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Stock status and future perspectives for pikeperch, *Sander lucioperca* in Aras Dam Reservoir, Northwest Iran

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ABSTRACT
Pikeperch, *Sander lucioperca* is a commercially valuable species with a high market acceptance. Its stocks are declining due to environmental disturbances, pollution, and especially overfishing. One of the main feeders of the Caspian Sea is Aras River, and the Aras Dam reservoir is one of the main inland fisheries sources in Northwest Iran. The most recent catch maximum sustainable yield (CMSY++) model was applied to estimate fisheries reference points of pikeperch in Aras Dam reservoir using catch data from October 2013 to March 2022 for applying fast management strategies, in addition to biometric data during the fishing season in 2023 for calculating the length-weight relationship. The values of both B/BMSY and F/FMSY were estimated to be smaller than 1.0. The MSY was estimated as 20.3. In 2013 and 2014, the amount of catch was more than the MSY, and the species has been under fishing pressure. Due to the high fishing pressure, the amount of catch has always been lower than the MSY in the following years. In this situation, the biomass is less than the BMSY, which has created a critical condition for pikeperch stock in the Aras Dam reservoir. In general, the continuation of this trend and the failure to adjust the exploitation of this stock will lead to stock reduction and depletion. Therefore, the estimations obtained from the modeling of this study recommend that the policy makers and fisheries managers to adjust illegal fishing and pay attention to the annual harvest limit for pikeperch stock, as well as protection of the nursery grounds for sustainable fisheries in the Aras Dam reservoir.

Keywords: Pikeperch, Sustainable fisheries, Stock status, Data limited method, $CMSY^{++}$, Aras Dam reservoir.

INTRODUCTION
Pikeperch, *Sander lucioperca* is a key predatory fish species, member of the percid family, lives in both fresh and brackish waters and is a commercially valuable species with a high market acceptance (Steenfeldt *et al.* 2015). The fast-growing trait of pikeperch compared to other percids improves its great potential and makes it a notable species for both commercial and recreational fishers (Arlinghaus & Mehner 2004; Policar *et al.* 2019). It also plays important ecological and regulatory roles (Ranåker *et al.* 2014). Inland aquatic ecosystems and the majority of freshwater fish species are mainly exposed to human impacts, habitat degradation, pollution, and climate change (Reid *et al.* 2019). Hence, its stocks are declining and its status is uncertain due to overfishing, environmental disturbances and pollution (Mustamäki *et al*. 2014; Jakubavičiūtė *et al*. 2022; Falahatkar *et al.* 2024). Decrease in pikeperch abundance is also reported due to overfishing or even recreational catches as to be the main driver for the population declines (Falahatkar *et al.* 2018; Andrašūnas *et al*. 2022; Dainys *et al*. 2022; Jakubavičiūtė *et al*. 2024). In Iran, annually, for recovery program, millions of fingerlings are released into the rivers of the Caspian Sea to enhance fish stocks artificially (Falahatkar *et al.* 2018). Most of the wild broodstocks are captured from the reservoir behind Aras Dam in Northwest Iran by beach seine net during the late fall and

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Received:
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winter (Falahatkar *et al.* 2018). Unfortunately, there is no data on the survival of pikeperch after releasing into the water bodies. In 2021, over 1.8×10^6 pikeperch fingerlings with a mean weight of 1–1.5 g were released into the Aras Dam reservoir by the West Azerbaijan Fisheries Office, Northwest Iran; however, the restocking program was not continued in the following years in this reservoir.

One of the most feeders of the Caspian Sea is Aras River, an important internationally, originates from Turkey, across from Armenia, Iran, and Azerbaijan. It has specific hydropolitical interactions, socio-economic and ecological consequences (Mirzaei *et al*. 2020; Hajihoseini *et al.* 2023). Inland and coastal fisheries are vital to local communities (Lynch *et al*. 2016; Funge-Smith 2018). One of the main inland fisheries sources in Northwest Iran is Aras Dam reservoir, harvesting annually over 3.7×10^3 metric ton (mt) legally and illegally (Mohebbi 2021; Sattari *et al*. 2024) from more than 12 species of overall 27 species in the Aras River ecosystem (Abbasi & Sarpanah 2001) and supports local fisherman's economy. Unfortunately, the catch of pikeperch in Aras Dam decreased due to overfishing and illegal fishing which concerns local legal fisherman economy. Moreover, Aras Dam is highly important as supplying wild pikeperch broodstocks for other fish hatchery centers for the Caspian Sea restocking program (Falahatkar *et al.* 2018). Therefore, this ecosystem is vital for both local and other regions of Iran.

