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# DIET AND FEEDING HABITS OF PREDATORY FISHES AROUND ANCHORED FISH AGGREGATING DEVICES IN THAI WATERS, THE ANDAMAN SEA

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**ABSTRACT:** The deployment of anchored fish aggregating devices (AFADs) in Thai waters in the Andaman Sea was expected to enhance pelagic fish resources and provide benefits to fishers. This study aimed at comparatively describing the diet and feeding habits of large predatory fishes caught in three areas (*i.e.*, reference station, AFADs at 500 m depth, and AFADs at 1,000 m depth). Fishing surveys were operated in the three areas using trolling line, pelagic longline, and drifting vertical line during 2010–2011. A total of 44 stomach samples were collected from eight predatory fish species, and 22 prey taxa were found and categorized into four groups (*i.e.*, fishes, cephalopods, crustaceans, and others). Fishes were the most important prey group for great hammerhead, bigeye thresher, savalai hairtail, great barracuda, and swordfish; cephalopods were for snake mackerel; and crustaceans were for kawakawa and yellowfin tuna. The major prey group available in each area was fishes. The feeding relationships among predatory fishes, preys, and secondary preys in the two areas of AFADs were more complex than in the area of reference station. The AFADs were considered to provide the feeding requirements of pelagic fish resources in Thai waters in the Andaman Sea though further studies are necessary to improve this knowledge.

**Keywords:** Fish aggregating device, Tuna, Billfish, Diet, Feeding habit, Andaman Sea

## INTRODUCTION

Anchored fish aggregating device (AFAD) is an artificial or natural object deployed by fishers for enhancing or gathering pelagic fish resources for capture fisheries. The structure of AFADs mainly consisted of anchor or sinker, mooring line or rope, and float (Beverly *et al*. 2012; Kumamoto 2013; Karama and Matsushita 2019); besides, mid-water aggregators (*e.g*., rope, fishing net (Beverly *et al.* 2012) and coconut/palm fronds (Karama and Matsushita 2019)) were often attached on the mooring line or under the float. For the deployment, AFADs may be placed in shallow water (50–100 m depth) or deep water (500–1,500 m depth); however, the deep water AFADs are generally more successful in attracting tuna schools than shallow water AFADs (Pillai and Mallia 2007). Moreover, AFAD provides other benefits for artisanal and commercial fisheries, for example, reducing searching time and fuel consumption as well as increasing fishery production (Sharp 2011). In AFAD fishery, the target species include tunas, billfishes, mackerels, dolphinfish, and jacks (Beverly *et al*. 2012) caught by various fishing gears, including ring net, purse seine, pole and line, vertical longline, trolling line, handline, and drop stone (Sharp 2011; Beverly *et al*. 2012; Albert *et al*. 2014; MRAG 2017).

Tunas is a group of migratory fish distributed in the Pacific, Atlantic, and Indian Oceans. In the Indian Ocean, the tunas migrate seasonally around the ocean. For vertical distribution, juvenile tunas associate with floating objects near the sea surface, and adults dive into deeper layers. This group of fish is considered as commercial fish with high market value. The increasing consumption of sashimi and canned tuna led to the increase of fishing efforts for raw materials in the food industry. During 2000–2006, the catch of Thai tuna longliners in the Indian Ocean ranged from 94 t to 414 t with the value of USD 0.46 million–2.42 million (Nootmorn *et al*. 2010).

The Andaman Sea has an area of about 780,000 km$^2$ located in the Eastern Indian Ocean between the Andaman and Nicobar Islands and the Malay Peninsula (Satapoomin 2011). Several studies had been carried out in the Andaman Sea on the biodiversity of marine organisms, particularly plankton and fishes. Charoenvattanaporn *et al*. (2018) found at least 146 phytoplankton species, including diatoms, dinoflagellates and cyanobacteria in the offshore areas around Similan Islands. Raghunathan *et al*. (2009) revealed that 96 zooplankton species were found in the continental slope region of the Andaman and Nicobar archipelago (western Andaman Sea) comprising annelids, foraminiferans, molluscs, copepods, amphipods, and other crustaceans. Munk *et al*. (2004) reported 109 families of fish larva collected around the continental shelf and shelf slope in Thai waters with the dominant groups, including carangids, apogonids, myctophids, bothids, gempylids, scombrids, trichiurids, and nemichthyids. Satapoomin (2011) also reported that there were 1,746 fish species from 198 families found in the Andaman Sea.

