

ORIGINAL ARTICLE

Population parameters and length-weight relationship of frigate tuna, *Auxis thazard* (Lacepède, 1800) in the Persian Gulf and the Gulf of Oman (Hormozgan Province)

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Article history:

Accepted 19 April 2024

Abstract

The frigate tuna, *Auxis thazard* is one of the economic pelagic fish faunas with wide distribution in the coastal waters of the Persian Gulf and the Gulf of Oman (Hormozgan province). This research was conducted to determine the population dynamics parameters of the frigate tuna using the length frequency data collected from 5 main landing sites in the Iranian waters of the Persian Gulf and the Gulf of Oman (Hormozgan province) during a period of 12 months from January 2022 to December 2022. During the study period, 399 fish were examined. The results showed that the range of fork length (FL) and weight of the female fish was 24.1-38.5 cm (with an average \pm standard error of 30.1 ± 0.14 cm) and 0.26-0.95 kg (with an average of 0.46 ± 0.006 kg), respectively and in males were 25-39 cm (with an average of 31.3 ± 0.33 cm) and 0.28-1.1 kg (average of 0.51 ± 0.017 kg). Meanwhile, the mode of FL frequency was observed 28-30 cm (53.6%) in females and 30-34 cm (70%) in males. The b value of the fork length-weight relationship for females and males was 2.67 and 2.75, respectively, which revealed that the growth pattern in both sexes was negative allometric. Von Bertalanffy's growth parameters including FL_{∞} , K, and t_0 were estimated as 44 cm (Y^{-1}), 0.52 (Y^{-1}), and -0.28, respectively. The total, natural, and fishing mortality rates were estimated at 2.38 (Y^{-1}), 1.04 (Y^{-1}), and 1.34 (Y^{-1}), respectively. The recorded result revealed that overfishing occurs on frigate tuna stock in this area.

Keywords: Frigate tuna, Growth and mortality parameters, Allometric growth, Persian Gulf and Gulf of Oman.

INTRODUCTION

The family Scomridae with 52 valid species recorded worldwide (Fricke et al. 2023) and 13 species in the southern waters of Iran (Eagderi et al. 2019) is one of the most dominant pelagic fishes in the Persian Gulf and the Gulf of Oman (Hormozgan province). The frigate tuna, *Auxis thazard* (Lacepède, 1800) is a highly migratory species that spreads in coastal and deep waters of the Atlantic and Pacific oceans (Maguire et al. 2006; Herrera & Pierre 2009). Like other tunas, this fish is one of the important sub-coastal migratory species in the waters of the Indian Ocean and associated seas of tropical and subtropical regions (Ghosh et al. 2012). The maximum depth of the presence of this species has been reported up to 50 meters (Pierre & Herrera 2009). The different methods of catching this species in the Indian Ocean are primarily long lines, hand hooks, and gill nets, and it is often seen as an important species in the implicit

catch of purse seine industrial vessels. According to the reports of the Indian Ocean Tuna Commission (IOTC), catches of frigate tuna are highly concentrated, with 90% of catches accounted for by four countries in recent years: Indonesia (57.5%), Pakistan (12.8%), I.R. Iran (10.4%) and India (7.9%) (IOTC-2020).

This species is one of the dominant tuna fishes in the southern waters of Iran, and in terms of catch, it is after Skipjack tuna, *Katsuwonus pelamis* (Linnaeus, 1758), longtail tuna, *Thunnus tonggol* (Bleeker, 1851), yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788), kawakawa tuna, *Euthynnus affinis* (Cantor, 1849) and Narrow-barred Spanish mackerel, *Scomberomorus commerson* (Lacepède, 1800) in the area so that the catch statistics of the last 3 years show that this species with an average catch of 9610 tons per year, accounts for 3.7% of the total annual catch of tuna fish in southern Iran (Statistical

