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20 Years Later: Updated Stock Assessment of Snappers in Northeast Brazil Using an Integrated Stock Assessment Framework

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ABSTRACT

We updated the stock status of *Lutjanus analis*, *Lutjanus jocu*, *Lutjanus synagris*, and *Ocyurus chrysurus* harvested along the Brazilian northeastern coast. Stock boundaries were defined according to the Marine Ecoregion classifications at a finer scale, to reflect the population structure of each species. Data were exclusively from the handline fishing fleet, with removals obtained from fisheries national statistics and published commercial fishery records. Length compositions were from commercial and scientific surveys. Abundance indices were estimated from data from three projects and Brazilian official fishery statistics reports. Growth parameters were from the literature, and natural mortality was estimated using the Natural Mortality Tool. Data were analyzed using the Stock Assessment Continuum Tool. Three of the four species were currently overexploited, with populations having declined by > 70% from 1950 to 2021. In contrast, *O. chrysurus* yield did not exceed sustainable thresholds, although stocks were declining. Without appropriate management measures, *O. chrysurus* could also become overexploited. Our results emphasize the need to integrate these species into Brazil's fishery management plans to prevent further stock depletion and ensure long-term sustainability.

1 | Introduction

Snapper (family Lutjanidae) are tropical and subtropical marine species found in many parts of the world with high socioeconomic commercial and recreational value (Grimes 1987; Duarte and García 1999; Freitas et al. 2011). Historically, snappers were widely exploited for income by many small-scale fishing communities in Brazil, for landings and high market value (Resende et al. 2003). As key predators, snappers are often grouped with similar species like groupers (snapper-grouper complex) due to their life-history traits, trophic ecology, habitat use, and fishery dynamics (Coleman et al. 2000; Heyman 2014). Species within the snapper-grouper complex typically share life-history traits like relatively slow growth, late maturity, and spawning aggregations that contribute to their vulnerability to overexploitation (Chuenpagdee and Pauly 2005; Schärer-Umpierre et al. 2014; França et al. 2021). In Brazil, especially in the Northeast Region, 12 snapper species are targeted by fishing fleets, with *Lutjanus analis* (mutton snapper), *L. jocu* (dog snapper), *L. synagris* (lane snapper), and *Ocyurus chrysurus* (yellowtail snapper), supporting the largest landings (Resende et al. 2003). Adults of these species inhabit rocky bottoms or coral reefs, while juveniles are more commonly found in coastal waters associated with coastal reefs, seagrass meadows, or estuarine zones and share trophic ecology characteristics, with a diet based mainly on fish and crustaceans, and to a lesser extent, mollusks and annelids (Lessa et al. 2004; Monteiro et al. 2009).

In the 1950s, Portuguese fishers introduced vertical longlines, known as *Pargueiras*, to Brazilian fleets as an alternative to tuna fisheries that were already starting to decline (Resende et al. 2003). Since then, snappers were target species of several fishing fleets that peaked in the 1980s before declining thereafter (Ivo and Sousa 1988; Ximenes and Fonteles-Filho 1988). The decline was usually attributed to the depletion of stocks of southern red snapper (*Lutjanus purpureus*), which was the most fished snapper that was later supplanted by other snapper species. Since the 1990s, snappers accounted for ~40% of total landings by demersal fisheries in Brazil due to increased production of other snapper species, including *L. analis*, *L. jocu*, *L. synagris*, and *O. chrysurus*, which were mainly fished in Northeast Brazil (Resende et al. 2003; Olavo 2004; Klippel et al. 2005; Frédou et al. 2009a; Begossi et al. 2012). In the early 2000s, the Brazilian government's REVIZEE project (Lessa et al. 2004) conducted stock assessments of several fish species, including snappers, using age-structured Virtual Population Analysis (VPA) and the Thompson and Bell Yield-Per-Recruit model (Lessa et al. 2004; Frédou et al. 2009b, 2009a). Despite identifying overfishing and overexploitation, management plans were never implemented for these fisheries. To make matters worse, the official Brazilian fisheries statistical program—ESTATPESCA (Aragao 2008) ceased to exist in 2007, thereby stopping the collection and processing of fishery data, especially for coral reef fishes (Frédou et al. 2017; Silva et al. 2021, 2025).

Some stock assessment approaches use data-limited models that attempt to maximize use of available limited data (Chrysafi and Kuparinen 2015; Dowling et al. 2019; Cope et al. 2023; Cope 2024a). For example, when data on abundance indices and age and growth are unavailable or of low quality, data-limited methods can provide ways to move forward by outlining assumptions and exploring uncertainty (Cope 2024a). Catch-based models use catch time series that can be combined with species life-history data (e.g., growth equation parameters, maximum length, and age) and assumptions of stock status to estimate sustainable catches (Cope 2013). Other methods are based on length-frequency distributions (LFD) and life history to estimate sustainable fishing rates and current relative stock status, such as mortality estimators based on average length that assume fishing mortality directly influences average length of catches (Gedamke and Hoenig 2006; Pons et al. 2020; Then et al. 2018). LFD data is easy and cheap to collect; hence, it is usually the primary (or only) type of data collected in data-limited fisheries (Hordyk et al. 2015; Mildenberger et al. 2017). Because integrated models can be flexible to available data types, data-limited methods can be built in the same modeling framework (Cope 2024a). Fisheries management often aims to optimize yield while balancing environmental impacts and socioeconomic impacts (Sainsbury et al. 2000; Garcia et al. 2003); hence, it is highly variable and influenced by multiple factors that can change over time. Additionally, lack of comprehensive data in developing countries and small-scale fisheries often hinders development of effective management plans (Cope et al. 2023).

Most fish stocks and associated fisheries in Northeast Brazil, including snappers, are data-limited, which necessitates alternative assessment methods. We updated stock assessments for four economically important lutjanid species in Northeast Brazil: *L. analis*, *L. jocu*, *L. synagris*, and *O. chrysurus* using the Stock Assessment Continuum Tool (SACT) (Cope 2024a, 2024b) an integrative stock assessment model with historical catch data, length compositions, available abundance indices, and life history. We sought to determine if stocks of *L. analis*, *L. jocu*, *L. synagris*, and *O. chrysurus* were being overexploited, and if so, to estimate reference points for fishery harvest management.

2 | Methods

2.1 | Stock Definition

Stock assessments were defined within boundaries for snapper stocks of the Brazilian northeastern coast according to defined marine ecoregions (MEs) definitions (Spalding et al. 2007; Figure 1). This definition was selected based on regional homogeneity of species composition, habitats, oceanographic characteristics, and fishery dynamics within the ME of the northeastern Brazilian coast, which has high levels of biodiversity and is considered a priority for management and conservation (CBD 2014; Eduardo et al. 2018). The region includes several Marine Protected Areas (e.g., "APA Costa dos Corais",

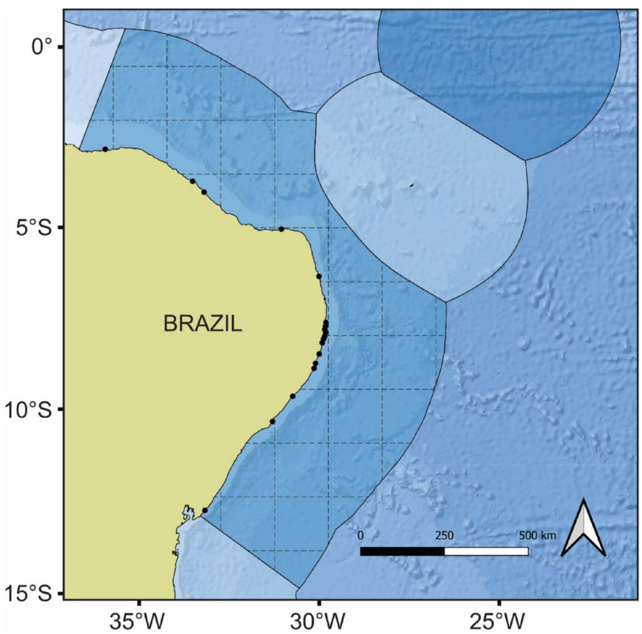

FIGURE 1 | Study area with delimitations of Marine Ecoregions on the Northeastern coast of Brazil. The cross-hatched area represents the snapper stock area in the Northeast Brazil ME. Black dots along the coast represent landing ports.

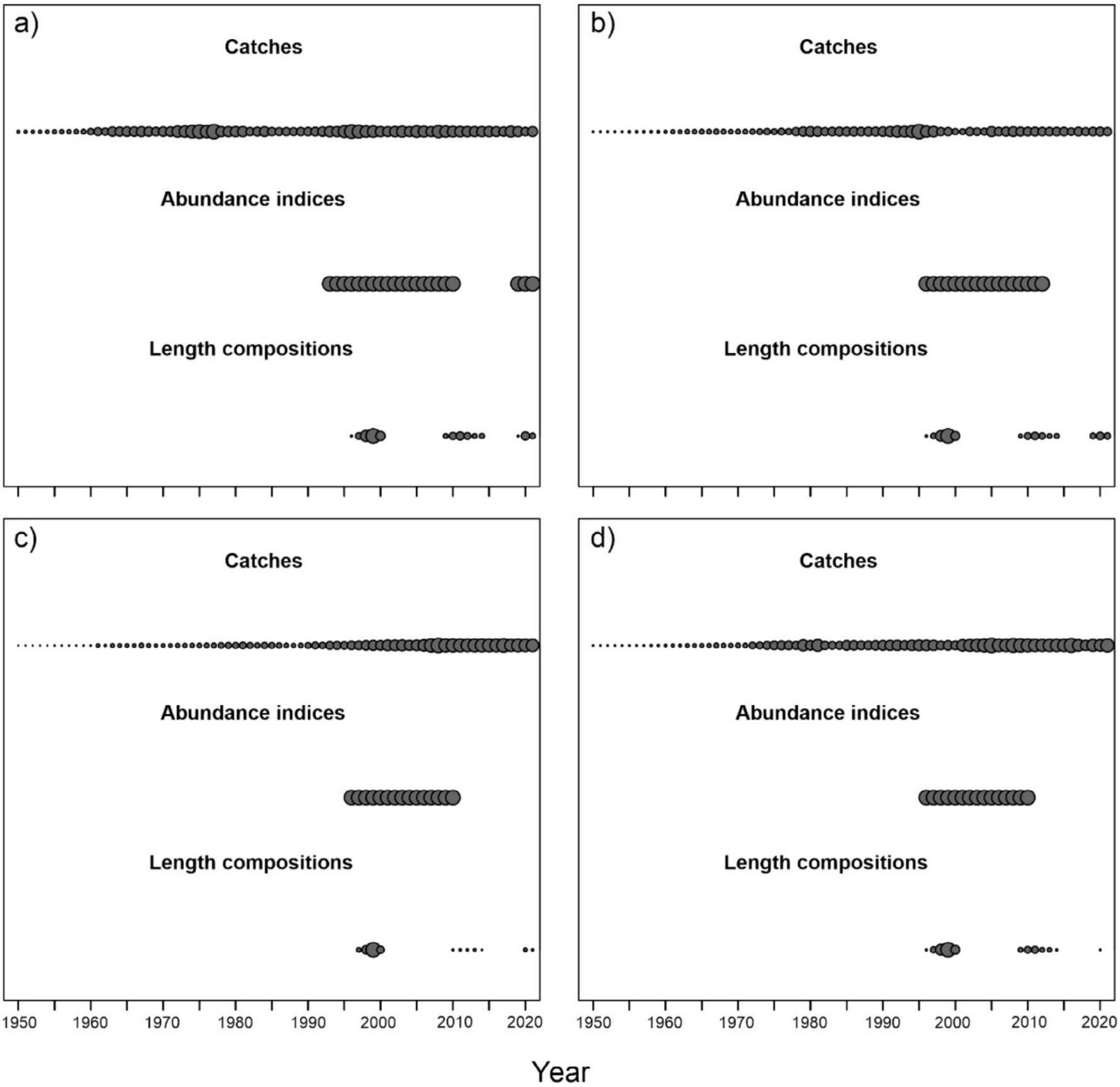

FIGURE 2 | Catches, abundance indices, and length compositions used in stock assessments of (a) *Lutjanus analis*, (b) *Lutjanus jocu*, (c) *Lutjanus synagris*, and (d) *Ocyurus chrysurus* along the northeastern Brazilian coast during 1950–2021. Bubble sizes are scaled top represent the absolute values of catches, abundance indices, and the number of individuals measured for length compositions.

"APA Guadalupe", "APA Barra de Mamanguape"; Ferreira and Maida 2007). Using MEs as the boundary for stock definition provided an appropriate proxy for inferring stock boundaries in the Southwest Atlantic and offered more accurate and finer results than broader systems like Large Marine Ecosystems (LMEs). This was especially relevant for species like snappers, which may have population structures that align with finer ecological scales, such as those defined by MEs. Recent research on otolith shape and chemical composition of *Lutjanus synagris* identified dissimilarities among populations across different MEs (Dos Santos et al. 2022). However, individuals did not differ significantly within the Northeast Brazil ME, which reinforced the idea of a single stock in this area. In contrast, otolith characteristics differed significantly between Eastern and Northeast Brazil MEs, which suggested these areas should be treated as distinct management units. Although this evidence suggests separation of stocks between different MEs, further large-scale studies comparing age composition, growth, mortality, and reproduction along a latitudinal gradient are required to substantiate a hypothesis of distinct stocks across these regions.