In 2008, the Department of Fisheries (DOF), Thailand and the Southeast Asian Fisheries Development Center (SEAFDEC) deployed AFADs at the depth of about 1,000 m in Thai waters in the Andaman Sea (SEAFDEC 2010), which was about 320 km away from Phuket Province, Thailand (Ekmaharaj *et al*. 2009). The purpose of AFADs deployment was to enhance the fishing ground in this area to catch large pelagic fishes, *i.e*., tunas and billfishes. Since tuna fishing grounds are usually located on the high seas, one of the expected benefits of the deployed AFADs closer to the coast was to reduce the fuel cost of fishers. As a fishing ground in Thai waters in the Andaman Sea, the study of Darumas and Chumchuen (2019) reported that there were 36 fish species, including tunas, billfishes, and other large pelagic fishes caught by pelagic longline (same as tuna longline). Around the deployed AFADs at about 1,000 m depth, Chumchuen *et al*. (2011) also reported that a total of 25 fish species (tunas, billfishes, sharks, and others) were caught by pelagic longline. The deployed AFADs were inferred to be able to aggregate tunas, but the locations were quite far for Thai fishers; therefore, the deployment of AFADs closer to the coastal area was considered to aggregate tunas. Accordingly, SEAFDEC deployed AFADs in the area of about 500 m depth in 2010 (SEAFDEC 2010). The structures of the deployed AFADs in Thai waters in the Andaman Sea were cement blocks for the anchor, polyethylene rope for the mooring line, steel buoy or a bunch of plastic buoys for the float, and untwisted polyethylene ropes or used fishing nets for the mid-water aggregator (SEAFDEC 2010), which were similar to the AFADs in other waters reported by Beverly *et al*. (2012) and Karama and Matsushita (2019).

Information on the feeding habits of marine fishes, such as the predator-prey relationships, is useful to assess the role of marine fishes in the ecosystem (Bachok *et al*. 2004). In order to understand the diet and feeding habits of large pelagic fish resources around AFADs, stomach content analysis is necessary. In the Equatorial Atlantic Ocean, for example, the dominant diet was photichthyid fish for small-sized individuals of tunas and scombrid fish for large yellowfin tuna (*Thunnus albacares* (Bonnaterre, 1788)); moreover, the minor diet were crustaceans and cephalopods (Ménard *et al*. 2000). In the Western Indian Ocean, the dominant prey for skipjack tuna (*Katsuwonus pelamis* (Linnaeus, 1758)) and yellowfin tuna were fishes, crustaceans, and squids (Roger 1994).

The stomach content data were, therefore, considered to implicate fisheries to understand the feeding habits of the target species in AFAD fishery, particularly tunas and billfishes, and to enhance their foraging ground that would support sustainable AFAD fishery. The main objective of this study was to comparatively describe the diet and feeding habits of large predatory fishes, including tunas and billfishes, caught by trolling line, pelagic longline and drifting vertical line in three areas (*i.e*., reference station, AFADs at 500 m depth and AFADs at 1,000 m depth) in Thai waters in the Andaman Sea.

## MATERIALS AND METHODS

### Study area

This study was carried out in Thai waters in the Andaman Sea (latitude 8.0–8.5 ˚N and longitude 95.5–97.5 ˚E) (Fig. 1) during the three cruises of fishing survey operated by M.V. SEAFDEC in December 2010, February 2011, and May–June 2011. The five sampling stations were categorized into three areas, namely: reference station or the area without AFAD (one sampling station), AFADs at 500 m depth (two sampling stations), and AFADs at 1,000 m depth (two sampling stations). The reference station had the bottom depth of about 500 m and was set at more than 20 km from the southeast direction of AFADs at 500 m depth. For AFADs at 500 m depth, the deployment location was based on the consultation among researchers and related stakeholders in tuna fisheries supply-chain. Moreover, the deployment location of AFADs at 1,000 m depth was decided by the SEAFDEC and the DOF, Thailand (SEAFDEC 2010).

