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ORIGINAL ARTICLE

Length-based stock assessment of Wahoo (*Acanthocybium solandri* Cuvier, 1832) in the Northern Oman Sea: alarming exploitation rates and urgent conservation measures

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Abstract
This study presents a length-based stock assessment of Wahoo (*Acanthocybium solandri*) in the northern Oman Sea, revealing critical overexploitation signals. Biological data from 415 Wahoo specimens collected between 2021 and 2024 in the northern Oman Sea were analyzed using bootstrapped ELEFAN approaches. The present study provides key growth and mortality parameters for Wahoo (*A. solandri*) in the Oman Sea (Iran), estimated using the bootstrapped ELEFAN_SA approach. The asymptotic length (L_∞) was 170 (range: 146–181cm), with a growth coefficient (K) of 0.26 yr^{-1} (range: 0.17–0.54yr^{-1}) and a theoretical age at zero length (t_0) of -0.72yr (range: 0.06–1.03yr). The growth performance index (Φ′) was 3.91 (range: 3.76–4.11), indicating consistent growth characteristics. The ensemble natural mortality rate, integrating estimates from nine independent methods, yielded a mean (±SD) of 0.35±0.13 $year^{-1}$ (95% CI: 0.27–0.43), while fishing mortality (F) was considerably higher at 1.20yr^{-1}, leading to a total mortality (Z) of 1.55±0.22yr^{-1}. The exploitation rate (E= F/Z) was 0.77, suggesting that the Wahoo population in this region is under fishing pressure, potentially nearing overexploitation. These findings highlight the need for improved fisheries management to ensure sustainable stock levels. The SPR, B/B0, B/BMSY and F/FMSY indices with uncertainty estimates calculated using bootstrap for Wahoo (*A. solandri*) in the northern Oman Sea 0.45 (95% CI: 0.35-0.55), 0.56(95% CI: 0.42-0.69), 1.10(95% CI: 0.90-1.30) and 3.42(95% CI: 2.82-4.01), respectively. The results indicate severe overexploitation, with an exploitation rate (E= 0.77) and F/FMSY ratio (3.42) significantly exceeding sustainable thresholds. Immediate management interventions—including fishing effort reduction, strengthened Monitoring, Control and Surveillance (MCS) systems, and implementation of ecosystem-based fisheries management (EBFM)—are urgently required to comply with global sustainability targets, particularly SDG 14.4. Proactive measures are essential to restore the stock, safeguard marine biodiversity, and ensure the long-term viability of fisheries-dependent communities in the region. This assessment establishes the first comprehensive baseline for Wahoo management in the northern Oman Sea, demonstrating the efficacy of length-based methods for data-poor fisheries while underscoring the necessity of regional cooperation to facilitate species recovery.

Keywords: *Acanthocybium solandri*, Length-based stock assessment, Oman Sea, Overexploitation,Sustainable fisheries management

INTRODUCTION

Global fisheries are confronting severe sustainability challenges, with the proportion of biologically sustainable fish stocks declining from 90% in 1974 to 67% in 2022, driven by overexploitation, habitat degradation, and climate change (FAO 2024). Emerging projections (Sharma et al. 2025) indicate that nearly one-third of global fish stocks are now overfished, signaling a persistent decline in sustainable fisheries. This crisis is particularly acute in tropical regions such as the Oman Sea, where weak governance frameworks exacerbate stock depletion. Urgent interventions—including enhanced monitoring, control, and surveillance (MCS), combating illegal, unreported, and unregulated (IUU) fishing, and adopting ecosystem-based fisheries management (EBFM)—are essential to meet UN Sustainable Development Goal (SDG) 14.4, which targets the restoration of overfished stocks to maximum sustainable yield (MSY) levels by 2030.

Data-limited assessment methods have become increasingly vital for sustainable fisheries management, particularly in regions where conventional stock assessments are constrained by insufficient biological or catch data. These approaches provide practical solutions for evaluating fish stocks when comprehensive datasets are unavailable, enabling managers to make informed decisions

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despite information gaps (Prince et al. 2015). Techniques such as catch-only models offer reliable alternatives for assessing stock status, especially for bycatch species or small-scale fisheries in developing nations. By incorporating life history parameters, environmental factors, and limited catch data, these methods help establish biological reference points and evaluate exploitation levels. Their flexibility allows application across diverse ecosystems, from coastal fisheries to large pelagic stocks, making them essential tools for preventing overfishing and promoting ecosystem-based management in data-poor scenarios. This approach is particularly relevant for emerging fisheries or regions with limited monitoring capacity, where traditional assessment methods would be impractical or cost-prohibitive to implement (Dowling et al. 2019; Kindong et al. 2022).

The Oman Sea, a semi-enclosed marginal sea of the Indian Ocean, is one of Iran's most vital marine ecosystems, extending from the Strait of Hormuz to the Pakistan border. Covering approximately 181,000 km² with depths exceeding 3,500 meters, it supports exceptional marine biodiversity (AminRad 2018; Taghvimotlagh et al. 2006). However, the region faces serious threats from overfishing, illegal fishing, and climate change. Urgent action is needed, including ecosystem-based management, expansion of marine protected areas, and stronger cross-border cooperation. Preserving this ecosystem is essential for local food security and its strategic role as a key maritime corridor. Sustainable management that balances economic use with environmental conservation is critical for regional stability and ecological integrity (Taghvimotlagh et al. 2006; AminRad 2018). Based on the study "Fishes of the Sea of Oman" (Eagderi et al. 2026), this marine basin covers approximately 181,000km² with depths exceeding 3,500 meters and supports high biodiversity. A total of 1,047 fish species (947 bony fishes and 100 sharks and rays) has been identified, of which 86 species are recorded for the first time in this sea. The order Acanthuriformes (225 species) and the family Carangidae (57 species) are the most diverse. Regarding IUCN conservation status, 747 species are of Least Concern, 43 are Vulnerable, 26 are Endangered, and 21 are Critically Endangered.

The Wahoo (*Acanthocybium solandri*) is a fast-growing pelagic species from the Scombridae family, widely distributed in tropical and subtropical oceans. It can reach up to 2.5 meters in length and over 80 kg in weight, with swimming speeds up to 97km/h, making it a prized target for sport fishers. Although often confused with king mackerel, it can be distinguished by its sleeker body and distinct markings. Commonly caught as bycatch in commercial fisheries, it is also targeted recreationally. Females grow larger than males, with a female-biased sex ratio. Spawning seasons vary regionally (winter in the Eastern Atlantic, summer elsewhere). Sexual maturity occurs early, with females maturing at about 90 cm fork length, typically within one year (Zischke et al. 2013; Kindong et al. 2022; Collette & Nauen 1983; Froese & Pauly 2024). According to the checklist "Fishes of the Sea of Oman" (Eagderi et al. 2026), *Acanthocybium solandri*, commonly known as the Wahoo, is a member of the family Scombridae and has been recorded in the Sea of Oman, with its occurrence in Iranian waters previously reported by Psomadakis et al. (2015). The species is classified by the IUCN as Least Concern (LC) and has a circumglobal distribution in tropical and warm temperate seas, including the Caribbean Sea and the Mediterranean Sea. Ecologically, the Wahoo is an oceanic, epipelagic species that is typically found either solitary or in small, loose aggregations, feeding on fishes and cephalopods, while its eggs and larvae are also pelagic.

Management of wahoo fisheries is complicated by limited biological data, especially in less-studied regions like the in the northern Oman Sea. Recent research highlights the importance of using multiple assessment methods to accurately estimate key population parameters. For example, the ELEFAN-Bootstrap approach has proven effective for growth analysis, while length-based methods like LBSPR provide valuable stock status indicators (Zischke et al. 2013; Kindong et al. 2022).

Although multiple studies have investigated biological and ecological aspects of Wahoo species (Hogarth 1976; Kishore & Chin 2001; Lee 2008; McBride et al. 2008; Zischke et al. 2013; Kindong et al. 2022), comprehensive stock assessment research in the northern Oman Sea remains absent. The Wahoo fishery in the northern Oman Sea exemplifies these global challenges, where overexploitation and lack of regional management threaten its sustainability. Current stock assessment challenges stem from data limitations, particularly in understudied regions. Modern analytical approaches, including integrated length-frequency analyses and Bayesian biomass estimation methods, have improved assessment accuracy. This study aimed to assess the stock status of wahoo (*A. solandri*) in the northern Oman Sea using length-based methods. By analyzing growth, mortality, and exploitation rates, we sought to evaluate the sustainability of current fishing practices and provide science-based recommendations for fisheries management to prevent overexploitation and support long-term resource conservation.