2.2 | Data

Data were from the commercial handline fishing fleet, which composed more than 95% (Aragao 2008) of the catches of these species. Fisheries data for snapper assessments consisted of catch, length-frequency data, and abundance index (Figure 2). Historical catch data were obtained from official reports on commercial fisheries from 1950 to 2007 (Aragao 2008), a reconstruction from 2008 to 2015 separated by state (Freire et al. 2021), and a compilation of catch time series from the Sea Around Us Project (Sea Around Us 2024), revised and extended by the REPENSAPESCA Project until 2021 (Ferreira et al. 2022) by geographical units (Northeastern Brazilian states) and taxonomic units (species) of interest for stock assessment purposes (Figure 3).

Length compositions were from REVIZEE, PRO-ARRIBADA, and REPENSAPESCA projects. The REVIZEE project during the 1990s collected large amounts of data from the Brazilian EEZ from the industrial fishing fleet based in Natal-BR, landings from

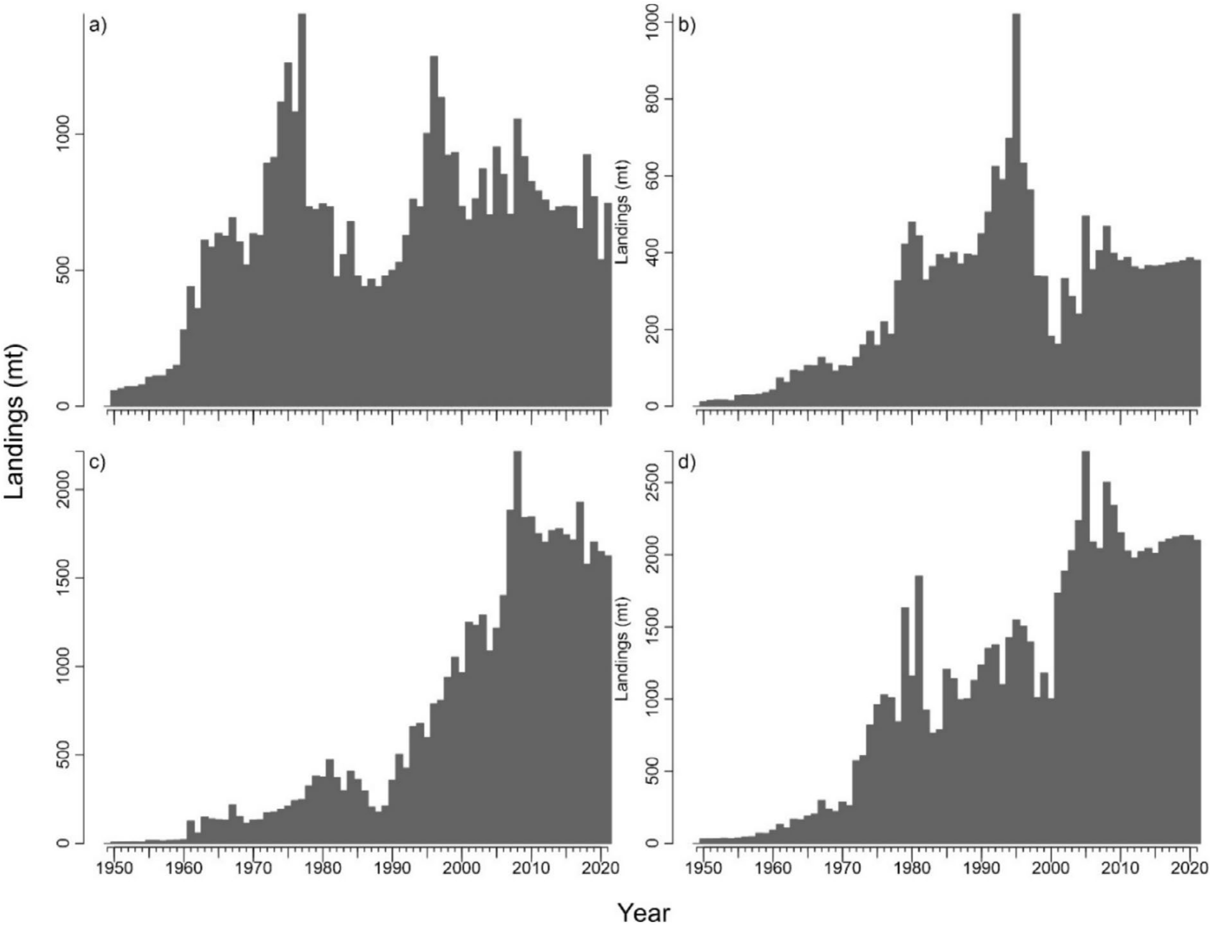

FIGURE 3 | Landings of (a) *Lutjanus analis*, (b) *Lutjanus jocu*, (c) *Lutjanus synagris*, and (d) *Ocyurus chrysurus* along the northeastern Brazilian coast during 1950–2021.

small-scale artisanal fishing fleets from various fishing communities in the Northeast states, and data from scientific surveys (MMA 2006). Data were collected monthly from five northeastern Brazilian states: Ceará, Rio Grande do Norte, Pernambuco, Alagoas, and Bahia (Frédou 2004). The PRO-ARRIBADA project, implemented in 2008, provided basic information about feeding and reproductive aggregations of socioeconomically important fish species. The project covered four broad areas, two of which were within the range of the Northeast Brazil ME and provided length data from 2009 to 2014. The REPENSAPESCA project, which aimed to assess trends in the fisheries and the population structure of commercially important reef fish, provided length composition from 2019 to 2021. Although official commercial fishery records ceased in 2007, post-2007 sampling continued at the same landing sites using the same protocols established during the earlier monitoring programs. While this ensured methodological consistency, the representativeness of post-2008 data relative to the broader commercial fishery cannot be conclusively verified. This limitation was explicitly recognized in our analysis and interpretation.

Abundance was indexed as catch-per-unit-of-effort (CPUE = kg/day, catch in kg per day at sea for each vessel). CPUE was estimated using data from the REPENSAPESCA project (from the state of Rio Grande do Norte), the PRO-ARRIBADA project (from the state of Pernambuco), and the ESTATPESCA program, Brazil's official fishery statistics until 2007 (states of Rio Grande do Norte, Paraíba, Pernambuco, and Bahia). Raw CPUE was used because standardization was not possible due to a lack of factors that can influence catch and effort, such as depth, vessel type, and spatiotemporal distribution. Diversity of sources and heterogeneity of data, such as differences in fleet type or fishing area, also hindered standardization of CPUE; hence, abundance was indexed solely as raw CPUE.

2.3 | Life History

Growth parameters for most species were sourced directly from peer-reviewed studies within the stock area. However, for *L. analis*, no peer-reviewed literature was available within the stock area, so growth parameters were estimated using the FishLife package (Thorson et al. 2017), which provides standardized life-history estimates based on phylogenetic and ecological covariates. The instantaneous natural mortality coefficient (M) was estimated for all species using the Natural Mortality Tool (NMT) (Cope and Hamel 2022) based on the arithmetic mean of four estimators that rely on maximum observed age: $M = 4.889 * T_{\max}^{-0.916}$, $M = \exp\left(1.717 - 1.01 * \ln\left(T_{\max}\right)\right)$ (Then et al. 2015), $M = 5.4 / T_{\max}$ (Hamel and Cope 2022), and $M = 3k / \left(\exp\left(k * \left(\left(0.302 * T_{\max}\right) - T_0\right)\right) - 1\right)$ (Alverson and Carney 1975).

2.4 | Population Dynamics

Biomass and stock status indicators were estimated using the SACT framework (Cope 2024b) that uses the Stock Synthesis age-structured modeling framework (Methot and Wetzel 2013) as a flexible integrated analysis to model variable data availability to estimate population dynamics (Cope 2013). This approach requires input parameters for natural mortality (M), von Bertalanffy growth parameters (L_{inf}, K, and t_0), sizes at 50% and 95% maturity and selectivity, coefficients of the weight–length and fecundity–weight relationships, parameters of the stock-recruit relationship (steepness and initial recruitment at the carrying capacity *lnR*0), and catch, length, and (if available) relative abundance (Figure 4). Due to a lack of data on fecundity at weight, fecundity–weight coefficients were set to be the same as the weight–length relationship. Steepness (h) was set to 0.7, the estimated mean value for Perciformes based on the *FishLife* package (Thorson et al. 2017; Thorson 2020). Initial selectivity inputs were estimated using the catch-curve method in the *TropFishR* package (Mildenberger et al. 2017), as preliminary estimates of the size at full selectivity based on observed length-frequency data. These values were then used to set the initial parameters for the prior distributions in SACT as part of our modeling approach. The model can estimate selectivity but relies heavily on these priors in data-limited contexts due to absence of detailed gear-specific or age-structured data. In our assessment, selectivity was semi-informed and initialized using empirical estimates that subsequently allowed adjustment within bounds defined by priors during model fitting. This intermediate approach balanced the need for model flexibility with limitations of sparse data, to reduce parameter uncertainty while maintaining biological plausibility. Reference points for spawning stock biomass (*SSB*) included spawning biomass at maximum sustainable yield (SSB_{MSY}) as a minimum stock size threshold (MSST) and 125% of SSB_{MSY} as a management target (SSB_{target}). The instantaneous fishing mortality (F) reference point was the fishing mortality at maximum sustainable yield (F_{MSY}). Reference points were estimated by SACT based on life-history parameters provided as model inputs, including growth, natural mortality, maturity, and length-at-capture, under assumptions of constant selectivity and no explicit stock–recruitment relationship.

2.5 | Assessing Uncertainty

Catch time series were composed of three linked sources: (1) for 1970–2007, catches were from the official Brazilian program of data collection, ESTATPESCA (Aragao 2008), which compiles all national fishery statistics as the most reliable catch information; (2) for 1950–1969 and 2008–2015, Freire et al. (2021) reconstructed marine commercial landings data by systematically addressing gaps and inconsistencies in Brazil's official fisheries statistics from national statistics, scientific literature, and expert consultations to estimate unreported catches, discards, and other components absent from official records; and (3) for 2016–2021, Ferreira et al. (2022) used a similar approach to extrapolate reconstructions for selected species. Given the lack of official catch statistics during the last decade, we evaluated the sensitivity of stock status estimates to uncertainty in post-2015

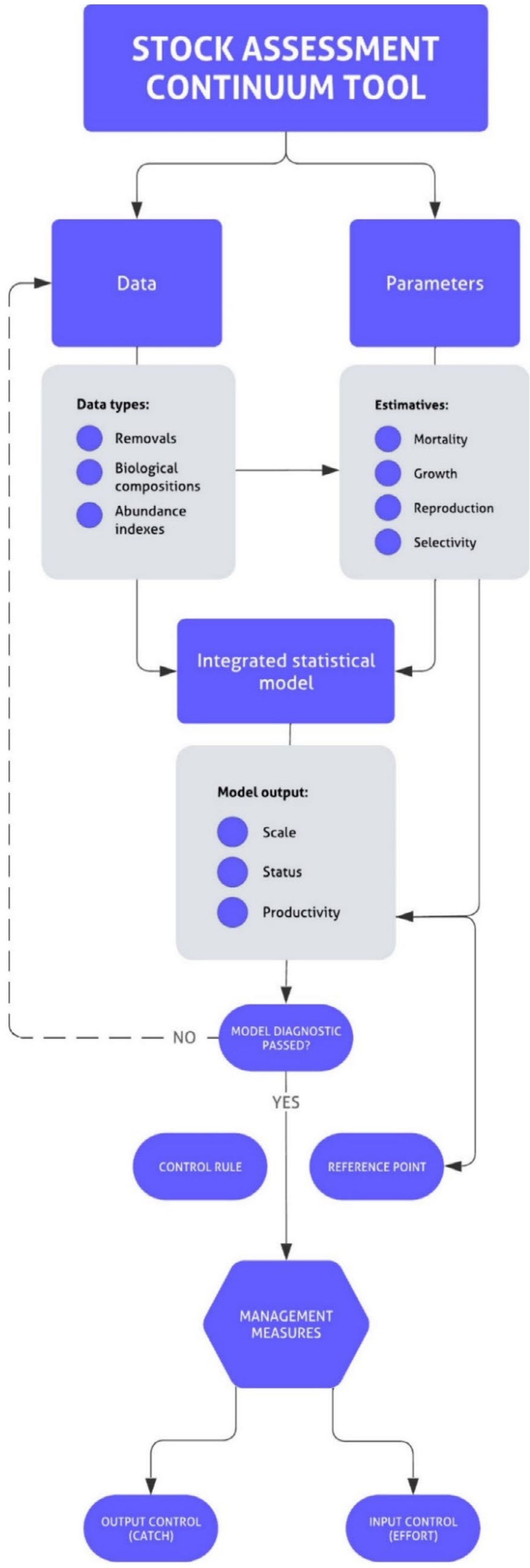

FIGURE 4 | Flow chart illustrating the Stock Assessment Continuum Tool work path used to assess status of stocks of *Lutjanus analis*, *Lutjanus jocu*, *Lutjanus synagris*, and *Ocyurus chrysurus* along the northeastern Brazilian coast during 1950–2021. Solid arrows indicate guidance regarding flow of the process from the top to the bottom. The dotted line indicates a detour path if diagnostic tests fail.