Globally, the status of many fish populations remains almost unexplored and unassessed, which magnifies the potential of stock depletion risk or inadequate management measures (Hilborn *et al*. 2020). It's confirmed, the data-poor or data-limited status of most inland fisheries and therefore rarely estimated with standard quantitative stock methods (Jakubavičiūtė *et al*. 2024). Recent progress in data-limited methods such as that of the Catch Maximum Sustainable Yield (CMSY; Froese *et al.* 2013; Rainer *et al.* 2017) help data-poor stocks to estimate fisheries reference points for better understanding of stock status of fish and finally apply relevant management strategies. It is widely applied for evaluating stocks of different fish species; about 400 European stocks (Froese *et al*. 2018), Chinese fisheries (Ju *et al*. 2020; Andrašūnas *et al*. 2022; Sarr *et al*. 2023; Chen *et al*. 2024) and Iran (Haghi Vayghan *et al.* 2021; Haghi Vayghan & Agh 2022; Haghi Vayghan & Ghanbarzadeh 2022; Haghi Vayghan & Ghanbarzadeh 2023). In Europe, Jakubavičiūtė *et al.* (2022, 2024) concluded that the data-limited stock assessment methods are practical for fast assessing fish population status and confirmed an urgent need to improve pikeperch scientific monitoring and assessment of recreational catches. Overall, data-limited methods are specifically important in light of quick oscillating environmental conditions and increasing information regarding to fishing, especially unknown stocks. Therefore, in this study, we assessed pikeperch stock status in Aras Dam reservoir using the recent CMSY^{++} methods and the length-weight relationship of this commercially important species to find out the fisheries reference point for policy makers to move towards sustainable fisheries.

MATERIALS AND METHODS

Study Area and Fisheries Data

Aras River is one of the most important and largest rivers in Northwest Iran (Fig. 1), reaches the Caspian Sea after joining the Kurastream (Çelekli *et al*. 2019). Its fish diversity comprises over 27 detected fish species (Abbasi & Sarpanah 2001). The sources of the catch time series data from beach seine net fishing (950 m length, 18 m heigh and 35 mm center part mesh size) for the last 10 years from 2013 to 2022 were collected from the West Azerbaijan Fisheries Office, Northwest Iran and entered into the CMSY^{++} model to calculate stock indices. Legal fishing time by fishing companies starts in late September and finishes in early April due to the policy of fisheries office.

Biometric data and length-weight relationship calculation

In order to obtain the length-weight relationship of pikeperch, 407 specimens were investigated by referring to Fishing Cooperatives once a week for six months (October 2023-March 2024). Each specimen was measured for total length (TL) to the nearest 0.1 cm and weighted to the nearest 0.1 g using a measuring board and a digital scale, respectively.

Parameters of the length–weight relationship were calculated by fitting the power function to length and weight data (Equation 7).

$$W = a \times (TL)^b \qquad (7)$$

where, W is the weight (g), TL is the total length (cm), *a* is the intercept and *b* is the allometry coefficient (Le Cren 1951). Pauly (1984) *t* test was used to determine if the slope of relationships was significantly different from 3. The test was significant when $p < 0.05$.

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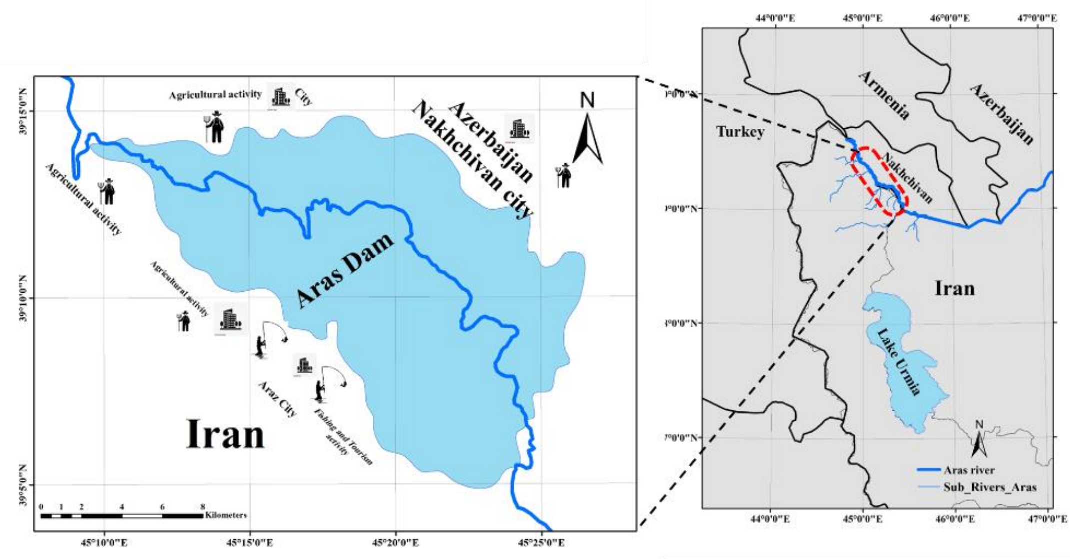