MATERIAL AND METHODS

Population dynamics parameters and exploitation ratio of Wahoo were studied from August 2021 to February 2024 and data were collected from three landing sites: Konark, Pozem, and Gowatar. Three fishing places in the ports of Pasabandar (61˚30´E, 24˚44´N), Pozm (60˚28´E, 25˚14´N) and Konarak (60˚28´E, 25˚60´N) were chosen for the sampling of *A.solandri* in the northern Oman Sea (Iran) (Fig. 1).

From March 2021 to March 2024, Wahoo landings at Gwarat, Pozem, and Konarak ports were systematically monitored. Random samples were collected from the catches landed at these fishing harbors for further analysis. Each sampled Wahoo underwent biometric assessment, with Fork length (FL) measured to the nearest 1mm precision using a calibrated ruler.

Growth Studies: Asymptotic length (L∞, cm FL) and growth rate (K) were estimated using the Electronic Length Frequency Analysis (ELEFAN) technique, implemented in the TropFishR package (Mildenberger et al. 2017)with uncertainty addressed

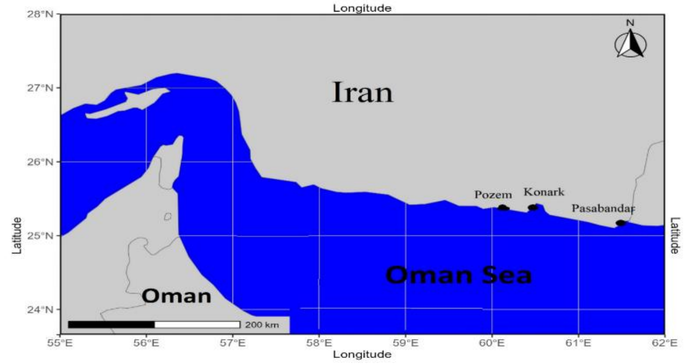

Fig.1. Map shows the area of Wahoo (*Acanthocybium solandri*) sampling sites in the northern Oman Sea (Iran).

via 1,000 bootstrap iterations. The Pauly empirical equation (Froese & Binohlan 2000) was applied to calculate the theoretical age at zero length (t_0) using the formula:

1) t_0 $(\text{Log}(-t_0) = -0.3922 - 0.2752\ \text{Log}\ L_\infty - 1.038\ \text{Log}\ K)$

To compare growth performance across species, the growth performance index (Φ′) was computed as:

2) $\Phi' = \text{Log}(K) + 2\ \text{Log}(L_\infty)$

The growth parameter estimation incorporated robust statistical approaches to enhance result reliability. Bootstrap resampling techniques (Schwamborn et al. 2018; 2019) were implemented to strengthen the precision of L∞ and K estimates. Advanced analytical procedures from the fishboot package were utilized, including two distinct computational approaches: 1) the ELEFAN_GA method employing genetic algorithm optimization, and 2) the ELEFAN_SA technique based on simulated annealing principles (Schwamborn et al. 2018; 2019). These sophisticated analytical frameworks enabled comprehensive examination of length-frequency distributions while simultaneously evaluating parameter estimation uncertainties. Parameter space was carefully delineated based on biological plausibility, with growth coefficients (K) restricted to 0.1-0.8 per annum and maximum length parameters (L∞) bounded between 140-180cm FL. These biologically meaningful constraints were derived from systematic evaluation of contemporary research on wahoo population dynamics (Kindong et al. 2020, 2022), ensuring the ecological validity of model outputs while maintaining statistical rigor.

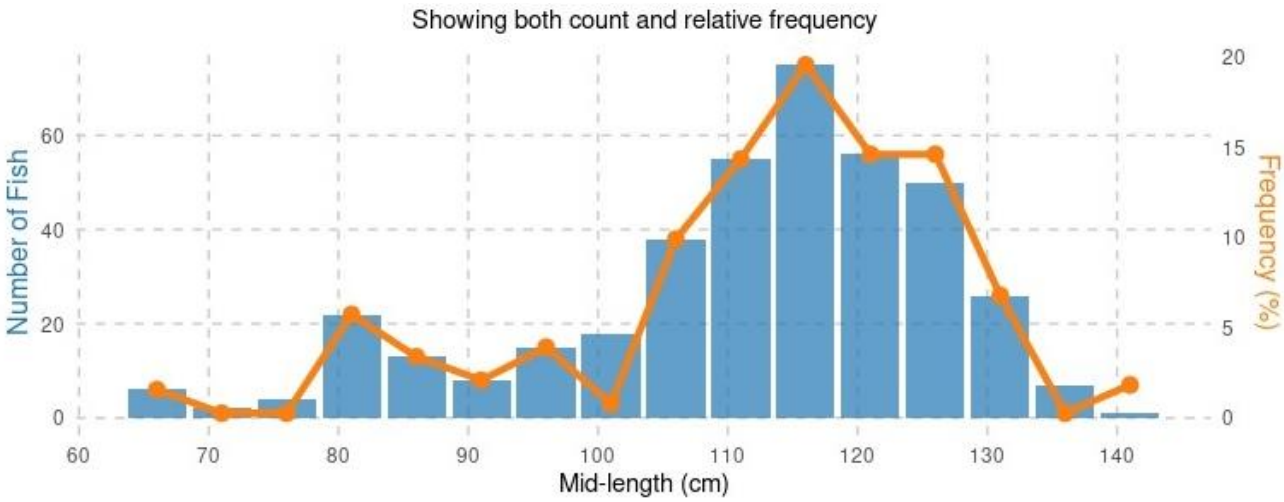

Fig.2. The length frequency data of Wahoo (*Acanthocybium solandri*) in the northern Oman Sea.

Ensemble-based natural mortality (M) estimation: We employed a multi-model ensemble approach to estimate natural mortality (M), combining nine established methods (Gislason et al. (2010), Chen & Watanabe (1989), Brodziak et al. (2011), Pauly (1980), Alverson & Carney (1975), two variants from Then et al. (2014), and Hewitt & Hoenig (2005) and Hoenig (1983) to account for methodological uncertainty. Each method's point estimate was converted into a distribution by simulating 1,000 log-normal random samples (SDlog= 0.25) to reflect inherent variability (Karp et al. 2022). The ensemble estimate was derived as the arithmetic mean of all simulated values, providing a robust, integrated estimate with quantified uncertainty (SD and 95% CI). This approach mitigates reliance on any single method and better captures the true range of plausible M values for stock assessment. The ensemble mortality estimate ($M_{ensemble}$) was calculated by combining simulations from k different methods: where Msim, j is the j-th log-normal random sample from method i, with σ=0.25representing methodological uncertainty (Dietterich 2000).

$$3)\quad Mensemble = \frac{1}{N.k}\sum_{i=1}^{K}\sum_{j=1}^{N} Msim(j)$$

Total mortality (Z) was derived from length-converted catch curve analysis. Fishing mortality (F) was then calculated as: F= Z−M. The exploitation rate (E), defined as the proportion of fishing mortality relative to total mortality (Sparre & Venema 1998), was computed as: E=F/Z. Additionally, the maximum lifespan of the fish (*tmax*) was estimated following Froese & Pauly (2017) using the equation: $t_{max}=t_0+K3$.

