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Research Article

Stock assessment of wels catfish (*Silurus glanis* Linnaeus, 1758) in the Aras Dam reservoir, northwest Iran

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Keywords

Stock management,
Wels catfish,
Sustainable fisheries,
Stock assessment modeling,
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Abstract

The wels catfish (*Silurus glanis*) is a widely distributed freshwater species of considerable ecological and commercial importance. Among its principal habitats is the Aras reservoir in northwestern Iran, where it constitutes one of the dominant targets of the regional fishery. However, unregulated fishing has led to a reduction in the stock abundance. The present study investigated the length–weight relationship and assessed the stock status of wels catfish in the Aras Dam reservoir. Stock assessment was conducted using the CMSY^{++} model. Model outputs indicated that both the relative stock size (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) were below unity, suggesting that the stock is currently subject to excessive fishing pressure. The maximum sustainable yield (*MSY*) was estimated at 2.98 metric tons. Historical data revealed that actual catches consistently exceeded the *MSY* until 2015. Thereafter, owing to intensive exploitation and a subsequent decline in stock biomass, annual catches fell below the *MSY*. The Kobe plot analysis demonstrated that overfishing has driven the population into the overfished quadrant. Collectively, these findings underscore the urgent necessity of implementing ecosystem-based fisheries management strategies. In particular, stricter regulation of fishing practices, enforcement of annual catch limits, reduction of fishing effort, and control of illegal harvest are strongly recommended to halt further depletion and to ensure the long-term sustainability of Wels catfish in the Aras Dam reservoir.

Article info

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Introduction

Aquatic resources play a crucial role in the economic, social, and nutritional development of human societies worldwide (Meusch *et al.,* 2003). Neglecting the management of these resources has led to the depletion of aquatic stocks, often with irreversible socio-economic consequences (Ojelade *et al*., 2019). The Wels catfish (*Silurus glanis*), a member of the family Siluridae and order Siluriformes, is widely distributed in both fresh and brackish environments across Eastern Europe, Anatolia, and Central Asia. In Iran, this species occurs in wetlands, rivers, and various inland water bodies, primarily in the northwest and northeast regions, including the catchment areas of Lake Urmia, the Caspian Sea basin, and possibly the Tajan River basin (Esmaeili *et al*., 2017; Saadati, 1977). Its most important habitats are the Anzali International Wetland in Gilan Province and the Aras reservoir in northwestern Iran (Amiri *et al*., 2018). The Aras River, of significant international importance, originates in Turkey and flows along the borders of Armenia, Iran, and Azerbaijan, ultimately forming the Aras Dam reservoir (Hajihoseini *et al.,* 2023). The Aras reservoir is a key inland fishery in northwestern Iran, sustaining the livelihoods of local fishers. Owing to its favorable ecological conditions, it supports the reproduction and growth of numerous freshwater species, including Wels catfish. Annual catches, legal and illegal combined, exceed 3,700 tons and include a variety of commercially valuable species (Abbasi and Sarpanah, 2001; Mohebbi, 2021). Illegal fishing, mostly conducted by unauthorized fishers, targets both non-commercial and valuable commercial species (Haghi Vayghan *et al.,* 2025). The Wels catfish, which holds significant economic value in many countries worldwide, is also one of the most important commercial fish species in the Aras Dam reservoir. Its fast growth, long lifespan, palatable boneless flesh, and suitability for aquaculture and recreational fishing make it highly valuable in many countries (Linhart *et al*., 2002; Cucherousset *et al*., 2018; Zibiene and Zibas, 2019). Because its flesh closely resembles that of sturgeon in taste and texture, and given the decline in sturgeon catches in the Caspian Sea (Amiri *et al*., 2018), Wels catfish is heavily exploited in Iran, including Aras Dam reservoir, and often illegally marketed as sturgeon meat. Despite its critical ecological role in aquatic ecosystems, overfishing and inadequate stock management have led to a severe decline in its population (Behmanesh *et al*., 2021).