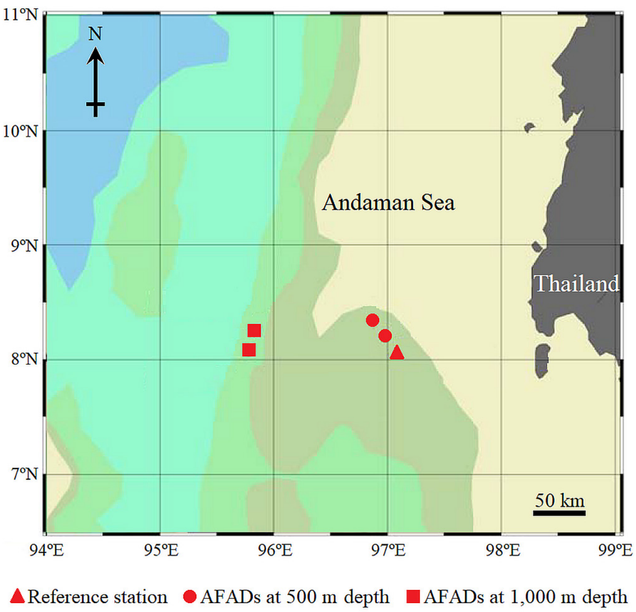


**Figure 1.** Sampling stations for predatory fishes in Thai waters in the Andaman Sea between 2010 and 2011 (modified from SEAFDEC 2010).

**Fishing operation**

The predatory fish samples were caught during the fishing surveys using trolling line, pelagic longline, and drifting vertical line. The trolling line was operated using 4–5 lines and artificial baits with the trolling speed of 5–9 km/h for a distance of 13 km covering the area of about 7 km$^2$ of each sampling station. For the pelagic longline, the total number of hooks for each operation was 400–500 hooks and the soaking time was 12–17 h (shot in the evening and hauled in the morning). For the drifting vertical line, 6–9 vertical lines (each vertical line was attached with 8 hooks) were used, and the soaking time was 14–17 h (shot in the afternoon and hauled in the morning). Pelagic longline and drifting vertical line were operated using mackerels as baits. More details of the three fishing gears and operations were described in SEAFDEC (2010; 2011).

The data on fishing effort and catch of each fishing operation was acquired from SEAFDEC (2010; 2011) to estimate the fishing efforts (hooks) and catch per unit efforts (CPUEs, individuals/1,000 hooks) made by the three fishing gears.

**Stomach sampling and analysis**

This study focuses on the large predatory fishes, including tunas and billfishes which are important fishery resources in the AFAD fishery. During the fishing surveys, each large predatory fish sample was identified as well as its weight (kg) and body length (cm) were measured onboard. Small predatory fishes were excluded from this study. Each large predatory fish was dissected using knife and scissors to remove stomach sample. Each stomach sample was wrapped with plastic film and kept frozen until laboratory work (Hassani *et al*. 1997).

In the laboratory, each stomach sample was weighed (g) and dissected. Each content or primary prey (hereafter referred to as "prey") in stomach samples was removed and identified to the lowest taxonomic level possible under stereo and compound microscopes. This study adopted the occurrence, numerical, and gravimetric (dry weight) methods (Hyslop 1980) for the stomach content analysis of preys. Moreover, the stomach of preys in good condition (with low digestive level) were dissected to observe and record secondary preys of the predatory fishes.

**Data analysis**

The data from fishing surveys, including information on fishing operations, fishing efforts, and catches, was verified using the cruise reports of SEAFDEC (2010; 2011). Due to the combination of the three fishing gears for catching the predatory fishes, we applied the standardization of fishing efforts and CPUEs from Stamatopoulos and Abdallah (2015) to estimate fishing efforts from all fishing gears and to examine the abundance of the predatory fishes among the three areas represented by CPUE from all fishing gears.