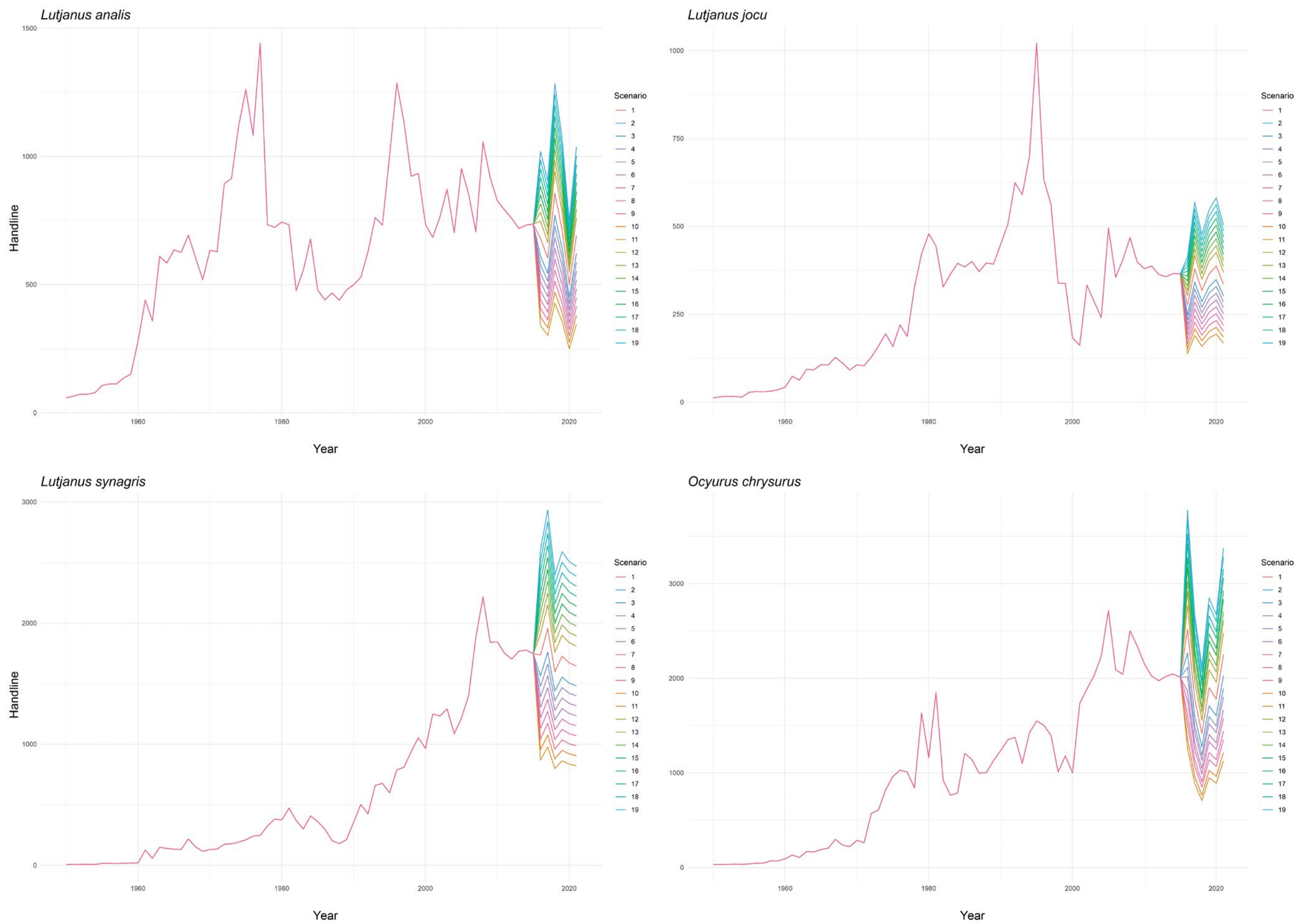

FIGURE 5 | Alternative catch scenarios for 2016–2021 used in sensitivity analyses of stock status estimates of (a) *Lutjanus analis*, (b) *Lutjanus jocu*, (c) *Lutjanus synagris*, and (d) *Ocyurus chrysurus* along the northeastern Brazilian coast during 1950–2021. Each line represents a hypothetical catch trajectory, scaled by ±10% to ±50% (in 5% increments) relative to the base scenario while preserving the original scale.

catch data. Specifically, we tested 18 alternative catch scenarios for each species during 2016–2021, by adjusting removals by ±10% to ±50%, in 5% increments, from a baseline scenario derived by Freire et al. (2021) and Ferreira et al. (2022), while maintaining the same trend trajectory (Figure 5). These catch trajectories were used to evaluate the robustness of stock status estimates to uncertainty in recent removals by systematically testing how sensitive model outputs are to reasonable variations in catch levels. Each scenario was subject to full model fitting and sensitivity analysis. To integrate results across all scenarios, we applied an ensemble modeling framework in which each scenario was weighed equally. Stock Synthesis outputs were processed to extract key management metrics (e.g., fishing mortality, biomass ratios, and recruitment), constructed probability distributions from their estimates and uncertainties, and combined them into weighted ensemble trajectories. The equal weighting scheme reflects our assumption that all scenarios were equally plausible representations of the system, avoiding subjective prioritization. The ensemble outputs, including mean trajectories, uncertainty bounds, and Kobe plot quadrant probabilities, provide a more robust synthesis than individual scenario assessments by accounting for variability across model structures and assumptions. This approach ensures that management inferences are derived from a balanced integration of all available evidence. A bootstrap routine was then used to quantify the probability that each species fell into one of four risk categories, defined by relative fishing mortality and spawning stock biomass within the Kobe plot framework. In the green quadrant (lower right), the stock is not overfished, and no overfishing is occurring, which is considered low risk, indicating a sustainable and healthy stock status. The orange quadrant (upper right) reflects a stock that is not overfished, but overfishing is occurring, representing moderate risk and signaling potential need for management action. In the yellow quadrant (lower left), the stock is overfished, but overfishing is not occurring, also indicating moderate risk. Finally, the red quadrant (upper left) represents stocks that are both overfished and experiencing overfishing, a high-risk scenario typically requiring urgent intervention. For the final model, convergence was tested using the Carvalho et al. (2021) method, which provides a diagnostic flow chart for model outputs. The first test included checking if the Hessian matrix was positive and definite, to ensure the function converged to a unique maximum likelihood estimate. The second test was a jitter analysis of initial values to ensure global convergence. The third test was for random distribution of residuals that indicated model assumptions were acceptable. The fourth test was a sensitivity analysis of productivity parameters to verify consistency of results. The last test was a 5-year retrospective analysis to verify consistency of results over time.

TABLE 1 | Input parameters used in the Stock Assessment Continuum Tool reference model for (a) *Lutjanus analis*, (b) *Lutjanus jocu*, (c) *Lutjanus synagris*, and (d) *Ocyurus chrysurus* sampled along the northeastern Brazilian coast during 1950–2021 (*Sources*: 1—Lessa et al. 2004; 2—Previero et al. 2011; 3—Schwamborn et al. 2023, 4—de Araújo et al. 2002).

	Lutjanus analis			*Lutjanus jocu*			*Lutjanus synagris*			*Ocyurus chrysurus*		
Parameter	**Value**	**CI**	**Source**	**Value**	**CI**	**Source**	**Value**	**CI**	**Source**	**Value**	**CI**	**Source**
Maximum age A_{max}	29	—	1	29	—	1	22	—	1	19	—	1
Mean age at 50% maturity A_{50}	2.27	—	1	2.89	—	1	1.81	—	1	2.24	—	1
VBGF Asymptotic length L_∞	92.3	—	Fishlife	87.8	—	2	59.7	—	3	56.7	—	4
VBGF growth coefficient $k_{yr}{}^{-1}$	0.16	—	Fishlife	0.10	—	2	0.20	—	3	0.13	—	4
VBGF Age at length 0 t_0	NA	—	Fishlife	−1.49	—	2	NA	—	3	−0.77	—	4
Mean length at 50% maturity L_{50}	28.00	—	1	32.4	—	1	18.1	—	1	20.1	—	1
Mean length at 95% maturity L_{95}	34.00	—	1	36.4	—	1	23.3	—	1	26.0	—	1
Natural Mortality M	0.21	0.17–0.25	—	0.22	0.19–0.25	—	0.24	0.20–0.28	—	0.29	0.25–0.34	—
WL relationship—α	0.02	—	1	0.02	—	1	0.01	—	1	0.03	—	1
WL relationship—β	2.96	—	1	2.97	—	1	3.08	—	1	2.74	—	1
Weight-based fecundity coefficient	0.02	—	—	0.02	—	—	0.01	—	—	0.03	—	—
Weight-based fecundity exponent	2.96	—	—	2.97	—	—	3.08	—	—	2.74	—	—
Steepness h	0.70	—	—	0.70	—	—	0.70	—	—	0.70	—	—

3 | Results

3.1 | Diagnostic Analysis

The input parameters used in the Stock Assessment Continuum Tool reference model for four snapper species (*Lutjanus analis*, *Lutjanus jocu*, *Lutjanus synagris*, and *Ocyurus chrysurus*) sampled along the northeastern Brazilian coast between 1950 and 2021 are shown in Table 1. These parameters include life-history traits such as maximum age, age and length at maturity, growth parameters from the von Bertalanffy Growth Function (VBGF), natural mortality rates, weight–length relationships, fecundity estimates, and the steepness parameter (h) of the stock–recruitment relationship. Data sources include peer-reviewed studies and the FishLife database, as indicated. Where confidence intervals (CIs) are available, they are reported alongside the parameter estimates.

Key stock status indicators for the four snapper species, based on the Stock Assessment Continuum Tool results, are depicted in Table 2. The unfished spawning stock biomass (SSB) estimates represent the total reproductive biomass if no fishing had occurred. The catch at maximum sustainable yield (MSY) is the estimated highest average annual catch that can be maintained without depleting the stock. The spawning stock biomass at MSY (SSB_{MSY}) indicates the reproductive biomass level that supports MSY. Ratios comparing the 2021 spawning stock biomass to SSB_{MSY} (SSB_{2021}/SSB_{MSY}) indicate whether the stock is above or below sustainable levels. Fishing mortality at MSY (F_{MSY}) is the rate of fishing that achieves MSY, while the ratio of fishing

TABLE 2 | Spawning stock biomass (SSB), catch at maximum sustainable yield (MSY), stock biomass at MSY, SSB in 2021 in relation to SSB at MSY, fishing mortality at MSY, fishing mortality in 2021 in relation to fishing mortality at MSY, and stock biomass status estimated with the Stock Assessment Continuum Tool for *Lutjanus analis*, *Lutjanus jocu*, *Lutjanus synagris*, and *Ocyurus chrysurus* sampled along the northeastern Brazilian coast during 1950–2021.

	Lutjanus analis		***Lutjanus jocu***		***Lutjanus synagris***		***Ocyurus chrysurus***		
Parameter	**Estimates**	**SD**	**Estimates**	**SD**	**Estimates**	**SD**	**Estimates**	**SD**	**Dimension**
Spawning stock biomass unfished	7500	236	3348	209	8090	631	11,793	1412	Tons
Catch at maximum sustainable yield (MSY)	638	20	403	25	807	63	1941	228	Tons
Stock Spawning Biomass at MSY (SSB_{MSY})	2409	76	1162	72	2683	210	3659	433	Tons
SSB_{2021}/SSB_{MSY}	0.586	—	0.814	—	0.779	—	1.422	—	—
Fishing mortality at MSY (F_{MSY})	0.126	0.001	0.146	0.001	0.146	0.001	0.208	0.002	$Year^{-1}$
F_{2021}/F_{MSY}	1.831	—	1.002	—	2.629	—	0.859	—	—
Stock biomass status	Overexploited and under overexploitation		Overexploited and under slight overexploitation		Overexploited and under heavy overexploitation		Underexploited and not under overexploitation		—

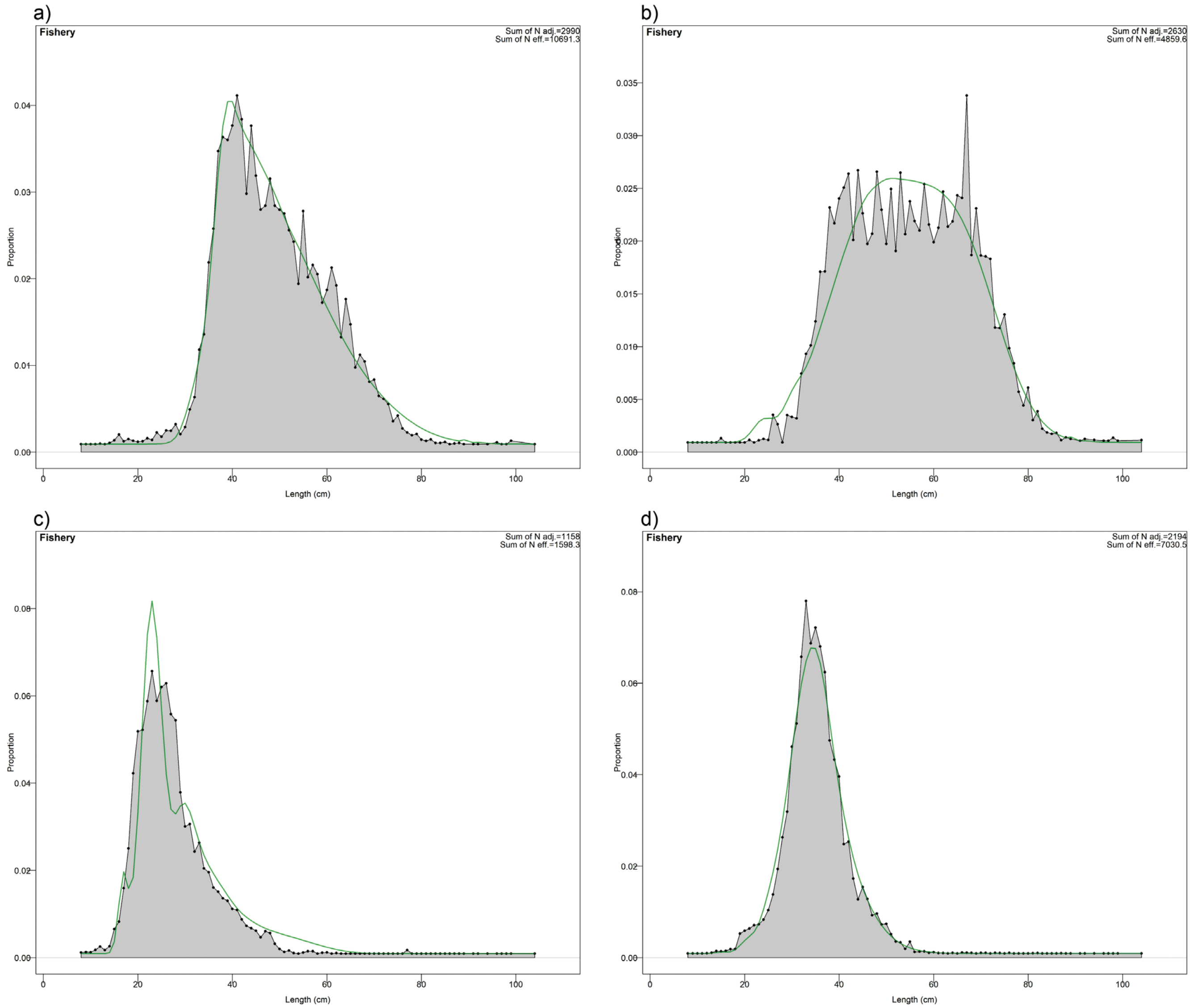

FIGURE 6 | Length distributions of (a) *Lutjanus analis*, (b) *Lutjanus jocu*, (c) *Lutjanus synagris*, and (d) *Ocyurus chrysurus* sampled along the northeastern Brazilian coast during 1950–2021. Dots indicate observed values, and green lines indicate model estimates.

mortality in 2021 to F_{MSY} (F_{2021}/F_{MSY}) indicates current fishing pressure relative to sustainable limits. Finally, the stock biomass status categorizes each stock as overexploited or underexploited and whether overfishing is occurring. These metrics provide a comprehensive view of stock health and fishing pressure to guide management decisions.