Data on the life-history traits of Wels catfish in the Aras Dam reservoir remain scarce, with most studies focusing on diet, reproduction, population structure, growth, and physiology (Bahrami Kamangar and Rostamzadeh, 2015; Amiri *et al*., 2018; Behmanesh *et al*., 2021; Behmanesh *et al*., 2022). The formulation of effective management strategies necessitates robust information on species stock status. Yet, in the Aras Dam reservoir, the paucity of data on Wels catfish precludes the application of complex assessment models. Accordingly, data-limited methods constitute the only feasible pathway for establishing preliminary biological reference points to guide management. The Catch-MSY^{++} (CMSY^{++}) model is one of the latest data-limited stock assessment methods that can estimate fisheries reference points for a better understanding of the stock status of fish and finally apply relevant management strategies. The CMSY^{++} model has emerged as a valuable tool in fisheries management, particularly in regions where comprehensive biological surveys are limited and conventional assessment methods are not feasible. This model provides estimates of critical fisheries reference points, including maximum sustainable yield (*MSY*), biomass at MSY (B_{MSY}), and fishing mortality at MSY (F_{MSY}), all of which serve as fundamental benchmarks for sustainable fisheries management. Despite their importance, many global fisheries lack officially defined reference points, leaving exploitation levels and stock status uncertain (Froese *et al*., 2017; Zhang *et al*., 2018; Ji *et al*., 2019). Incorporating such reference points facilitates the development of effective management policies and strengthens ecosystem-based fisheries management (Zhou *et al*., 2017; Hill *et al*., 2020). The present study aimed to examine the length–weight relationship of Wels catfish and apply the CMSY^{++} model to estimate key reference points and assess stock status in the Aras Dam reservoir using catch data from 2013 to 2022. The findings are expected to support ecosystem-based management by informing the establishment of sustainable annual catch limits for this species.

Materials and methods

Study area

The study was conducted in the waters of the Aras reservoir, located in West Azerbaijan Province, Iran, at approximately 39.19°N latitude and 45.31°E longitude (Fig. 1). Catch data of the Wels catfish population from the Aras Dam reservoir over a 10-year period (2013–2022) were obtained from daily reports of Fisheries Cooperatives 18 and 19, provided by the West Azerbaijan Fisheries Department (Fig. 2). These data were used as input for the stock assessment model to calculate stock indices. Catch was collected by fishermen at a predetermined fixed location using beach seine nets (950 m length, 18 m height, and 35 mm mesh size in the central part of the net). This fixed location was selected by expert fishermen based on areas of high fish abundance. The fishing period typically extends from October to March.

Length-weight relationship sampling

In the fishing season, from late October 2023 to the end of March 2024, weekly visits were made to the Aras fishing cooperatives for biometric sampling. Over 64 Wels catfish individuals were measured. Total length was measured using a fish measuring board with 0.1 cm precision, and weight was recorded using a digital scale with 0.1 g accuracy. Length–weight relationship was calculated by fitting the power function ($W=a \times (TL)^b$) to length and weight data (Ricker, 1975). Log-transformation was used on length and weight data to fit the least square linear regression model:

$$\log W = \log a + b \log TL \qquad (1)$$

where, W is the body weight (g), TL the total length (cm), a the intercept of the fitted regression curve, and b the slope of the length-weight relationship regression (allometric coefficient).

