Research Article

Stock Assessment of Kawakawa (*Euthynnus affinis* Cantor, 1849) in the Persian Gulf and Oman Sea (Iranian Southern Waters), Using Data Limited Approach

Seyed Ahmadreza Hashemi[1], Mastooreh Doustdar[2], Asadullah Ali Muhammad[3]* and Reza Abbaspour Naderi[4]

[1]Offshore Fisheries Research Center, Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization, Chabahar, Iran; [2]Iranian Fisheries Science and Research Institute, Agricultural Research Education and Extension Organization, Tehran, Iran; [3]Fisheries and Coastal Development Department Government of Balochistan, Pakistan; [4]Iran Fisheries Organization (IFO) Tehran, Iran.

Abstract | To develop a framework for investigating the catch tendency and valuation of the optimized catch limit of the *Euthynnus affinis* (Kawakawa) stock by gathering catch records in the Iranian southern waters. In this study, two methods were used to determine the biological reference points (BRPs) of Kawakawa in Iranian southern waters (the Persian Gulf and Oman Sea). Catch data were gathered for 26 years (1997–2022), and R software and the limited data technique were used to determine the optimal catch limit. During this time, the average catch (Ct) was 22439 tonnes (95% confidence interval 18299 -26638 tonnes), and it has climbed considerably over the previous 20 years (R = 0.88, P <0.05). By using the catch-maximum sustainable yield (Catch-MSY), extension of Catch-MSY (CMSY), optimized catch-only model (OCOM), Regression tree models Zhou-boosted (Zhou-BRT), and stochastic surplus production model in continuous-time (SPiCT), the average (maximum-minimum) maximum sustainable yield (MSY), current biomass to the biomass of MSY (B/BMSY), the ratio of the current fishing mortality to fishing mortality rate of MSY (F/Fmsy), and saturation (S=B/K) ratio were obtained. The maximum sustainable yield (MSY) in several models, the ratio of current fishing mortality to fishing mortality rate of MSY (F/Fmsy), and the current biomass to MSY biomass (B/BMSY) did not differ substantially from the one-sample t-test (P<0.05). The study's previous year's results (mean of B/BMSY=0.94±0.16) indicated that the Kawakawa stock's exploitation ratio is full fishing (full exploitation), and no proposals for increasing the exploitation ratio or fishing effort were made.

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***Correspondence** | Asadullah Ali Muhammad, Fisheries and Coastal Development Department Government of Balochistan, Pakistan; **Email:** asadcemb@gmail.com
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Introduction

Fisheries science helps people make decisions about how to manage fish. This advice might have predictions about how much fish can be caught at different levels of fishing, and it usually includes an estimate of how much effort is needed to catch the most fish without harming the population (King, 2007). To keep fishing at a level that won't harm fish populations, it is imperative to find a balance between how many fish are caught and how many are born and grow. It's important to understand the biology of fish populations so to catch maximum fish as possible without hurting the environment or the fish population (Jenning *et al*., 2000).

Signs of overfishing of key fish species and other aquatic resources have been prominent in recent years. The proportion of fish caught at the biologically sustainable level (BSL) and biologically sustainable level (BUL) was about 90% in 1974 and about 67% in 2016 (FAO, 2018). Total fish capture in Iran reached nearly 800,000 tonnes, of which 720,000 tonnes (more than 90%) came from southern Iranian waters (IFO, 2023).

Today, length-based models such as length-based integrated mixed effects (LIME), length-based spawning potential ratio (LBSPR), and length-based Bayesian models (LBB) and catch-based methods such as maximum sustainable catch (Catch-MSY), Depletion-Based Resource Loss Analysis (DBSRA), Simple Resource Synthesis (SSS), Catch-MSY (CMSY), and Length-based models used in data-poor fisheries globally (known as "data-poor" or "data-limited" fisheries) (Wetzel and Punt, 2015).