For the stomach contents, all prey taxa found in stomach samples were categorized into four prey groups, *i.e.*, fishes, cephalopods, crustaceans, and others. Taxa richness (*S*) and Shannon-Wiener diversity (*H*) index (Rodríguez-Preciado *et al*. 2014) as well as Pielou's evenness (*J*) index (Kaur *et al*. 2017) were estimated for each predatory fish from the diet found in their stomach. For each prey group or taxon, the frequency of occurrence (% *F*) (Patimar 2008), percentage by number (% *N*), percentage by weight (% *W*), index of relative importance (*IRI*) (Pinkas *et al*. 1971), and percentage of *IRI* (% *IRI*) (Demirhan *et al*. 2007) were calculated.

For the statistical analysis, the % *IRI* among the four prey groups was compared for the eight predatory fish species and three areas using the Chi-square test followed by Tukey-type multiple pairwise comparisons for proportions (Zar 2010) to define the most important prey group as the major food source. A significance level ($\alpha$) of 0.05 was applied for the statistical analyses.

The feeding habits of the predatory fishes were comparatively described among the three areas through feeding relationship map illustration using the data on the predatory fishes, preys, and secondary preys that occurred in the three areas.

## RESULTS

**Predatory fish samples**

A total of 23 fishing operations was carried out using the three fishing gears, and 44 samples of large predatory fishes were caught from the three areas (Table 1). Most of the fishing operations was performed by trolling line; however, most of the samples was caught by pelagic longline, particularly in the area of AFADs at 500 m depth. The results indicated that the main fishing gear that captured the predatory fish samples was the pelagic longline.

The standardized fishing efforts among the three areas were 643–1,478 hooks. The standardized CPUEs of the predatory fishes among the three areas were 3.11 individuals/1,000 hooks, 17.60 individuals/1,000 hooks, and 11.12 individuals /1,000 hooks for the reference station, AFADs at 500 m depth, and AFADs at 1,000 m depth, respectively. Based on the standardized CPUEs among the three areas, the two areas of AFADs had higher abundance of predatory fishes than in the area of reference station. This could be the result of AFADs deployment that enhanced or gathered pelagic fish resources; therefore, information on diet and feeding habits of the predatory fishes caught in the three areas was necessary to clarify the predator-prey relationships around AFADs.

Eight species of large predatory fish samples were captured from the three areas, including two species of cartilaginous fish ($n$ = 3) and six species of teleost fish ($n$ = 41) which were composed of several commercial species, including tunas and billfishes (Table 2). The predatory fish samples comprised mainly of yellowfin tuna followed by savalai hairtail (*Lepturacanthus savala* (Cuvier, 1829)) and swordfish (*Xiphias gladius* Linnaeus, 1758). For the three areas, only two predatory fish species (*i.e*., savalai hairtail and swordfish) were captured in the area of reference station; besides, six predatory fish species (*i.e*., great hammerhead (*Sphyrna mokarran* (Rüppell, 1837)), savalai hairtail, swordfish, snake mackerel (*Gempylus serpens* Cuvier, 1829), kawakawa (*Euthynnus affinis* (Cantor, 1849)), and yellowfin tuna) and four predatory fish species (*i.e*., bigeye thresher (*Alopias superciliosus*

Lowe, 1841), great barracuda (*Sphyraena barracuda* (Edwards, 1771)), swordfish, and yellowfin tuna) were captured in the area of AFADs at 500 m depth and AFADs at 1,000 m depth, respectively. Among the samples, the smallest size of predatory fish had a total length of about 0.3 m (*i.e.*, kawakawa), while the largest size had a total length of almost 2.8 m (*i.e.*, bigeye thresher). It should be noted that small predatory fishes, *e.g.*, pelagic stingray (*Dasyatis violacea* (Bonaparte, 1832)) and oilfish (*Ruvettus pretiosus* Cocco, 1833) were also captured during the fishing surveys; however, the small predatory fishes were not included in this study.