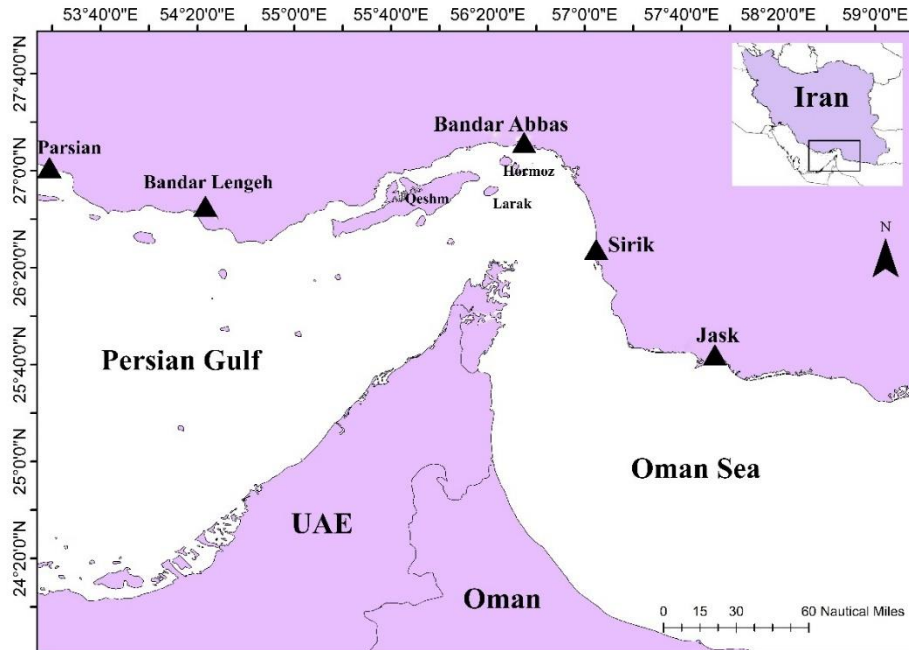


Fig.1. Sampling locality of *Auxis thazard* in the Persian Gulf and Sea of Oman, Iran (filled triangular sign).

Yearbook of Iranian Fisheries 1401).

So far, many studies have been conducted on different species of scombrid fish in the Persian Gulf and the Gulf of Oman (southern waters of Iran), which have more focused on the stock assessment of dominant species in the region (Darvishi et al. 2003) as well as population dynamics and reproduction and feeding aspects of the dominant species in the region, including the *T. albacares* (Kaymaram 2000; Darvishi et al. 2005; Hashemi et al. 2020), *T. tonggol* (Darvishi et al. 2004; Kaymaram et al. 2013; Darvishi 2016; Haghi Vayghan et al. 2021), *S. commerson* (Ghodrati Shojaei et al, 2007; Darvishi et al. 2009; Kaymaram et al. 2010; Hosseini et al. 2015; Hashemi & Doustdar 2021), *S. guttatus* (Hashemi & Doustdar 2022), *K. pelamis* (Hashemi et al. 2021) and *Euthynnus affinis* (Darvishi et al. 2004). The only study, that determined the growth and mortality rates and exploitation ratio of the frigate tuna, was conducted by Darvishi et al. (2020). In this study, the population dynamics parameters of the frigate tuna were analyzed in the coastal waters of the Persian Gulf and the Gulf of Oman. Also, the length-weight relationship was evaluated for this species. The recorded results can provide the information needed for the protection and

optimal catch management of this species in the region.

MATERIALS AND METHODS

Sampling was carried out monthly from five major landing centers of this species in Hormozgan province, from west to east, including Parsian, Bandar lengeh, Bandar Abbas, Sirik, and Jask regions (Fig. 1) for one year from January 2022 to December 2022. The measured biometric data included total length (TL), fork length (FL) with an accuracy of one centimeter, and total weight (W) with an accuracy of 0.1 kg, then, the fish were dissected to determine their sex.