Fig. 1. Aras Dam Reservoir and fishing location in Northwest Iran.

The CMSY^{++} method

CMSY^{++} is an advanced state-space Bayesian method for stock assessment that estimates fisheries reference points (MSY, F_{MSY}, B_{MSY}) as well as status or relative stock size (B/B_{MSY}) and fishing pressure or exploitation (F/F_{MSY}) from catch and (optionally) abundance data, a prior for 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. This model is a more advanced model from the Catch-MSY model developed by Martell & Froese (2013), and the basis of both of these models is the modified Schaefer surplus production model, which allows the fitting of abundance indicators if such information is accessible. The CMSY^{++} version is a further development of the CMSY method presented in Froese *et al*. (2017), which overcomes several of the disadvantages of CMSY. A major improvement for CMSY and BSM is the introduction of multivariate normal priors for r and k in log space, replacing the previous uniform prior distributions. This allowed also for a simplified determination of the 'best' r-k pair in CMSY and faster run times.

The CMSY^{++} is based on the first derivative of the logistic curve of population growth, with numbers of individuals replaced by the sum of their body weights (Schaefer 1991) Equation 1:

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

where 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. Present of these lognormal error terms is left in subsequent equations. Thus, if a plausible estimate of start biomass and k is accessible to determine the unexploited and initial stock size, and if a reasonable estimate of r can be assumed from life-history traits [as done in FishBase; Froese & Pauly (2023)], a time series of biomass, based on the time series of catches, can be projected, with maximum sustainable fishing mortality $F_{\mathrm{MSY}} = r/2$ and minimum biomass that can produce maximum sustainable yield (MSY) as $B_{\mathrm{MSY}} = k/2$. This approach, is known as "stochastic reduction analysis" (Kimura & Tagart 1982; Walters *et al.* 2006).

If the stock biomass is severely depleted and falls below 0.25 k, recruitment will often be reduced; this is expressed by Equation 2being slightly modified in Equation 1:

$$B_{t+1} = Bt + \left(\frac{4Bt}{k} r\right)\left(1 - \frac{Bt}{k}\right) Bt - C_t | \frac{Bt}{k} < 0.25 \qquad (2)$$

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.

Caspian J. Environ. Sci.
Received:
DOI:
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The Schaefer model can be declared as a function of r and MSY, without k (Equation 3); however, this adjustment does not change the dynamics of the model and the new term for surplus production seems less intuitive than the original one (Equation 1):

$$B_{t+1} = B_t + r.B_t - \frac{(rB_t)^2}{4MSY} - C_t \qquad 3)$$

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 4:

$$(B/k)_{t\,prior} = \frac{1 + A_t\sqrt{1 - C_t/MSY_{prior}}}{2} \qquad (4)$$

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

This equation details how a point estimate of relative equilibrium biomass (B/k) was 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 5:

$$\frac{C}{MSY} = (4\frac{B}{k} - (2\frac{B}{k})^2 \,.RC \qquad (5)$$

where RC indicates recruitment correction with RC = 4 B/k if $B/k < 0.25$ and RC = 1 otherwise (same as in Equation 2).

The equilibrium curve for the Fox (1970) model was estimated from Equation 6:

$$\frac{C}{MSY} = e\frac{B}{k}\,(1 - \log\left(e.\frac{B}{k}\right)) \qquad (6)$$

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.