**Prey composition and major food source**

Table 3 shows that a total of 22 prey taxa was found in the stomach samples of the eight predatory fish species caught from the three areas. For each predatory fish species, the taxa richness of preys ranged between 1 and 15, and swordfish had the highest taxa richness followed by yellowfin tuna. For the *H* index, yellowfin tuna had the highest value followed by swordfish. For the *J* index, great barracuda had the highest value followed by savalai hairtail.

In terms of study areas, the highest taxa richness of preys was in the area of AFADs at 1,000 m depth followed by the areas of AFADs at 500 m depth and reference station. For the *H* index, the two areas of AFADs had similar values which were higher than the area of reference station. For the *J* index, the three areas had similar values that ranged between 0.57 and 0.72.

Table 4 shows the values of % *F*, % *N*, % *W*, and % *IRI* for each prey (by group or taxon) found in the stomach samples of the eight predatory fish species. Fishes, cephalopods, and crustaceans similarly occurred in the stomach samples; however, fishes, in terms of number and weight, were the most dominant prey group. Also, fishes were the most important prey group with the highest % *IRI* with a value of more than 65 %. Moreover, the % *IRI* of others prey groups (*i.e.*, macroalgae, *Turbinaria* sp., and unidentified organisms) was very low (less than 0.1 %).

**Table 1.** Number of fishing operations, standardized fishing efforts, number of predatory fish samples, and standardized catch per unit effort (CPUE) of predatory fish from three fishing gears operated in three study areas (A: reference station; B: AFADs at 500 m depth; C: AFADs at 1,000 m depth) in Thai waters in the Andaman Sea during 2010–2011.

| | Fishing gear | Study area | | | |
|---|---|---|---|---|---|
| | | A | B | C | Total |
| Number of fishing operations (operations) | Trolling line | 1 | 6 | 3 | 10 |
| | Pelagic longline | 1 | 2 | 2 | 5 |
| | Drifting vertical line | 1 | 3 | 2 | 6 |
| | All fishing gears | 3 | 11 | 7 | 21 |
| Standardized fishing efforts (hooks) from all fishing gears | | 643 | 1,478 | 1,439 | 3,560 |
| Number of predatory fish samples (individuals) | Trolling line | 0 | 14 | 4 | 18 |
| | Pelagic longline | 2 | 11 | 10 | 23 |
| | Drifting vertical line | 0 | 1 | 2 | 3 |
| | All fishing gears | 2 | 26 | 16 | 44 |
| Standardized CPUE (individuals/1,000 hooks) from all fishing gears | | 3.11 | 17.60 | 11.12 | 12.36 |

**Table 2.** Species, body weight (BW), fork length (FL), and total length (TL) of predatory fishes caught from three study areas in Thai waters in the Andaman Sea during 2010–2011. (*n*: number of predatory fish samples, *d*: number of non-empty stomachs, NA: not available).

| Common name (Scientific name) | *n* | *d* | Reference station | | | AFADs at 500 m depth | | | AFADs at 1,000 m depth | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BW (kg) | FL (cm) | TL (cm) | BW (kg) | FL (cm) | TL (cm) | BW (kg) | FL (cm) | TL (cm) |
| Great hammerhead (*Sphyrna mokarran*) | 1 | 1 | | | | 80.0 | NA | 247.0 | | | |
| Bigeye thresher (*Alopias superciliosus*) | 2 | 1 | | | | | | | 58.0–65.0 | NA | 276.0–277.0 |
| Savalai hairtail (*Lepturacanthus savala*) | 9 | 4 | 1.1 | NA | 135.0 | 0.8–1.8 | NA | 107.5–133.0 | | | |
| Great barracuda (*Sphyraena barracuda*) | 3 | 2 | | | | | | | 3.6–4.4 | 81.0–92.0 | 88.0–96.0 |
| Swordfish (*Xiphias gladius*) | 9 | 8 | 4.3 | 133.5 | 129.5 | 4.0–4.3 | 129.0–131.0 | 120 | 8.6–65.0 | 141.0–255.0 | 153.0–270.0 |
| Snake mackerel (*Gempylus serpens*) | 1 | 1 | | | | 1.2 | 93.0 | 99.5 | | | |
| Kawakawa (*Euthynnus affinis*) | 1 | 1 | | | | 0.3 | 27.5 | 29.0 | | | |
| Yellowfin tuna (*Thunnus albacares*) | 18 | 17 | | | | 0.4–1.8 | 28.5–47.5 | 30.5–50.0 | 1.6–50.0 | 46.0–143.0 | 56.0–158.0 |