The SACT estimation fitted size composition data well (Figure 6; Table 2). For all four species, diagnostics were within the acceptable range. Final gradients of model outputs were small (< 0.001), and Hessian matrices for parameters were positive and definite. Residuals for length compositions and abundance indices were randomly distributed, except for the length composition of *O. chrysurus* (Figure S1). All 50 jitter runs for each species were stable despite variation in initial values, with most runs converging to the same solution as the base model for each species (Figure S2). For all species, final model outputs for biomass and fishing mortality were not sensitive to variation in natural mortality or steepness (Figure S3). Retrospective analyses indicated low bias for most species, except *L. analis*, due to an imbalance in the sample size among final years (Figure S4).

3.2 | *Lutjanus analis*

Removals increased until the mid-1970s and reached a historical peak in 1977 before declining sharply in the 1980s (Figure 3a). Thereafter, removals increased between 1988 and 1996 and stabilized thereafter. Length composition data for 1996–2000, 2009–2014, and 2019–2021 were well fit by the model (Figure 6a). The abundance index did not deviate significantly from the fitted trend but decreased abruptly at the end of the period (Figure 7a).

Total stock biomass (*B*) estimates fluctuated from 15,000 t in 1950 to 2900 t in 2021 (Figure 8a). A steady equilibrium in stock spawning biomass (*SSB*) between the early 1980s and 2010 was

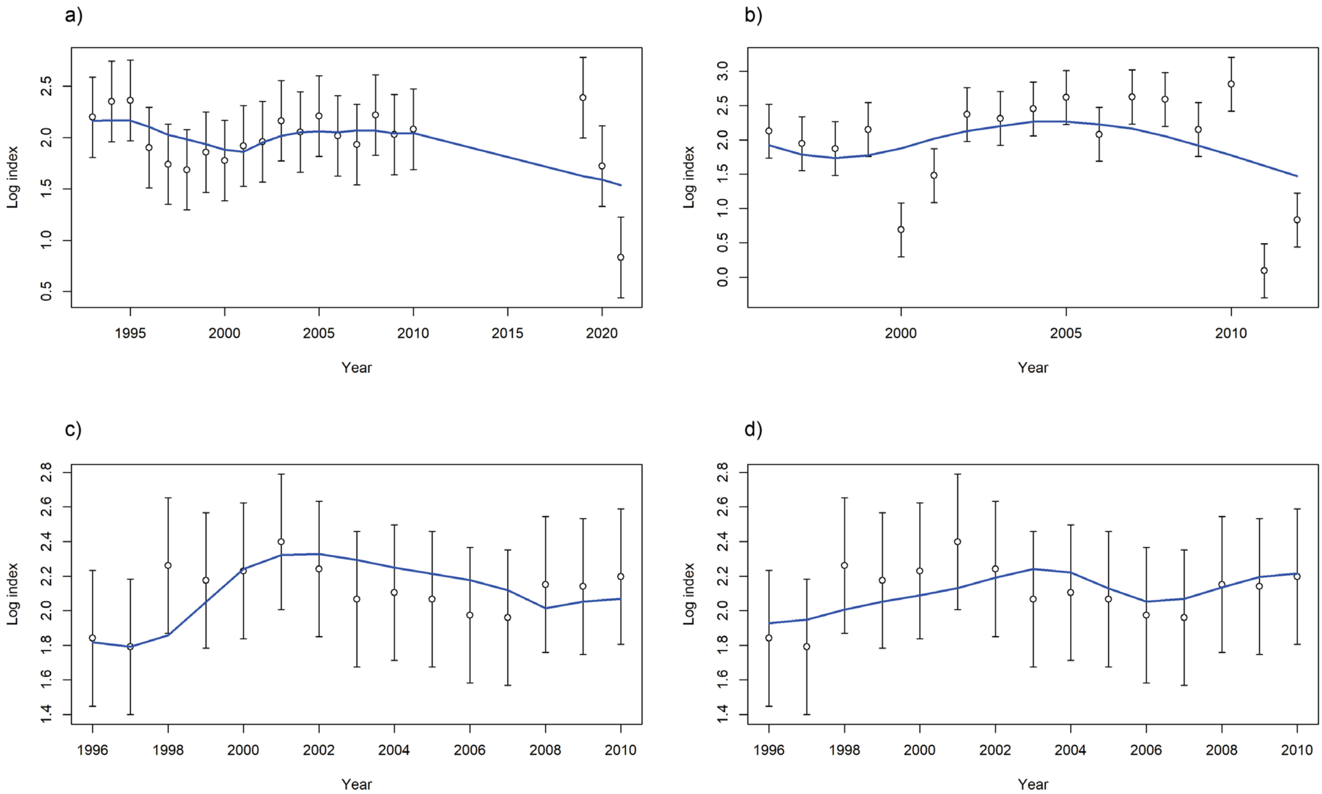

FIGURE 7 | Index of abundance of (a) *Lutjanus analis*, (b) *Lutjanus jocu*, (c) *Lutjanus synagris*, and (d) *Ocyurus chrysurus* sampled along the northeastern Brazilian coast during 1950–2021. Dots represent observed values, blue lines indicate model estimates, and vertical lines indicate coefficient of variation.

below B_{MSY}. Relative spawning biomass ranged from 99.6% at the beginning of the period to 14% in 2021, near B_{target} since the late 1970s, with low signs of recovery before a sharper decline in the last decade (Figure 8b). Current spawning biomass was below the limit ($SSB_{2021} / SSB_{MSY} \approx 0.44$). Recruitment fluctuated greatly in the last two decades (Figure 8c), with peaks in 1999 (> 2200 recruits) and 2014 (~1900 recruits). Fishing mortality after 1974 surpassed $F / F_{MSY} = 1$, and was lower only briefly between 1980 and 1994, before rising again until the end of the period ($F_{2021} / F_{MSY} \approx 2.38$; Figure 8d).

3.3 | *Lutjanus jocu*

Removals increased until the late 1990s and then declined sharply before plateauing in 2007 (Figure 3b). Length composition data for 1996–2000, 2009–2014, and 2019–2021 were well fit by the model (Figure 6b). Most length composition data was from the REVIZEE project in the 1990s, but the last decade was well represented. The abundance index was only available from 1995 through 2014 and was missing for the end of the period (Figure 7b).

Total biomass was relatively steady, before declining sharply in 1988 and again in 1996, when it declined ~66%, with a recovery between 1997 and 2002, and a decline thereafter, when it declined 43% until the end of the period (Figure 9a). Spawning stock biomass declined to below 30% of initial values, and by the beginning of the last decade, the stock was below the limit ($SSB_{2021} / SSB_{MSY} \approx 0.82$; Figure 9b). Recruitment was dynamic throughout the period, with large recruitments in 1994, 1995, and 1996 (Figure 9c). Fishing mortality increased steadily until the last decade, to surpass MSY (Figure 9d), but was at sustainable levels by the end of the period ($F_{2021} / F_{MSY} \approx 1$).

3.4 | *Lutjanus synagris*

Removals were below 500 tons in early decades, before rising above 1500 tons between 1992 and 2008, where they stayed thereafter (Figure 3c). Length compositions were based on low sample sizes (Figure 6c) and the abundance index was only available before 2010 (Figure 7c).

Total biomass declined steadily since the beginning of the period, increasingly after the 1970s (Figure 10a), with a partial recovery between 1998 and 2003, and a decline thereafter. Spawning stock biomass first dropped below MSY at the end of the 1990s, recovered until 2015, and declined sharply to low levels thereafter (Figure 10b) ($SSB_{2021} / SSB_{MSY} \approx 0.78$). Recruitment was relatively steady, with peaks in 1997, 2007, and 2016 (Figure 10c). Fishing mortality was constant until 1990, but increased regularly thereafter, to surpass F_{MSY} after 2000, and was dangerously high by the end of the period (Figure 10d) ($F_{2021} / F_{MSY} \approx 2.59$).

3.5 | *Ocyurus chrysurus*

Removals increased since the start of the period, especially after 1972, and surpassed 2000 tons in 2003 and remained stable

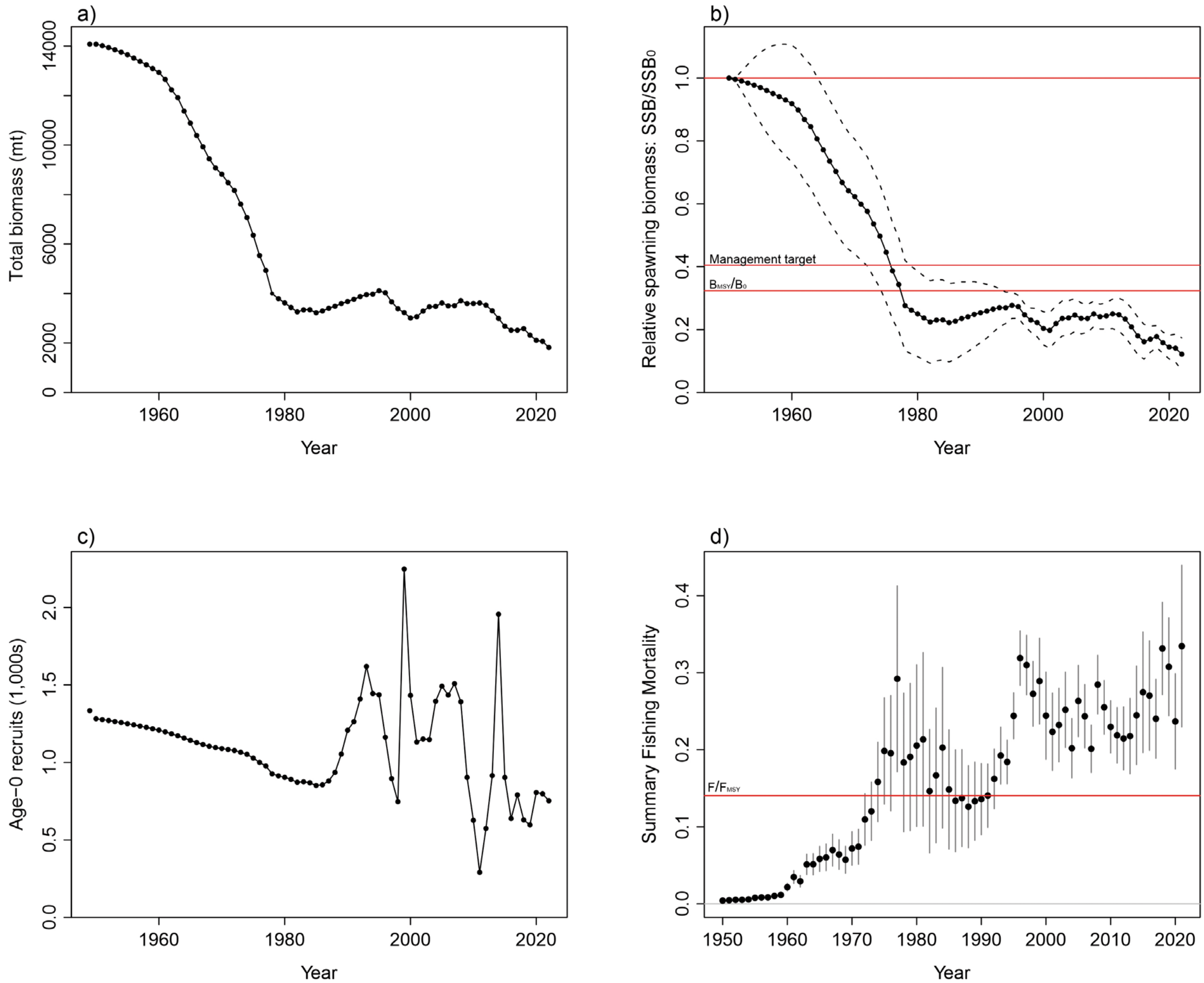

FIGURE 8 | Spawning stock biomass (SSB) (a), relative spawning biomass SSB/SSB_0 (red horizontal lines represent relative SSB at MSY and the management goal of 25% above MSY) (b), age-0 recruitment (c), and fishing mortality (red horizontal line represents fishing mortality at MSY) (d) estimated by the Stock Assessment Continuum Tool for *Lutjanus analis* along the northeastern Brazilian coast during 1950–2021.

since then (Figure 3d). Length compositions were from 1996 to 2000 and 2009 to 2014, and lacking thereafter, except in 2020 (Figure 6d). The abundance index was available from 1995 to 2011 and missing thereafter (Figure 7d).

