Review

Available online at
www.heca-analitika.com/ljes

Leuser Journal of Environmental Studies

Vol. 1, No. 2, 2023

The Effect of Life History on *Alopias pelagicus* Overexploitation Vulnerability: A Literature Review

Yuni Tri Hewindati [1,*] and Dhian Novita Sari [2]

[1] Program of Biology, Department of Mathematics and Natural Sciences, Faculty of Science and Technology, Universitas Terbuka; hewindati@ecampus.ut.ac.id (Y.T.H)
[2] National Hospital Universitas Diponegoro; dhiannovita01@staff.undip.ac.id (D.N.S)

* Correspondence: hewindati@ecampus.ut.ac.id

Article History

Received 30 June 2023
Revised 24 July 2023
Accepted 2 August 2023
Available Online 8 August 2023

Keywords:
Alopias pelagicus Nakamura 1935
Life history
Inclusion criteria
Overexploitation

Abstract

Alopias pelagicus Nakamura 1935 or pelagic thresher shark is an epipelagic species of shark prone to overexploitation due to its epipelagic habitat and slow life history. In 2019, based on existing data on abundance and exploitation, *A. Pelagicus* was included in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species with the category of endangered (EN). This literature review analyzed the relationship between *A. pelagicus* life history and overexploitation susceptibility. The method used is a comprehensive search of international journals in online databases from ScienceDirect and Google Scholar with certain inclusion and exclusion criteria. Based on the criteria, seven out of 270 search results of international journal articles were included for the analysis. The results from the seven journal articles shows that *A. pelagicus* has a slow life history or k-selected life history. This life history is characterized by slow sexual maturity, low fecundity, long gestation period, annual reproductive cycle, slow growth, long lifespan, and low natural mortality rate. This life history makes *A. pelagicus* prone to overexploitation because if the mortality rate of catching exceeds the natural mortality rate, it will take a long time for *A. pelagicus* to return to their original population size.

1. Introduction

Alopias pelagicus Nakamura 1935 (*A. pelagicus*) or Pelagic Thresher Sharks, belongs to one of three species under the family Alopiidae, order Lamniformes, and class Chondrichthyes [1]. *A. pelagicus* is a widespread pelagic oceanic species found over deep water in tropical and subtropical waters in the Indo-Pacific Ocean [2]. However, Arostegui et al. [3] mention that *A. pelagicus* lives at depths ranging from 200-300 m in the mesopelagic zone and most nights at 50-150 m in the epipelagic zone. In Indonesia, *A. pelagicus* can be found in the waters of the Indian Ocean starting from western Sumatra to southern Nusa Tenggara, South China Sea, Pacific Sea, Makassar Strait, Sulawesi Sea, Banda Sea, and Arafura Sea [4].

Overexploitation of *A. pelagicus* greatly affects the survival of the species. In observations made by White [5] at various fish landing sites in Indonesia, *A. pelagicus* contributed 13% to the total biomass of all sharks recorded. In a study conducted in Alor, East Nusa Tenggara, between July 2018 and May 2019, it was shown that 18.2% of fish caught on fishing lines were A. pelagicus [6]. This is because *A. pelagicus* has a history of slow life that affects the survival, growth, and reproduction of the species [7]. A slow life history means that the species has a slow growth rate with low reproductive output, long gestation period, longer age-at-maturity, long lifespan, large body size, and low population growth rates. According to Rigby et al. [1], *A. pelagicus* has a very low annual population increase of

0.033. The species reproduces viviparously, and the embryo receives nutrition from the mother (*maternal input*) by means of oophagus [8]. *A. pelagicus* reproduces regardless of the seasons. *A. pelagicus* matures sexually at a moderate age and has two embryos per birth where each uterus contains one embryo [5, 9]. If a female gives birth once a year, *A. pelagicus* can produce about 40 embryos per generation [2].

A. pelagicus has different generation lengths depending on where it lives. On average, A. pelagicus has a generation length of 16.5 years in Taiwanese waters and 20.6 years in Indonesian waters. According to Rigby et al. [1], a generation lasts 18.5 years on average around the world. Additionally, depending on where it is, *A. pelagicus* has different age-at-maturity. Female *A. pelagicus* has varies age-of-maturity, from 9 years in Taiwan to 13.2 years in Indonesia, while they live to maximum age of 24 years in Taiwan and 28 years in Indonesia, according to Liu et al. [2] and Drew et al. [10].