Determination of Maturity Length (Lmat = L50): Maturity length (Lmat= L_{50}) was estimated from asymptotic length ($L\infty$) using the empirical formula (Froese & Binohlan 2000):

$$(4)\quad \log(L_{50}) = 0.8979\times\log(L\infty) - 0.0782$$

***Length-based spawning potential ratio (LB-SPR)* model:** There is a need for several bio-factors related to WHA species to estimate the LB-SPR, including L (asymptotic length calculated using the growth curve of von Bertalannfy), M/K (M= instantaneous natural mortality rate; K= the growth coefficient of von Bertalannfy), L_{95} (lengths at 95% maturity) and L_{50} (lengths at 50% maturity). Size at 50% and 95% maturity were considered as 85 and 90cm, respectively. The WHA species asymptotic growth averages the highest size of 65cm according to the Lm/L∞ value of 0.51. The specific estimated parameters SL50, SL95, F/M ratio and SPR by year are presented in Figure 3. According to 95% confidence intervals (95%CI) regarding SPR estimates, the estimates of relative fishing pressure and selectivity are presented below. Most SPR values were estimated in different years to be below 0.40 which is the proxy for B_{MSY}. This population might be experiencing overfishing based on these results. Key experimental references established empirical relationships between B/B0, B/BMSY, F/FMSY, and

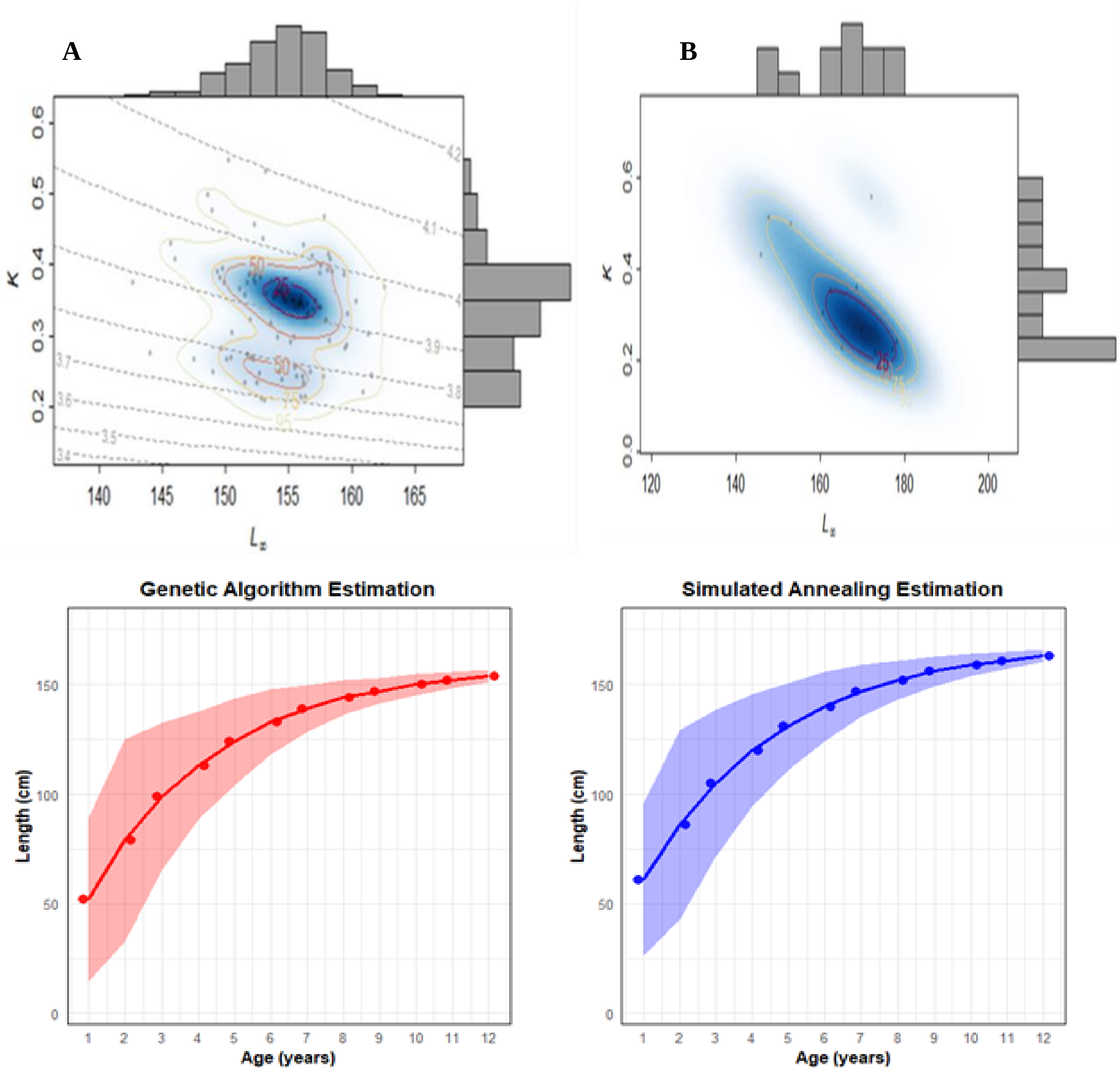

Fig.3. Growth curve (A= bootstrapped ELEFAN_GA, B= bootstrapped ELEFAN_SA) derived from frequency data of Wahoo (*Acanthocybium solandri*) length in the northern Oman Sea.

spawning potential ratio (SPR) in fish stock assessment (Froese et al. 2019; ICES, 2021). These relationships were defined as: FMSY = M (natural mortality rate), B/B_0 = SPR/0.8, and B/B_0= 0.5 × B/BMSY.

Statistical analysis: To quantify uncertainty, mean values and corresponding confidence bounds were calculated across all bootstrap iterations. For this species, 1,000 bootstrap samples were generated by resampling the original dataset with replacement (DiCiccio & Efron 1996). The TropFishR, data-limited, forecast, fish boot packages and R (4.2.0) software (R Core Team. 2022), and R studio (2024.12.1) were used to analyze the data. Normality of the data was assessed using the Kolmogorov–Smirnov test, and a significance level of 0.05 was adopted. To compare population dynamic values between male and female lengths the student's t-test, including both paired and independent versions, was employed.

RESULTS

During the study period, we analyzed 415 Wahoo specimens in the laboratory. The Fork length (FL) and total weight (TW) ranged from 66–140 cm and 2375-15000 gr, the average Fork length (±SD) and average

Table 1. Contrast of biological characteristics of Wahoo (*A. solandri*) with other studies.

Method	L∞ (cm FL)	K (yr^{-1})	t_o (yr^{-1})	Φ'	AIC	BIC
bootstrapped ELEFAN_GA	158 (147-161)	0.29 (0.2-0.46)	-0.4 (0.15-0.62)	3.91 (3.71-4.04)	125	126
bootstrapped ELEFAN_SA	170 (146-181)	0.26 (0.17-0.54)	-0.72 (0.06-1.03)	3.91 (3.76-4.11)	103	104

total weight (±SD) for Wahoo was 113±11 and 9444±2333, respectively (Fig. 2).

The present study provides key growth and mortality parameters for Wahoo (*Acanthocybium solandri*) in the northern Oman Sea (Iran), estimated using the bootstrapped ELEFAN_SA approach (Table1). The asymptotic length (L∞) was 170cm FL (range: 146–181cm), with a growth coefficient (K) of 0.26yr^{-1} (range: 0.17–0.54yr^{-1}) and a theoretical age at zero length (t_0) of -0.72yr (range: 0.06–1.03yr). The growth performance index (Φ′) was 3.91 (range: 3.76–4.11), indicating consistent growth characteristics. The natural mortality rate (M) was 0.35±0.13yr^{-1}, while fishing mortality (F) was considerably higher at 1.20 yr^{-1}, leading to a total mortality (Z) of 1.55±0.22 yr^{-1}. The exploitation rate (E= F/Z) was 0.77, suggesting that the Wahoo population in this region is under fishing pressure, potentially nearing overexploitation. These findings highlight the need for improved fisheries management to ensure sustainable stock levels (Table 2).

The comparison between the bootstrapped ELEFAN_GA and ELEFAN_SA methods for estimating the growth parameters of Wahoo (*Acanthocybium solandri*) reveals notable differences in their results. The ELEFAN_GA method estimated a lower asymptotic length (L∞= 158cm, range: 147–161mm) compared to ELEFAN_SA (L∞= 170cm, range: 146–181mm), suggesting potential variability in length predictions. The growth coefficient (K) was slightly higher in ELEFAN_GA (0.29yr^{-1}) than in ELEFAN_SA (0.26yr^{-1}), indicating faster growth under the GA approach. Both methods produced similar growth performance indices (Φ′≈ 3.91), though ELEFAN_SA showed a wider range (3.76–4.11). The AIC and BIC values were lower for ELEFAN_SA (103 and 104, respectively) compared to ELEFAN_GA (125 and 126), suggesting better model fit and parsimony with the simulated annealing (SA) approach. However, the broader confidence intervals for SA's parameters (e.g., t_0) may reflect higher uncertainty (Fig. 3 and Table. 1). The lower AIC and BIC values for ELEFAN_SA suggest its superior fit, though the wider confidence intervals indicate higher uncertainty in parameter estimates compared to ELEFAN_GA. Overall, while ELEFAN_SA appears statistically preferable, further validation is needed to assess biological plausibility (Fig.3).