Total biomass decreased steadily between the start of the period and 1996, with a peak between 1997 and 2001, after which the stock sharply declined until 2014, when it stabilized until the end of the period (Figure 11a). Spawning stock biomass was never below MSY but crossed the B_{target} into the precautionary zone ($SSB_{2021} / SSB_{MSY} \approx 1.42$) in the last decade (Figure 11b). Recruitment increased steadily, with peaks in 1993, 1998, and 2004 (Figure 11c). Fishing mortality was below the reference point of $F / F_{MSY} = 1$ in the entire period but increased in the last decade ($F_{2021} / F_{MSY} \approx 0.86$; Figure 11d).

3.6 | Uncertainty

For each species, different landing scenarios converged to the same final status. *L. analis* had an 88.9% probability of being overfished and experiencing overfishing, and an 11.1% probability of being overfished but not experiencing overfishing (Figure 12a). *L. synagris* had a 96.6% probability of being overfished and experiencing overfishing, and a 3.1% probability of experiencing overfishing but not being overfished (Figure 12b). *L. jocu* had a 49.6% probability of being overfished and experiencing overfishing, a 43.3% probability of being overfished but not subject to overfishing, and a 7.1% probability of being neither overfished nor undergoing overfishing (Figure 12c). *O. chrysurus* had a 57.0% probability of being neither overfished nor subject to overfishing, and a 39.0% probability of experiencing overfishing but not being overfished (Figure 12d). Stock status estimates were generally robust to uncertainty in catch data. Consistency among scenarios, particularly for *L. analis* and *L. synagris*, indicated stability in assessment outcomes despite uncertainty in catch assumptions.

4 | Discussion

Ours is the first formal and comprehensive stock assessment of all four snapper species on the northeast coast of Brazil in the past 20 years. Our primary objective was to highlight the critical need for science-based management of demersal fisheries in the region. Our results revealed clear evidence of prolonged

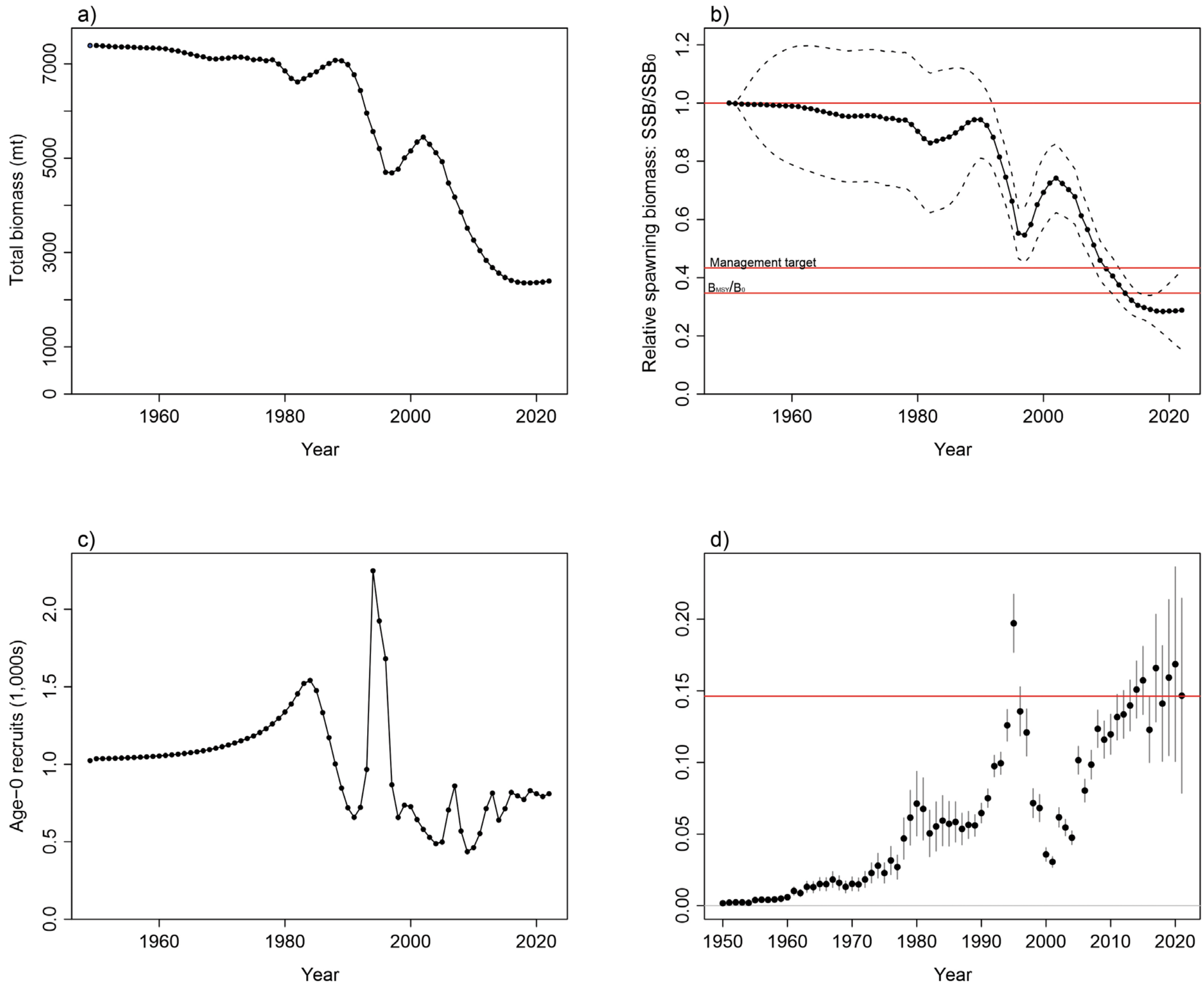

FIGURE 9 | Spawning stock biomass (SSB) (a), relative spawning biomass SSB/SSB_0 (red horizontal line represents relative SSB at MSY and the management goal of 25% above MSY) (b), age-0 recruitment (c), and fishing mortality (red horizontal line represents fishing mortality at MSY) (d) estimated by the Stock Assessment Continuum Tool for *Lutjanus jocu* along the northeastern Brazilian coast during 1950–2021.

overexploitation of some of the assessed stocks, which has yet to be addressed by any formal management framework in the region but highlights an urgent need for a regulatory framework to prevent further depletion of these stocks. By updating the status of these key fisheries, we aimed to facilitate the integration of scientific assessment into regional management planning to stimulate the adoption of sustainable harvest strategies. Our study, therefore, is pivotal for bridging the gap between scientific assessment and the development of active management policies in the region. Although assessments of other fisheries resources have been completed, such as shrimp (de Barros et al. 2021; Peixoto et al. 2021; Aragão et al. 2022), recent assessments of demersal fish in the North and Northeast regions are rare (Ferreira et al. 2022). While the REPENSAPESCA project preliminarily assessed the status of these species, it relied on the Large Marine Ecosystem (LME16) approach, which may have led to mixed signals due to the potential presence of distinct stocks in different regions. In contrast, we used marine ecoregions (MEs), which are considered a more appropriate boundary for stock definition, for finer-scale and more accurate assessments. Using historical catch and length data and abundance indices, we evaluated the status of the four main socioeconomically important snapper species caught along the northeastern coast of Brazil. Our results indicated that three of the four stocks have been overexploited for at least a decade, with estimated fishing mortality still much higher than sustainable levels. This suggests that these stocks are currently being overexploited.

An advantage of the Stock Assessment Continuum Tool is its flexibility in handling multiple types of data, including catch data, length compositions, abundance indices, and life-history (LH) information, which is particularly valuable for data-limited fisheries, such as ours (Methot and Wetzel 2013), to allow for a more refined and data-informed assessment of stock status (Rudd et al. 2021). This flexibility allows the evaluation of how different data types contribute to model outputs and where key assumptions, such as selectivity or mortality, drive uncertainty (Cope et al. 2023; Cope 2024a; Rudd et al. 2021). This allows practitioners to identify which inputs are most informative and where improved data collection would reduce model uncertainty. However, depending on the inputs provided and the assumptions made, the model output was still data-limited, even when using a complex modeling framework (Cope 2024a). One limitation of SACT for data-limited fisheries was selectivity (Cope 2024a, 2024b). For data-limited fisheries like ours, the lack of data on gear- and size-specific selectivity

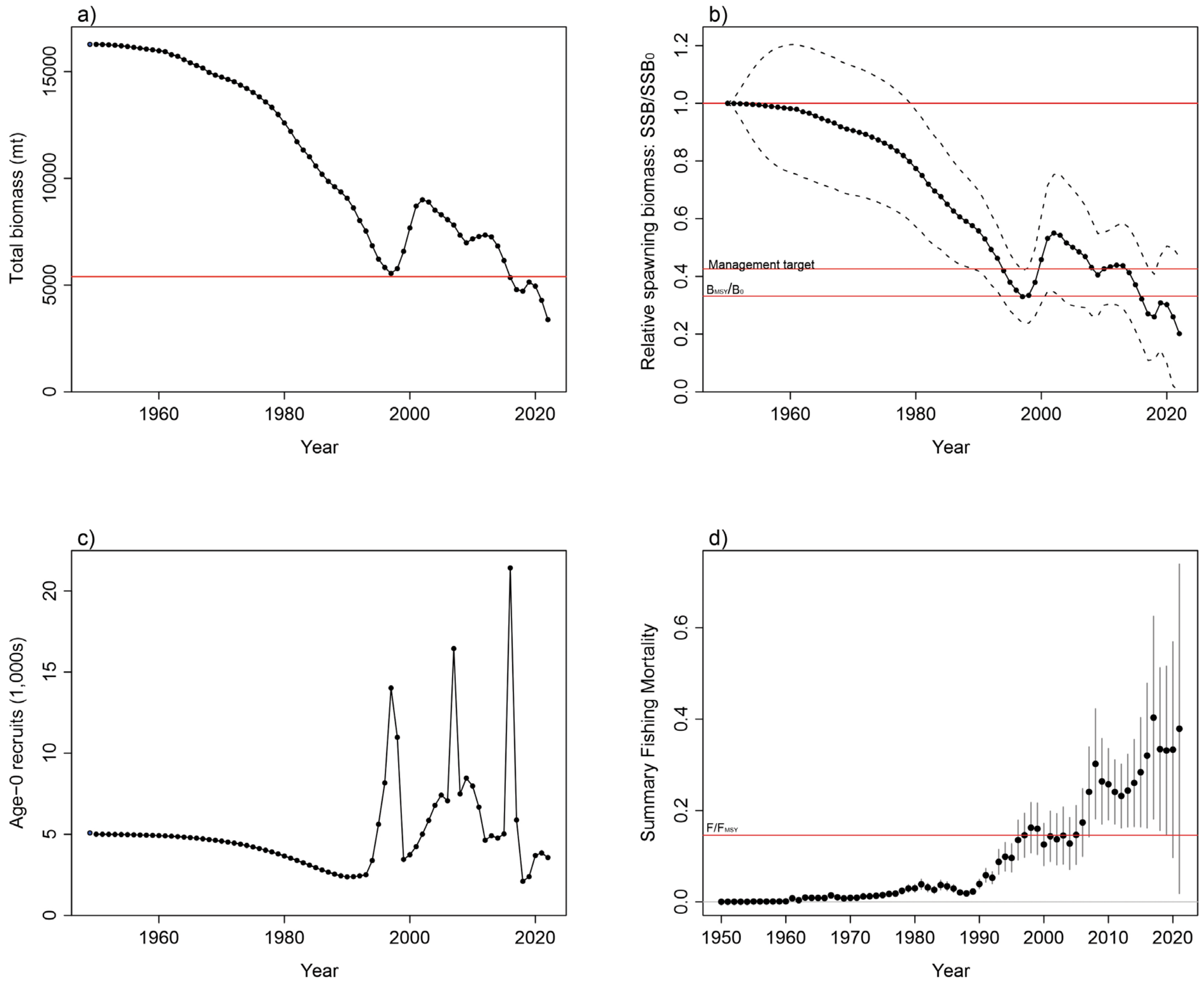

FIGURE 10 | Spawning stock biomass (SSB) (a), relative spawning biomass SSB/SSB$_0$ (red horizontal lines represent relative SSB at MSY and the management goal of 25% above MSY) (b), age-0 recruitment (c), and fishing mortality (red horizontal line represents fishing mortality at MSY) (d) estimated by the Stock Assessment Continuum Tool for *Lutjanus synagris* along the northeastern Brazilian coast during 1950–2021.

necessitates the use of simplified or assumed selectivity curves, which may introduce bias in model outputs if the true selectivity differs significantly from these assumptions (Hovgard and Lassen 2000; Cope 2024a). As a result, model estimates of fishery mortality, biomass, and stock status can be sensitive to assumptions, thereby underscoring the need for caution when interpreting results and for future efforts to improve empirical data on gear performance and size-at-capture (Chen et al. 2003; Hoshino et al. 2014). Thus, while SACT offers a comprehensive approach, the quality of output is influenced by the quality and breadth of available data (Cope 2024a). Our study also demonstrated the importance of incorporating sensitivity analyses to more accurately characterize uncertainty in model specifications (Tagliarolo et al. 2021).