A. pelagicus is particularly vulnerable to overfishing because its epipelagic habitat is within the range of small-scale fishing, artinasal gill rings and unregulated fishing rods. This is demonstrated by the population decline trend in the Pacific Northwest, which decreased by 34.3% over the last 20 years [11]. Additionally, between 1990 and 2004, *A. pelagicus* in the waters east of Taiwan had a decline in spawning per recruit (SPR), which suggests a slight overexploitation of the species [12]. According to Dharmadi et al. [13], the capture of *A. pelagicus* also decreased by 34.9% in the Indian Ocean between 2002 and 2007. Furthermore, there was an important decline in CPUE (catch per unit effort) for the Alopiidae family in the West Central Pacific seas between 2012 and 2015. Thus, this decrease in CPUE possibly means that fish populations cannot support harvesting rates [14].

Based on existing data on abundance and level of exploitation, in 2019, *A. pelagicus* was included in The International Union for Conservation of Nature (IUCN) *Red List of Threatened Species* with the category of endangered [1]. Another measure of protection of *A. pelagicus* is the inclusion of *A. pelagicus* in Appendix II of the *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES) in 2016. This means that there must be regulations governing the trading of these commodities on a global scale to ensure that their usage does not jeopardize the sustainability of nature. For protection efforts in Indonesia, it is regulated by Article 73 of the Regulation of the Minister of Marine Affairs and Fisheries No. 30 of 2012. the Regulation of the Minister of Marine Affairs and Fisheries No. 26 of 2013, and Chapter X Article 39 of Regulation of the Minister of Marine Affairs and Fisheries No. 12 of 2012. These regulations restrict fishing permits on the high seas.

Given the importance of *A. pelagicus* sustainability, this study analyzes the effect of life history on *A. pelagicus* overexploitation vulnerability based on an in-depth review of international journal articles published in 2013-2023, specifically on aspects of morphology, reproduction, and growth parameters.

2. Data Collection

Data collection was conducted from April to July 2023. A thorough search of worldwide journal articles published over a ten-year period, from 2013 to 2023, was done for journal articles on *A. pelagicus*. Based on exclusion and inclusion criterias, a search was carried out in online databases using Google Scholar and ScienceDirect. The exclusion criterias are non-research articles, articles which did not explain the life history or exploitation vulnerability of *A. pelagicus*, and unavailable in full-text. The inclusion criteria included keywords "*Alopias pelagicus*" and "*life history, growth, age, reproduction/reproductive, exploitation.*"

The article search flow is presented in Figure 1. The selection of the journal articles using the inclusion criteria were conducted through the following:

1. A search for full-text articles with the keyword "Alopias pelagicus" yielded 270 articles.
2. Based on those 270 articles, selection was made using the keywords "life history, growth, age, reproduction/reproductive, exploitation", resulted in 41 articles.
3. In the 41 article abstracts, a detailed review of the relationship between the life history of *A. pelagicus* and exploitation vulnerability was undertaken, yielding 15 papers.
4. Lastly, in the seven articles, a thorough analysis of the relationship between *A. pelagicus'* life cycle and exploitation vulnerability was carried out, resulted in 7 articles.

The data obtained from seven articles of inclusion search results were analyzed qualitatively by looking at the variables of reproduction age and growth and natural mortality rate to get an overview of the population dynamics of *Alopias pelagicus.* Knowledge of life history and exploitation rate (E) is used to determine the sustainability of fish production management. An in-depth evaluation of reproduction, age and growth, and natural mortality rates yielded the following results.