The program in R studio which implements the CMSY^{++} method (Froese *et al*. 2023) was used to estimate the status of fishery stocks in the Aras Dam reservoir for the species. Furthermore, the Bayesian state-space Schaefer surplus production model (BSM; Millar & Meyer 1998) that is part of CMSY^{++} R-code was applied to calculate for variability in both population dynamics (process error) and measurement and sampling (observation error) (Thorson *et al.* 2014; Froese *et al*. 2017). At the end of running CMSY^{++} estimates routine fisheries reference points to explore the stock status of the species. All data files and R-code of the method were available in the Supplement of Froese *et al*. (2023).

RESULTS

The Catch trends of pikeperch in Aras Dam reservoir is shown in Fig. 2. According to the trend, the annual catch of pikeperch decreased from 2013 to 2022 in this reservoir.

The main parameters of fisheries reference points for pikeperch, according to CMSY^{++} were estimated by the model and presented in Table 1. The model showed that the biological reference points of both B/B_{MSY} and F/F_{MSY} were mostly smaller than 1.0. This is an indication of the overfished of pikeperch in the Aras Dam reservoir (Fig. 3B).

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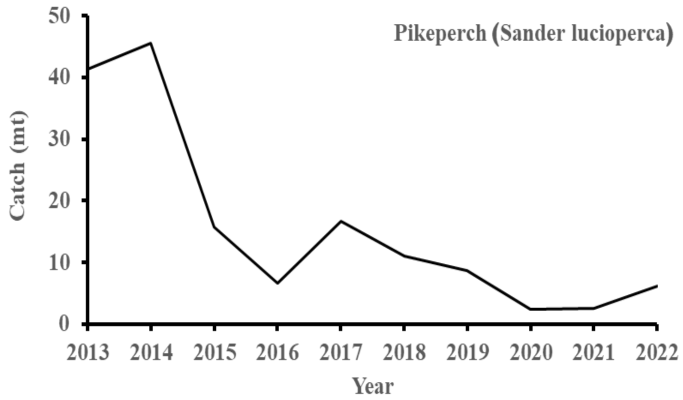

Fig. 2.The Catch trends of pikeperch, *Sander lucioperca* in the waters of the Aras Dam reservoir from 2013 to 2022.

CMSY^{++} output of predicted total catch versus MSY graph indicated the decreasing trend of fishing from 2013 to 2022. Despite this, a slight decrease in the size (biomass) of the stock has been observed during these years (Fig. 3C). Based on the obtained fisheries reference points, the MSY was estimated as 20.3 mt. In 2013 and 2014 the amount of catch has been more than the MSY. In fact, the species has been under fishing pressure, and due to the high fishing pressure during the mentioned years, the amount of biomass has decreased drastically. In addition, in the following years, the amount of catch has always been lower than the MSY.

According to the Kobe plot and the stated conditions, the pikeperch of Aras Dam reservoir has been overfished (Fig. 3B). In this situation, the current biomass of the stock is less than the biomass of the MSY, which has created critical condition for pikeperch stock in the reservoir.

The matrix of the length-weight regression equations of the pikeperch population along with associated correlation coefficients (r), allometric coefficients b and constants a are presented in Fig. 4. Pauly's t test showed that the b was significantly higher than the theoretical value of 3 ($p < 0.05$) indicating a positive allometric growth type for the population of pikeperch in the Aras Dam reservoir.

Table 1: Fisheries reference points by CMSY++ method for pikeperch, *Sander lucioperca* (values in parenthesis represent the 2.5th and 97.5th percentiles). Indicators are based on thousand mt.

Fisheries Reference point	**Estimated values (minimum-maximum)**
Biomass in last year	0.439(0.21-0.76)
MSY	0.0203 (0.0143 - 0.0303)
B_{MSY}	0.569 (0.418 - 1.11)
F_{MSY}	0.0357 (0.019 - 0.0494)
B/B_{MSY}	0.62 (0.383-0.862)
F/F_{MSY}	0.362 (0.194-0.838)
F	0.0105(0.00554-0.0221)
Relative biomass in last year	0.31 k (0.191-0.431)
K	1.14 (0.836 - 2.22)
F/(r/2)	0.362 (0.194-0.838)
(r)	0.0714 (0.0381 - 0.0989)
B/K	0.39
Depletion level	Medium
B/k range	0.439(0.21-0.76)
Trophic level	4