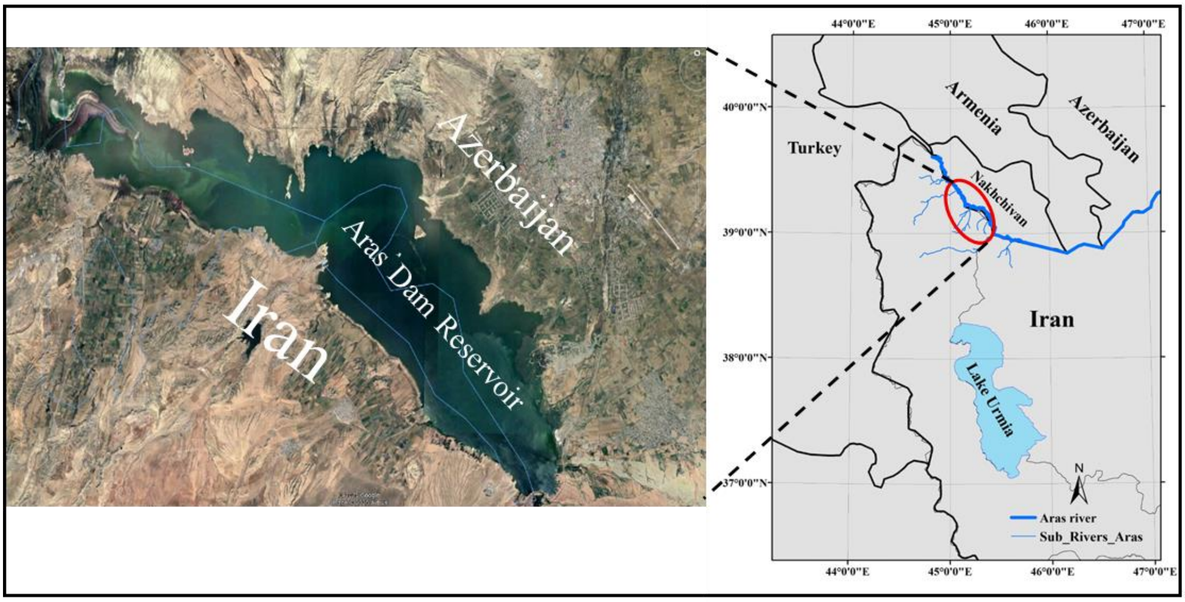

Figure 1: Geographical location of the Aras Dam reservoir in West Azerbaijan Province, Iran.

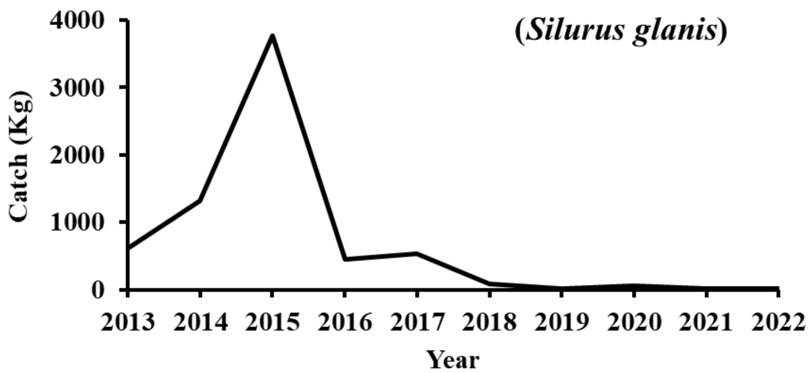

Figure 2: The catch trends of the Wels catfish, *Silurus glanis* in the waters of the Aras Dam reservoir from 2013 to 2022.

The Student's t-test was used to compare the value of the slope "*b*" with 3 at a significance level of 5% according to the equation below (Pauly, 1984):

$$t = \frac{SD_{TL}}{SD_W} \times \frac{|b-3|}{\sqrt{1-r^2}} \times \sqrt{n-2} \quad (2)$$

where SD_{TL} is the standard deviation of the transformed logarithm of total length; SD_W is standard deviation of the transformed logarithm of weight; n is the number of specimens used in the calculation. Growth type was isometric if the b-value is statistically equal to 3, otherwise allometric growth (negative allometric growth when $b<3$ and positive allometric growth when $b>3$).