Kawakawa (*Euthynnus affinis*) is a type of tuna fish that travels around the top layer of the ocean. It can be found in many warm waters in the Indo-Pacific area. This species lives in the western Pacific Ocean, from Malaysia to Mainland China, Taiwan, and southern Japan (Yesaki, 1989, 1994; TaghaviMotlagh *et al*., 2009; Hashemi *et al*., 2010, Hashemi, 2020). Kawakawa is a type of fish that is often found in shallow waters, and is usually caught in set nets. It can also be caught in gill nets, long lines, and small purse seines, but not as often (Yasaki, 1989, 1994). Between 1997 and 2022, the average amount of Kawakawa caught each year was about 2240 tons (IFO, 2023).

Although kawakawa is an economically significant fish, little is known about its evaluation; several authors have studied different parts of the fish's biology. It appears that the overall capture of kawakawa has risen significantly over the previous two decades. Different aspects of biological work of kawakawa have been done by different authors (Talebzadeh, 1997; Darvishi *et al*., 2003; TaghaviMotlagh *et al*., 2009; Hashemi *et al*., 2010; Hashemi, 2020) however, there hasn't been much study done in Iran on the species' stock assessment. Within this framework, the primary goal of this research is to offer biological benchmarks and additional population dynamics data needed for *Euthynnus affinis* management.

Materials and Methods

A 26-year record of tuna catches (mostly in metric tons) in the Persian Gulf and the Sea of Oman (Iran) (Figure 1) is compiled by an Iranian fishing company (1997 to 2022).

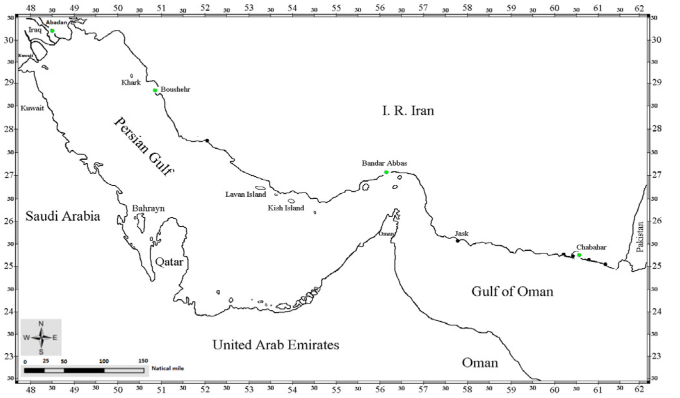

Figure 1: *Location of four sites in Coastal Waters of the Persian Gulf and Sea of Oman.*

Catch-MSY method (SIR algorithm)

Catch-MSY method based on resource reduction analysis (Martell and Froese, 2013), and the dynamic state is based on the Schaefer production model (Martell and Froese, 2013).

$$Bt = \lambda 0k \; expvt \; t = 1$$
$$Bt + 1 = [Bt + rBt\,(1 - Bt / k) - Ct] \; expvt \; t > 1,$$

Bt, Ct, and K represent biomass, catch, and capacity respectively. The method error follows a lognormal structure and νt is independent, with a normal distribution of mean 0 and variance σ2. The initial depletion level λ0 is typically assumed to be 1 for basic stock. Martell and Froese (2013) assigned depletion level ranges for initial and current levels based on their analysis of 98 stocks in the RAM database (Ricard *et al*., 2012). In year one, B/k (λ01, λ02) was 0.5-0.9 for max catch <0.5 and 0.3-0.6 otherwise. In the last year, B/k (λ1, λ2) was 0.01-0.4 for max catch <0.5 and 0.3-0.7 otherwise.

C-MSY (CMSY) method (Monte-Carlo algorithm)

The C-MSY and Graham-Shaefer models share characteristics and both use catch time data to estimate maximum sustainable yield and fisheries reference points. CMSY requires prior distributions on r and k, as well as biomass at the beginning (Froese *et al*., 2017). Subsequent biomass is generated using a Schaefer equation (Martell and Froese, 2013).

$$B_{y+1} = B_y + rB_y (1- B_y / k)\, es^1 - Ct\, es^2$$

This approach computes carrying capacity (K) based on resource saturation (S) and depletion (d) using formulae to determine instantaneous population growth (r). The maximum sustainable yield (MSY) is calculated from MSY = rk/4, and Bmsy = K/2. A tentative range for r is set based on the sustainability of stocks, with highly sustainable stocks assigned r values between 0.6 and 1.5. Population growth rates were calculated using the irf formula, which involves the inverse range coefficient and 3/r high – r low (Froese *et al*., 2017).