The Table 2 presents various methods and equations used to estimate natural mortality (M) for a fish species, along with their corresponding mean values and 95% confidence intervals (95% CI). The ensemble natural mortality rate (Mensemble), integrating estimates from nine independent methods, yielded a mean (±SD) of 0.35±0.13 $year^{-1}$ (95% CI: 0.27–0.43). Individual methods produced estimates ranging from 0.13 (Brodziak et al. 2011) to 0.52 $year^{-1}$ (Then et al. 2014 v1), reflecting methodological divergence. The ensemble means closely aligned with the central tendency of constituent methods (median: 0.36; overlapping CIs of Hoenig 1983, Chen & Watanabe 1989; Hewitt & Hoenig 2005,), while its broader uncertainty interval (SD= 0.13 vs. method-specific SDs of 0.03–0.13) captured cross-method variability. This synthesis suggests that the true M for this stock likely falls within 0.27–0.43 yr^{-1}, with the ensemble providing a more robust estimate than any single method alone (Fig. 4).

LB-SPR model: Last year, biometric measurements were used to estimate the life history parameters of Wahoo (*A.solandri*). The size at 50% and 95% (1.1

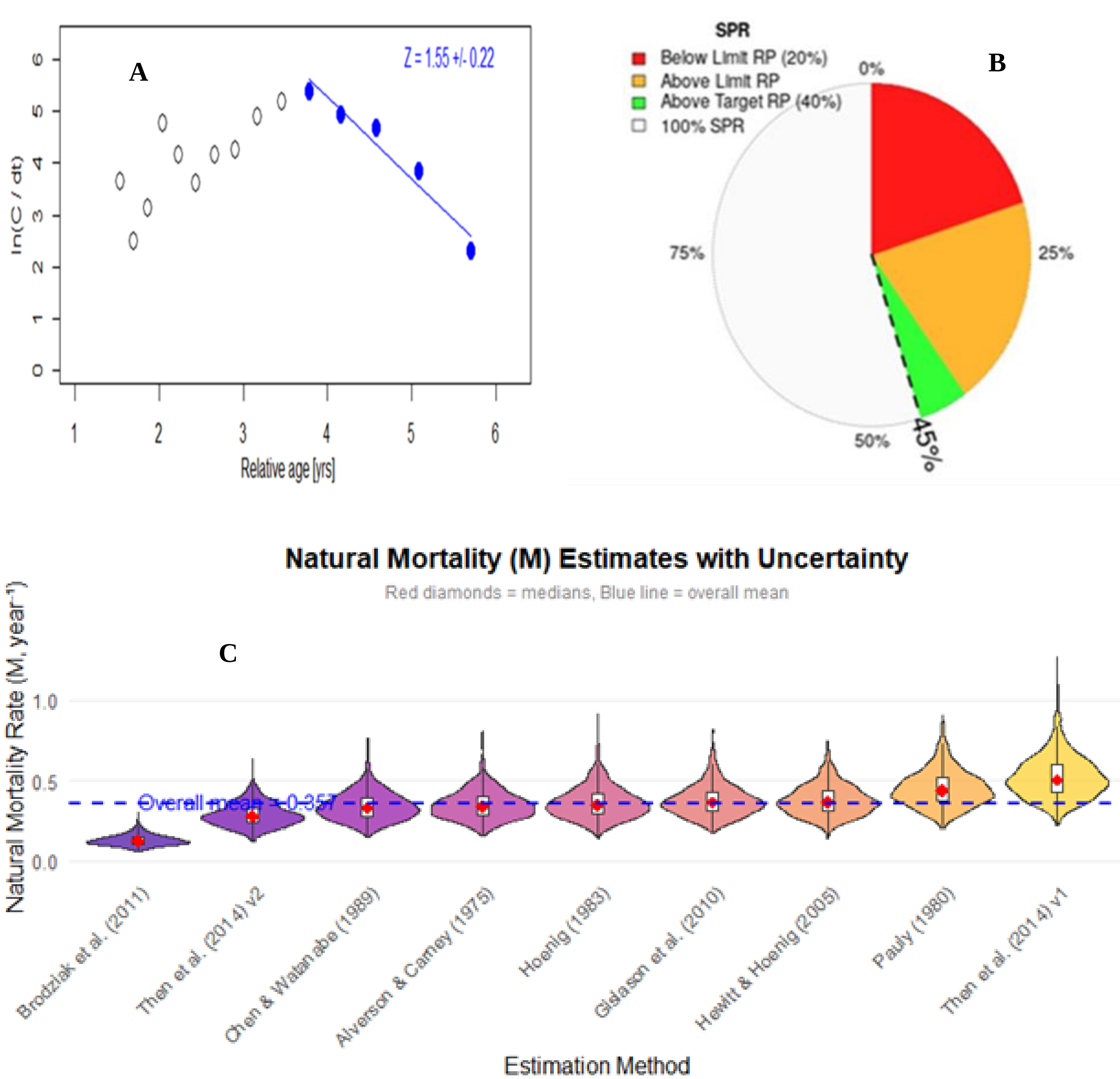

Fig.4. Exploitation coefficient curve (A), output of LBSPR model (B) and Ensemble Natural Mortality (M) methods(C) of Wahoo (*Acanthocybium solandri*) in the northern Oman Sea.

size at 50%) maturity was determined to be 84cm and 92cm, respectively. Based on the ratio of L_m/L_∞= 0.49, the asymptotic growth (L_∞) for this species was estimated at 170 cm, representing the maximum theoretical size. Current fishing pressure is alarmingly high, with F/M>2.5, exceeding the level associated with maximum sustainable yield (MSY; F/M=1.0). The spawning potential ratio (SPR) of the population is estimated at approximately 45%, indicating full exploitation. The 95% confidence intervals (95% CI) for SPR estimates suggest that relative fishing pressure and selectivity have remained high across multiple years. Most SPR values were consistently below 0.40, the commonly used proxy for BMSY (biomass at MSY).

These findings indicate that the Wahoo population is likely experiencing overfishing, necessitating immediate management interventions to ensure sustainable harvest levels. The SPR, B/B0, B/BMSY and F/FMSY indices with uncertainty estimates calculated using bootstrap for Wahoo (*A. solandri*) in the northern Oman Sea 0.45 (95% CI: 0.35-0.55), 0.56(95% CI: 0.42-0.69), 1.10(95% CI: 0.90-1.30) and 3.42(95% CI: 2.82-4.01), respectively (Fig. 5).

Table 2. Natural mortality (M) methods and equations used. L∞ (170cm FL), K (0.26) and t_0 (-0.72) are von Bertalanffy growth function parameters, Tmax (12) is the maximum observed age. L50 (84cm FL) is length at first maturation, L (113cm FL) is the observed length mean, T is temperature (˚C), and t is age. In this study, the temperature was T= 26°C.

References	Equations for M	Mean (95% Cl)
Gislason et al. (2010)	M= exp (0.55-1.61×log (current length)+1.44×log (Linf)+log(K))	0.37±0.09 (0.31-0.42)
Chen & Watanabe (1989)	M= K/(1-exp (-K×(tmax/2-0)))	0.34±0.08 (0.28-0.39)
Brodziak et al. (2011)	M= K×(L50/Linf)	0.13±0.03 (0.10-0.15)
Pauly (1980)	M= exp (-0.0152-0.279×log (Linf)+0.6543×log (K)+ 0.4634×log(temp))	0.45±0.11 (0.37-0.51)
Alverson & Carney (1975)	M= (3×K)/(exp (0.38×tmax×K)-1)	0.35±0.09 (0.28-0.42)
Then et al. (2014)	M_then1= 4.899×tmax$^{(-0.916)}$	0.52±0.13 (0.43-0.60)
Then et al. (2014)	M_then2= 4.118×K$^{0.73}$×Linf $^{(-0.33)}$	0.28±0.07 (0.23-0.33)
Hewitt & Hoenig (2005)	M= exp (1.44-0.982×log(tmax))	0.38±0.09 (0.37-0.51)
Hoenig (1983)	M= exp (1.46-1.01×log(tmax))	0.36±0.09 (0.29-0.42)
-	Ensemble M (Mensemble)	0.35±0.13 (0.27-0.43)