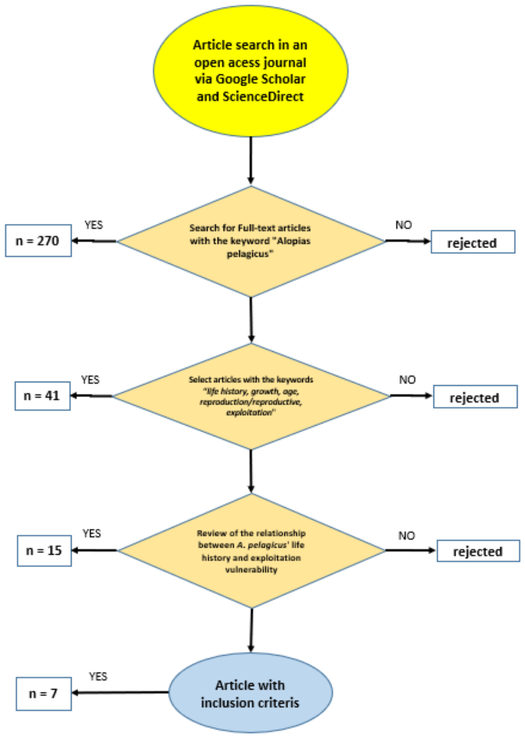

Figure 1. Stages of searching for articles in an Inclusive manner.

Table 1 presents the summary of the seven articles analyzed. As the results shown, the parameters that relate *A. pelagicus'* life history and its rate of exploitation included reproduction, age and growth, and natural mortality rate. Although environmental influences, such as temperature, can affect faster growth, earlier maturation, and mortality of marine fish organisms in the history of life, these dynamics have not been assessed. As such, the criteria used in this study are only those related to reproductive strategy, size-at-birth, sexually mature size, age-at-maturity, gestation period, reproductive cycle, and sex ratio in embryos.

3. Growth of *A. Pelagicus*

The growth of *A. pelagicus* indicates that the species has a k-selected life history characterized by slow growth [10, 15], slow sexual maturity [10, 16], long life span [15], low fecundity [16], and low natural mortality rate [15]. Those findings were consistent with the findings of Stevens et al. [17], who discovered that chondrichtyans were especially prone to exploitation due to their K-selected life history. As previously stated, the K-selected life history is distinguished by slow growth, slow sexual maturity, long lifespan, low fecundity, low natural mortality rate, and a significant correlation between the number of pups produced and parental biomass size.

The size at birth observed by Romero-Caicedo et al. [16] is about 136 cm - 142 cm TL (total length) with a morphology very similar to that of adult sharks. This size at birth is close to the growth model made by Drew et al., [10] which ranges from 151.6 cm - 154.8 cm TL. The sex ratio of the embryo is 1:1. *A. pelagicus* also exhibits an annual reproductive cycle [16]. Research conducted by Varghese et al. [18] stated that *A. pelagicus* did not have a resting phase in its reproductive cycle.

4. Reproduction of *A. Pelagicus*

The reproductive strategy of *A. pelagicus* is closely related to several parameters, thus are, reproductive strategy; size at birth, size-at-maturity, age-at-maturity, gestation period, reproductive cycle, and sex ratio in embryos [10, 16, 18]. A study conducted by Varghese et al. [18] showed that during the 9-month gestation period, *A. pelagicus* has a reproductive strategy of aplacental viviparity by embryonic oophagus. Oophagus means eating eggs, in this reproductive strategy additional nutrients are given to developing embryos in the form of unfertilized eggs. During the first few weeks the embryo gets nutrients from the yolk sac, then the mother will provide additional nutrition in the form of unfertilized eggs in the embryo [8]. In a study conducted by Romero-Caicedo et al. [16], *A. pelagicus* had fecundity of 2 embryos (1 embryo per uterus each). After the yolk is consumed, the embryo gets its nutrition from unfertilized egg wrapped in a capsule produced by the mother. This capsule can be found in the mouth of the embryo that has length of 4.5-9 cm and a width of 1.44 cm. A summary of the analysis results is presented in Table 2.

Research by Drew et al. [10] in 82 males and 24 females *A. pelagicus*, found that *A. pelagicus* reached the youngest sexual maturity at the age of 12 years in both males and females, with males measuring 263.3 cm TL and females measuring 296.9 cm TL. While the oldest age of sexual immaturity is 17 years (size 305.5cm TL) for males and 13 years (size 282.5cm TL) for females. The estimated average age-at-maturity is 10.4 years for males and 13.2 years for females in Indonesian waters. The results of this study also showed that the growth model of female *A. pelagicus* was slightly faster than male (Figure 2). This is because female *A. pelagicus* is born slightly larger. While the highest estimated age of male and female *A. pelagicus* is 24 years (with a maximum size of 316.6-cm and 325 cm TL respectively).