To establish the length-weight relationship, the commonly used relationship $W = aL^b$ was applied (Pauly 1983), Where: W is the weight (kg), L is the fork length (cm), a is the intercept (condition factor) and b is the slope (growth coefficient). A linear equation ($\ln W = \ln a + b \ln FL$) was fitted for log-transformed data. The parameters a and b were estimated using power regression and the coefficient of determination (R^2) to show the fork length-weight relationship. The parameter b is a shape parameter for the body form of the fish species. In theory, one might

expect that the exponent b would have a value of roughly $b=3$ because the volume of a 3-dimensional object is roughly proportional to the cube of length for a regularly shaped solid. Computing b value estimated with 3 was tested by using the t-test (Pauly 1983):

$$t = ((s.d(L)/(s.d(W)) \times ((b - 3)/(\sqrt{1 - r^2})) \times (\sqrt{n - 2}))$$

Where: s.d. (L) is the standard deviation of the ln FL values, and s.d. (W) is the standard deviation of the ln W values, n being the number of fish used in the computation. The value b is different from 3 if t is greater than the table value for t in $n-2$ df. (Pauly 1983).

The values of K and TL_{∞} were estimated for total sex using the von Bertalanffy growth equation:

$$L_t = L_{\infty} (1 - \exp(-K(t-t_0)))$$

Where L_t is the fork length at time t , L_{∞} is the asymptotic length (cm), K is the growth coefficient (Y^{-1}), and t_0 is the hypothetical age when the size of the fish is zero. Considering the number of male fish caught in this research was very low compared to the females, therefore, the data of the combination of the two sexes were used in estimating the growth and mortality parameters. Using input data from length frequencies and the ELEFAN1 program in FiSAT II software, asymptotic length (FL_{∞}) and growth coefficients (K) were estimated for combined sex. To find the best growth curve passing through the maximum number of peaks, different starting samples and starting lengths were subjected to goodness-of-fit tests by assessing the ESP/ASP ratio (R_n).

To have a comparison between the estimated growth parameters of *A. thazard* from this study with those from other studies, \emptyset' (an index for the comparison of growth performance in marine animals with the von Bertalanffy type of growth) was used. Details on growth comparison using \emptyset' as an index are discussed in Pauly & Munro (1984):

$$\emptyset' = \text{Log } K + 2 * \text{Log } L_{\infty}$$

From the estimate of growth parameters (K , FL_{∞}), the instantaneous rate of annual total mortality (Z) was estimated using the length converted catch equation (Pauly 1983). The instantaneous rate of natural mortality (M) was obtained using Pauly's empirical

formula (Sparre & Venema 1998):

$$\ln M = -0.0152 - 0.279 \times \ln L_{\infty} + 0.6543 \times \ln K + 0.463 \times \ln T$$

Where L_{∞} is the asymptotic total length (cm), K is the growth coefficient (Y^{-1}) and T is the annual average of water temperature ($^{\circ}\text{C}$): in the covering area in which it was 27.5°C . Because the schooling behavior reduces the vulnerability of an organism to predation by other aquatic animals, therefore, many researchers multiplied the amount of natural mortality obtained from the above model by 0.8 (Pillai et al. 1993), which in calculating this according to the schooling behavior of this fish, the above-mentioned coefficient was applied to the amount of M for the frigate tuna.

From estimates of the growth parameters (K , FL_{∞}), the instantaneous rate of total mortality (Z) was estimated using a length-converted catch curve in FiSAT II software (Pauly 1983). To estimate the theoretical lifespan, the (t_{max}) of *A. thazard* was obtained using Pauly's formula (1983).

$$T_{\text{max}} = 3/k + t_0$$

Subtracting the estimates of M and Z , the instantaneous rate of fishing mortality (F) is given by:

$$F = Z - M$$

The exploitation rate $E = F / Z$

The biological reference points considered in this research were F_{opt} and F_{limit} (Patterson 1992). where in:

F_{opt} : the optimal fishing mortality rate is equal to 50% of the natural mortality rate ($F_{\text{opt}} = M/2$)

F_{limit} : The limit of the fishing mortality rate is equal to 66% of the natural mortality rate ($F_{\text{limit}} = 2M/3$).