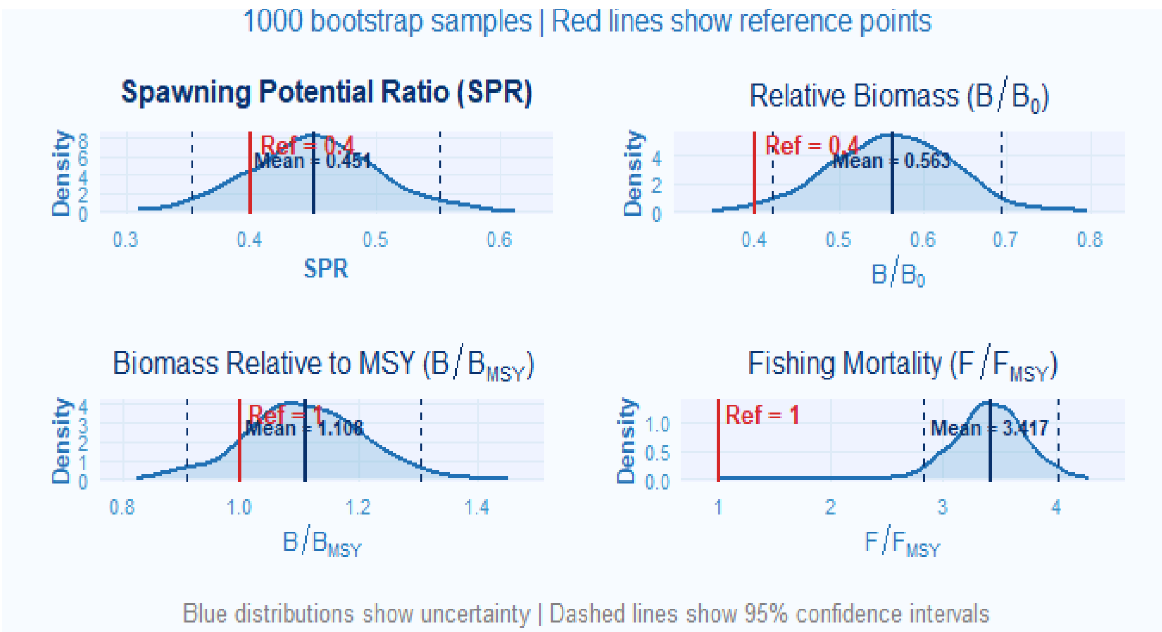

Fig.5. The SPR, B/B_0, B/BMSY and F/FMSY indices for Wahoo (*Acanthocybium solandri*) in the northern Oman Sea, with associated uncertainties estimated by non-parametric bootstrapping (1000 replicates).

DISCUSSION

The AIC and BIC values were lower for ELEFAN_SA compared to ELEFAN_GA, suggesting better model fit and parsimony with the simulated annealing (SA) approach. The bootstrapped ELEFAN approach, to estimate life history parameters for data-limited fisheries like the wahoo (*A. solandri*) in the Tropical Eastern Atlantic Ocean. The Bootstrap ELEFAN method is a powerful tool for estimating growth parameters in data-limited fisheries, as it incorporates uncertainty into the analysis through resampling techniques. By applying bootstrapping, this method provides confidence intervals for key parameters like asymptotic length (L∞) and growth rate (K), enhancing the reliability of the results. This approach is particularly valuable for species such as wahoo, where traditional aging methods (e.g., otolith analysis) may be impractical or unavailable. The Bootstrap ELEFAN method also allows for model comparison using criteria like AIC and BIC, ensuring that the best-fitting growth model is selected. Its ability to handle limited and noisy length-frequency data makes it indispensable for fisheries assessments in regions where comprehensive data collection is challenging

Table 3. Contrast of biological characteristics of Wahoo (*Acanthocybium solandri*) with other studies (LF= length frequency, OT= Otoliths).

References	Region	Method	L∞ (cm)	K (yr^{-1})	t_o (yr^{-1})	tmax (yr)	Φ′	M (yr^{-1})	F (yr^{-1})	Z (yr^{-1})	E
Hogarth (1976)	West Central Atlantic	OT	215	0.15	-3.67	4	3.21	-	-	-	-
Kishore & Chin (2001)	West Central Atlantic	OT	153	0.34	-1.54	10	3.76	-	-	-	-
Lee (2008)	waters off eastern Taiwan	OT	156	0.24	-1.63	9	3.43	-	-	-	-
McBride et al. (2008)	Northwest Atlantic	OT	170	0.38	-1.63	9	4.04	-	-	-	-
Zischke et al. (2013)	Coral Sea off eastern Australia	OT	149	1.58	-0.17	7	4.55	-	-	-	-
Kindong et al. (2022)	Tropical Eastern Atlantic	LF	161	0.47	-0.64	12.1	3.97	0.36	0.39	0.75	0.52
Present study	Oman Sea (Iran)	LF	170	0.26	-0.72	11.5	3.91	0.35±0.13	1.20	1.55±0.22	0.77

(Schwamborn et al. 2018, 2019; Mildenberger et al. 2017). The comparative analysis of Wahoo (*Acanthocybium solandri*) populations across different regions reveals significant variations in growth and mortality parameters. While Zischke et al. (2013) reported the highest growth coefficient (K= 1.58 yr^{-1}) in the Coral Sea, indicating rapid growth, studies from the West Central Atlantic showed much slower growth rates (K= 0.15–0.34 yr^{-1}). The present study in the Oman Sea estimated an asymptotic length ($L\infty$= 170cm FL) and a moderate growth rate (K= 0.26yr^{-1}), closely resembling findings from the Northwest Atlantic (McBride et al. 2008). The growth performance index (Φ′) further highlights these regional differences, with higher values in the Coral Sea (4.55) compared to the Oman Sea (3.91). These discrepancies likely arise from environmental conditions, methodological approaches (otoliths vs. length frequency), and sample size variations. The consistency in Φ' values across studies suggests that growth patterns are more stable than mortality rates, which are heavily influenced by fishing pressure. To ensure long-term stock viability, management measures such as reducing fishing effort, implementing size limits, and enhancing international collaboration for data-poor regions are essential. Future research should adopt multi-method approaches, as demonstrated by Kindong et al. (2022), to improve stock assessment accuracy in data-limited fisheries.

Mortality and exploitation rates provide crucial insights into fishery sustainability. In the Oman Sea, the high total mortality (Z= 1.55yr^{-1}) and exploitation rate (E= 0.77) exceed natural mortality (M= 0.35yr^{-1}), suggesting potential overfishing. In contrast, Kindong et al. (2022) reported a more balanced exploitation rate (E= 0.52) in the Tropical Eastern Atlantic, indicating relatively sustainable fishing pressure. The lack of mortality data in earlier otolith-based studies limits comprehensive comparisons, but the alarming E value in the Oman Sea underscores the urgent need for stricter fisheries management. The observed regional differences in Wahoo biology likely stem from complex interactions between environmental and anthropogenic factors. While fishing pressure remains the primary threat, climate-driven changes in sea surface temperature and prey availability (Cheung et al. 2016; Hashemi et al. 2020) may further impact population dynamics. Integrating climate projections (e.g., IPCC scenarios) with stock

assessments could help predict long-term population trends under changing environmental conditions.
Table 3.

The natural mortality (M) estimates for this fish species, derived from multiple established methods, exhibit a moderate range of variation. These findings highlight the influence of methodological differences on M estimates, emphasizing the need to consider species-specific life history traits—such as growth parameters ($L\infty$, K), maximum age (Tmax), and maturation size (L50)—when selecting an appropriate model. Given the consistency among key methods, the mean value of $0.35 yr^{-1}$ appears reliable for fisheries management applications, though the associated uncertainty (95% CI: 0.27–0.43) should be accounted for in risk assessments. Accurately quantifying M is challenging due to its dependence on species biology, environmental factors, and ecosystem dynamics. Reliable M estimates are essential for setting sustainable fishing limits, evaluating stock health, and designing management strategies. Overestimating M can lead to overly permissive fishing quotas; while underestimating it may result in overly restrictive measures. Thus, using a suite of methods to derive a range of M values ensures more robust and precautionary management decisions, particularly for data-poor fisheries like wahoo in the Eastern Atlantic (Kindong et al. 2022).

