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Diet analyses of the pelagic thresher shark, *Alopias pelagicus* (Lamniformes: Alopiidae), from the Lombok Strait waters, Indonesia

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Abstract. *Alghozali FA, Salsabila R, Gustianto MWD, Putri HMIH, Himawan MR, Yuneni RR, Hatmoro CK, Rezkiani M. 2023. Diet analyses of the pelagic thresher shark,* Alopias pelagicus *(Lamniformes: Alopiidae), from the Lombok Strait waters, Indonesia. Biodiversitas 24: 3708-3714.* The pelagic thresher shark, *Alopias pelagicus*, is an endangered shark species estimated to be declining in the Pacific and Indian Oceans because of overexploitation, including from target fisheries and bycatch. Despite its importance in providing better information for species management, the ecological aspects of this species are still rarely studied. This study aims to provide information on the feeding ecology of the pelagic thresher sharks from the Lombok Strait. Stomach samples from 178 specimens were sampled from 2020-2021, and 149 stomachs that contained food contents were analyzed for species diet characterization. Prey Species Accumulation Curve slope values are <0.1 and the percentage of prey coverage for all sharks combined is 92.1%, suggesting reliable inventory in the number of prey represented. The resulting diet indexes suggest that *A. pelagicus* in Lombok Strait waters is a specialist predator (Ba=0.3) with few prey variations (H=2.21) and no competition between sexes and maturity stages of the species (C=0.64 and 0.81, respectively). The top three prey species found for *A. pelagicus* in the study area are the *Auxis thazard* (85.8 %IRI), *Sthenoteuthis oualaniensis* (8.5 %IRI), and *Dasyscopelus spinosus* (1.11 %IRI). A better understanding of the overlap of *A. pelagicus* and its diet, which includes economic fish commodities, will inform authorities to develop better fisheries and conservation management for the species in Indonesia.

Keywords: Diet, elasmobranch, feeding characteristics, prey, stomach content

INTRODUCTION

The pelagic thresher shark, *Alopias pelagicus* (Nakamura 1935), is one of the three species of the Alopiidae family found between offshore and deep-water to a depth of 300 m (Weigmann 2016) throughout the tropical and subtropical waters globally (Rigby et al. 2018). Despite being a migratory species, genetic evidence revealed two different populations between the eastern and western Pacific Ocean, which led to the possibility of a population staying all year round in a particular region (Cardeñosa et al. 2014), including those in the Indian Ocean. The shark exhibits slow growth rates and late maturity age, with males maturing at 10 years while females at 13 (Drew et al. 2015) with an average maturity size of 250-300 cm in total length for both sexes (Ebert et al. 2013). Females give birth to one to two pups during each gestation period of 9 months while the embryo grows by consuming the vitellus from the egg and later feed on other unfertilized eggs or known as aplacental vivipary with oopaghy (Romero-Caicedo et al. 2014).

The pelagic thresher shark is listed in the Convention on International Trade in Endangered Species (CITES) Appendix II list. It is also globally assessed as Endangered in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. It is estimated to be declining in the Pacific and Indian Oceans because of overexploitation, including from target fisheries and bycatch (Rigby et al. 2018), mostly from longlines and nets (Martínez-Ortiz et al. 2015; Temple et al. 2019). The species is mostly retained for their fins and meat (Dent and Clarke 2015; Fields et al. 2018), although the liver, oil, and skin are also sought as derivative products (Jabado et al. 2015). The pelagic thresher shark is estimated to have a high post-release mortality rate related to capture fisheries or recreational fishing, as modeled for the *A. vulpinus*, with a mortality rate of 78% and 0% if hooked on the tail and mouth, respectively (Sepulveda et al. 2015). Studies on pelagic thresher sharks in Indonesia are mostly about its fisheries and biology, while their ecological aspects are still rarely studied despite their importance in providing better information for species management (Dharmadi et al. 2015a; Sembiring et al. 2015; Arostegui et al. 2020). The catch of this species in the Indian Ocean has declined since 2002-2021, especially from commercial tuna fisheries. This may be caused by either the reduced number of fishing efforts (causing underestimated population assessment) or a true decline in the population abundance (Fahmi and Dharmadi 2015; Dharmadi et al. 2015b; FAO 2023). The situation is further worsened due to the inexistence of conservation measures on the species in Indonesia in practice, considering that CITES regulations only apply to international trade and the Indian Ocean Tuna Commission (IOTC); the resolution that bans the retention of this species cannot be implemented on small-scale fisheries (Ichsan 2021).