RESULTS

Descriptive statistics and fork length-weight relationship: The fork length (FL) for females and males ranged from 24.1-38.5cm and 25-39cm, respectively. The mean (\pm SE) FL was 30.1 ± 0.14 cm for females and 31.3 ± 0.33 cm for males. The fork length changes of female *A. thazard* showed that the highest average FL was in April and May 2022 and the lowest was in June to July 2022. In males, the highest average FL was observed in March to April 2022, and September 2022, and the lowest average

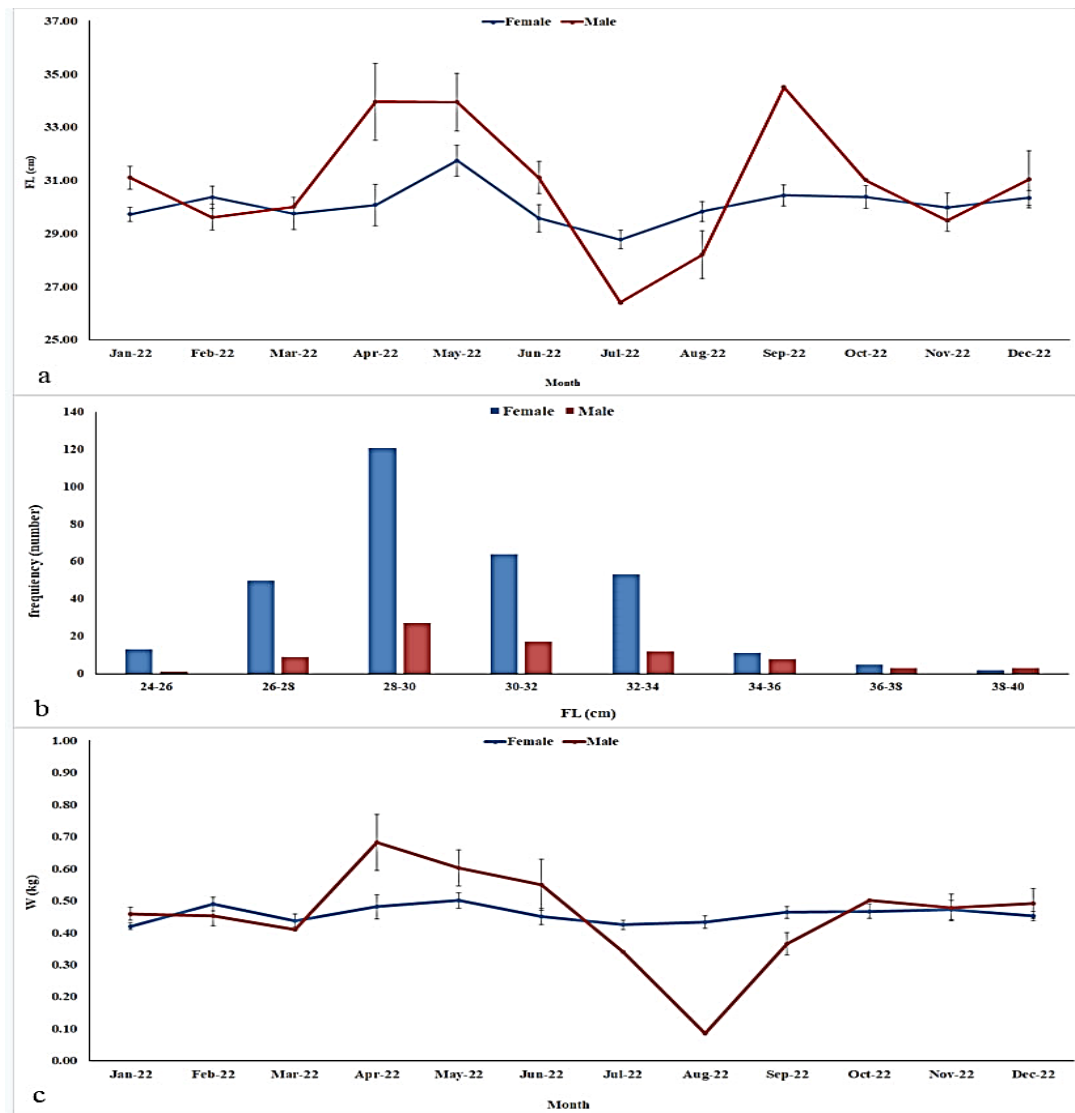


Fig.2. a, fork length changes (mean \pm s.e) in different months; b, the frequency of FL in the study period; c, changes in weight (mean \pm s.e) in different months of male and female *Auxis thazard* in coastal waters of the Persian Gulf and the Sea of Oman, Iran.

fork length was observed in March 2022. Meanwhile, the mode of FL frequency was observed in 28-30cm (53.6%) for females and 30-34 cm (70%) for males (Fig. 2a, b). The range of weight during the study period was 0.26-0.95kg (with an average of 0.46 ± 0.006 kg), and 0.28-1.1kg (average of 0.51 ± 0.017 kg) for females and males, respectively (Fig. 2c).