Estimation of fishery reference points

In the present research, the recently developed CMSY^{++} framework was applied to determine key fisheries reference points for the Wels catfish population. CMSY^{++} is an advanced state-space Bayesian framework for stock assessment that estimates key fishery reference points, including *MSY*, F_{MSY}, and B_{MSY}, as well as stock status (B/B_{MSY}) and fishing pressure (F/F_{MSY}). The model utilizes catch data, optional abundance indices, prior information on resilience or productivity (r), and broad priors for the ratio of biomass to unfished biomass (B/K) at the beginning, an intermediate year, and the end of the time series. CMSY^{++} represents an extension of the Catch-MSY model developed by Martell and Froese (Martell and Froese, 2013), both of which are based on the modified Schaefer surplus production model that accommodates abundance indicators when available. The CMSY^{++} framework further builds on the CMSY approach described by Froese *et al.* (2017), addressing several of its limitations. A notable enhancement in CMSY^{++} and the Bayesian Surplus Model (BSM) is the use of multivariate normal priors for r and K in logarithmic space, replacing the uniform priors employed previously. This modification facilitates a more straightforward identification of the optimal r–K pairs and results in faster model execution.

The CMSY^{++} approach utilizes the derivative of the logistic growth model, substituting individual counts with aggregated body mass to estimate population dynamics (Schaefer, 1991; Equ. 3):

$$B_{t+1} = \{B_t + r\left(1 - {}^{B_t}/_{k}\right) - C_t e^{\varepsilon_t}\}e^{\eta_t} \quad (3)$$

Here B_t is the biomass and C_t is the catch in tonnes in year t, r (year^{-1}) is the intrinsic rate of population growth, and k represents the carrying capacity of the environment for this population in tonnes, εt is the normally distributed observation error of catches and ηt is the process error, respectively, and are implemented as lognormal error terms. Presence of these lognormal error terms is left in subsequent equations.

When credible estimates of the initial biomass and carrying capacity are available, along with plausible growth rates derived from species-specific life-history parameters (*e.g.,* FishBase; Froese and Pauly, 2023), the model allows projection of biomass trajectories based on historical catch data. Within this framework, the maximum sustainable fishing mortality is defined as $F_{MSY}= r/2$, and the biomass level that can sustain maximum yield is $B_{\mathrm{MSY}} = k/2$. This approach is known as "stochastic reduction analysis" (Kimura and Tagart, 1982; Walters *et al.*, 2006).

When stock biomass becomes heavily depleted, falling below 25% of the carrying capacity (0.25 k), recruitment is typically impaired. This effect can be incorporated by a slight modification of Equation 3, as expressed in Equation 4.

$$B_{t+1} = Bt + \left(\frac{4Bt}{k}r\right)\left(1 - \frac{Bt}{k}\right)Bt - C_t | \frac{Bt}{k} < 0{,}25 \quad (4)$$

where ($4Bt/k$) causes a linear reduction of r if biomass drops below $k/4$, to calculate for reduced recruitment and thus productivity at low population size. Half of B_{MSY}, which is $k/4$ in the Schaefer model context, is usually selected as the proxy demarcation of the biomass below which recruitment may be impaired.

The Schaefer model can alternatively be expressed in terms of the intrinsic growth rate (r) and maximum sustainable yield (*MSY*), without explicitly including the carrying capacity (k) (Equation 5). Nevertheless, this reformulation does not alter the underlying population dynamics, and the resulting expression for surplus production is generally considered less intuitive than the original formulation presented in Equation 3.

$$B_{t+1} = B_t + r, B_t - \frac{(rB_t)^2}{4MSY} - C_t \qquad (5)$$

To keep the original form of the CMSY base model (Equation 2) with parameters r and k, the within-stock correlation between r and k was calculated for in a multivariate lognormal (MVLN) distribution implemented by: (i) drawing a big sample (n=10 000) of independent random deviates of $\log(\tilde{r})$ and $\log(\widetilde{MSY})$ from their prior distributions; (ii) computing the corresponding $\log(\tilde{k}) = \log(4) + \log(\widetilde{MSY}) - \log(\tilde{r})$; and (iii) computing the means and the covariance of $\log(\tilde{r})$ and $\log(\tilde{k})$, which are (iv) then forwarded as covariance matrix for the r–k ~ MVLN prior in the CMSY^{++} and BSM model formulations.