As part of ecological studies on pelagic thresher sharks, the diet composition and feeding habits of the species have only been studied on specimens from Ecuador, Northern Peru, and the Galapagos Marine Reserve (Rosas-Luis et al. 2017; Páez-Rosas et al. 2018; González-Pestana et al. 2019). Studying the ecological role of the shark will be important for understanding the relations between the top predator (pelagic thresher shark) and its prey and as references to design an effective population management strategy (Polo-Silva et al. 2009; Polo-Silva et al. 2013; Páez-Rosas et al. 2018; Calle-Morán and Galván-Magaña 2020), especially considering the looming risk of climate change that may affect important habitat and ecosystem for the species (Birkmanis et al. 2020). In Indonesia, however, there are no previous studies on the pelagic thresher shark diet. This study aims to provide the feeding ecology of the pelagic thresher sharks information from the Lombok Strait by analyzing their stomach contents and diet characteristics.

MATERIALS AND METHODS

Study area

Stomach samples were collected between August-September 2020 and July-September 2021 at Pengalon Beach, Karangasem District, Bali Province (8°32'40.1"S 115°29'50.8" E). The stomach samples were discarded products from pelagic thresher sharks that landed in Pengalon Beach that were caught as the main target of small-scale longline fisheries (*Auxis thazard* as bait). Samples were collected during this period of each year as local fishers only fished for the thresher sharks in these months, which they considered "shark season". Those local artisanal fisheries' fishing ground is around the waters of Lombok Strait near Penida Island and between Penida Island-West Lombok (Figure 1).

Sample and data collection

Stomach samples were randomly collected from each landed shark and then stored in plastic bags. Each shark was measured for its fork, pre-caudal, total length (FL, PCL, and TL), and sexed, including maturity for males and females (immature: male <267 cm; female <280 cm; mature: male ≥267 cm; female ≥280 cm) based on size (Ebert et al. 2021), and pregnancy for females. Samples were processed at our temporary field station near the beach. Stomach contents were sorted, counted, and weighed (to the nearest 0.01 g). Each prey item was then identified to the lowest taxonomic level possible using a species identification guide for teleosts, elasmobranchs, and cephalopods (Carpenter et al. 1998; Jereb and Roper 2005; Xavier and Cherel 2009). Any baits discovered among the stomach contents are easily differentiated by the hook marks left in any *A. thazard* found, which was separated before counting prey items. Hook marks were defined as holes created by a hook puncturing through the fish's left side to the right side (two holes), either on the head or body area.