Ensemble methods play a critical role in modern fisheries stock assessments by integrating multiple models or estimation approaches to account for structural uncertainty and improve the robustness of management advice. As highlighted in the NOAA Technical Memorandum (Karp et al. 2022), ensemble approaches are increasingly adopted for species like Pacific blue marlin and tropical tunas, where divergent model structures or data conflicts exist. By combining outputs from multiple models—each representing plausible hypotheses about stock dynamics—ensembles provide a more comprehensive estimate of natural mortality (M), biomass trends, and fishing mortality rates, while quantifying uncertainty through variance across models. Ensemble-derived M estimates often fall within narrower confidence intervals than individual methods, enhancing decision-making for overfishing limits (OFLs) and acceptable biological catches (ABCs). The approach also supports adaptive management in data-limited scenarios, as seen in reef fish assessments, where ensemble weights are informed by cross-validation or likelihood profiles (Han et al. 2021). Ultimately, ensembles bridge gaps between conflicting data sources, improve diagnostic transparency, and reflect the NOAA's emphasis on "using all available information" to advance sustainable fisheries management (Karp et al. 2022).

Martell and Froese (2013) developed a foundational framework for catch- and growth-based stock assessment methods, which was later refined by researchers to address the critical need for fisheries reference points in data-poor stocks (Froese et al. 2016). This approach has proven particularly valuable for data-limited fisheries, yielding reliable and scientifically credible estimates of stock status. In the northern Oman Sea, the Wahoo stock exhibits concerning trends based on key indicators: the B/BMSY index shows a consistent decline, while the F/FMSY ratio exceeds maximum sustainable yield (MSY) levels and continues to rise. These patterns suggest the population is transitioning from fully exploited to overexploited (Arrizabalaga et al. 2012). Fishery status is commonly evaluated using the B/BMSY ratio, with stocks categorized as: Under-exploited: $B/BMSY \geq 1.2$ Fully exploited: $0.8 \leq B/BMSY < 1.2$, Overexploited: $0.2 \leq B/BMSY < 0.8$, Collapsed: $B/B MSY < 0.2$. This classification system is widely adopted in fisheries science and management, supported by extensive research (Branch et al. 2011; Anderson et al. 2012) and institutional guidelines (Hilborn 2021; ICES 2023; NOAA 2023). The Wahoo's trajectory in the northern Oman Sea underscores the urgency of implementing science-based management measures to prevent further depletion.

The biomass-to-carrying-capacity ratio ($S = B/K = B/B0 \approx 0.5$ B/BMSY) serves as a critical biological reference point for stock assessment. In the northern Oman Sea, this ratio was estimated at 56% for Wahoo

(*Acanthocybium solandri*), indicating moderate population depletion (Palomares & Froese 2017; Sharma et al. 2025). Optimal B/K values vary across species, typically ranging between 30–60%: Fast-growing species (e.g., small pelagic) thrive at lower ratios (~30–40%). Slow-growing species require higher ratios (~50–60%) to maintain sustainable populations. A minimum threshold of 20–30% is widely accepted; values below this range signal severe depletion (Gabriel & Mace 1999). Exploitation rates and biomass levels directly modulate population growth and B/K dynamics (Zhou et al. 2017). Current data reveal that Wahoo harvests in the northern Oman Sea exceed maximum sustainable yield (MSY), underscoring the need for: 1) Reduced fishing effort to align with sustainable catch limits. 2) Rebuilding strategies, as recovery of overexploited stocks are slow—often requiring 2–3 times the species' lifespan (FAO 2018; Sharma et al. 2025). Proactive management measures are imperative to halt further decline and initiate stock recovery, ensuring ecological resilience and long-term socioeconomic benefits for fishing communities.

The length-based spawning potential ratio (LB-SPR) analysis estimated an SPR of 0.45 (45%) for this population, indicating the stock currently maintains biologically sustainable levels, though showing concerning declines in recent decades. While LB-SPR benchmarks classify stocks with SPR<0.2 as depleted and those >0.4 as sustainable, the model output revealed unusually narrow 95% confidence intervals that approached near-definitive ranges. Despite an SPR of 45%, which is marginally above the 40% precautionary benchmark, excessive fishing pressure indicates the population is on the brink of collapse. This anomaly likely contributed to the model's suboptimal fit score and suggests potential limitations in the current assessment. The LB-SPR approach quantifies the impacts of fishing pressure on population age and size structure. This provides valuable insights for fisheries management (Froese et al. 2016). However, unregulated fishing poses significant risks, particularly when combined with elevated natural (M) and fishing (F) mortality rates affecting pre-recruit stages (Froese et al. 2017). Length-frequency indicators have proven effective for informing management strategies (Froese et al. 2016), yet the LB-SPR method remains underutilized in research applications. To enhance the reliability of stock assessments, future studies should: 1-Validate LB-SPR outputs through comparison with independent assessment methods. 2-Investigate the causes of unrealistically narrow confidence intervals. 3-Expand application of the method to additional case studies. This multi-method verification approach would strengthen confidence in LB-SPR results and promote broader adoption in fisheries management frameworks.

CONCLUSION

This study reveals a critical status for Wahoo (*Acanthocybium solandri*) stocks in the northern Oman Sea, with key indicators—including an exploitation rate (E= 0.77), fishing mortality (F = 1.20 yr^{-1}), and spawning potential ratio (SPR= 45%)—signaling full exploitation and imminent overfishing. The ensemble-based natural mortality estimate (M= 0.35±0.13yr^{-1}) was pivotal in quantifying uncertainty and integrating diverse methodological perspectives, offering a more reliable foundation for management than any single method.The F/FMSY ratio (3.41) and B/BMSY (1.10) further demonstrate that current harvest levels far exceed sustainable thresholds. These findings expose the inadequacy of existing management measures to curb fishing pressure. Urgent interventions are required to prevent stock collapse, including: 1) Reduction of fishing effort, 2) Enhanced monitoring, control, and surveillance (MCS) systems, 3) Implementation of ecosystem-based fisheries management (EBFM) and 4) Prioritizing ensemble methods in future assessments to enhance robustness to align with SDG 14.4 targets. This study not only provides the first scientific baseline for Wahoo stock assessment in the Oman Sea but also underscores the effectiveness of length-based methods in data-limited contexts. Proactive governance is critical to rebuilding stocks, conserving marine biodiversity, and supporting fishing communities.

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REFERENCES

Alverson, D.L. & Carney, M.J. 1975. A graphic review of the growth and decay of population cohorts. ICES Journal of Marine Science 36(2): 133-143.

Amini Rad, T. 2018. Stock assessment and determination of distribution pattern of dominant *Babylonia* snail species in coastal waters of Sistan and Baluchestan Province. Iranian Fisheries Science Research Institute - Offshore Fisheries Research Center (Chabahar). 155 p.

Anderson, S.C.; Branch, T.A.; Ricard, D. & Lotze, H.K. 2012. Assessing global marine fishery status with a revised dynamic catch-based method and stock-assessment reference points. Journal of Marine Science 1(2): 20-26.

Arrizabalaga, H.; Murua, M. & Majkowski, J. 2012. Global status of tuna stocks: summary sheets. Revista de Investigación Marina, AZTI-Tecnalia 19(8): 645–676.

Bartulovic, V.; Glamuzina, B.; Conides, A.; Dulcic, J.; Lucic, D.; Njire, J. & Kozul, V. 2004. Age, growth, mortality and sex ratio of sand smelt, *Atherina boyeri*, Risso, 1810 (Pisces: Atherinidae) in the estuary of the Mala Neretva River (Middle-Eastern Adriatic, Croatia). Journal of Applied Ichthyology 20: 427-430.

Brodziak, J.; Ianelli, J.; Lorenzen, K. & Methot, R.D. 2011. Estimating natural mortality in stock assessment applications. NOAA Technical Memorandum NMFS-F/SPO-119, 38 p.

Branch, T.A.; Jensen, O.P.; Ricard, D.; Ye, Y. & Hilborn, R. 2011. Contrasting global trends in marine fishery status obtained from catches and from stock assessments. Conservation Biology 25(1): 777-786.

Castellano-Mendez, M.; Gonzalez-Manteiga, W.; Febrero-Bande, M.; Prada-Sanchez, J. M. & Lozano-Calderon, R. 2004. Modelling of monthly and daily behavior of the run off the Xallas River using Box-Jenkins and neural networks methods. Journal of Hydrology 296: 38-58.

Chen, S. & Watanabe, S. 1989. Age dependence of natural mortality coefficient in fish population dynamics. Nippon Suisan Gakkaishi 55(2): 205-208.

Chen, Y.; Song, L.; Liu, Y.; Yang, L. & Li, D. 2020. A review of the artificial neural network models for water quality prediction. Applied Sciences 10(5776): 2-49.