The Fork length-weight relationship of *A. thazard* had a high R^2 value (Table 1) and the b value for females and males was 2.67 and 2.75, respectively was significantly lower than 3 ($P<0.05$), indicating that growth in both sexes of this species is negatively allometric.

Growth Parameters and Performance Index (Φ'): The

Von Bertalanffy's growth parameters including FL_{∞} , K, and t_0 were estimated as 44 cm, $0.52 (Y^{-1})$, and -0.28 , respectively. Given the recorded results, the fork length of frigate tuna reached 18.16 cm at the end of the first year, 28.64 cm in the second year, and 34.78 cm in the third year. The estimated values for the growth performance index (Φ') of *A. thazard* during the present investigation was 3 for combined sex. In this study, the frigate tuna has at least four cohorts in most months of the year (Fig. 3).

Mortality and Exploitation Rate: The total mortality rate (Z) was $2.38 (Y^{-1})$. The natural and fishing mortality rates of *A. thazard* in the study area were calculated as $1.04 (Y^{-1})$, and $1.34 (Y^{-1})$, respectively. The exploitation rate (E) was 0.56 (Fig. 4). According

Table 1. Length-weight relationship in different sexes of *Auxis thazard* and its components in the Persian Gulf and Sea of Oman, Iran.

<i>A. thazard</i>	Range (Min-Max)		$W=aFL^b$	a	b	n	R^2	t
	FL (cm)	W (Kg)						
female	24.1-38.5	0.26-0.95	$W=0.00005*(FL)^{2.67}$	0.00005	2.67	319	0.85	5.06
male	25-39	0.28-1.1	$W=0.00004*(FL)^{2.75}$	0.00004	2.75	80	0.83	1.72

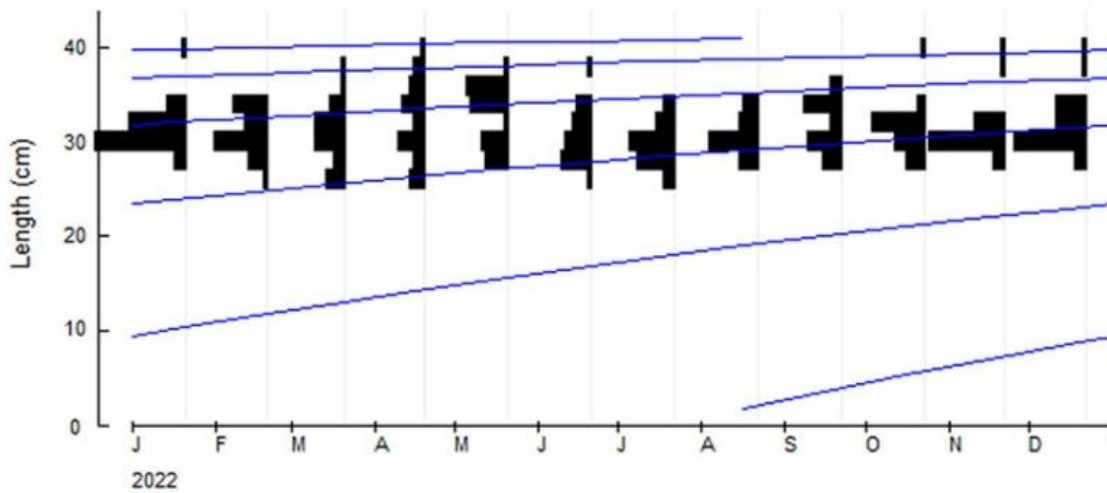


Fig.3. Total length frequency distribution with growth curves of *Auxis thazard* in the Persian Gulf and the Sea of Oman, Iran.