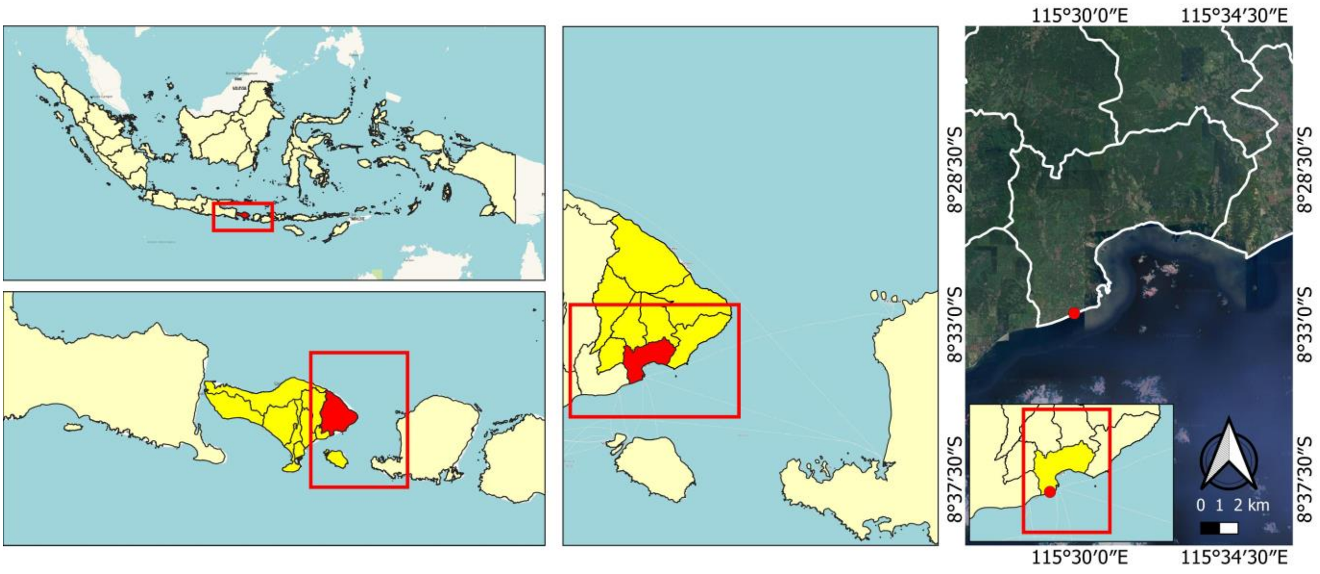

Figure 1. Sample collection sites at Pengalon Beach in Bali Province, Indonesia and local fishers' fishing ground area estimate in Lombok Strait

Data analysis

Prey species accumulation curve

In order to determine if the samples collected are representative to describe the diet of the shark population used for this study, a prey species accumulation curve was constructed by plotting the number of cumulative prey species found against the number of stomach samples collected (excluding empty stomach samples) using the BiodiversityR package (Kindt and Coe 2005) in R (Rstudio Team 2020). The Clench equation was used to calculate the percentage of prey species observed: $N=a \times n/(1+b\times n)$; $\%Sobs=N/(a/b)$, and the slope value of the curve: $SL=a/(1+b\times n)^2$, where N is the number of prey species found, n is the number of stomachs sampled, %Sobs is the percent of prey species observed, and a and b are fitting constants (Jiménez-Valverde and Hortal 2003). Furthermore, each calculation was conducted on the overall (both sexes) male, female, immature, and mature grouping. A slope value lower than 0.1 indicates a reliable inventory of prey species representations (Soberón and Llorente 1993; Jiménez-Valverde and Hortal 2003).

Diet analysis

The diet of the pelagic thresher shark was analyzed using three methods: 1. Numerical (%N), percentage of the total number of individuals of a prey species relative to the total number of all prey, gravimetric (%W), percentage of the total weight of a prey species relative to the total weight of all prey, and frequency of occurrence (%FO), percentage of the total number of stomach samples in which a prey species was found (Hyslop 1980). These methods were used to calculate the index of relative importance (IRI): $IRI=(\%N+\%W)\times\%FO$ (Pinkas et al. 1971). The importance of each prey species found was then described and represented in the percentage of IRI: $\%IRI=(IRI_i/\sum^{n}_{i=1}IRI_i)\times 100$ (Cortés 1997).

The Levin's Index was used to estimate the pelagic thresher shark niche breadth (Ba): $B=1/\sum P_i^2$; $Ba=(B-1)/(N-1)$, where N is the total number of prey species, and P_i is the proportion of each prey species, with values (0 to 1) below 0.6 show a specialist predator diet while values above 0.6 show a generalist diet (Labropoulou and Eleftheriou 1997). Shannon-Wiener Index (H) was used to describe the diversity of prey in the diet: $H=-\sum^{n}_{i=1}P_i\times \ln P_i$, with values (0 to 6) below 3 showing a small variety of prey species (non-diverse diet) while values above 3 show a great variety of diet (diverse) (Labropoulou and Eleftheriou 1997). Diet overlaps (C) between sexes and maturity stages (immature-mature) were analyzed using the Morisita-Horn Index: $C=2(\sum^{S}_{i=1}P_{ai}\times P_{bi})/(\sum^{S}_{i=1}P^2_{ai}\times P^2_{bi})$, where P_{ai} and P_{bi} are the proportion of each prey species for each pelagic thresher shark categories compared, with values between 0 and 0.29 showing low overlap, values between 0.3 and 0.59 showing medium overlap, and values over 0.6 showing the high overlap of diet (Horn 1966; Langton 1982; Smith and Zaret 1982).

RESULTS AND DISCUSSION

Results

A total of 178 *Alopias pelagicus* stomachs (122 in 2020, 56 in 2021) were sampled, comprising 38 males and 140 females, with 29 (16.3%) being empty samples (8 males, 21 females). The samples comprised 33 immature and 116 mature sharks; only stomachs with food contents were analyzed. The total length (TL) range of analyzed *A. pelagicus* was between 167-315 cm for males and 162-368 cm for females, with 20 of the females being pregnant.