A feed-forward Artificial Neural Network (ANN; Fritsch *et al*., 2019) was selected for classifying stock status as being above or below the *MSY* level to accommodate Equation 6:

$$(B/k)_{t\,prior} = \frac{1 + A_t\sqrt{1 - C_t/MSY_{prior}}}{2} \qquad (6)$$

This equation only gives real number solutions if $Ct <= MSY_{prior}$. Therefore, its application was restricted to cases where $Ct < 0.99\ MSY_{prior}$.

This equation details how a point estimate of relative equilibrium biomass (B/k) originated from catch relative to *MSY*. Catch and biomass are almost in equilibrium in real-world stocks and the width and shape of uncertainty differ with the position of the equilibrium point estimate in Bt/k–Ct/MSY space.

The equilibrium curve for the interplay between relative biomass (B/k) and relative catch (C/MSY) for the modified Schaefer model was derived from Equation 7:

$$\frac{C}{MSY} = (4\frac{B}{k} - (2\frac{B}{k})^2, RC \qquad (7)$$

Where, RC indicates recruitment correction with RC=4 B/k if $B/k < 0.25$ and RC=1 otherwise (same as in Equation 4).

The equilibrium curve for the Fox (1970) model was estimated from Equation 8:

$$\frac{C}{MSY} = e\frac{B}{k}\ (1 - \log\left(e, \frac{B}{k}\right)) \qquad (8)$$

Where, e stands for Euler's number 2.718.

The relative biomass (B/B_{MSY}) in the final year, which expresses the status of a stock, can be calculated by CMSY^{++}. In addition, Kobe plot based on relative fishing mortality coefficients and the ratio of fishing mortality to maximum sustainable fishing mortality (B/B_{MSY} and F/F_{MSY}) was used to assess the stock status for the most recent year.

Software and statistical analysis

The CMSY^{++} method was implemented using the R programming environment (Froese *et al*., 2023) to analyze the status of fishery stocks in the Aras Dam reservoir for the target species. In addition, the Bayesian state-space Schaefer surplus production model (BSM; Millar and Meyer, 1998), integrated within the CMSY^{++} R package, was employed to account for uncertainties arising from both population dynamics (process error) and measurement or sampling variability (observation error) (Thorson *et al*., 2014; Froese *et al*., 2017). Following the execution of the CMSY^{++} estimation routine, key fisheries reference points were derived to evaluate the stock status. All relevant datasets and R-code for the analysis are provided in the supplementary material of Froese *et al*.

(2023). Statistical significance and confidence intervals were assessed at the 0.05 level. Graphs and numerical calculations were produced using Microsoft Excel.

Results

The total length of the sampled Wels catfish ranged from 54 to 142 cm (mean±SD: 89.49±26.75 cm), and their total weight ranged from 1,010 to 15,101 g (mean±SD: 6,154.52±5,068.83 g). The length–weight relationship of the population was characterized, with parameters *a* and *b* estimated (Fig. 3). Statistical comparison of the observed slope against the critical t-value, following Pauly's method, showed no significant deviation from 3 ($p>0.05$), indicating isometric growth.

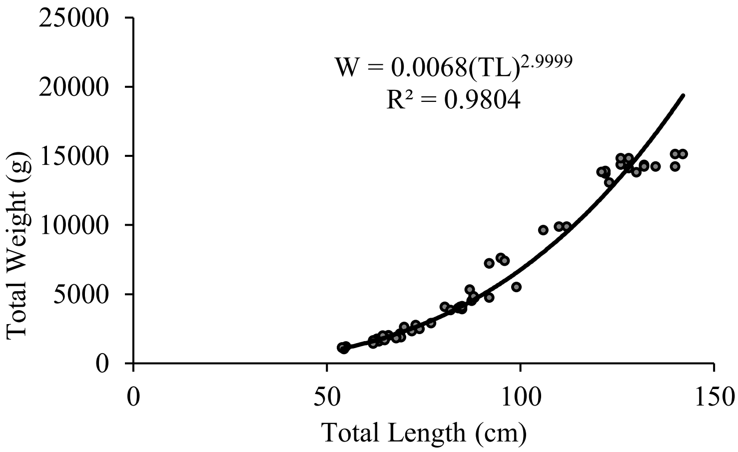

Figure 3: Length-weight relationship of the Wels catfish, *Silurus glanis* in the Aras Dam reservoir.