Cheung, W.W.L.; Reygondeau, G. & Frölicher, T. L. 2016. Large benefits to marine fisheries of meeting the 1.5°C global warming target. Science 354(6319): 1591-1594.

Collette, B.B. & Nauen, C.E. 1983. *FAO Species Catalogue. Vol. 2. Scombrids of the World. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date*. Rome: FAO. FAO Fish. Synop. 125(2): 137.

DiCiccio, T.J. & Efron, B. 1996. Bootstrap confidence intervals. Statistical Science 11(3): 189-212.

Dietterich, T.G. 2000. Ensemble methods in machine learning. In: Multiple Classifier Systems. MCS 2000. Lecture Notes in Computer Science. Springer, Berlin, Heidelberg, 1857.

Dowling, N.A.; Wilcox, C.; Mangel, M. & Pascoe, S. 2019. Assessing opportunity and flexibility in data-limited fisheries. Fish and Fisheries 20(2): 198-214.

Eagderi, S.; Mouludi-Saleh, A.; Fricke, R.; Alavi-Yeganeh, M. S.; Mousavi-Sabet, H. & Çiçek, E. 2026. Fishes of the Sea of Oman. *Iranian Journal of Ichthyology*, 13 (Special Issue): 1-152.

FAO. 2024. *The State of World Fisheries and Aquaculture 2022 - Meeting the sustainable development goals*. Rome. 227 p.

Froese, R. & Binohlan, C. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Journal of Fish Biology 56: 758-773.

Froese, R.; Demirel, N. & Sampang, A. 2015. An overall indicator for the good environmental status of marine waters based on commercially exploited species. Marine Policy 51(1): 230-237.

Froese, R.; Demirel, N.; Gianpaolo, C.; Kleisner, K.M. & Winker, H. 2016. Estimating fisheries reference points from catch and resilience. Fish and Fisheries 18(3): 506-526.

Froese, R.; Winker, H.; Coro, G.; Demirel, N.; Tsikliras, A.C.; Dimarchopoulou, D.; Scarcella, G.; Probst, W.N.; Dureuil, M. & Pauly, D. 2019. Estimating stock status from relative abundance and resilience. ICES Journal of Marine Science 77(2): 527-538.

Froese, R. & Pauly, D. eds. 2024. *FishBase*. World Wide Web electronic publication. www.fishbase.org, version (10/202024), accessed at www.fishbase.org in November/December 2015.

Gabriel, W.L. & Mace, M.M. 1999. A review of biological reference points in the context of the precautionary approach. 5th NMFS NSAW. NOAA Tech. Memo. NMFS-F/SPO-40: 35-45.

Gislason, H.; Daan, N.; Rice, J. C. & Pope, J. G. 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries 11(2): 149-158.

Han, Q.; Shan, X.; Jin, X.; Gorfine, H.; Yang, T. & Su, C. 2021. Data-limited stock assessment for fish species devoid of catch statistics: Case studies for *Pampus argenteus* and *Setipinna taty* in the Bohai and Yellow Seas. Frontiers in Marine Science 8: 766499.

Hashemi, S.A.R.; Doustdar, M.; Gholampour, A. & Khanehzaei, M. 2020. Length-based fishery status of yellowfin tuna (*Thunnus albacares* Bonnaterre, 1788) in the northern waters of the Oman Sea. Iranian Journal of Fisheries Sciences 19(6): 2790-2803.

Hewitt, D.A. & Hoenig, J.M. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin 103(2): 433-437.

Hilborn, R.; Hively, D.; Baker Loke, N.; de Moor, C.L.; Kurota, H.; Kathena, J.; Mace, P. M.; Minto, C.; Parma, A. M.; Quiroz, L.C. & Melnychuk, M. 2021. Global status of groundfish stocks. Fish and Fisheries 1(1): 22-911-928.

Hogarth, W.T. 1976. Life-history aspects of the wahoo *Acanthocybium solandri* (Cuvier and Valenciennes) from the coast of North Carolina. PhD Dissertation. North Carolina State University, Raleigh, NC, USA.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82(1): 898-903.

ICES. 2021. *Workshop on Data-Limited Methods (WKLIFE)*. ICES Scientific Reports 3: 53. 194 p.

ICES. 2023. ICES (International Council for the Exploration of the Sea) Advice on Fishing Opportunities. Available at: https://www.ices.dk/ . Available at: https://academic.oup.com/icesjms.

Iranian Fisheries Organization (IFO). 2024. Statistics Department; Fisheries Statistical Yearbook. 25 p. (In Persian)

James, G.; Witten, D.; Hastie, T. & Tibshirani, R. 2021. *An introduction to statistical learning: With applications in R* (2nd ed.). Springer.

Jayakody, D. 1991. Fishery, population dynamics and breeding biology of *Panulirus homarus* on the south coast of Sri Lanka. Theses from Faculty of Natural Sciences legacy departments, University of Stirling. 381 p.

Karp, M.A.; Peter, K.; Kristan, B.; Jon, B.; Felipe, C.; Kiersten, C.E.J. Dick; Dana, H.; Daniel, H.; James, I.; Skyler, S.; Kyle, S. & Ian, T. 2022. Common model diagnostics for fish stock assessments in the United States. NOAA Tech. Memo. NMFS-F/SPO-240A, 27 p.

Kindong, R.; Gao, C. & Tian, S. 2020. Achille Pandong, Qiuyun Ma, Feng Wu & Ousmane Sarr. 2020. Stock status assessments of five small pelagic species in the Atlantic and Pacific Oceans using the Length-Based Bayesian Estimation (LBB) Method. Frontiers in Marine Science 7: 592082.

Kindong, R.; Wu, F.; Sarr, O.; Dai, L.; Tian, S. & Dai, X. 2022. Life history of wahoo, *Acanthocybium solandri*, in the Tropical Eastern Atlantic Ocean – the importance of applying a suite of methods for fisheries assessment in data-limited situations. Oceanological and Hydrobiological Studies 51(1): 115-132.

Kishore, R. & Chin, X. 2001. Age and growth studies at the CFRAMP/IMA regional age and growth laboratory progress of work done and future approaches. In: SinghRenton, S. (Ed.), CARICOM Fishery Report 9, CARICOM Fisheries Unit, Belize City, Belize, pp. 74-89.

Lalèyè, P.A. 2006. Length-weight and length-length relationships of fish from the Ouémé River in Bénin (West Africa). Journal of Applied Ichthyology 22: 502-510.

Lee, T.M. 2008. Estimation of life history parameters, biological reference points, and associated uncertainties for wahoo (*Acanthocybium solandri*) in the waters off eastern Taiwan. Master's thesis, National Taiwan University.

Mashaii, N. 1999. Investigation of commercial exploitation status of spiny wahoo in Sistan and Baluchestan waters. Offshore Fisheries Research Center - Chabahar. 163p. (In Persian)

Mashaii, N.; Rajabipour, F.; Shakouri, A. & Khoddami, S. 2013. An investigation on some ecological aspects of the rock wahoo, *Panulirus homarus* in Ramin area, south east of Iran. Journal of Marine Science and Technology Research 7(4): 22–34.

Martell, S. & Froese, R. 2013. A simple method for estimating MSY from catch and resilience. *Fish and*

Fisheries 14(4): 504-514.

McBride, R.S.; Richardson, A.K. & Maki, K.L. 2008. Age, growth, and mortality of wahoo, *Acanthocybium solandri*, from the Atlantic coast of Florida and the Bahamas. Marine and Freshwater Research 59(9): 799-807.

NOAA. 2023. Fish Stock Sustainability Index (FSSI): Status of U.S. Fisheries. National Oceanic and Atmospheric Administration.

Palomares, M.L.D. & Froese, R. 2017. Training on the use of CMSY for the assessment of fish stocks in data-poor environments. Workshop report submitted to the GIZ by Quantitative Aquatics, Inc. Q-quatics Technical Report No. 2. Bay, Laguna, Philippines. p. 58.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. ICES Journal of Marine Science 39(2): 175-192.

Pauly, D. & Lam, V.W.Y. 2016. Chapter 6.1: The Status of fisheries in large marine ecosystems. In: IOC-UNESCO and UNEP (2016). *Large marine ecosystem: Status and trends*. United Nations Environmental Programme, Nairobi, pp. 113-137.

Phillips, B.F. & Melville-Smith, R. 2006. Panulirus species: Chapter 11. In: *Wahoos: Biology, management, aquaculture and fisheries* (BF Phillips ed), Blackwell Scientific Publications, Oxford, pp. 359-384.