All Prey Species Accumulation Curve (SAC) (Figure 2) showed a slope value of <0.1 and a percentage of prey coverage of 92.1% for the combined sexes (overall), 78.3% for males, 91.3% for females, 73.9% for immature, and 90.7% for mature shark. Diet analysis was done using the overall group of samples as it will provide the best representation (92.1%) of the sampled *A. pelagicus* in the study area.

A total of 20 prey items were identified, comprising mostly Teleostei and cephalopods (Table 1). The top three prey items found are the frigate tuna *Auxis thazard* (85.8%IRI), purpleback flying squid *Sthenoteuthis oualaniensis* (8.5%IRI), and spiny lanternfish *Dasyscopelus spinosus* (1.1%IRI) while other prey items have %IRI value of <1 except for the grouped unidentified Teleostei.

Levin's index showed that the *A. pelagicus* population analyzed are specialist predators with a niche breadth (Ba) of 0.3 and a small variety of prey based on the Shannon-Wiener (H) index of 2.21 which is reflected in the dominance of *A. thazard* as a prey item. The diet between males-females and the immature-mature sharks of the analyzed population showed high overlap according to the Morisita-Horn (C) index of 0.64 and 0.81, respectively.

Discussion

The samples collected during the study are due to the targeted catch of *Alopias pelagicus* from artisanal fishers from a village near the sampling site. The fishers used mini longlines with an average of 9-13 hooks per gear, with *A. thazard* as the sole bait (unpublished WWF data 2020), mainly due to their abundance and availability for fishers to acquire them. This practice occurs every day between July-October and varies between years. At the same time, fishers mainly catch *A. thazard* as a main commodity outside of the shark season (based on direct observation and no published information).

The top three prey found for the *A. pelagicus* population studied are the frigate tuna *A. thazard*, purpleback flying squid *S. oualaniensis*, and spiny lanternfish *D. spinosus*. A different composition, as shown in Table 2. was found for studies on *A. pelagicus* and *Alopias* spp. in Ecuador and Peru, where the main prey are Cephalopods, notably the humboldt squid *Dosidicus gigas*, neon flying squid *Ommastrephes bartramii*, and patagonian squid *Doryteuthis gahi*, and some Teleostei including the Panama lanternfish *Benthosema panamense* (same family as *D. spinosus* in Myctophidae) and South Pacific hake *Merluccius gayi*. Common prey items found between the population in Lombok Strait and the referred studies are the *A. thazard*, which are not as dominant, and *S. oualaniensis*, which also shows similar importance in Ecuador and Peru. However, a study of the *A. pelagicus* diet from the Southern Sea of Korea showed similar results to this study, where the most important preys are Teleostei and various cephalopods prey compared to the other studies. The variation in prey for *A. pelagicus* is assumed to be due to the difference in prey and their abundance in South American and Asian waters, particularly between cephalopods and Teleostei species (FAO 2022).

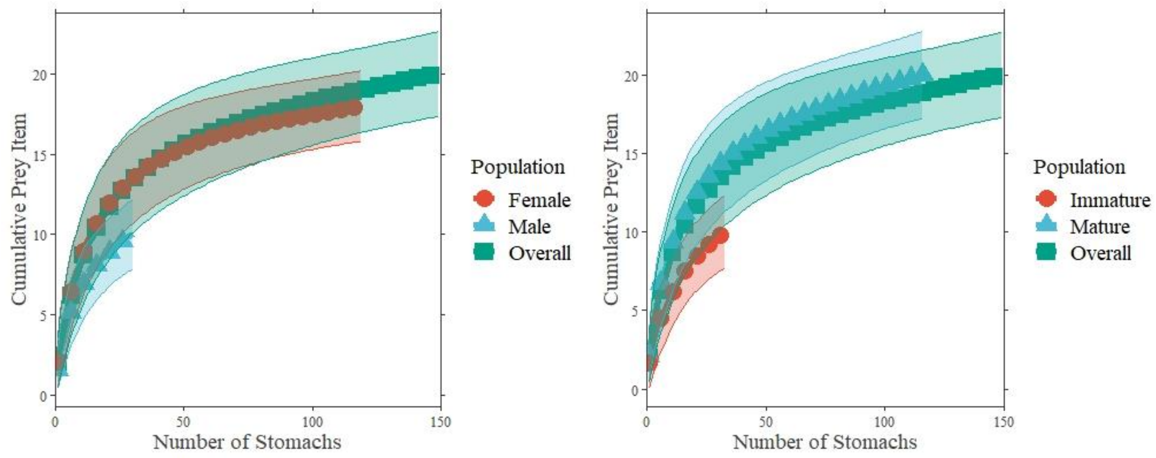

Figure 2. Prey Species Accumulation Curve of *Alopias pelagicus* sampled from Lombok Strait waters from both sexes combined (overall), as well as for male and female sharks separately (left); and immature and mature sharks separately (right).