Estimated fisheries reference points for Wels catfish are presented in Table 1.

Table 1: Fisheries reference points by CMSY^{++} method for the Wels catfish, *Silurus glanis* (values in parentheses represent the 2.5th and 97.5th percentiles). Indicators are based on thousand mt.

Fisheries Reference Points	Estimated average values (minimum-maximum)
Biomass in the last year	0.0664 (0.0349-0.112)
MSY	0.00298(0.00204 - 0.0044)
B_{MSY}	0.0809(0.0573 - 0.152)
F_{MSY}	0.0368(0.0202 - 0.0523)
B/B_{MSY}	0.704(0.47-0.925)
F/F_{MSY}	0.54(0.297-1.07)
F	0.0169(0.00921-0.0334)
Relative biomass in last year	0.352 *k*(0.235-0.463)
K	0.162(0.115 - 0.303)
F/(r/2)	0.54(0.297-1.07)
(r)	0.0736(0.0405 - 0.105)
B/K	0.41
Depletion level	Medium
B/k range	0.303-0.369
Trophic level	4.4

Both biological indicators, B/B_{MSY} and F/F_{MSY}, were below 1.0, suggesting that the stock is currently subjected to unsustainable exploitation. CMSY^{++} model outputs, which assess total catches relative to the maximum sustainable yield (*MSY*), revealed a declining catch trend from 2013 to 2022, accompanied by a corresponding reduction in stock biomass (Fig. 4b). The *MSY* for this species was estimated at 2.98 metric tons.

Historical catch trends indicate that catches exceeded the *MSY* until 2015, after which continued fishing pressure combined with reduced stock biomass led to catches falling below the *MSY*.

Kobe plot analysis further confirmed that overfishing has resulted in the majority of the stock being classified within the overfished zone, indicating an unfavorable stock status (Fig. 4b and d).