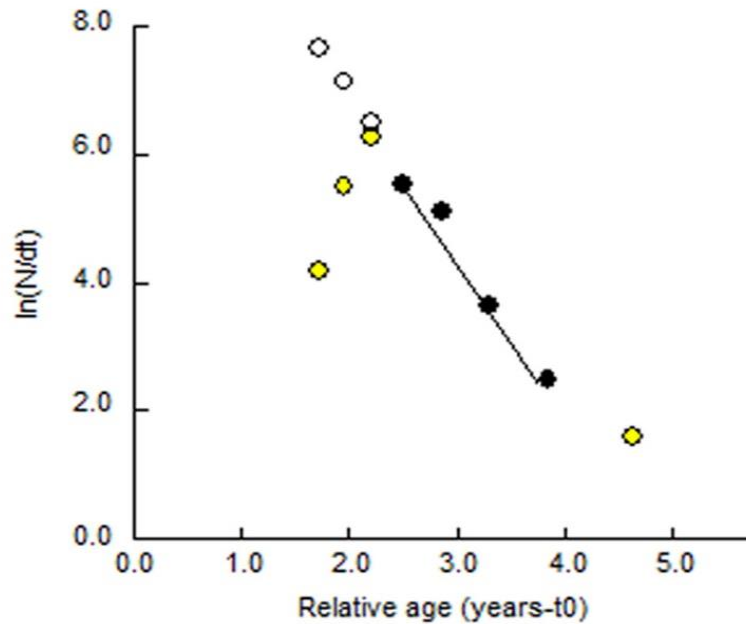


Fig.4. The length-converted catch curve of *Auxis thazard* in the Persian Gulf and the Sea of Oman, Iran.

to the calculation of the natural mortality rate, F_{opt} and F_{limit} values were calculated as 0.52 and 0.68 per year, respectively.

DISCUSSION

In this study, the biometric data of 399 frigate tuna specimens was measured during one year. The FL ranged between 24.1 and 39 cm. Roberts et al. (1997) reported the fork length of *A. thazard* in New Zealand

waters to be between 26 and 41cm, which shows a larger length range compared to the present study. This range for the same species that landed in Thailand waters was 25-45 (Tao et al. 2012). Ghosh et al. (2012) presented the length of fish caught in Indian waters from 18 to 54 cm and the maximum frequency of *A. thazard* was in the length range of 36-34 cm. In the present study, the maximum length frequency of fish was in the length range of 28-30 cm for females and 30-34 cm for males. In other reports on Indian waters, the fork length of frigate tuna in the western region of these waters was reported at 18 to 56cm (Abdussamad et al. 2013), and in the Andhra Pradesh region was recorded between 20 to 46cm (Iswarya & Sujatha 2012). The observed differences in the length sizes of similar species of tuna fish in different regions can be considered affected by used the different fishing gears, the length size of the trapped migrant groups, and the presence of different age groups in the same area and at a certain time (Yesaki 1994).

The length-weight relationship and the estimated components can provide accurate information about the growth pattern of fish, the determination of biomass, and their ecology. Also, used in stock assessment models. These relationships can show valuable information about the fish's living environment, life cycles, and even the health of the species (Froese et al. 2011). In the present study, the value of a and b in the fork length-weight relationship of female *A. thazard* was estimated at 0.0005 and 2.67, respectively. These values in males were 0.0004 and 2.75, respectively, which indicated negative Allometric growth patterns in both sexes. Ghosh et al. (2012) noted the positive allometric growth of this species in Indian waters. They estimated the value of a at 0.001 and 3.17 for b . Bahou et al. (2016) reported the a and b values of the fl-w relationship for female frigate tuna at 0.00723, and 3.206, respectively in coastal marine waters of Côte d'Ivoire. The reason for the difference in the values of a and b can depend on changes in environmental conditions, fish physiology, gender, gonadal development, the amount of food available, time and method of sampling, as well as the study area (Biswas 1993).

The relationship between the length and age of frigate tuna revealed that the fork length of this fish at the end of the first year reached 18.16cm, the second year was 28.64 cm and the third year was 34.87cm. Hamidi et al. (2018) found that *A. thazard* in the waters of western Aceh during a rapid growth process has a length of approximately 48 cm at three years of age. Ghosh et al. (2012) found the length of frigate tuna to be 40.65 cm in the first year and 52.75 cm in the second year in their report in Indian waters. A comparison of the obtained results shows that this species has fast growth, especially up to the age of two years. Scientists believe that the strategy of rapid growth in the early stages of life is a reaction on the part of aquatic animals to avoid predation by other organisms (Lessen & Medley 2001).