To achieve the desired model sampling, the prior process error variance should be 0.2 and the explanatory error must be 0.1 according to (Froese *et al*., 2017). Exploit records for the first and last year are used, and the previous preliminary relative biomass ranges from 0.1 to 0.4, while the most recent relative biomass ranges from 0.2 to 0.65. The initial median relative biomass in 2005 was 0.5 to 0.9 over a year. Martell and Froese (2013) and Froese *et al*. (2017) for CMSY details.

Optimized catch only method (OCOM)

Zhou *et al*. (2016) developed an optimized catch-only method that uses time series data without prior distribution knowledge. The approach employs an infinite dictionary for both r and K, where 0 < K < ∞ and 0 < r < ∞. The maximum K is bounded by r = 0 and the maximum r is bounded by the smallest possible K due to negative correlation between the parameters. The approach aims to find viable ranges for r and K, with the most likely value of r among any combination on the curve. It excludes improbable results through trials, resulting in a posterior-focused catch-based technique for estimating biological reference points (Zhou *et al*., 2016).

This method optimizes final biomass to estimate valid combinations of r and K values for a fixed depletion rate. 500 simulations are run without additional constraints on valid pairs. Unviable trajectories are removed. The Max K = 50 * max (C) and Min K = max (C). Initial K population is set logarithmically between these values for higher density of lower K. The depletion phase ranges from 0.05 to 0.8 in 0.05 increments while r values vary from 0.1 to 2. Biomass dynamics model is run with constraints Bt ≤ K, Bt > 0, and B > C.

Zhou-boosted regression tree models (Zhou-BRT)

Use Zhou-BRT model to estimate saturation (B/K) and B/BMSY time series from catch time series. Zhou-BRT is trained on RAM Legacy database and estimates saturation based on 56 catch statistics. The pre- and post-peak catch, recent subseries, and entire catch time series are all fitted using linear regression coefficients. Values from two BRT models with decreased bias correction (8 and 38 predictors) are used to forecast saturation. B/BMSY is estimated to be twice the saturation, or twice the score of Saturation (S). The upper and lower 95% confidence intervals correspond to the high and low values, respectively. Using the zBRT saturation estimate can provide a depletion prior for advanced depletion analysis, as catch-MSY, DCAC (Dick and MacCall, 2011), DCAC (MacCall, 2009), and catch-MSY. Zhou *et al*. (2018) suggest that this can be a useful tool. In 2018, they used the zBRT method to create a catch-only stock decline analysis and determine preceding 12-month depletion.

Stochastic surplus production model in continuous-time (SPiCT)

The SPiCT model is a type of model that is based on the Pella-Tomlinson model. It allows for different shapes of the production curve, not just a symmetrical one. You can find more information about the SPiCT model and its different options in the book written by Pedersen and Berg (2017). The model has a basic structure that can include errors in the process and what is observed, as well as models that assume there are no errors in what is observed. SPiCT thinks that the numbers of fish caught might have mistaken, and it also tries to figure out how much error there is in estimating how many fish are left in the water (Mildenberger *et al.*, 2020; Cai *et al.*, 2023). The SPiCT can use some general guesses about the production curve and observation errors, or it can analyze the data without any guesses (Biais, 2022). Utilizing the R package spict v.1.2.8, which can be found at https://github.com/DTUAqua/spict. Statistical analyses were performed with R software (R Core Team, 2022), R studio (2022.12.0), SPSS (26) software package and a significance level of 0.05 was adopted.