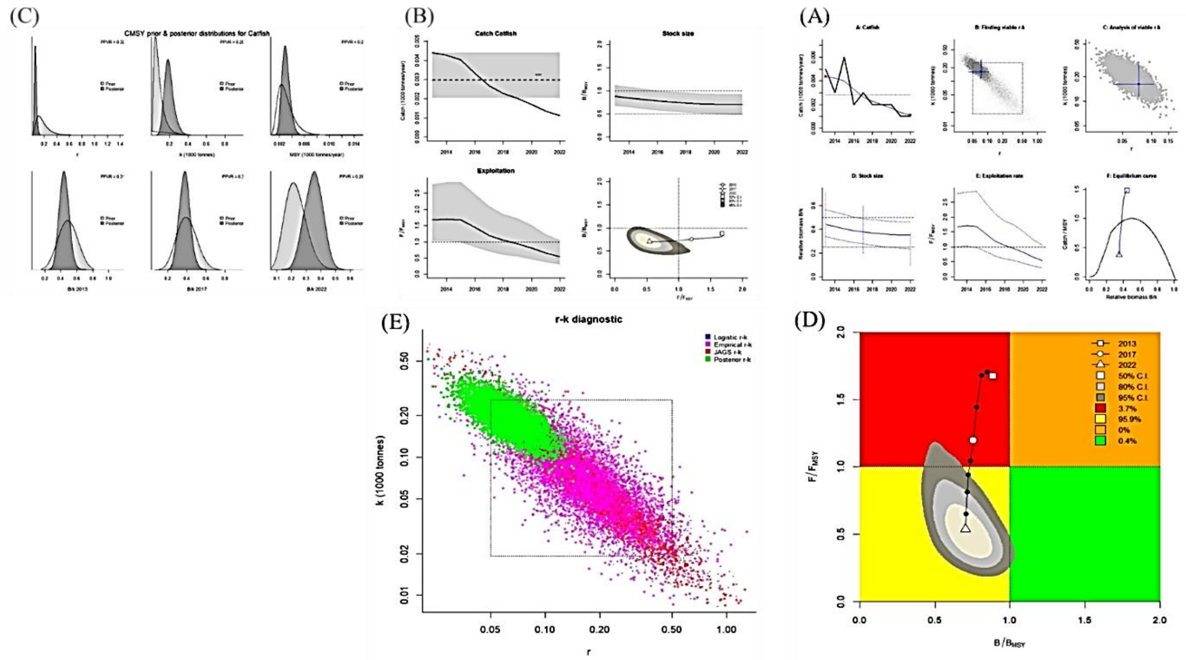

Figure 4: Results of the catch-maximum sustainable yield (CMSY^{++}) model for the Wels catfish, *Silurus glanis*, in the waters of the Aras Dam reservoir from 2013 to 2022. A: shows the time series of catches and smoothed data as used in the estimation of prior biomass by the default rules; B: is the stock size and exploitation trend; C: the priors (light grey), and posterior understanding (dark grey) of the stock; D: is a Kobe phase plot and E: observed r-k correlations.

Discussion

The present study provides a comprehensive assessment of the Wels catfish population in the Aras Dam reservoir, focusing on the biological characteristics and stock status of this species. In many aquatic species, due to the lack of sufficient and reliable data for applying complex stock assessment models and abundance- or age-based methods, formal assessment of stock status is often challenging. The new version of CMSY^{++} addresses the limitations of Catch-MSY and offers key advantages including faster execution, the use of neural networks and artificial intelligence for predicting initial stock status from catch time series, and the generation of various analytical charts (Froese *et al*., 2023). Based on the results, biological reference points, including

B/B_{MSY} and F/F_{MSY} for Wels catfish, were found to be below 1.0, indicating overexploitation and that current fishing mortality exceeds sustainable thresholds. These findings are consistent with global evidence demonstrating that overfishing leads to long-term declines in stock biomass and productivity (Ojelade *et al*., 2019; Froese *et al*., 2023). The CMSY^{++} outputs revealed a decline in catches from 2013 to 2022, along with reductions in biomass, confirming that the population is under unsustainable exploitation. Historical catches exceeding the estimated *MSY* of 2.98 metric tons until 2015 further highlight the pressure on the stock and the urgent need for effective management interventions. The Kobe plot analysis corroborated these results, showing that the majority of the stock resides within the overfished quadrant, emphasizing the urgency of management measures. Visual tools like the Kobe plot are invaluable for communicating stock status and facilitating decision-making, particularly when resources for intensive field surveys are limited. Aras Dam reservoir possesses high fisheries potential in the northwest of the country. However, due to inadequate management, its aquatic stocks face serious threats. Economic fish stock damage in the reservoir- particularly for freshwater prawn and carp species- has been reported due to overfishing (Haghi Vayghan and Agh, 2022; Haghi Vayghan and Ghanbarzadeh, 2025a). In recent years, the abundance of pikeperch, (*Sander lucioperca*) populations has declined significantly in the Aras Dam (Haghi Vayghan and Ghanbarzadeh, 2025b). Similar overfishing trends have been observed in other freshwater and marine systems, including the Caspian Sea and various Turkish reservoirs, where poor enforcement, inadequate stock assessments, and unregulated harvest have contributed to the decline of economically important species such as sturgeon, Carp, and Asp (Bahrami Kamangar and Rostamzadeh, 2015; Fazli *et al*., 2020; Mohebbi, 2021; Fazli *et al*., 2023). Besides overfishing, factors such as extensive habitat pollution and considerable chemical fluctuations in aquatic environments have contributed to this decline (Khanipour *et al*., 2018). Furthermore, Wels catfish is also highly valued for its quality flesh, which in European markets commands higher prices than common carp, trout, sterlet, and frozen marine fish (Linhart *et al.,* 2002). Locally, given the similarity of Wels catfish meat to sturgeon, in recent years, it has been harvested in large quantities in the Aras Dam reservoir and sold as sturgeon meat, leading to a severe depletion of its local stocks (Behmanesh *et al.,* 2022). Neglecting the management of these resources has led to the depletion of marine stocks, resulting in irreversible socio-economic consequences (Ojelade *et al*., 2019).