In this research, the growth parameters FL_{∞} and K were estimated as 44cm and 0.52 per year, respectively. Usually, the asymptotic length varies from point to point, because the estimate of the asymptotic length is strongly influenced by the largest length found in the population under study (Binohlan & Froese 2000). The asymptotic length value calculated in this research is lower than the values obtained by Hartaty & Setyadji (2017), Ghosh et al. (2012), Abdussamad et al. (2013), and Joseph et al. (1987) and more than the studies by Hamidi et al. (2018), Ghosh et al. (2010). On the other hand, the estimated growth rate is lower than the values reported by Hamidi et al. (2018), Ghosh et al. (2012), Ghosh et al. (2010), and Abdussamad et al. (2013) and more than the calculations presented by Hartaty & Setyadji (2017) and Joseph et al. (1987) (Table 2). One of the obvious characteristics of a stock is that in different periods, its growth parameters are proportional to each other in a specific geographical area (Pauly 1984). The phi prime index is used to compare the growth coefficients of similar fishes (Pauly & Munro 1984). Zapadaeva (2021) has calculated the value of ϕ for the frigate tuna to be 5.1 and in the present study, this value was calculated as 3. The difference in the estimation of growth indices, even though the use of different methods causes differences in its calculations, but the difference in growth indices

Table 2. Population dynamics parameters of *Auxis thazard* in different areas.

FL ∞ (cm)	K	t ₀	M	F	Z	ϕ'	Region	Reference
54.50	1.02	-0.0118	1.53	7.30	8.83	3.48	Indian Sea	Pillai and Ganga (1985)
48.44	0.51	-0.3598	0.90	0.23	1.14	3.08	Taiwan	Zhenbin et al. (1991)
46.60	0.93	-0.0153	1.48	4.49	5.97	3.31	Veraval, India	Ghosh et al. (2010)
57.95	1.20	-0.0075	1.65	4.89	3.24	3.61	India	Ghosh et al. (2012)
48.18	0.52	-0.3319	0.91	0.40	1.31	3.08	Taiwan	Tao et al. (2012)
57.95	1.2	-0.0075	-	-	-	3.61	India	Abdussamad et al. (2013)
48.6	0.48	-	-	-	-	3.05	Northeast Atlantic	Zapadaeva (2021)
44	0.52	-0.28	1.04	1.34	2.38	3	Persian Gulf and Sea of Oman	Present Study

largely depends on the measured length class (Dudley et al. 1992), although Haddon (2011) believes that environmental differences such as access to food, temperature, etc. have a greater effect in this regard.

Total mortality is the basis of the theories related to an exploited stock, and the higher this value, the faster the stock declines and the lower the maximum life span. The total mortality depends on human factors (related to fishing mortality rate) and natural factors (related to natural mortality), and actually, all factors that reduce the survival rate and consequently the stock amount (Cadima 2003). The total, natural, and fishing mortality rates in this study were estimated as 2.38, 1.04, and 1.34 (Y⁻¹), respectively that is lower than the values reported (Table 2) in the Indian waters (Pillai & Ganga 1985; Ghosh et al. 2010, 2012), and more than in the Taiwan waters (Zhenbin et al. 1991; Tao et al. 2012). Hamidi et al. (2018) calculated these values for frigate tuna in the waters of West Aceh as 1.48, 1.46, and 0.02 (per year), respectively. In another study, total mortality was 4.89 (Y⁻¹), natural mortality was 1.65 (Y⁻¹), and fishing mortality was 3.24 (Y⁻¹) reported in Indian waters for this species (Ghosh et al. 2012).