Results and Discussion

The amounts (1000 t) of trend catch of Kawakawa species showed in Figure 2 and it has a positive and significant correlation with time (sig. 0.95 (0.89-0.98), P<0.05). The average catch (min-max) of this period was 22.4 (7-41), respectively, and the average catch was significantly increase for the twenty-six years (Figure 2).

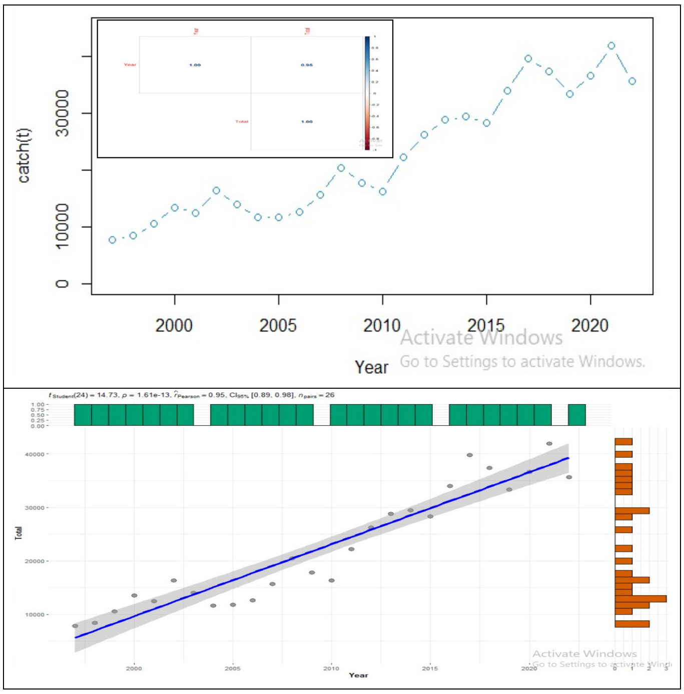

Figure 2: *Fishing trend of Kawakawa in coastal waters of the Persian Gulf and Sea of Oman.*

The software used information about how many fish were caught each year and how fast the fish grow to start making models of the fish populations (initial growth 0.2-0.8 per year). It used a method called Catch-MSY, CMSY, OCOM, ZBRT, SPiCT, and Monte Carlo simulation. The starting amount of living matter was between 0. 5 to 0.9, and the ending amount was between 0. 2 to 0.6. The results from running the Monte Carlo simulation 10,000 times are shown in Table 1. The average values (95% confidence interval) of B/B_{MSY}, F/Fmsy and maximum sustainable yield (MSY) and saturation ($S=B/K=0.5B/B_{MSY}$) ratio are shown in Table 1.

Average (maximum-minimum) of maximum sustainable yield (MSY), biomass of MSY (B_{MSY}) and current fishing mortality to fishing mortality rate of MSY (F/Fmsy) saturation (S = B/K) ratio based on Catch-MSY, CMSY, OCOM, ZBRT, SPiCT model was estimated and the mean reference points show significant difference by statistical tests (P < 0.05), but saturation (S= B/K) ratio have no significant difference (P > 0.05).

A strong and positive correlation has between the B/B_{MSY} values in Catch-MSY, CMSY, OCOM models (P<0.05), and negative correlation with B/B_{MSY} value in SPiCT model (Figure 4). The range of the current biomass to the biomass of MSY (B/B_{MSY}), the proportion between MSY's fishing fatality rate and current fishing mortality (F/Fmsy) and maximum sustainable yield (MSY) and saturation (S=B/K) ratio in different method present in Table 1 and Figure 3.