The relationship between the total length and length of the clasper of *A. pelagicus* is sigmoid, meaning that as the total length of the body increases, the length of the clasper also increases until it reaches its maximum length [13]. The results of the analysis from the study of Briones-Mendoza *et al* [19], showed a decrease in the average size of male *A. pelagicus* worldwide. This decline can be

Table 1. Article analysis results of *A. pelagicus*

No	Subject	Method	Sample	Result	Ref.
1	Growth of *A. pelagicus* (length of male and female)	Landed individuals were sexed and measured in cm. The taken measured were precaudal (PCL) and interdorsal (IDL). L_T could not be measured because the landed individual lacked the superior lobe of its caudal fin.	1236 individuals (711 females and 525 males)	• The length of female A. pelagicus varies from 67.2 to 184 cm PCL, while males range from 69.0 to 178.4 cm PCL. • The most commonly captured size class for *A. pelagicus* is 147.2−157.2 cm PCL. • The sex ratio is 1.35 F: 1 M.	[19]
		The measured biological parameters consist of fork length (FL) in centimeters and sex. The sex ratio was assessed using the Chi-square test. Thresher sharks' length-weight relationship is described by the cubic law equation W = a(LT)^b. The growth of thresher sharks is determined using the von Bertalanffy growth equation.	1410 individuals	• The results showed that the structural size of pelagic thresher sharks ranged from 60-270 cm FL with mode being 140 cm FL. • Estimated allometric coefficient is b=3.2899 for female and b=3.1636 for male. The relationship between weight and length on both male and female sharks showed positive allometric growth (b>3). • The estimated growth parameters for Von Bertalanffy for this species were L∞ = 278.52 cm FL, K = 0.16 / year and t0 = 0.01285) / year following the equation: *LL*(*t*)=278,52(1-*e*(-0,16(t+0,01285)). • The proportion of male to female thresher sharks was found to be 1:2.82, representing 26% males and 74% females. Using a Chi-square test with a 95% confidence level (α = 0.05), the calculated value of t (173.15) was greater than the critical t-value (3.84). This indicates that the sex ratios of males and females are significantly imbalanced.	[15]
		The measurement of the clasper in cm is taken from the inner groove of the ventral fin to the tip of the clasper. The length frequency, sex ratio, clasper length, and gonad maturation of fish were analyzed.	399 individuals	• The length frequency of male *A. pelagicus* is lowest in the total length range of 150-170 cm (immature), while the highest frequency seen ranges from total length 251-270 cm with mode being 260 cm (adult, non-reproductive). • The lowest frequency of female *A. pelagicus* is found in the total length size range of 291-310 cm (adults), with the highest length frequency appearing between 231-250 cm. • The male to female sex ratio of *A. pelagicus* is 1:1 (P>0.05). Catches of this species have decreased by 34.9% in the last six years. This shows that the abundance of *Alopias pelagicus* that previously existed in the Indian Ocean has decreased significantly.	[13]
		The age and growth characteristics of A. pelagicus were determined by examining the thinly cut vertebral growth bands. A total of 159 vertebrae were collected from three Indonesian fish markets over a span of 5 years. To estimate growth parameters, a multi-model analysis approach was employed.	159 individuals (89 males and 70 females)	• Suitable models for males and females of *A.. pelagicus* are three-parameter logistics (L∞ = 316.9 cm LT, K = 0.2) and von Bertalanffy's two-parameter model (L∞ = 328.1 cm LT, K = 0.12). • The highest age estimation for male and female *A. pelagicus* was 24 years (316.6 and 325.0 cm LT, respectively).	[10]