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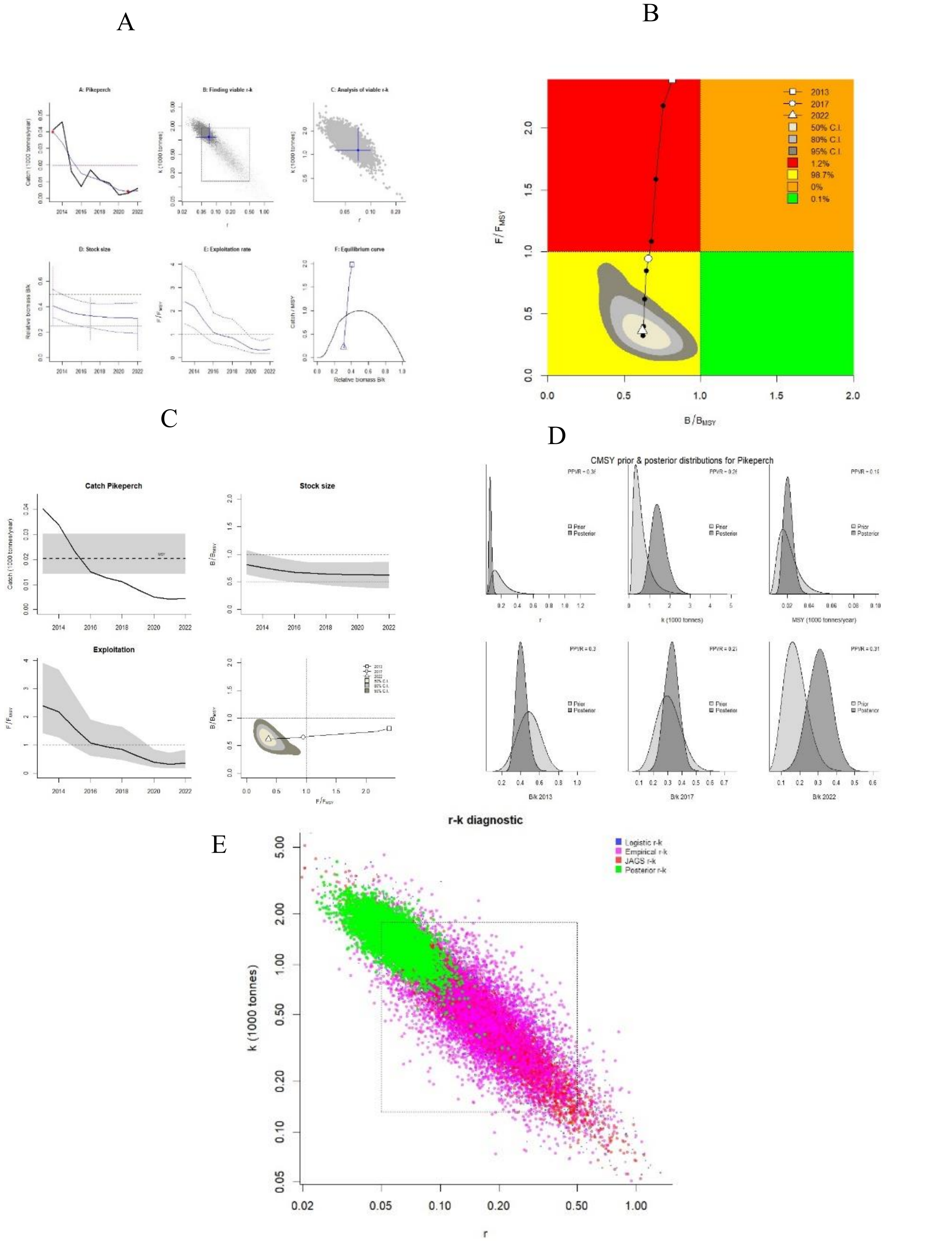

Fig. 3. Results of catch-maximum sustainable yield (CMSY++) model for pikeperch, *Sander lucioperca* in the waters of the Aras Dam reservoir from 2013 to 2022. A: shows the time series of catches and smoothed data as used in the estimation of prior biomass by the default rules; B: is a Kobe phase plot; C: shows the stock status and catches relative to MSY (dashed line) as estimated by CMSY++, with indication of 95% confidence limits in light grey, D: Comparison of prior and posterior densities; E: Diagnostic plot of different methods to generate prior distributions for r and k.