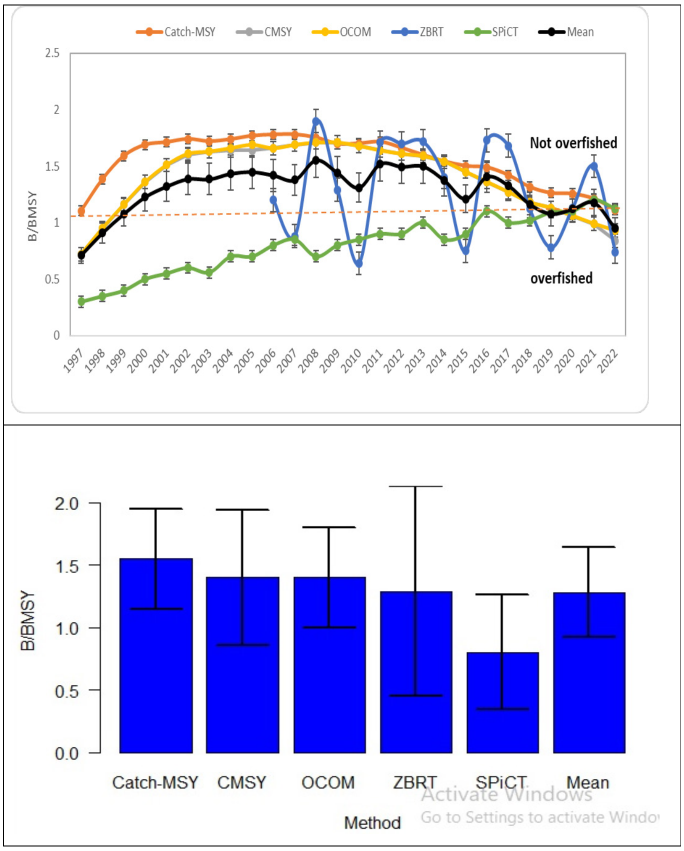

Figure 3: *Comparison of averages and trends B/B_{MSY} value of Kawakawa in Coastal waters of the Persian Gulf and Sea of Oman.*

Links Researchers

Table 1: *Comparison of different indices of data-limited approach for Kawakawa in the Persian Gulf and Oman Sea. The range of the maximum sustainable yield (MSY), current biomass to the biomass of MSY (B/B_{MSY}), the ratio of the current fishing mortality to fishing mortality rate of MSY (F/Fmsy) and saturation (S=B/K) ratio in different method.*

Indices/models	Catch-MSY Mean (max-min)	CMSY Mean (max-min)	OCOM Mean (max-min)	ZBRT Mean (max-min)	SPiCT Mean (max-min)	Mean
MSY (1000 tonnes)	36 (16-66)	27 (24-31)	31 (27-35)	-	33 (18-60)	31±0.4
B/Bmsy	1.55(1.1-1.7)	1.40(0.8-1.97)	1.40(0.5-1.99)	1.29(0.6-1.97)	0.80(0.5-2)	1.28±0.2
F/Fmsy	-	0.28(0.2-0.39)	0.35(0.2-0.45)	-	0.94(0.3-1.2)	0.34±0.06
S=B/K	0.54	0.42	0.44	0.65	0.59	0.55±0.11

Table 2: *Definition of fish stock status, based on indexes in the final year of a time series.*

B/B_0=B/K=S	B/B_{MSY}	F/F_{MSY}	Depletion	Stock status
≥ 0.6	≥ 1	<1	Very low	Healthy stock/under fished stock
< 0.2	0.5 – 1.0	<1	Very strong	Recovering stock
0.2 – 0.4	< 0.5	<1	Strong	Stock outside of safe biological limits
0.4 – 0.6	0.5 – 1.0	>1	Medium	Fully /overfished stock
0.2 – 0.4	0.2 – 0.5	>1	Strong	Stock outside of safe biological limits
< 0.2	< 0.2	>1	Very strong	Severely depleted stock/ Collapsed

Figure 4: *Correlation of B/B_{MSY} value of Kawakawa in Coastal Waters of the Persian Gulf and Sea of Oman.*

This species has moderate flexibility (r= 0.2-0.8) in terms of intrinsic population growth rate, which affects its ability to withstand fishing pressure and recover from declining fish stocks. The intrinsic population growth rate is a critical modeling and fishing management parameter. Different flexibility classifications are assigned based on the rate values: high flexibility (r = 0.6-1.5), moderate flexibility (r = 0.2-1.0), low flexibility (r = 0.05-0.5), and very low flexibility (r < 0.015-0.1) (Martell and Froese, 2013; Froese *et al*., 2018; Zhou *et al*., 2016).