No	Subject	Method	Sample	Result	Ref.
		All specimens were sexed, measured for their total length (L_T) in centimeters (cm) and weighed in grams (g). The mathematical equation describing the Length-Weight (LWR) relationship used is W = a(L_T)b, where W is the total weight (g), L_T is the total length (cm), and A and B are regression coefficients.	122 individuals	• The length range of *A. Pelagicus* is 138-347 cm. • The composition of the length and average length of sharks in this study showed that the catch was dominated by juveniles. • Estimated allometric coefficient is b=2.687. • *A. pelagicus* showed negative allometric growth for the sexes collected b < 3 (faster length gain compared to weight gain).	[12]
		The total length (TL) and precaudal length (PL) of each individual were measured.	241 individuals (101 males, 40 females)	• Male sharks range from 68 to 183 cm in length precaudal (PL); females range from 70 to 180 cm PL. • Sex ratio of *A. pelagicus* in this study is 1.4F:1M (x^2 = 6.31, P<0.05). There were no statistical different in the sex-ratio of adults and juveniles (x^2 =2.65, P>0.05 and x^2 = 3.66, P>0.05, respectively).	[1]
2	Reproduction aspects of *A. pelagicus*	In males, the length of the clasper (CL) and other sex characteristics were measured.	525 males	• The males of the pelagic thresher shark registered 161 (30.73%) specimens with non-calcified claspers, while 363 (69.27%) presented total calcification. • For male *A. pelagicus* the inflection point of clasper length adjustment, is 134.2 cm PCL and first sex maturity (L_{50}) is estimated at 136.0 cm PCL.	[19]
		Growth parameters were estimated using a multi-model analysis approach.	159 individuals (89 males and 70 females)	• The estimated age-at-maturity for males is 10.4 years, while for females, it is 13.2 years. These estimates are the highest recorded for this particular species.	[13]
		The sexual maturity of males is measured from the condition of the clasper, while females from the condition and measure the ovarian follicles. If there are embryos, then sex, TL and weight are recorded.	241 individuals (101 males, 40 females)	• *A. pelagicus* is oophagus, the embryos consume vitellus from the egg and later feed on unfertilized eggs produced by the mother that are covered by a capsule. • Size-at-birth is between 136 and 142 cm TL in the Ecuadorian Pacific. • The size at maturity (PL_{50}) for males proposed in this study is 144.3 cm PL or 268.6 cm TL and the PL_{50} estimated for females is 151.4 cm PL or 282.60 TL. • One embryo in each uterus (the litter size is two). • The sex ratio in embryos is 1F:1M. • Estimated gestation period is 9 months with annual reproduction cycle.	[1]
		The sex of specimens was determined by examining the presence of claspers. The testes of the males and ovaries, eggs, oviducal glands and utery of the females were measured and weighed. In pregnant females, embryos were extracted from the uterus, counted, sexed, measured, and weighed.	656 individuals	• *A.pelagicus* is using oophagy as mode of giving nutrition to embryos. • Size at birth is estimated to be 137.8-142 cm. • The size at maturity (LT_{50}) is 254.96 cm for males and 271.39 cm for females in Arabian sea. • The number of embryos in *A. pelagicus* is always two. • The sex ratio in embryos were close to parity. • The reproductive aspects of *A. pelagicus* are consistent with previous reports from other ocean regions.	[11]

No	Subject	Method	Sample	Result	Ref.
3	Mortality	Mortality parameters include total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were calculated.	1410 individual	• Mortality parameters include total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F), respectively 0.796/year, 0.295/year and 0.50/year. • The exploitation rate (E) of pelagic thresher sharks is 0.73/year. Thus, the capture rate of *A. pelagicus* indicated an overfishing condition.	[15]

Table 2. Reproduction parameters of *A. pelagicus*.

R	Lb (cm)	Lm (cm)	Tm (year)	f	Gp (month)	Rc (year)	Sr	Source
Embrionic oophagus	136 - 142	263,3 (male) 296,9 (female)	10.4 (male) 13.2 (female)	2	9	1	1:1	[10, 16, 18]

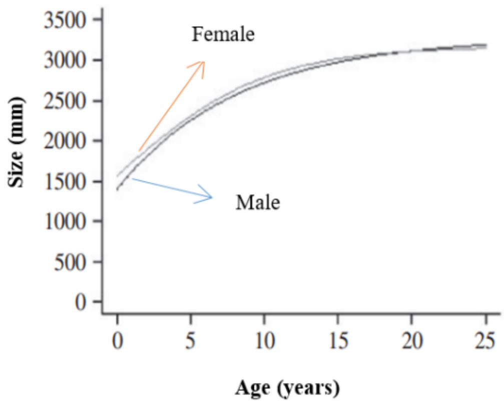

Figure 2. *A. pelagicus* growth model graph. Modified from [10].

attributed to a strategic response to population autoregulation as the species is exposed to severe exploitation, something that has been reported previously in pelagic sharks.