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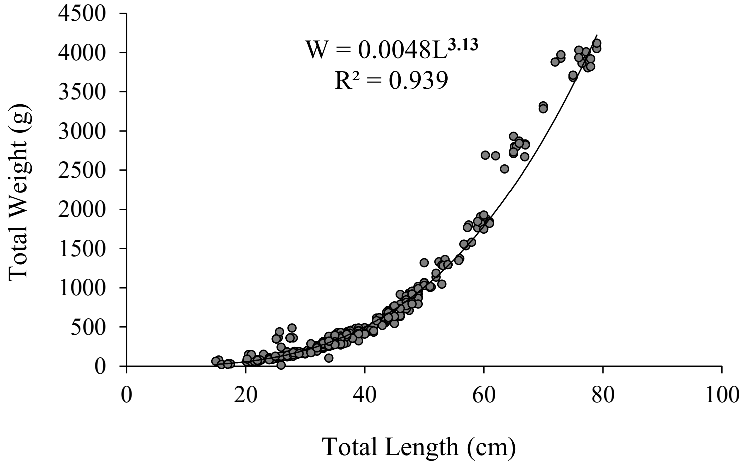

Fig. 4. Length-weight relationship of pikeperch, *Sander lucioperca* in the Aras Dam reservoir.

DISCUSSION

Most of stock assessment models need a lot of data making their performance generally limited to worthy- or very abundant- species (Harley *et al*. 2011; Harley *et al*. 2014); however, less mind is paid to other species (Pauly 2006; Costello *et al*. 2012; Costello & Ovando 2019). In this regard, over 80% of the world's fisheries by numbers and approximately half by catch do not have formal analytical assessments (Costello *et al*. 2012; Hilborn *et al*. 2020). However, science-based catch limits are essential knowledge for effective fishery management (Melnychuk *et al*. 2017). MSY is frequently applied as a reference point for fishery stock assessment, and the status of the fishery is usually reported in terms of B/B_{MSY} (Schaefer 1954; Costello & Ovando 2019). Understanding of the nature of stock dynamics is of great importance for the prevention of stock depletion and for rebuilding depleted stocks. In this study, $CMSY^{++}$ which is a latest data-limited stock assessment method was applied to estimate the exploitation status of pikeperch, *Sander lucioperca* stock in the Aras Dam reservoir. This new version of CMSY model has also been used for determination of other stock status worldwide (Froese *et al*. 2023). A key advantage of applying this approach was that it works in data-limited stocks (catch time series), yet calculates results that can aid policy and government decisions at national and regional levels. According to the results, the biological reference points of *B*/*B*MSY and *F/FMSY* based on $CMSY^{++}$ method were estimated smaller than 1.0 for pikeperch, indicating the overfished status of this species in recent years in the Aras Dam reservoir. Factors such as overfishing, as well as environmental factors that affect survival of stocks, are considered to be factors affecting the pressure on various stocks (Mateus & Estupiñán 2002).

In general, today, marine resources play an important role in the economic, social and nutritional development of human societies in the world, and the lack of resource management leads to damage to marine stocks, resulting in irreparable economic and social consequences (Clark 2006). Damage to economic stocks in the Aras Dam reservoir has also been reported for the common carp, *Cyprinus carpio* (Haghi Vayghan & Ghanbarzadeh, Unpublished data) and the freshwater Crayfish, *Astacus leptodactylus* (Haghi Vayghan & Agh 2022) due to overfishing. In other water resources, including the Caspian Sea, stocks of bony fish, including pikeperch, have declined in recent decades. Abdolmalaki (2005), evaluated the status of pikeperch stock in the Iranian coastal of the Caspian Sea during 2000-2001, reporting that the amount of catch was more than MSY and identified overfishing as the most important factor reducing the stock of this species in the region. Also, Abdolmalaki and Ghaninezhad (2001) reported that overfishing of the pikeperch stocks in 1994 caused a sharp decline in the catch of this species (80%) in 1995 in the Caspian Sea. $CMSY^{++}$ output of the present study showed a decreasing trend of pikeperch fishing from 2013 to 2022 in the Aras Dam reservoir and the MSY was estimated as 20.3 mt. In 2013 and 2014 the amount of catch has been higher than the MSY. In fact, the species has been under fishing pressure, hence, the amount of biomass has decreased drastically. In this situation, the biomass is less than the B_{MSY}, which has created critical condition for this stock. Pikeperch as a bony fish is a commercially important species and its catch has been fluctuated in recent years. In 2022, more than 252 mt of legal and nearly 410 mt of illegal and legal catch has been recorded in the Aras Dam reservoir, about 2.4% was related to pikeperch (based on West Azerbaijan fishing data). In the Aras Dam reservoir, pikeperch is supplying highest commercial value, with annual

