pauly, D., 2023. New developments in the analysis of catch time series as the basis for fish stock assessments: The CMSY++ method. Acta Ichthyol. Et. Piscat. 53, 173–189. https://doi.org/10.3897/aiep.53.105910.

FURG/SEMA, 2020. Boletim da pesca industrial marinha no Rio Grande do Sul – 2019. Laboratório de Recursos Pesqueiros Demersais e Cefalópodes, Instituto de Oceanografia, FURG, Rio Grande, 28 pp.

Gianelli, I., Orlando, L., Cardoso, L.G., Carranza, A., Celentano, E., Correa, P., et al., 2023. Sensitivity of fishery resources to climate change in the warm-temperate Southwest Atlantic Ocean. Reg. Environ. Change 23 (2), 49. https://doi.org/10.1007/s10113-023-02039-6.

Haimovici, M., 1987. Estratégia de amostragens de comprimentos de teleósteos demersais nos desembarques da pesca de arrasto no litoral sul do Brasil. Atl. ântica 9 (1), 65–82.

Haimovici, M., Cardoso, L.G., 2017. Long-term changes in the fisheries in the Patos Lagoon estuary and adjacent coastal waters in southern Brazil. Mar. Biol. Res. 13, 135–150. https://doi.org/10.1080/17451000.2016.1248841.

Haimovici, M., Peres, M.B., 2005. Polyprion americanus Bloch & Schneider, 1801. In: Cergole, M.C., Ávila-da-Silva, A.O., Wongtschowski, C.L.D.B.R. (Eds.), Análise das principais pescarias comerciais da região Sudeste-Sul do Brasil. Série Documentos REVIZEE–Score Sul, Instituto Oceanográfico da USP, São Paulo, pp. 124–131.

Haimovici, M., Andriguetto Filho, J.M., Sunye, P.S., 2014. A pesca marinha e estuarina do Brasil: estudos de caso multidisciplinares. Editora da Universidade Federal do Rio Grande (FURG), Rio Grande.

Haimovici, M., Kikuchi, E., Cardoso, L.G., Moralles, R., 2020. The population dynamics of the red porgy Pagrus pagrus along southern Brazil before its fishery collapse in the 1980s: a baseline study. Aquat. Living Resour. 33, 10. https://doi.org/10.1051/alr/2020009.

Haimovici, M., Cavole, L.M., Cope, J.M., Cardoso, L.G., 2021. Long-term changes in population dynamics and life history contribute to explain the resilience of a stock of Micropogonias furnieri in the SW Atlantic. Fish. Res. 237, 105878. https://doi.org/10.1016/j.fishres.2021.105878.

Haimovici, M., Kikuchi, E., Cardoso, L.G., 2022. Changes in the population structure and life history associated with long-term intense fishing of the Argentinian croaker Umbrina canosai in southern Brazil. Aquat. Living Resour. 35, 12. https://doi.org/10.1051/alr/2022012.

Haimovici, M., Kikuchi, E., Rodrigues, L., Martins, R.S., Sant'Ana, R., Ávila-da-Silva, A. O., Perez, J.A.A., Cardoso, L.G., 2025. A review of the scientific production and research output on the demersal marine fishery resources of the Brazilian meridional margin, SW Atlantic. Rev. Fish. Biol. Fish. 35, 2041–2063. https://doi.org/10.1007/s11160-025-09992-1.

Hilborn, R., Amoroso, R.O., Anderson, C.M., Baum, J.K., Branch, T.A., Costello, C., et al., 2020. Effective fisheries management instrumental in improving fish stock status. Proc. Natl. Acad. Sci. 117 (4), 2218–2224. https://doi.org/10.1073/pnas.1909726116.

Hixon, M.A., Johnson, D.W., Sogard, S.M., 2014. BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. ICES J. Mar. Sci. 71 (8), 2171–2185.

IBAMA, 2007. Estatística da pesca 2007 – grandes regiões e unidades da federação. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, Brasília, p. 113.

Lindgren, F., Rue, H., Lindstrom, J., 2011. An Explicit Link Between Gaussian Fields and Gaussian Markov Random Fields: the stochastic partial differential equation approach (with discussion). J. R. Stat. Soc. Ser. B 73 (4), 423–498.

Martell, S., Froese, R., 2013. A simple method for estimating MSY from catch and resilience. Fish Fish 14 (4), 504–514. https://doi.org/10.1111/j.1467-2979.2012.00485.x.

Martins, A.S., Haimovici, M., 2016. Seasonal mesoscale shifts of demersal nekton assemblages in the subtropical South-western Atlantic. Marine Biology Research 13 (1), 88–97. https://doi.org/10.1080/17451000.2016.1217025.

Maunder, M.N., Punt, A.E., 2004. Standardizing catch and effort data: a review of recent approaches. Fish. Res. 70 (2-3), 141–159.

Methot, R.D., Wetzel, C.R., 2013. Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142, 86–99. https://doi.org/10.1016/j.fishres.2012.10.012.

Miranda, L.V., Haimovici, M., 2007. Changes in the population structure, growth and mortality of striped weakfish Cynoscion guatucupa of southern Brazil between 1976 and 2002. Hydrobiologia 589, 69–78. https://doi.org/10.1007/s10750-007-0712-3.