Analysis by Chodrijah et al. [15] on *A. pelagicus* in Indonesian waters, showed a scale comparison between length and weight in the growth pattern of *A. pelagicus* is positive allometric both in males and females. It means weight gain is faster than length gain. This result is not in line with the results of the calculation of the length and weight scale of *A. pelagicus* in the Southeast Arabian Sea by Najmudeen et al. [20] whose result is negative allometric. This difference is likely due to some internal and external factors. Internal factors can be physiological conditions, genetics, sex, age, as well as parasites and diseases. Meanwhile, the external factors may come from environment factors such as temperature, pH, salinity, geographical location, biological conditions such as gonad development, and food availability in both waters.

5. Mortality of A. Pelagicus

As an organism that fits into the k-selected criteria, *A. pelagicus* has a low natural mortality of 0.295. In line with this, Prince et al. [21] stated that fish with low natural mortality have a relatively long-life cycle, low reproduction, and slow stock turnover. The length of one generation of *A. pelagicus* in Indonesia is 20.6 years and globally 18.5 years. Judging from the time of sexual maturation shows a fairly long time, which is 10.4 years in males and 13.2 years in females.

Mortality due to fishing is the possibility of fish dying from fishing over a period of time, in which all cause of death will affect fish populations [22]. The results of the analysis showed that the mortality of capture (F) in *A. pelagicus* was higher than the natural mortality (M). This condition was reported by Chodrijah *et al* [15], who conducted research in 2015-2016 and calculated that *A.pelagicus* has 0.295/year of natural mortality, 0.50/year of estimated capture mortality, and 0.796/year of total mortality rate (Z).

6. Population Dynamics of *A. pelagicus*

Understanding population dynamics of a species can be used to estimate the relationship between life history and the level of exploitation vulnerability. The aspects of population dynamics are growth models, age groups, mortality rates, and exploitation rates. Life span of a species can affect the sexual maturation of a species. Species with long life span tends to have late sexual maturity. Based on the results of analysis of the data obtained, *A. pelagicus* has k-selected life history with characteristics of late sexual maturity, low fecundity, long gestation period, and an annual reproductive cycle. This condition causes a low population increase every year, which is only 0.033 [1].

The growth coefficient (K), indicated by the increase in length of *A. pelagicus,* is related to age and reproductive time. According to the calculations of Drew et al. [10], the growth of *A. pelagicus* reaches an asymptotic length (L_∞) of 316.9 cm TL with a growth coefficient of 0.2. While data from Chodrijah et al. [15] to achieve L_∞ of 278.52 cm FL (*fork length*) the growth coefficient is 0.16. A low growth coefficient means that it takes a long time for the fish to reach its maximum length. Varghese et al. [18] distinguishes between male and female sizes. In their study, the size of adult female *A. pelagicus* was longer than male, namely 144 cm to 319 cm (245.02±34.37) cm for females and 142 cm - 312 cm (249.98±29.95) cm for males.

The rate of exploitation (E) is used to determine the sustainability of fish production management. Fish stocks are at maximum and sustainable levels if they have a value of F = M or exploitation rate (E) = 0.5. If the E value is greater than 0.5, it can be categorized as over biological capture [23]. According to Chodrijah *et al* [15], the estimated exploitation rate (E) *of A. pelagicus* in Indonesian waters is 0.73. These results shows that the capture of *A. pelagicus* shows the level of overexploitation or overfishing in the Indian Ocean Southern Java waters.

Due to its k-selected life history, *A. pelagicus* is particularly vulnerable to overexploitation. On the relationship between age growth in size, the size of *A. pelagicus* in being a sign of age and sexual maturity of it. Based on this correlation, Dharmadi et al. [13] stated that *A. pelagicus* with a size below 275 cm should not be caught because it is sexually immature. Releasing sexually immature fish back into the sea is essential to ensure fish sustainability. In addition, it is necessary to manage and regulate fishing quotas of *A. pelagicus*, especially in Indonesian waters. The population dynamics of most sharks are characterized by slow growth, late maturity, and low fecundity. Varghese added almost all types of sharks can only sustain a modest fishing level without depletion and stock collapse.