The length-weight relationship of Wels catfish in the Aras Dam reservoir was calculated, and the coefficients *a* and *b* were estimated. The slope of the regression line for the length-weight relationship did not significantly differ from 3, indicating isometric growth. Kahraman *et al*. (2014) reported the length-weight relationship of this species in the Sakarya River, Turkey, as $W = 0.0032L^{3.2216}$, indicating positive allometric growth. Alp *et al.* (2011) reported the length-weight relationships for males and females in a Turkish dam lake as $W = 0.0104L^{2.9133}$ and $W = 0.0038L^{3.1295}$, respectively. Annual length-weight relationships may vary seasonally depending on sexual maturity, diet, stomach fullness, sampling techniques, sample size, regional or seasonal effects, and sampling duration (De Giosa *et al.,* 2014; Orduna *et al.,* 2023). Unfortunately, approximately 70–75% of fish in this major aquatic resource are harvested illegally by unauthorized local fishers (Mohebbi, 2021), undermining regulatory efforts, diminishing economic returns, and threatening local livelihoods; finally causing serious damage to the regional fisheries and local employment. This scenario parallels conditions in the Caspian Sea and other regional water bodies, where lack of enforcement and insufficient awareness of stock status have led to unsustainable exploitation and fisheries collapse (Bahrami Kamangar and Rostamzadeh, 2015; Fazli *et al.,* 2023).

The study's findings have direct management implications. If current fishing practices continue without intervention, the Wels catfish population—and potentially other key species—face severe depletion, which would have significant ecological consequences. Therefore, understanding the status of species stocks within an ecosystem can prevent irreversible depletion and facilitate optimal management for stock recovery. Accordingly, fisheries management authorities should implement a suite of strategies including strict enforcement against illegal fishing; the establishment and enforcement of species-specific annual allowable catch limits based on scientifically determined reference points, protection and restoration of spawning and nursery habitats to enhance recruitment and long-term population resilience; continuous monitoring of stock status, growth patterns, and environmental conditions to facilitate adaptive management and community engagement and awareness programs to encourage responsible fishing practices and stakeholder compliance. Modern stock assessment tools such as CMSY^{++} provide robust frameworks for fisheries management by integrating catch-based modeling with predictive algorithms, addressing the limitations of traditional assessment methods. By combining modeling outputs with field observations, managers can make informed, ecosystem-based decisions to ensure ecological sustainability and the long-term resilience of fish populations. Incorporating these approaches into adaptive management cycles allows periodic reassessment of stock status and adjustment of management measures in response to changing environmental conditions.

Conclusion

This study highlights the urgent need for coordinated management of Wels catfish in the Aras Dam reservoir. CMSY^{++} modeling outputs, showing a decline in catches from 2013 to 2022 along with corresponding reductions in biomass, confirm that the population is experiencing unsustainable exploitation. The combination of biological indicators and advanced modeling provides a comprehensive understanding of stock status and informs actionable strategies for sustainable fisheries management. Implementing these measures will help prevent stock collapse and support the long-term ecological integrity of the Aras Dam reservoir. Future research should focus on quantifying the effects of environmental stressors, evaluating the effectiveness of management interventions, and refining adaptive management strategies to ensure the long-term sustainability of the fishery.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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