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catches of 41.4 to 6.2 mt from 2013 to 2022 (declining trend, Fig. 2). There have been various concerns raised over the sustainability of this fishery, as many fisheries harvest a large proportion of the pikeperch soon after or even before reaching maturity, recreational fishing pressure may be intense. Decreasing water quality, overfishing, predation, and destruction of spawning grounds have also been contributing to the population decline. In recent years, because of two factors including overfishing and the destruction of nursery grounds of pikeperch due to human activities, the stock biomass (size) of this species has been greatly reduced, and as a result of this fishing pressure and depletion of the stock, in the years after 2013, the amount of harvesting has never been able to reach the MSY which has created fragile conditions for this stock in the Aras Dam reservoir. Jakubavičiūtė *et al*. (2024), assessed the status of nine pikeperch stocks across six European countries using Bayesian surplus production model (BSM) and reported that three stocks were strongly depleted, with estimated biomasses considerably lower than the biomass at maximum sustainable yield (B_{MSY}). Other stocks were close to their estimated B_{MSY}.

In general, the continuation of this trend and the failure to adjust the exploitation of this stock, will lead to stock reduction and depletion. Therefore, the estimations obtained by this study recommend to the decision makers to adjust fishing pressure, manage illegal fishing activities, set the annual harvest limit for pikeperch, and protect the nursery grounds in the Aras Dam reservoir.

Length–weight relationship parameters (*a*, *b*) are used to assess fish stocks and populations (Ricker 1954; Tang 1985). The length-weight relationship is also used to estimate the average weight for a given length group, and converting length observations into weight provides a measure of biomass (Froese & Rainer 2006; Froese *et al.* 2011). In the current study, the *b* value was within the expected range of 2.5–3.5 (Froese & Rainer 2006). The value of *b* for pikeperch was 3.13, indicating a tendency towards positive allometry according to the *t* test ($p < 0.05$). Altay *et al.* (2023) showed that the *b* value in the length-weight relationship of pikeperch in Beyşehir reservoir was 2.921. Pérez-Bote & Roso (2012) in the Alcántara Reservoir, South-western Spain estimated the *b* value of the male and female pikeperch were 3.09 and 3.16 respectively. Akbarzadeh *et al*. (2009) and Abdolmaleki (2004) reported the b value of the length-weight relationships of pikeperch in the Aras Dam reservoir and Caspian Sea were lower than 3, hence its growth pattern was negative allometric. The length-weight relationship parameters (*a*, *b*) of the fish are affected by a series of factors such as season, habitat, gonad maturity, sex, diet, stomach fullness, health, preservation techniques, and annual differences in environmental conditions (Froese & Rainer 2006). Such differences in values b can be ascribed to one or a combination of most of the factors including differences in the number of specimens examined, area/season effects, and distinctions in the observed length ranges of the specimens caught, to which duration of sample collection can be added as well (Moutopoulos & Stergiou 2002).

CONCLUSION

This study determined the stock status of pikeperch in the Aras Dam reservoir by combining recent $CMSY^{++}$and length-weight relationship methods and recommended the adjustment of annual harvest as the simple fisheries management strategies, particularly for data-poor stocks to guarantee the sustainable yield of this species in this reservoir. Due to the high fishing pressure, the amount of catch has always been lower than the MSY in the following years. Hence, the biomass was less than the B_{MSY}, which has created critical condition for pikeperch stock in the reservoir. In general, the continuation of this trend and the failure to adjust the exploitation of this stock, will lead to stock reduction and depletion. Therefore, the estimations obtained from the data-limited modeling recommend to apply an urgent policy by decision makers and fisheries managers to adjust illegal fishing, and pay attention to the annual harvest limit for pikeperch stock and protection of the nursery grounds for sustainable fisheries in the Aras Dam reservoir. We also recommend that catch only methods could be treated as a temporary stepping-stone while sufficient data (e.g. size or age composition) would be available for more reliable methods to be applied.

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Authors contributions

A. H. V was responsible for data collection, formal analysis, and writing original draft. M. Gh was responsible for data curation, writing, reviewing, analysis and editing the manuscript. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST: The authors declare no conflict of interest.

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