7. Conclusions

A. pelagicus has a slow life history or k-selected life history, it characterized by late sexual maturity, low fecundity, long gestation period, annual reproductive cycle, slow growth, long life span, and low natural mortality rate. This life history makes A. *pelagicus* prone to overexploitation. It means if the capture mortality rate exceeds the natural mortality rate, it will take a long time for *A. pelagicus* to return to its original population size. In waters of Indonesia, the exploitation rate of *A. pelagicus* is overfished, thus, management and regulation of fishing quotas are needed, especially in Indonesian waters, precisely in the Indian Ocean Southern Java waters.

Author Contributions: Conceptualization, Y.T.H. and D.N.S.; methodology, Y.T.H.; software, D.N.S.; validation, Y.T.H and D.N.S.; formal analysis, Y.T.H.; resources, D.N.S.; data curation, Y.T.H. and D.N.S.; writing—original draft preparation, D.N.S.; writing—review and editing, Y.T.H.; visualization, Y.T.H.; supervision, Y.T.H.; All authors have read and agreed to the published version of the manuscript.

Funding: This work received no external funding.

Data Availability Statement: Data collection was conducted through a thorough search of open-access journal articles around the world published over a ten-year period, from 2013 to 2023. Searches are conducted in online databases using Google Scholar and ScienceDirect based on exclusion and inclusion criteria.

Conflicts of Interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

References

1. Rigby, C. L., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M. P., Herman, K., Jabado, R. W., Liu, K. M., Marshall, A. (2019). Alopias pelagicus. The IUCN Red List of Threatened Species 2019: e. T161597A68607857
2. Liu, K.-M., Chen, C.-T., Liao, T.-H., Joung, S.-J. (1999). Age, growth, and reproduction of the pelagic thresher shark, Alopias pelagicus in the Northwestern Pacific, *Copeia*, 68–74
3. Arostegui, M. C., Gaube, P., Berumen, M. L., DiGiulian, A., Jones, B. H., Røstad, A., Braun, C. D. (2020). Vertical movements of a pelagic thresher shark (Alopias pelagicus): Insights into the species' physiological limitations and trophic ecology in the Red Sea, *Endangered Species Research*, Vol. 43, 387–394
4. Fahmi, D., Dharmadi, D. (2013). Tinjauan status perikanan hiu dan upaya konservasinya di Indonesia, *Direktorat Konservasi Kawasan Dan Spesies Ikan, Kementerian Kelautan Dan Perikanan. Jakarta*
5. White, W. T. (2007). Biological observations on lamnoid sharks (Lamniformes) caught by fisheries in eastern Indonesia, *Journal of the Marine Biological Association of the United Kingdom*, Vol. 87, No. 3, 781–788. doi:10.1017/S0025315407056391
6. Shidqi, R. A., Sari, D. R., Capriati, A., Kurniasih, E. M. (2019). *Population Risk and Alternative Fisheries Management of Thresher Sharks in Indonesia : Final Report*, Conservation Leadership Programme, Banten
7. Ebert, D. A., Bigman, J. S., Lawson, J. M. (2017). Biodiversity, Life History, and Conservation of Northeastern Pacific Chondrichthyans, 9–78. doi:10.1016/bs.amb.2017.07.001
8. Parsons, G. R., Hoffmayer, E. R., Hendon, J. M., Bet-Sayad, W. V, Rocha, M. J., Arukwe, A., Kapoor, B. G. (2008). A review of shark reproductive ecology: life history and evolutionary implications, *Fish Reproduction*, Vol. 1, 435–469
9. White, W. T., Last, P. R., Stevens, J. D., Yearsly, G. K. (2006). *Economically important sharks and rays of Indonesia*
10. Drew, M., White, W. T., Dharmadi, Harry, A. V., Huveneers, C. (2015). Age, growth and maturity of the pelagic thresher shark Alopias pelagicus and the scalloped hammerhead Sphyrna lewini, *Journal of Fish Biology*, Vol. 86, No. 1, 333–354. doi:10.1111/jfb.12586
11. Tsai, W.-P., Liu, K.-M., Joung, S.-J. (2010). Demographic analysis of the pelagic thresher shark, Alopias pelagicus, in the north-western Pacific using a stochastic stage-based model, *Marine and Freshwater Research*, Vol. 61, No. 9, 1056. doi:10.1071/MF09303
12. Liu, K.-M., Chang, Y.-T., Ni, I.-H., Jin, C.-B. (2006). Spawning per recruit analysis of the pelagic thresher shark, Alopias pelagicus, in the eastern Taiwan waters, *Fisheries Research*, Vol. 82, Nos. 1–3, 56–64. doi:10.1016/j.fishres.2006.08.013
13. Dharmadi, Fahmi, Wiadnyana, N. N. (2013). Biological aspects and catch fluctuation of the pelagic thresher shark, Alopias pelagicus from the Indian Ocean, *PROCEEDINGS of the Design*