One of the most efficient uses of mortality rates is in estimating exploitation rates. Using the exploitation ratio alone is a quick way to know the status of the stock being harvested. The optimal exploitation ratio of 0.5 is used in fisheries management where little information is available on the age and length structures of stocks (Pauly 1984). In the present study, the exploitation ratio was estimated as 0.65. In the

study by Ghosh et al. (2012), the E value was calculated as 0.66, but since the E_{max} value was higher than the exploitation ratio, the possibility of fishing development was raised. Hamidi et al. (2018) reported the E value as only 0.01 in the waters of West Aceh, based on the proposal to increase the fishing effort. Considering the value of the exploitation coefficient of more than 0.5 in this research and also the higher value of the estimated fishing mortality (1.34 Y⁻¹) compared to F_{opt} and F_{limit} (estimated at 0.52 and 0.68 per year, respectively), it seems that the overfishing occurs on frigate tuna stock in this area.

Given recorded results of this study, more than 50% of the frigate tuna that caught during the year were between 2-3 years old. Also, the mortality and exploitation coefficients estimated revaluated overfishing of *A. thazard* stocks in the region, which requires joint measures by the Persian Gulf and the Gulf of Oman countries, which have same reserves stocks to manage the optimal exploitation of this species.

ACKNOWLEDGMENT

We would like to thank the University of Hormozgan for providing facilities, as well as the fishing community of the Hormozgan province for their cooperation and for creating suitable conditions during the sampling period.

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مقاله کامل

شاخص‌های پویایی جمعیت و رابطه طول-وزن ماهی تون منقوش *Auxis thazard* (Lacepède, 1800) در آب‌های خلیج فارس و دریای عمان (استان هرمزگان)

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چکیده: تون منقوش *Auxis thazard* یکی از ماهیان سطح‌زی با اهمیت اقتصادی بالا و پراکنش وسیع در آب‌های کرانه‌ای دریای عمان و خلیج فارس می‌باشد. این تحقیق با هدف بررسی پارامترهای پویایی جمعیت ماهی تون منقوش با استفاده از اطلاعات جمع‌آوری شده از ۵ مرکز اصلی تخلیه صید آن در آب‌های ایرانی خلیج فارس و دریای عمان (محدوده استان هرمزگان) طی مدت ۱۲ ماه از دی‌ماه ۱۴۰۰ الی آذر ۱۴۰۱ انجام شد. در طی دوره مورد مطالعه تعداد ۳۹۹ ماهی مورد بررسی قرار گرفت. نتایج نشان داد دامنه طول چنگالی و وزن ماهی صید شده ماده به ترتیب ۳۸/۵-۲۴/۱ سانتی‌متر (با میانگین ± 0.14 سانتی‌متر) و ۰/۹۵-۰/۲۶ کیلوگرم (با میانگین ± 0.06 کیلوگرم) و در جنس‌های نر تون منقوش به ترتیب ۲۵-۳۹ سانتی‌متر (با میانگین ± 0.33 سانتی‌متر) و ۰/۲۸-۱/۱ کیلوگرم (با میانگین ± 0.17 کیلوگرم) بود. بیشترین فراوانی طولی جنس‌های ماده در بازه طول چنگالی ۲۸ تا ۳۰ سانتی‌متر (۵۳/۶٪) و در جنس‌های نر در بازه طول چنگالی ۳۰ تا ۳۴ سانتی‌متر (۷۰٪) مشاهده شد. مقدار *b* در رابطه طول چنگالی-وزن برای جنس‌های ماده و نر به ترتیب ۲/۶۷ و ۲/۷۵ به دست آمد که نشان داد الگوی رشد در هر دو جنس ماهی تون منقوش آلومتریک منفی بود. پارامترهای رشد وون برتالانفی شامل *K*، *FL ∞* و *t₀* به ترتیب ۴۴ سانتی‌متر طول چنگالی، ۰/۵۲ (در سال) و ۰/۲۸- برآورد شد. میزان مرگ‌ومیر کل، طبیعی و صیادی به ترتیب برابر با ۲/۳۸، ۱/۰۴ و ۱/۳۴ در سال برآورد شدند. نتایج ثبت شده نشان داد که صید ماهی تون منقوش در این منطقه تحت فشار صیادی است.

کلمات کلیدی: تون منقوش، پارامترهای رشد و مرگ و میر، رشد ناهمگون، خلیج فارس و دریای عمان.