Results of our assessment using the Stock Assessment Continuum Tool confirmed stock assessments of *L. analis*, *L. jocu*, and *L. synagris* as overfished and experiencing overfishing more than 20 years ago (Frédou et al. 2009a, 2009b). Previous assessments using traditional age-structured methods, Virtual Population Analysis (VPA), and Yield-Per-Recruit models indicated that *L. analis*, *L. jocu*, and *L. synagris* were overfished and subject to overfishing, whereas *O. chrysurus* was under significant exploitation pressure (Frédou et al. 2009a). Consistency among modeling approaches and assessment periods suggests a persistent pattern of overexploitation for these species that reinforces the need for management intervention. In contrast, our assessment of *O. chrysurus* stock status (not overfished and not undergoing overfishing) differed from the earlier assessment (overexploited), perhaps because more recent data used in our assessment, despite gaps and limitations, captured changes in fishing effort or stock recovery since the earlier assessment. Alternatively, methodological differences between the earlier assessment (Frédou et al. 2009a) and ours may have influenced how exploitation status was interpreted, particularly in the absence of fishery-independent data. Finally, shifts in fleet behavior, species targeting, or market dynamics may have altered fishing pressure on *O. chrysurus* relative to other species. This historical comparison supports the credibility of the current assessment while emphasizing the chronic nature of overfishing for most snapper stocks and highlighting the value of regular stock assessments using updated methods and data to track changes in exploitation status over time to guide the development of effective, adaptive management strategies.

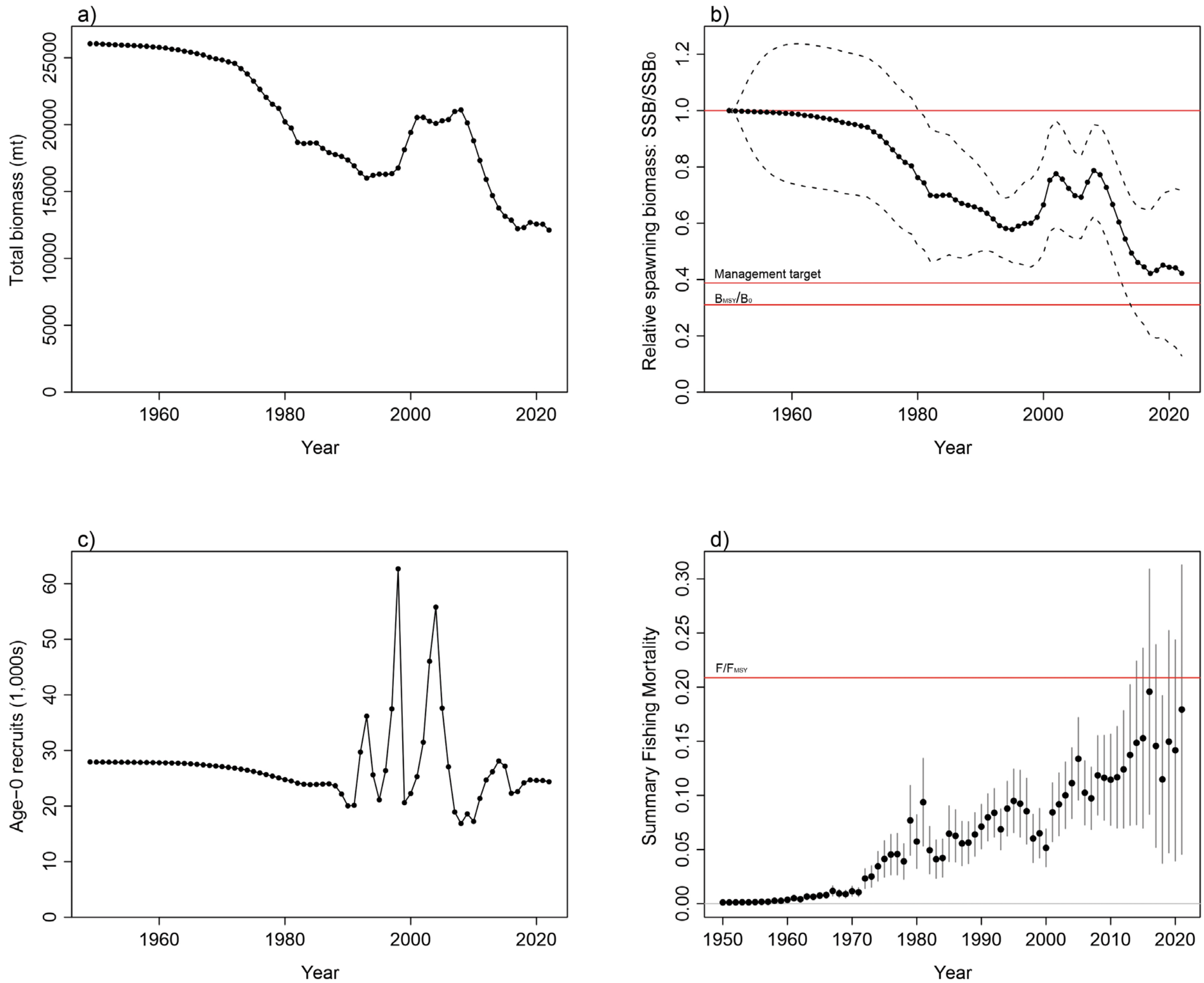

FIGURE 11 | Spawning stock biomass (SSB) (a), relative spawning biomass SSB/SSB_0 (red horizontal lines represent relative SSB at MSY and the management goal of 25% above MSY) (b), age-0 recruitment (c), and fishing mortality (red horizontal line represents fishing mortality at MSY) (d) estimated by the Stock Assessment Continuum Tool for *Ocyurus chrysurus* along the northeastern Brazilian coast during 1950–2021.

Table 2 highlights important contrasts in the exploitation status and fishing pressure across the four snapper species studied along the northeastern Brazilian coast. Notably, *Lutjanus analis* and *Lutjanus synagris* exhibited clear signs of overexploitation, characterized by spawning biomass levels below sustainable targets and fishing mortality rates substantially exceeding biological reference points. For *L. synagris*, these results closely align with findings from García-Caudillo et al. (2024) for the southern Gulf of Mexico, where the species was also found to be overfished, highlighting similar pressures across different parts of the species' range and reinforcing concerns about stocks' depletion. This combination indicates that these stocks are under significant stress from current fishing activities, and without effective management interventions, their recovery may be compromised. The situation calls for management measures such as closed seasons or closed fishing areas to alleviate fishing pressure and allow rebuilding of reproductive capacity (Shertzer et al. 2024). *Lutjanus jocu*, meanwhile, presents a relatively more moderate picture. Although its spawning biomass is somewhat depleted, fishing mortality is only slightly above sustainable levels. This suggests that while the stock is vulnerable, it may respond positively to management aimed at reducing fishing effort to avoid further depletion, as seen in other cases (SEDAR—Southeast Data, Assessment, and Review 2021; Bacheler et al. 2025), and continued monitoring will be critical to detect trends and ensure that exploitation remains within safe biological limits. In contrast, *Ocyurus chrysurus* stands out as currently underexploited, with spawning biomass above sustainable reference points and fishing mortality below the threshold associated with maximum sustainable yield. These patterns mirror those observed in García-Caudillo et al. (2024), where the species was also found to be in relatively healthy condition under a precautionary assessment framework. This relatively favorable status offers an opportunity to implement precautionary management practices that maintain stock productivity and prevent overfishing before it becomes a concern (FAO 1995; Fisheries and Oceans Canada 2009). In conclusion, managing snapper fisheries in the Northeast of Brazil requires a multifaceted approach that integrates ecosystem considerations, climate change adaptation, precautionary principles, and strong stakeholder involvement. The present assessment underscores the critical role of improved data collection to enhance the accuracy and reliability of stock assessments to support evidence-based management. Our assessment highlights the limitations imposed by inconsistent or missing data, particularly in later years of the assessed period, which limits

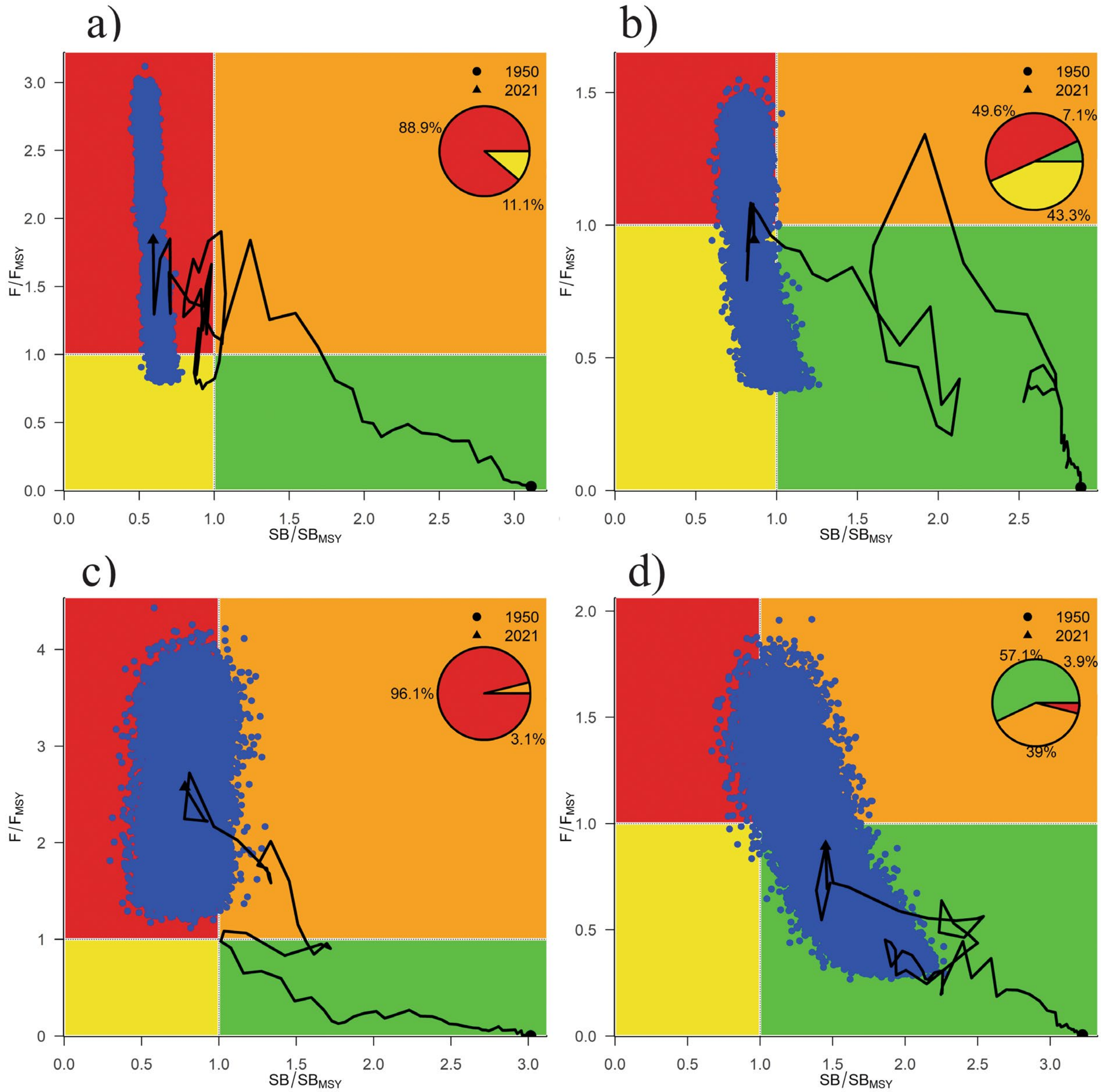

FIGURE 12 | Relative fishing mortality (F) in relation to relative spawning stock biomass (SSB) of (a) *Lutjanus analis*, (b) *Lutjanus jocu*, (c) *Lutjanus synagris*, and (d) *Ocyurus chrysurus* sampled along the northeastern Brazilian coast during 1950–2021. Red (top left) corresponds to "overfished and under overfishing"; green panel (bottom right) corresponds to "under no risk"; yellow (lower left) corresponds to "overfished"; and orange (upper right) corresponds to "under overfishing". Blue dots represent individual bootstrap runs for each combination of randomly sampled F and SSB. Pie charts indicate the probability of each species falling within each risk category.

detecting recent changes in fishing pressure, recruitment, and biomass. Establishing a systematic and continuous data collection program, including standardized catch records, biological sampling of length, age, and maturity, and fishery-independent surveys, is critical for reducing uncertainty in model estimates and strengthening the scientific basis of future assessments and the development of more responsive and precautionary management strategies (FAO 2005). Lack of a management response is a significant challenge in fisheries management in Northeast Brazil. Effective fisheries management requires integration of peer-reviewed science into decision-making processes, moving beyond academic stock assessments toward actionable management advice (Hilborn 2011). This highlights a need for more responsive and dynamic management that uses scientific data to foster collaboration among researchers, policymakers, and stakeholders. Strengthening the link between stock assessments and management actions through comprehensive and adaptive strategies will be crucial for ensuring the long-term sustainability of fish stocks and the communities that depend on them (Alcock 2004). Based on model results for *L. analis*, *L. jocu*, and *L. synagris*, these three fisheries are at risk if current fishing effort continues. This serves as an example of small-scale fisheries struggling due to neglect, with no consistent data collection or stock assessments. For *O. chrysurus*, although the fishery is currently at safe levels, increasing fishing pressure could lead to a precarious situation without proper management measures. Therefore, catch accounting, data collection, and accurate life-history estimates are needed to reduce uncertainty in results of stock assessments for these species, so we recommend these four species be prioritized for inclusion in future Brazilian fisheries management plans, including continuous on-site monitoring (i.e., recording landings and discards), control, and surveillance of the fisheries, along with continuous collection of biological samples, as well as for other species that share similar life-history traits or are associated with similar demersal fisheries on the Northeast coast. The protocol followed in this work, including life-history parameters estimation, stock assessment, and sensitivity analysis, can be replicated for other species of the Brazilian Northeast coast and elsewhere.