Symposium on Conservation of Ecosystem (2013)(The 12th SEASTAR2000 Workshop), Kyoto University Design School, 77–85

14. Rice, J., Tremblay-Boyer, L., Scott, R., Hare, S., Tidd, A. (2015). Analysis of stock status and related indicators for key shark species of the Western Central Pacific Fisheries Commission

16. Romero-Caicedo, A. F., Galván-Magaña, F., Martínez-Ortiz, J. (2014). Reproduction of the pelagic thresher shark Alopias pelagicus in the equatorial Pacific, *Journal of the Marine Biological Association of the United Kingdom*, Vol. 94, No. 7, 1501–1507. doi:10.1017/S0025315414000927

17. Stevens, J. D., Bonfil, R., Dulvy, N. K., Walker, P. A. (2000). The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems, *ICES Journal of Marine Science*, Vol. 57, No. 3, 476–494. doi:10.1006/jmsc.2000.0724

18. Varghese, S. P., Unnikrishnan, N., Gulati, D. K., Ayoob, A. E. (2017). Size, sex and reproductive biology of seven pelagic sharks in the eastern Arabian Sea, *Journal of the Marine Biological Association of the United Kingdom*, Vol. 97, No. 1, 181–196. doi:10.1017/S0025315416000217

19. Briones-Mendoza, J., Carrasco-Puig, P., Toala-Franco, D. (2021). Reproductive biology aspects of Alopias pelagicus and A. superciliosus (Lamniformes: Alopiidae) in the Ecuadorian

15. Chodrijah, U., Lestari, P., Prihatiningsih, Tirtadanu. (2021). Growth estimates of pelagic thresher shark (Alopias pelagicus Nakamura, 1935) in the Indian Ocean Southern Java waters, *IOP Conference Series: Earth and Environmental Science*, Vol. 674, No. 1, 012009. doi:10.1088/1755-1315/674/1/012009

Pacific, *Neotropical Ichthyology*, Vol. 19, No. 4. doi:10.1590/1982-0224-2021-0015

20. Najmudeen, T. M., Zacharia, P. U., Seetha, P. K., Sunil, K. T. S., Radhakrishnan, M., Akhildev, S., Sipson, A. (2019). Length–weight relationships of three species of pelagic sharks from southeastern Arabian Sea, *Regional Studies in Marine Science*, Vol. 29, 100647. doi:10.1016/j.rsma.2019.100647

21. Prince, J., Hordyk, A., Valencia, S. R., Loneragan, N., Sainsbury, K. (2015). Revisiting the concept of Beverton-––Holt life-history invariants with the aim of informing data-poor fisheries assessment, *ICES Journal of Marine Science*, Vol. 72, No. 1, 194–203. doi:10.1093/icesjms/fsu011

22. Sparre, P., Venema, S. C. (1999). Introduksi pengkajian stok ikan tropis, *Buku I. Manual. Pusat Penelitian Dan Pengembangan Perikanan. Jakarta. 438p*

23. Gulland, J. A. (1983). *Fish Stock Assessment: A Manual of Basic Methods*, *FAO/Wiley Series on Food and Agriculture*, Rome