**Table 3.** Preys (groups or taxa) occurred in the stomachs of each predatory fish and each study area in Thai waters in the Andaman Sea. (SPK: great hammerhead (*Sphyrna mokarran*), BTH: bigeye thresher (*Alopias superciliosus*), SVH: savalai hairtail (*Lepturacanthus savala*), GBA: great barracuda (*Sphyraena barracuda*), SWO: swordfish (*Xiphias gladius*), GES: snake mackerel (*Gempylus serpens*), KAW: kawakawa (*Euthynnus affinis*), YFT: yellowfin tuna (*Thunnus albacares*), A: reference station, B: AFADs at 500 m depth, C: AFADs at 1,000 m depth).

| Preys (groups or taxa) | Predatory fish | | | | | | | | Study area | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | SPK | BTH | SVH | GBA | SWO | GES | KAW | YFT | A | B | C |
| Fishes | + | + | + | + | + | - | + | + | + | + | + |
| *Scombrolabrax heterolepis* | - | + | - | - | + | - | - | - | - | - | + |
| *Nemicthys* sp. | - | - | + | - | - | - | - | - | + | + | - |
| Bramids | - | - | + | + | + | - | - | + | - | + | + |
| Carangids | - | - | + | - | + | - | - | - | + | - | + |
| Clupeids | - | - | - | - | + | - | - | - | - | + | - |
| Trichiurids | - | + | - | - | - | - | - | - | - | - | + |
| Other teleosts | + | + | + | + | + | - | + | + | + | + | + |
| Cephalopods | + | - | + | - | + | + | - | + | + | + | + |
| Squids | + | - | + | - | + | + | - | + | + | + | + |
| Ommastrephids | - | - | - | - | + | - | - | - | - | + | - |
| *Stenoteuthis oualanensis* | - | - | - | - | + | - | - | - | - | - | + |
| Cuttlefishes | - | - | - | - | + | - | - | - | - | - | + |
| Crustaceans | + | - | - | - | + | - | + | + | + | + | + |
| *Phronima* sp. | - | - | - | - | + | - | - | - | - | - | + |
| Lobsters | - | - | - | - | + | - | - | - | + | - | + |
| Scyllarids | - | - | - | - | - | - | - | + | - | - | + |
| Stomatopods | - | - | - | - | + | - | + | + | - | + | + |
| Shrimps | + | - | - | - | + | - | - | + | - | + | + |
| Pandalids | - | - | - | - | + | - | - | - | - | - | + |
| Crabs | - | - | - | - | - | - | - | + | - | + | + |
| Other crustaceans | - | - | - | - | - | - | - | + | - | + | + |
| Others | - | - | - | - | + | - | - | + | + | + | - |
| Macroalgae | - | - | - | - | + | - | - | - | - | + | - |
| *Turbinaria* sp. | - | - | - | - | - | - | - | + | - | + | - |
| Unidentified organisms | - | - | - | - | - | - | - | + | + | - | - |
| Taxa richness (*S*) | 3 | 3 | 4 | 2 | 15 | 1 | 2 | 10 | 6 | 12 | 16 |
| Shannon-Wiener diversity (*H*) | 0.95 | 0.87 | 1.26 | 0.69 | 1.35 | 0.00 | 0.50 | 1.49 | 1.29 | 1.55 | 1.57 |
| Evenness (*J*) | 0.86 | 0.79 | 0.91 | 1.00 | 0.50 | # | 0.72 | 0.65 | 0.72 | 0.63 | 0.57 |