Phillips, F.B. 2006. *Wahoos: Biology, management, aquaculture and fisheries*. Blackwell Publishing Ltd. First edition. 536p.

Phillips, F.B. 2013. *Wahoos: Biology, management, aquaculture and fisheries*. Blackwell Publishing Ltd. Second edition. 503p.

Psomadakis, P.N.; Osmany, H.B. & Moazzam, M. 2015. Field Identification Guide to the Living Marine Resources of Pakistan. FAO Species Identification Guide for Fishery Purposes. FAO Rome Italy. 386p.

Prince, J.D.; Hordyk, A. & Valencia, S.R. 2015. Revisiting the concept of data-limited fisheries. Fish and Fisheries 16(4): 518-530.

R Development Core Team. 2022. *R: A Language and Environment for Statistical Computing*. Vienna: Foundation for Statistical Computing.

Radhakrishnan, E.V.; Phillips, B.F. & Achamveetil, G. 2019. *Wahoos: Biology, Fisheries and Aquaculture*. Springer Nature Singapore Pte Ltd.

Roper, C.F.E.; Sweeney, M.J. & Nauen, C.E. 1984. *Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries*. FAO Fisheries Synopsis 125(1): 3.

Schwamborn, R.; Mildenberger, T.K. & Taylor, M.H. 2018. R package version 0.1. *Fishboot: Bootstrap-based Methods for the Study of Fish Stocks and Aquatic Populations*. https://github.com/rschwamborn/fishboot

Schwamborn, R.; Mildenberger, T.K. & Taylor, M.H. 2019. Assessing source of uncertainty in length-based estimates of body growth in populations of fishes and macroinvertebrates with bootstrapped ELEFAN. Journal of Ecological Modeling ۳۹۳ (C): 37-51.

Sharma, R.; Barange, M.; Agostini, V.; Barros, P.; Gutierrez, N. L.; Vasconcellos, M.; Fernandez Reguera, D.; Tiffay, C. & Levontin, P. 2025. Review of the state of world marine fishery resources – 2025. FAO Fisheries and Aquaculture Technical Paper, No. 721. Rome. FAO.

Situmorang, Y. M. L.; Omar, S. B. A. & Tresnati, J. 2021. Carapace length-body weight relationship and condition factor of painted rock wahoo *Panulirus versicolor* in Sorong waters, West Papua, Indonesia. AACL Bioflux 14(1): 519-535.

Taghvimotlagh, S.A.; Akhundi, M. & Shiraei, A.S. 2006. Analysis of fishing process and fishing potential based on statistics and catch data in Gulf and Oman waters. Journal of Fisheries Research 15(3): 45-35.

Then, A.Y.; Hoenig, J.M.; Hall, N.G. & Hewitt, D.A. 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(1): 82-92.

Vivekanandan, E. 2005. *Stock assessment of tropical marine fishes*. Indian Council of Agricultural Research, New Delhi, 115p.

Zischke, M.T.; Griffiths, S.P. & Tibbetts, I.R. 2013. Rapid growth of wahoo (*Acanthcybium solandri*) in the Coral Sea, based on length-at-age estimates using annual and daily increments on sagittal otoliths. ICES Journal of Marine Science 70(6): 1128-1139.

Zhou, S.; Chen, Z.; Dichmont, C.M.; Ellis, A.N.; Haddon, M.; Punt, A. E.; Smith, A.D.M.; Smith, D.C. & Ye, Y. 2016. *Catch-based methods for data-poor fisheries*. Report to FAO. CSIRO, Brisbane, Australia. 74p.

Zhou, S.; Punt, A.E.; Smith, A.D.M.; Ye, Y.; Haddon, M.; Dichmont, C.M. & Smith, D.C. 2017. An optimized catch-only assessment method for data poor fisheries. ICES Journal of Marine Science 1(2): 20-26.

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مقاله کامل

ارزیابی ذخایر ماهی *Acanthocybium solandri* Cuvier, 1832 براساس داده‌های طول‌سنجی در شمال دریای عمان: نرخ بهره‌برداری نگران‌کننده و ضرورت اقدامات حفاظتی فوری

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چکیده: این مطالعه به ارزیابی ذخایر ماهی شیر اقیانوسی (*Acanthocybium solandri*) در شمال دریای عمان براساس شاخص‌های طول‌سنجی می‌پردازد که نتایج آن نشان‌دهنده پیام های بحرانی از بهره‌برداری بیش از حد است. داده‌های زیستی مربوط به ۴۱۵ عدد ماهی که طی سال‌های ۲۰۲۱ تا ۲۰۲۴ از شمال دریای عمان جمع‌آوری شده بودند، با استفاده از روش‌های بوت‌استرپ در رویکرد الفان مورد تجزیه‌وتحلیل قرار گرفتند. در این پژوهش، پارامترهای کلیدی رشد و مرگ‌ومیر با بهره‌گیری از رویکرد الفان بوت‌استرپ شده برآورد گردید. طول نهایی (L_∞) معادل ۱۷۰ سانتی‌متر (در محدوده ۱۸۱–۱۴۶)، ضریب رشد (K) معادل ۰/۲۶ در سال (در محدوده ۰/۵۴-۰/۱۷) و سن صفر در طول صفر (t_0) معادل ۰/۷۲- سال (در محدوده۱/۳-۰/۶) تخمین زده شد. شاخص عملکرد رشد (Φ') نیز ۳/۹۱ محاسبه گردید که نشان‌دهنده ویژگی‌های رشد ثابت در منطقه است. نرخ مرگ‌ومیر طبیعی ترکیبی (M ensemble)، که از تلفیق نتایج ۹ روش مستقل به‌دست آمد، میانگین ۰/۳۵±۰/۱۳ در سال را نشان داد، در حالی که مرگ‌ومیر صیادی (F) به‌مراتب بالاتر و معادل ۱/۲۰ در سال بود که منجر به مرگ‌ومیر کل (Z) برابر با ۱/۵۵±۰/۲۲ در سال گردید. نرخ بهره‌برداری (E) معادل ۰/۷۷ برآورد شد که حاکی از فشار شدید صیادی بر جمعیت این گونه و نزدیکی به وضعیت بهره‌برداری بی‌رویه است. شاخص‌های وضعیت ذخیره شامل پتانسیل تخم‌ریزی نسبی (SPR)، نسبت زیست‌توده (B/B_0)، نسبت زیست‌توده به زیست‌توده در سطح حداکثر محصول پایدار (BMSY/B) و نسبت مرگ‌ومیر صیادی به سطح بهینه (FMSY/F) همراه با فواصل اطمینان ۹۵٪ ماهی شیر عمانی (*Acanthocybium solandri*) در آب‌های شمالی دریای عمان به‌ترتیب برابر با ۰/۴۵ (۰/۵۵-۰/۳۵)، ۰/۵۶ (۰/۶۹-۰/۴۲)، ۱/۱۰ (۱/۳۵-۰/۹)، ۳/۴۲ (۴/۰۱-۲/۸۲) برآورد شدند. نتایج نشان‌دهنده بهره‌برداری شدید و فراتر از حد مجاز از این ذخیره است، به‌طوری‌که نرخ بهره‌برداری و نسبت FMSY/F برابر با ۳/۴۲، به‌طور معنی‌داری از حدود پایداری فراتر رفته‌اند. مداخلات مدیریتی فوری شامل کاهش تلاش صیادی، تقویت سیستم‌های نظارت، کنترل و بازرسی (MCS) و اجرای مدیریت شیلاتی مبتنی بر اکوسیستم (EBFM) برای انطباق با اهداف توسعه پایدار جهانی (به‌ویژه هدف ۱۴,۴ از SDG) به‌شدت مورد نیاز است. اقدامات پیشگیرانه برای بازسازی ذخایر، حفظ تنوع زیستی دریایی و تضمین بقای طولانی‌مدت جوامع وابسته به صید در منطقه ضروری است. این ارزیابی، اولین ارزیابی جامع را برای مدیریت ماهی شیر اقیانوسی در شمال دریای عمان فراهم کرده و کارایی روش‌های مبتنی بر طول را برای شیلات با داده‌های محدود اثبات می‌کند.

کلمات‌کلیدی: *Acanthocybium solandri*، ارزیابی ذخایر مبتنی بر طول، دریای عمان، بهره‌برداری بیش از حد، مدیریت پایدار شیلات