4.1 | Broader Management Implications

Management of snapper stocks in Northeast Brazil cannot be considered in isolation because fisheries are multispecies and of low selectivity (Lessa 2006; Lucena-Frédou et al. 2021). Gear used by these fisheries often captures multiple species, so management must be part of an interconnected system, rather than focusing on single-species stock assessments (Frédou et al. 2009b). This multispecies perspective aligns with the principles of Ecosystem-Based Fishery Management (EBFM), which advocates for a holistic approach that incorporates ecological relationships, such as predator–prey dynamics, habitat dependencies, and species interactions, into management plans (Garcia et al. 2003). The four assessments presented here enhance understanding of the status of snapper stocks in Northeast Brazil, where stock assessments and data-driven management are limited. Our results are intended to inform ongoing discussions within local fisheries co-management councils and governmental bodies, such as the Brazilian Ministry of Fisheries (MPA) and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), particularly as Brazil advances toward more structured and adaptive fishery management. Given the multispecies nature of these fisheries and data gaps in the region (MMA 2006; Lessa et al. 2004), this information can aid in prioritizing management actions, particularly when addressing data-poor fisheries. Currently, no harvest control rules or species-specific management plans exist for these stocks; hence, stock status information is essential for prioritizing management actions (Frédou et al. 2017; Silva et al. 2021, 2025). In the absence of data-rich assessments, our results can support the implementation of precautionary measures, including spatial or seasonal closures and participatory monitoring strategies. In addition to ecosystem complexities, climate change must be integrated into management strategies to ensure the long-term sustainability of snapper fisheries. Effects of climate change, such as ocean warming, changes in current patterns, and acidification are likely to alter fish distributions, reproductive cycles, and habitat suitability (Cheung et al. 2009; Petitgas et al. 2013; Sydeman et al. 2015). Such changes could exacerbate challenges already faced by multispecies fisheries, highlighting the need to incorporate climate-related variables into stock assessments and management plans (Vinther et al. 2004; Dolan et al. 2016). For instance, future management strategies could include adaptive measures that allow for flexible responses to shifting species distributions or altered ecosystem productivity to ensure management is still relevant under changing environmental conditions.

Our findings are relevant for future applications, such as Marine Spatial Planning (MSP) or Management Strategy Evaluation (MSE) frameworks tailored for the region. Adopting a precautionary approach within an adaptive management framework is crucial for addressing ecological and environmental uncertainties by promoting conservative catch limits and allowing for adjustments as new data become available to ensure management remains responsive to real-time ecosystem changes (Rodriguez-Perez et al. 2023). MSE can be valuable for enabling the testing of management strategies and, by simulating possible outcomes, it can identify the most effective strategies under conditions of uncertainty, as a key component of adaptive fisheries management in dynamic, data-poor fisheries (Butterworth 2007, 2008), like those in the Northeast of Brazil. However, effective fisheries management is not solely about ecological and environmental considerations but must also account for the socioeconomic realities of communities that depend on these resources (Garcia et al. 2003; Rodriguez-Perez et al. 2023). Snapper fisheries are vital to the livelihoods of many local fishers (Ivo and Sousa 1988; Resende et al. 2003; Frédou et al. 2009a), so management strategies need to balance ecological sustainability with socioeconomic well-being. Co-management practices that involve collaboration among government agencies, fishers, and local communities offer a pathway to achieving this balance. By involving stakeholders directly in decision-making, co-management can foster local stewardship, improve compliance with regulations, and ensure management is grounded in local knowledge and experience, while support for alternative livelihoods during closed seasons or stock recovery periods can help alleviate economic pressures on fishers to ensure short-term sacrifices lead to long-term benefits (Berkes 2009; Motta et al. 2002).

To integrate these considerations effectively, MSP and other management options like the Precautionary Approach (Dowling et al. 2019; Ono et al. 2019; Mildenberger et al. 2022) are valuable tools that can be employed. MSP facilitates the organization of ocean space to minimize conflicts and promote sustainable resource use by identifying and protecting critical habitats. A spatially explicit approach is particularly relevant for multispecies fisheries, such as snapper fisheries, by helping to safeguard essential fish habitats and optimize the allocation of ocean resources (Frédou et al. 2009b). By combining MSP with precautionary and adaptive management strategies, fisheries management in the Northeast of Brazil can become more resilient to environmental and socioeconomic changes by ultimately supporting the sustainability of fish stocks and reliant communities.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

References

Alcock, F. 2004. "The Institutional Dimensions of Fisheries Stock Assessments." *International Environmental Agreements* 4: 129–141. https://doi.org/10.1023/B:INEA.0000040416.45027.e4.

Alverson, D. L., and M. J. Carney. 1975. "A Graphic Review of the Growth and Decay of Population Cohorts." *ICES Journal of Marine Science* 36: 133–143.

Aragao, J. A. N. 2008. "Sistema de Geração de Dados Estatísticos da Pesca—ESTATPESCA: Manual Do Usuario." *Brasília: Ministério do Meio Ambiente* 1: 67.

Aragão, J. A. N., I. H. A. Cintra, K. C. D. A. Silva, et al. 2022. "Environmental Factors Associated With Southern Brown Shrimp (*Penaeus subtilis*) Yield at Brazilian Amazon Coast." *Ocean and Coastal Research* 70: e22020. https://doi.org/10.1590/2675-2824070.21102jana.

Bacheler, N. M., W. F. Patterson III, J. H. Tarnecki, et al. 2025. "Spatiotemporal Dynamics and Habitat Use of Red Snapper (*Lutjanus campechanus*) on the Southeastern United States Atlantic Continental Shelf." *Fisheries Research* 281: 107200. https://doi.org/10.1016/j.fishres.2024.107200.

Begossi, A., P. Lopes, and R. Silvano. 2012. "Co-Management of Reef Fisheries of the Snapper-Grouper Complex in a Human Ecological Context in Brazil." In *Global Progress in Ecosystem-Based Fisheries Management*. Alaska Sea Grant, University of Alaska Fairbanks.

Berkes, F. 2009. "Evolution of Co-Management: Role of Knowledge Generation, Bridging Organizations and Social Learning." *Journal of Environmental Management* 90, no. 5: 1692–1702. https://doi.org/10.1016/j.jenvman.2008.12.001.

Butterworth, D. S. 2007. "Why a Management Procedure Approach? Some Positives and Negatives." *ICES Journal of Marine Science* 64: 613–617.

Butterworth, D. S. 2008. "Some Lessons from Implementing Management Procedures." In *Fisheries for Global Welfare and Environment: Memorial Book of the 5th World Fisheries Congress 2008*, edited by K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard Jr., and M. J. Kaiser, 381–397. TERRAPUB.

Carvalho, F., H. Winker, D. Courtney, et al. 2021. "A Cookbook for Using Model Diagnostics in Integrated Stock Assessments." *Fisheries Research* 240: 105959.

CBD. 2014. "Ecologically or Biologically Significant Marine Areas (EBSAs)." Special Places in the World's Oceans.

Chen, Y., L. Chen, and K. I. Stergiou. 2003. "Impacts of Data Quantity on Fisheries Stock Assessment." *Aquatic Sciences* 65: 92–98. https://doi.org/10.1007/s000270300008.

Cheung, W. W. L., V. W. Y. Lam, J. L. Sarmiento, et al. 2009. "Projecting Global Marine Biodiversity Impacts Under Climate Change Scenarios." *Fish and Fisheries* 10: 235–251.

Chrysafi, A., and A. Kuparinen. 2015. "Assessing Abundance of Populations With Limited Data: Lessons Learned From Data-Poor Fisheries Stock Assessment." *Environmental Reviews* 24, no. 25: 38.

Chuenpagdee, R., and D. Pauly. 2005. *Slow Fish: Creating New Metaphors for Sustainability*. Implementation of International Fisheries Instruments and Factors of Unsustainability and Overexploitation in Fisheries.

Coleman, F. C., C. C. Koenig, G. R. Huntsman, et al. 2000. "Long-Lived Reef Fishes: The Grouper-Snapper Complex." *Fisheries* 25, no. 14: 21.

Cope, J. 2013. "Implementing a Statistical Catch-at-Age Model (Stock Synthesis) as a Tool for Deriving Overfishing Limits in Data-Limited Situations." *Fisheries Research* 142: 3–14.

Cope, J. 2024a. "The Good Practices of Practicable Alchemy in the Stock Assessment Continuum: Fundamentals and Principles of Analytical Methods to Support Science-Based Fisheries Management Under Data and Resource Limitations." *Fisheries Research* 270: 106859.

Cope, J. 2024b. "Stock Assessment Continuum Tool (Version 1.1.0)." [Computer software]. https://github.com/shcaba/SS-DL-tool.

Cope, J., N. A. Dowling, S. A. Hesp, et al. 2023. "The Stock Assessment Theory of Relativity: Deconstructing the Term "Data-Limited" Fisheries Into Components and Guiding Principles to Support the Science of Fisheries Management." *Reviews in Fish Biology and Fisheries* 33: 241–263.

Cope, J., and O. Hamel. 2022. "Upgrading From M version 0.2: An Application-Based Method for Practical Estimation, Evaluation and Uncertainty Characterization of Natural Mortality." *Fisheries Research* 256: 106493.

de Araújo, J. N., A. S. Martins, and K. G. da Costa. 2002. "Idade e Crescimento da Cioba, *Ocyururs chrysurus*, da Costa Central do Brasil." *Revista Brasileira de Oceanografia* 50, no. 47: 57.

de Barros, M. S. F., C. D. Lins de Oliveira, T. K. Pinto, et al. 2021. "Assessment of the Stock Status of Two Penaeid Shrimps in the Northeastern Brazil Marine Ecoregion and Implications for Their Management." *Regional Studies in Marine Science* 48: 102046.

Dolan, T. E., W. S. Patrick, and J. S. Link. 2016. "Delineating the Continuum of Marine Ecosystem-Based Management: A US Fisheries Reference Point Perspective." *ICES Journal of Marine Science* 73: 1042–1050. https://doi.org/10.1093/icesjms/fsv242.

Dos Santos, J. B. Q., C. M. Chiessi, S. Crivellari, et al. 2022. "Identification of Western South Atlantic Stocks of the Lane Snapper (*Lutjanus synagris*) From an Otolith Based Multi-Proxy Approach." *Fisheries Research* 253: 106356.

Dowling, N. A., A. D. M. Smith, D. C. Smith, et al. 2019. "Generic Solutions for Data-Limited Fishery Assessments Are Not So Simple." *Fish and Fisheries* 20: 174–188.

Duarte, L. O., and C. B. García. 1999. "Diet of the Mutton Snapper *Lutjanus analis* (Cuvier) From the Gulf of Salamanca, Colombia, Caribbean Sea." *Bulletin of Marine Science* 65: 453–465.

Eduardo, L. N., T. Frédou, A. S. Lira, et al. 2018. "Identifying Key Habitat and Spatial Patterns of Fish Biodiversity in the Tropical Brazilian Continental Shelf." *Continental Shelf Research* 166: 108–118.

FAO. 1995. *Precautionary Approach to Fisheries. Part 1: Guidelines on the Precautionary Approach to Capture Fisheries and Species Introductions*. FAO Fisheries Technical Paper No. 350, Part 1. Food and Agriculture Organization of the United Nations.

FAO. 2005. *The Use of Scientific Information in the Design of Management Strategies*. FAO Fisheries Technical Paper No. 424. Food and Agriculture Organization of the United Nations.

Ferreira, B. P., and M. Maida. 2007. "Características e Perspectivas Para o Manejo da Pesca na Area de Proteção Ambiental Marinha Costa dos Corais." In *Áreas Aquaticas Protegidas Como Instrumento de Gestão Pesqueira*, edited by D. Blanc, 41–51. Ministério do Meio Ambiente.

Ferreira, B. P., G. Olavo, and A. R. França. 2022. "Relatório-Síntese Do Projeto REPENSA/PESCA: Avaliação Ecossistêmica Dos Recursos Pesqueiros Demersais e Pelágicos Das Costas Norte e Nordeste: Subsídios Para o Ordenamento Pesqueiro Sustentável."

Fisheries and Oceans Canada. 2009. *A Fishery Decision-Making Framework Incorporating the Precautionary Approach*. Government of Canada. https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precaution-eng.htm.

França, A. R., G. Olavo, S. M. Rezende, et al. 2021. "Spatio-Temporal Distribution of Mutton Snapper and Dog Snapper Spawning Aggregations in the South-West Atlantic." *Aquatic Conservation: Marine and Freshwater Ecosystems* 31: 1596–1610.

Frédou, F. L., L. Kell, T. Frédou, et al. 2017. "Vulnerability of Teleosts Caught by the Pelagic Tuna Longline Fleets in South Atlantic and Western Indian Oceans." *Deep Sea Research* 140: 230–241. https://doi.org/10.1016/j.dsr2.2016.10.008.

Frédou, T. 2004. "The Fishing Activity on Coral Reefs and Adjacent Ecosystems. A Case Study of the Northeast of Brazil."