Table 1. Prey compositions of *A. pelagicus* with their size range (cm) sampled from Lombok Strait waters and analyzed for Index of Relative Importance (%IRI) based on prey number (N), weight in grams (W), and frequency of occurrence (FO)

Prey item	N	%N	W	%W	FO	%FO	IRI	%IRI	Size range (cm)
Teleostei									
Auxis thazard	222	24.56	25322.1	78.34	116	39.32	4046.23	85.862	17-25
Decapterus macarellus	21	2.32	1251	3.87	12	4.07	25.19	0.535	20-25
Psenopsis humerosa	8	0.88	196	0.61	6	2.03	3.03	0.064	7-9
Diodon holocanthus	4	0.44	193	0.60	3	1.02	1.06	0.022	4-7
Lagocephalus spadiceus	1	0.11	345	1.07	1	0.34	0.40	0.008	31
Trichiurus lepturus	54	5.97	153	0.47	10	3.39	21.85	0.464	15-17
Brama japonica	4	0.44	31	0.10	3	1.02	0.55	0.012	7-9
Dasyscopelus spinosus	164	18.14	383	1.18	8	2.71	52.41	1.112	8-11
Coryphaena hippurus	1	0.11	47	0.15	1	0.34	0.09	0.002	35
Sarda orientalis	1	0.11	69	0.21	1	0.34	0.11	0.002	36
Cheilopogon atrisignis	2	0.22	97	0.30	1	0.34	0.18	0.004	22-24
Cephalopods									
Sthenoteuthis oualaniensis	180	19.91	1203.5	3.72	50	16.95	400.59	8.501	20-26
Unidentified									
Small pelagic fish A	40	4.42	98.2	0.30	15	5.08	24.04	0.510	5-9
Small pelagic fish B	24	2.65	135	0.42	5	1.69	5.21	0.111	8-13
Unidentified fish A	35	3.87	198.3	0.61	13	4.41	19.77	0.419	6-9
Triggerfish A	1	0.11	9	0.03	1	0.34	0.05	0.001	6-7
Squid A	50	5.53	926	2.86	6	2.03	17.08	0.362	7
Shrimp A	8	0.88	21.3	0.07	4	1.36	1.29	0.027	13-16
Unidentified Teleostei	39	4.31	1460	4.52	18	6.10	53.88	1.143	9-12
Unidentified Cephalopods	45	4.98	184	0.57	21	7.12	39.49	0.838	8-34

Both *A. thazard* and *S. oualaniensis* are pelagic species widely distributed across Indonesian waters and are some of the main targeted marine commodities due to their abundance (FAO 2022). Considering both species, approximately small-sized specimens of *A. thazard* and *S. oualaniensis* of between 20-30 cm (possible maximum length of 65 cm) (Cayré and Marsac 1993), during the shark season and the seasonal presence of *A. pelagicus* within the studied location based on local fishing activities, *A. pelagicus* presence in the area possibly follows the existence of potentially small-sized prey, such as the *A. thazard*. The result and comparisons with other studies of the *A. pelagicus* diet suggest that the species' preferred prey are small to medium-sized pelagic or demersal animals between 5.5 cm (*B. panamense*) and 80 cm (common size for *D. gigas*) (Roper et al. 1984; Jereb and Roper 2005).