MPA, 2025. Boletim estatístico da pesca e aquicultura: boletim anual – estatística pesqueira e aquícola, volume II. Minist. ério da Pesca e Aquicultura Bras. ília 118.

Odebrecht, C., 2003. A Lagoa dos Patos no século XIX na visão do naturalista Hermann von Ihering. Editora Ecoscientia, Rio Grande, p. 100.

Pauly, D., Froese, R., 2021. MSY needs no epitaph—but it was abused. ICES J. Mar. Sci. 78 (6), 2204–2210.

Perez, J.A.A., Pezzuto, P.R., 2006. A pesca de arrasto de talude no Sudeste e Sul do Brasil: Tendências da frota nacional entre 2001 e 2003. Inst. Pesca 32 (. 2), 127–150.

Perez, J.A.A., Sant'Ana, R., 2022. Tropicalization of demersal megafauna in th[illegible]ern South Atlantic since 2013. Commun. Earth & Environ. 3, 227. https://doi.org/10.1038/s43247-022-00553-2.

Perez, J.A.A., Lucato, S.H.B., Andrade, H.A., Pezzuto, P.R., Rodrigues-Ribeiro, M., 1998. Programa de amostragem da pesca industrial desenvolvido para o porto de Itajaí, SC. Not. Tec. FACIMAR 2, 93–108.

Perez, J.A.A., Ávila-da-Silva, A.O., Cardoso, L.G., Dias, M.C., Haimovici, M., Pezzuto, P. R., Sant'Ana, R., 2024. Remodeling the demersal fishery management system of southeastern and southern Brazil. Desenvolv. e Meio Ambient. 63, 48–65.

Pio, V.M., González-Poblete, E., Pezzuto, P.R., Wahrlich, R., 2016. A cost–benefit analysis of three gillnet fisheries in Santa Catarina, Brazil: contributing to fisheries management decisions. Lat. Am. J. Aquat. Res. 44, 1096–1115. https://doi.org/10.3856/vol44-issue5-fulltext-19.

Punt, A.E., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A., Haddon, M., 2014. Management strategy evaluation: best practices. Fish Fish 17, 303–334.

Richardson, I.D., Moraes, M.N., 1960. A first appraisal of the landing and mechanism of the Santos fishery. Bol. do Inst. Oceanogr. áfico 11 (1), 5–85. https://doi.org/10.1590/S0373-55241960000100002.

Roos, M., Held, L., 2011. Sensitivity analysis in Bayesian generalized linear mixed models for binary data. Bayesian Anal. 6 (2), 259–278.

Rue, H., Martino, S., Chopin, N., 2009. Approximate Bayesian Inference for Latent Gaussian Model By Using Integrated Nested Laplace Approximations (with discussion). J. R. Stat. Soc. Ser. B 71, 319–392.

Schaefer, M.B., 1954. Some aspects of the dynamics of populations, important for the management of the commercial marine fisheries. Inter. -Am. Trop. Tuna Comm. 1, 7–56.

Schrödle, B., Held, L., Riebler, A., Danuser, J., 2011. Using integrated nested Laplace approximations for the evaluation of veterinary surveillance data from Switzerland: a case-study. J. R. Stat. Soc. Ser. C Appl. Stat. 60 (2), 261–279.

Sherman, K., 2005. The large marine ecosystem approach for assessment and management of ocean coastal waters. In: Hennessey, T.M., Sutinen, J.G. (Eds.), Large Marine Ecosystems, 13. Elsevier, pp. 3–16. https://doi.org/10.1016/S1570-0461(05)80025-4.

Spiegelhalter, D., Best, N., Carlin, B., Van Der Linde, A., 2002. Bayesian measures of model complexity and fit. J. R. Stat. Soc. B 64, 583–639.

UNIVALI/LEMA, 2023. Boletim estatístico da pesca marinha, estuarina, lagunar artesanal e industrial do estado de Santa Catarina: anos 2017–2019. Univ. do Val. do Itajaí Itajaí 64.

Valentini, H., Pezzuto, P.R., 2006. Análise das principais pescarias comerciais da região Sudeste-Sul do Brasil com base na produção controlada do período 1986–2004. Instituto Oceanográfico da USP, São Paulo, p. 56.

Vasconcellos, M., Haimovici, M., 2006. Status of white croaker Micropogonias furnieri exploited in southern Brazil according to alternative hypotheses of stock discreteness. Fish. Res. 80, 196–202. https://doi.org/10.1016/j.fishres.2006.03.008.

Watanabe, S., 2010. Asymptotic Equivalence of Bayes Cross Validation and Widely Applicable Information Criterion in Singular Learning Theory. J. Mach. Learn. Res. 11, 3571–3594.

Winker, H., Carvalho, F., Kapur, M., 2018. JABBA: just another Bayesian biomass assessment. Fish. Res. 204, 275–288. https://doi.org/10.1016/j.fishres.2018.03.012.

Yesaki, M., Bager, K.J., 1975. Histórico da evolução da pesca industrial em Rio Grande. Programa de Pesquisa e Desenvolvimento Pesqueiro do Brasil PNUD/FAO: Ministério da Agricultura SUDEPE. Série Doc. Técnicos 11, 1–15.