Frédou, T., B. P. Ferreira, and Y. Letourneur. 2009a. "Assessing the Stocks of the Primary Snappers Caught in Northeastern Brazilian Reef Systems. 1: Traditional Modeling Approaches." *Fisheries Research* 99: 90–96.

Frédou, T., B. P. Ferreira, and Y. Letourneur. 2009b. "Assessing the Stocks of the Primary Snappers Caught in Northeastern Brazilian Reef Systems. 2-A Multi-Fleet Age-Structured Approach." *Fisheries Research* 99: 97–105.

Freire, K. M. F., Z. d. S. de Almeida, J. R. E. T. Amador, et al. 2021. "Reconstruction of Marine Commercial Landings for the Brazilian Industrial and Artisanal Fisheries From 1950 to 2015." *Frontiers in Marine Science* 8: 659110.

Freitas, M. O., V. Abilhoa, and G. H. Costa e Silva. 2011. "Feeding Ecology of *Lutjanus analis* (Teleostei: Lutjanidae) From Abrolhos Bank, Eastern Brazil." *Neotropical Ichthyology* 9: 411–418. https://doi.org/10.1590/S1679-62252011005000022.

Garcia, S. M., A. Zerbi, C. Aliaume, et al. 2003. *The Ecosystem Approach to Fisheries*. Issues, Terminology, Principles. Institutional Foundations, Implementation and Outlook. Rome.

García-Caudillo, J. M., A. Balmori-Ramírez, and R. Morales-Azpeitia. 2024. "Análisis Poblacional y Estimación de Puntos de Referencia Para la Pesquería de Pargos (Perciformes:Lutjanidae) en el Golfo de México, 1980–2019." *Hidrobiológica* 34, no. 2: 121–131. https://doi.org/10.24275/NBVK4674.

Gedamke, T., and J. M. Hoenig. 2006. "Estimating Mortality From Mean Length Data in Nonequilibrium Situations, With Application to the Assessment of Goosefish." *Transactions of the American Fisheries Society* 135: 476–487. https://doi.org/10.1577/T05-153.1.

Grimes, C. B. 1987. "Reproductive Biology of the Lutjanidae: A Review." In *Tropical Snappers and Groupers: Biology and Fisheries Management*, edited by J. J. Polovina and S. Ralston, 239–294. Westview Press.

Hamel, O. S., and J. M. Cope. 2022. "Development and Considerations for Application of a Longevity-Based Prior for the Natural Mortality Rate." *Fisheries Research* 256: 106477.

Heyman, W. 2014. "Let Them Come to You: Reinventing Management of the Snapper-Grouper Complex in the Western Atlantic: A Contribution to the Data Poor Fisheries Management Symposium."

Hilborn, R. 2011. "Future Directions in Ecosystem Based Fisheries Management: A Personal Perspective." *Fisheries Research* 108, no. 2–3: 235–239. https://doi.org/10.1016/j.fishres.2010.12.030.

Hordyk, A., K. Ono, S. Valencia, et al. 2015. "A Novel Length-Based Empirical Estimation Method of Spawning Potential Ratio (SPR), and Tests of Its Performance, for Small-Scale, Data-Poor Fisheries ICES." *Journal of Marine Science* 72: 217–231.

Hoshino, E., E. J. Milner-Gulland, and R. M. Hillary. 2014. "Why Model Assumptions Matter for Natural Resource Management: Interactions Between Model Structure and Life Histories in Fishery Models." *Journal of Applied Ecology* 51: 632–641. https://doi.org/10.1111/1365-2664.12225.

Hovgard, H., and H. Lassen. 2000. *Manual on Estimation of Selectivity for Gillnet and Longline Gears in Abundance Surveys.* FAO Fisheries Technical Paper. No. 397. FAO 84 p.

Ivo, C. T. C., and M. J. B. Sousa. 1988. "Sinopse de Informações Sobre o Pargo, *Lutjanus purpureus* Poey (Pisces: Lutjanidae), no Norte e Nordeste do Brasil." *Arquivos de Ciências do Mar* 27: 57–67.

Klippel, S., G. Olavo, P. A. S. Costa, et al. 2005. "Avaliação dos Estoques de Lutjanídeos da Costa Central do Brasil: Análise de Coortes e Modelo Preditivo de Thompson e Bell Para Comprimentos." In *Pesca e Potenciais de Exploração de Recursos Vivos na Região Central da Zona Econômica Exclusiva Brasileira*, vol. 1, 1st ed., 83–98. Museu Nacional.

Lessa, R. P., J. L. Bezerra Júnior, and M. Nóbrega. 2004. "Recursos Pesqueiros na Região Nordeste." In *Dinâmica de Populações e Avaliação de Estoques Dos Recursos Pesqueiros Da Região Nordeste*, 158. Ministério do Meio Ambiente.

Lessa, R. P. T. 2006. "Recursos Pesqueiros da Região Nordeste." In *Avaliação Do Potencial Sustentável de Recursos Vivos Na Zona Econômica Exclusiva*, vol. 1, 1st ed., 159–190. Ministerio do Meio Ambiente.

Lucena-Frédou, F., L. N. Eduardo, A. S. Lira, et al. 2021. "Atividade Pesqueira Artesanal no Nordeste do Brasil." In *Ciências do Mar: Dos Oceanos do Mundo ao Nordeste do Brasil. Bioecologia, Pesca e Aquicultura*, vol. 2, 1st ed., 374–405. Via Design Publicações.

Methot, R. D., and C. R. Wetzel. 2013. "Stock Synthesis: A Biological and Statistical Framework for Fish Stock Assessment and Fishery Management." *Fisheries Research* 142: 86–99.

Mildenberger, T. K., C. W. Berg, A. Kokkalis, et al. 2022. "Implementing the Precautionary Approach Into Fisheries Management: Biomass Reference Points and Uncertainty Buffers." *Fish and Fisheries* 23: 73–92.

Mildenberger, T. K., M. H. Taylor, and M. Wolff. 2017. "TropFishR: An R Package for Fisheries Analysis With Length-Frequency Data." *Methods in Ecology and Evolution* 8: 1520–1527.

MMA. 2006. "Programa REVIZEE." In *Avaliação Do Potencial Sustentavel de Recursos Vivos Na Zona Economica Exclusiva*. Ministerio do Meio Ambiente.

Monteiro, D. P., T. Giarrizzo, and V. Isaac. 2009. "Feeding Ecology of Juvenile Dog Snapper *Lutjanus jocu* (Bloch and Shneider, 1801) (Lutjanidae) in Intertidal Mangrove Creeks in Curuçá Estuary (Northern Brazil)." *Brazilian Archives of Biology and Technology* 52: 1421–1430.

Motta, F. S., M. A. Freitas, F. A. Rolim, V. Abilhoa, and G. H. P. Filho. 2002. "Direct Evidence of a Spawning Aggregation of Cubera Snapper (*Lutjanus cyanopterus*) in Southeastern Brazil and Its Management Implications." *Fisheries Research* 252: 06399. https://doi.org/10.1016/j.fishres.2022.106339.

Olavo, G. 2004. "Caracterização da Pesca de Linha e Dinâmica das Frotas Linheiras da Bahia, Brasil." In *Pesca e Potenciais de Exploração de Recursos Vivos na Região Central da Zona Econômica Exclusiva Brasileira*, edited by P. A. S. Costa, A. S. Martins, and G. Oavo, vol. 13, 1st ed., 22. Museu Nacional.

Ono, K., Ø. Langangen, and N. C. Stenseth. 2019. "Improving Risk Assessments in Conservation Ecology." *Nature Communications* 10: 2836.

Peixoto, U. I., B. Bentes, H. A. Andrade, et al. 2021. "Length-Based Assessment of Southern Brown Shrimp Stock From Trawl Fisheries on the Amazon Continental Shelf." *Research, Society and Development* 10: e44410817394.

Petitgas, P., A. D. Rijnsdorp, M. Dickey-Collas, et al. 2013. "Impacts of Climate Change on the Complex Life Cycles of Fish." *Fisheries Oceanography* 22: 121–139.

Pons, M., J. M. Cope, and L. T. Kell. 2020. "Comparing Performance of Catch-Based and Length-Based Stock Assessment Methods in Data-Limited Fisheries." *Canadian Journal of Fisheries and Aquatic Sciences* 77: 1026–1037.

Previero, M., C. V. Minte-Vera, M. O. Freitas, et al. 2011. "Age and Growth of the Dog Snapper *Lutjanus jocu* (Bloch & Schneider, 1801) in Abrolhos Bank, Northeastern Brazil." *Neotropical Ichthyology* 9: 393–401.

Resende, S. M., B. P. Ferreira, and T. Frédou. 2003. "A Pesca de Lutjanídeos no Nordeste do Brasil: Histórico Das Pescarias, Características Das Espécies e Relevância Para o Manejo." *Bol Téc Cienc CEPENE* 11: 257–270.

Rodriguez-Perez, A., A. C. Tsikliras, G. Gal, J. Steenbeek, J. Falk-Andersson, and J. J. Heymans. 2023. "Using Ecosystem Models to Inform Ecosystem-Based Fisheries Management in Europe: A Review of the Policy Landscape and Related Stakeholder Needs." *Frontiers in Marine Science* 1: 119329. https://doi.org/10.3389/fmars.2023.1196329.

Rudd, M. B., J. M. Cope, C. R. Wetzel, et al. 2021. "Catch and Length Models in the Stock Synthesis Framework: Expanded Application to Data-Moderate Stocks." *Frontiers in Marine Science* 8: 663554. https://doi.org/10.3389/fmars.2021.663554.

Sainsbury, K. J., A. E. Punt, and A. D. M. Smith. 2000. "Design of Operational Management Strategies for Achieving Fishery Ecosystem Objectives." *ICES Journal of Marine Science* 57: 731–741.

Schärer-Umpierre, M. T., D. Mateos-Molina, R. Appeldoorn, et al. 2014. "Chapter Four—Marine Managed Areas and Associated Fisheries in the US Caribbean." In *Advances in Marine Biology*, edited by M. L. Johnson and J. Sandell, vol. 69, 129–152. Academic Press.

Schwamborn, R., M. O. Freitas, R. L. Moura, et al. 2023. "Comparing the Accuracy and Precision of Novel Bootstrapped Length-Frequency and Length-at-Age (Otolith) Analyses, With a Case Study of Lane Snapper (*Lutjanus synagris*) in the SW Atlantic." *Fisheries Research* 264: 106735.

Sea Around Us. 2024. https://www.seaaroundus.org/data/#/eez.

SEDAR—Southeast Data, Assessment, and Review. 2021. *SEDAR 73—South Atlantic Red Snapper Stock Assessment Report*. SEDAR. https://sedarweb.org/documents/sedar-73-stock-assessment-report-south-atlantic-red-snapper/.

Shertzer, K., S. Crosson, E. Williams, et al. 2024. "Fishery Management Strategies for Red Snapper in the Southeastern U.S. Atlantic: A Spatial Population Model to Compare Approaches." *North American Journal of Fisherise Management* 44: 113–131. https://doi.org/10.1002/nafm.10966.

Silva, M. L. S., H. A. Andrade, J. M. Cope, et al. 2025. "Length Reconstructions as an Alternative Approach to Data-Limited Fisheries." *Fisheries Research* 286: 107401. https://doi.org/10.1016/j.fishres.2025.107401.

Silva, M. R. O., M. G. Pennino, and P. F. M. Lopes. 2021. "Predicting Potential Compliance of Small-Scale Fishers in Brazil: The Need to Increase Trust to Achieve Fisheries Management Goals." *Journal of Environmental Management* 288: 112372. https://doi.org/10.1016/j.jenvman.2021.112372.

Spalding, M. D., H. E. Fox, G. R. Allen, et al. 2007. "Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas." *Bioscience* 57: 573–583.

Sydeman, W. J., E. Poloczanska, T. E. Reed, et al. 2015. "Climate Change and Marine Vertebrates." *Science* 350: 772–777.

Tagliarolo, M., J. Cope, and F. Blanchard. 2021. "Stock Assessment on Fishery-Dependent Data: Effect of Data Quality and Parametrisation for a Red Snapper Fishery." *Fisheries Management and Ecology* 28: 592–603.

Then, A. Y., J. M. Hoenig, N. G. Hall, et al. 2015. "Evaluating the Predictive Performance of Empirical Estimators of Natural Mortality Rate Using Information on Over 200 Fish Species." *ICES Journal of Marine Science* 72: 82–92.

Then, A. Y., J. M. Hoenig, and Q. C. Huynh. 2018. "Estimating Fishing and Natural Mortality Rates, and Catchability Coefficient, From a Series of Observations on Mean Length and Fishing Effort." *ICES Journal of Marine Science* 75: 610–620. https://doi.org/10.1093/icesjms/fsx177.

Thorson, J. T. 2020. "Predicting Recruitment Density Dependence and Intrinsic Growth Rate for All Fishes Worldwide Using a Data-Integrated Life-History Model." *Fish and Fisheries* 21: 237–251.

Thorson, J. T., S. B. Munch, J. M. Cope, et al. 2017. "Predicting Life History Parameters for All Fishes Worldwide." *Ecological Applications* 27: 2262–2276.

Vinther, M., S. A. Reeves, and K. R. Patterson. 2004. "From Single-Species Advice to Mixed-Species Management: Taking the Next Step." *ICES Journal of Marine Science* 61: 1398–1409. https://doi.org/10.1016/j.icesjms.2004.08.018.

Ximenes, M. O. C., and A. A. Fonteles-Filho. 1988. "Estudo da Idade e Crescimento do Pargo, *Lutjanus purpureus* Poey (Pisces: Lutjanidae), no Norte e Nordeste do Brasil." *Arquivos de Ciências do Mar* 27: 69–81.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** fme70008-sup-0001-AppendixS1.docx.