While *A. thazard* as the most dominant prey items are commonly found near the water surface, both *S. oualaniensis* and *D. spinosus* have a vertical distribution of ~1000 m (Jereb and Roper 2005) and ~700 m (Fricke et al. 2011) which shows the *A. pelagicus* studied may swim deep to forage for food, possibly to a depth of ~450 m in the studied area (NOAA Bathymetric Data Viewer 2022). This overlapping vertical distribution between *A. pelagicus* and these preys may be the reason for their primary diets in Lombok Strait, as matched by the other studies. As both *A. thazard* and *S. oualaniensis* have a year-round reproduction cycle within the same area (Collette and Aadland 1996; Jereb and Roper 2005), the presence of *A. pelagicus* within Lombok Strait may not be related to a foraging behavior on seasonal prey presence as they only occur during the shark season (July-September); *A. thazard* for instance, similar to some tuna and tuna-like species in Indonesia, is present throughout the year with peak months of production each year (Salmarika et al. 2022). A study on tiger shark *Galeocerdo cuvier* in Australia showed that a targeted predation behavior to a certain seasonal prey species needs to be accompanied by the consistent spatial presence of the predator during that season (Fitzpatrick et al. 2012). Therefore, a more specific and fisheries-independent study is required to understand their presence spatiotemporally.

The *A. pelagicus* in Lombok Strait are specialist predators due to their preference for small pelagic fish and squids prey, similar to other previous studies (Polo-Silva et al. 2013; González-Pestana et al. 2019; Calle-Morán and Galván-Magaña 2020) as corroborated by the low value of both the Levin's (Ba) and Shannon-Wiener (H) index (Flores-Martínez et al. 2017). This characteristic differs from the diet of the blue shark *Prionace glauca*, silky shark *Carcharhinus falciformis*, and scalloped hammerhead shark *Sphyrna lewini*, where all three are large pelagic species described as generalist predators (Flores-Martínez et al. 2017; Konan et al. 2018). However, the diet of a species may also differ based on the prey abundance and availability, as shown in *C. falciformis* in Ecuador waters, where they are described as specialist predators compared to the one in South West Mexico (Duffy et al. 2015; Estupiñán-Montaño et al. 2018). The specialized diet of small prey may also be due to the hunting mechanism of *A. pelagicus*, which uses its tail to hunt and stun prey, with a case of sardines as prey, as observed previously in the Philippines (Oliver et al. 2013). The overlapping diet between male-female and immature-mature *A. pelagicus* in Lombok Strait waters means there are no different prey preferences and competition between sexes and maturity stages in the area. The studies in Ecuador also showed high overlap between the sexes of *A. pelagicus* (Polo-Silva et al. 2013), including between maturity stages, and showed practically identical diets in Calle-Morán and Galván-Magaña (2020).

Table 2. Prey composition comparison of *Alopias pelagicus* between studies in Indonesia, Ecuador, Peru, and Korea

Study area	Prey item	%IRI	%N	Reference
Lombok Strait, Indonesia	*Auxis thazard*	85.8		*This study* (2022)
	Sthenoteuthis oualaniensis	8.5		
	Dasyscopelus spinosus (Myctophidae)	1.1		
Eastern Central Pacific Ocean, Ecuador	*Ommastrephes bartramii*	52.7		Calle-Morán and Galván-Magaña (2020)
	Dosidicus gigas	26.8		
	Sthenoteuthis oualaniensis	11.5		
	Merluccius gayi	7.9		
	Benthosema panamense (Myctophidae)	0.6		
Ecuador Waters	*Dosidicus gigas*	66.0		Polo-Silva et al. (2013)
	Benthosema panamense (Myctophidae)	30.0		
	Auxis thazard	0.5		
	Sthenoteuthis oualaniensis	2.9		
Peru Waters	*Dosidicus gigas*	74.5		González-Pestana et al. (2019)
	Doryteuthis gahi	5.8		
	Merluccius gayi	4.6		
Southern Sea, Korea	*Engraulis japonicus*		57.1	Huh et al. (2010)
	Trachurus japonicus		25.5	
	Todarodes pacificus		2.2	

Ultimately, the study describes the diet of *A. pelagicus* in Lombok Strait waters as a specialist predator with few prey variations and no competition between sexes and maturity stages. The most important prey to the species population in the study area is the *A. thazard*. Additionally, *S. oualaniensis*, and *D. spinosus*, although they cannot be considered important prey species, were also found more than the remaining prey species in the study, which fall in the preferred prey category of this species based on other previous studies, which are small pelagic fish and squid. This study is the first diet analysis of the species in Indonesia; further study should be conducted in other locations, primarily with large catches of the species, to better understand the species' diet in Indonesia, which may be affected by prey abundance and availability in a particular region. Moreover, a better understanding of the overlap of *A. pelagicus* and its diet, which includes economic fish commodities, will inform authorities to develop better fisheries and conservation management for the species in Indonesia. Furthermore, future studies should also include genetic identification of prey found in the stomach to identify the species accurately.

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