There is a strong correlation between intrinsic population growth (r) and other life history parameters, especially natural mortality (M). The quality model gives r = 1.73M for bony fish and r = 0.76M for elasmobranchs (Zhou *et al*., 2016). In addition, Froese *et al*. (2018) found that the intrinsic population growth rate (r) is approximately twice the maximum fish mortality rate (Fmsy) of the maximum sustainable catch, twice the natural mortality rate (M), 3 times the growth rate coefficient of the von Bertalanffy curve (K), 3 divided by the generation time (tgen) and nine divided through the most age (tmax).

In the present analysis, mean of amount of current biomass to biomass of maximum sustainable yield (B/B_{MSY}) indicated that Kawakawa species is in full exploitation condition (Table 2) for catching fisheries in the Persian Gulf and Oman Sea (Iran). In addition, current level of F/Fmsy calculated as increasing trend and towards complete exploitation situation (Arrizabalaga *et al*., 2012). Fisheries are rated using the B/B_{MSY} metric, with three categories: B/B_{MSY} ≥1/2 is underexploited, 0.8-1.2 is fully exploited, 0.2-0.8 is overexploited, and <0.2 indicates collapse (Branch *et al*., 2011; Anderson *et al*., 2012).

Mean of S= B/K= B/B_0 ratio (biomass relative to carrying capacity) show that this species had medium depletion or healthy stock in the Persian Gulf and Oman Sea (Iran). Based on available resources, stocks with B/K between 0.2-0.6 are fully exploited and those with B/K over 0.6 are lightly exploited.

Exploitation and population biomass impact population growth and sustainable yield biomass (Zhou *et al*., 2016) and our result indicating that don't need to increase fishing efforts for Kawakawa species in the Persian Gulf and Oman Sea. Rebuilding overexploited fishery stocks takes 2-3 times a species' life span (FAO, 2018).

All in all, the ZBRT method calculated more saturation (B/K) than the others, but the differences between these methods were not significant. It is suggested to use average of methods for less error in calculations. Estimating stock status is a first step and not a guarantee for management (Free *et al*., 2020). Using careful effort-based regulations and catch methods can improve B/B_{MSY} status and reduce overfishing risks. However, this approach may result in lower yield compared to more precise determination of status (Walsh *et al*., 2018).

We suggest using catch-only methods as a temporary measure until more reliable options are available. Various COMs have been created to estimate stock status under data limitations; however, these models make simplifying assumptions that increase the chances of bias and uncertainty in their estimates. Using catch-only models can lead to inaccurate and biased stock status estimates, which can impede effective control efforts (Ovando *et al*., 2022).

FAO (1993) says that the reference points (RPs) used in fishery management, such as maximum sustainable yield, are mainly helpful for assessing individual fish populations and not very useful for highly migratory fish like tunas. Many different places catch tuna as they migrate, but they only do it for a short time each year.

Conclusions and Recommendations

According to the terms and situation mentioned conditions assessed, and considering the sustainable fishing requirements, it is not possible to increase the catch of this species in the south of the country. Results of last year in this study (mean of B/B_{MSY}=0.94±0.16) showed that the exploitation ratio in Kawakawa stock is full fishing (full exploitation) and don't increase in exploitation ratio and fishing effort are proposed.

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Novelty Statement

Stock assessment delivers important evidence to know the actual valuation of the fish in the specific area and the growth and development of fish species and can be beneficial for emerging actual management plans for justifiable exploitation of the fish population.

Author's Contribution

Seyed Ahmed Reza Hashemi: Performed the experiment, conceptualization, execution and drafting of the manuscript.
Mastooreh Doustdar: Helped in writing and editing.
Asadullah Ali Muhammad: Helped in literature, format setting, and proofreading.
Reza Abbaspour Naderi: Helped in writing and editing.

Conflict of interest
The authors have declared no conflict of interest.

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