+ present; - absent; # cannot be estimated

**Table 4.** Frequency of occurrence (% *F*), percentage by number (% *N*), percentage by weight (% *W*), and percentage of the index of relative importance (% *IRI*) of each prey group or taxon found in stomach samples of predatory fishes caught from Thai waters in the Andaman Sea during 2010–2011 ($n$ = 44).

| Preys (groups or taxa) | % *F* | % *N* | % *W* | % *IRI* |
|---|---|---|---|---|
| Fishes | 52.27 | 45.25 | 77.91 | 65.58 |
| *Scombrolabrax heterolepis* | 9.09 | 6.85 | 19.48 | 4.40 |
| *Nemicthys* sp. | 4.55 | 0.66 | 2.56 | 0.27 |
| Bramids | 6.82 | 0.66 | 3.82 | 0.56 |
| Carangids | 6.82 | 0.66 | 10.64 | 1.41 |
| Clupeids | 2.27 | 0.22 | 0.09 | 0.01 |
| Trichiurids | 2.27 | 0.22 | 3.15 | 0.14 |
| Other teleosts | 43.18 | 35.98 | 38.17 | 58.79 |
| Cephalopods | 47.73 | 13.91 | 19.18 | 14.34 |
| Squids | 43.18 | 13.25 | 4.00 | 13.68 |
| Ommastrephids | 2.27 | 0.22 | 4.81 | 0.21 |
| *Stenoteuthis oualanensis* | 2.27 | 0.22 | 10.37 | 0.44 |
| Cuttlefishes | 2.27 | 0.22 | < 0.01 | 0.01 |
| Crustaceans | 50.00 | 39.96 | 2.49 | 20.00 |
| *Phronima* sp. | 2.27 | 0.22 | < 0.0001 | 0.01 |
| Lobsters | 4.55 | 1.33 | 0.43 | 0.15 |
| Scyllarids | 2.27 | 0.22 | < 0.0001 | 0.01 |
| Stomatopods | 34.09 | 23.62 | 0.64 | 15.19 |
| Shrimps | 9.09 | 1.55 | 0.68 | 0.37 |
| Pandalids | 4.55 | 0.88 | 0.19 | 0.09 |
| Crabs | 9.09 | 2.65 | 0.12 | 0.46 |
| Other crustaceans | 20.45 | 9.49 | 0.43 | 3.72 |
| Others | 9.09 | 0.88 | 0.42 | 0.08 |
| Macroalgae | 2.27 | 0.22 | 0.06 | 0.01 |
| *Turbinaria* sp. | 2.27 | 0.22 | 0.23 | 0.02 |
| Unidentified organisms | 4.55 | 0.44 | 0.14 | 0.05 |
| All taxa | 79.55 | 100.00 | 100.00 | 100.00 |

For each predatory fish, the % *IRI* of the four prey groups was calculated to describe the major food source. The % *IRI* among the four prey groups was significantly different for each predatory fish ($\chi^2 >$ 17,485; $p < 0.001$); moreover, our results showed that fishes, cephalopods, and crustaceans were the most important prey groups for different predatory fishes (Fig. 2). Fishes were the most important prey group for great hammerhead, bigeye thresher, savalai hairtail, great barracuda, and swordfish; cephalopods were the most important prey group for snake mackerel; and crustaceans were the most important prey group for kawakawa and yellowfin tuna. The results indicated that there were different major food sources among the eight predatory fish species.

Considering the three areas, the % *IRI* among the four prey groups was significantly different for each area ($\chi^2 > 10{,}511$; $p < 0.001$); besides, fishes were the most important prey group for the three areas (Fig. 3). It should be noted that crustaceans were considered to be the potential important prey group in the area of AFADs at 500 m depth because of its high % *IRI* (41.8 %). The results inferred that fishes were the major food sources which was available in the three areas.

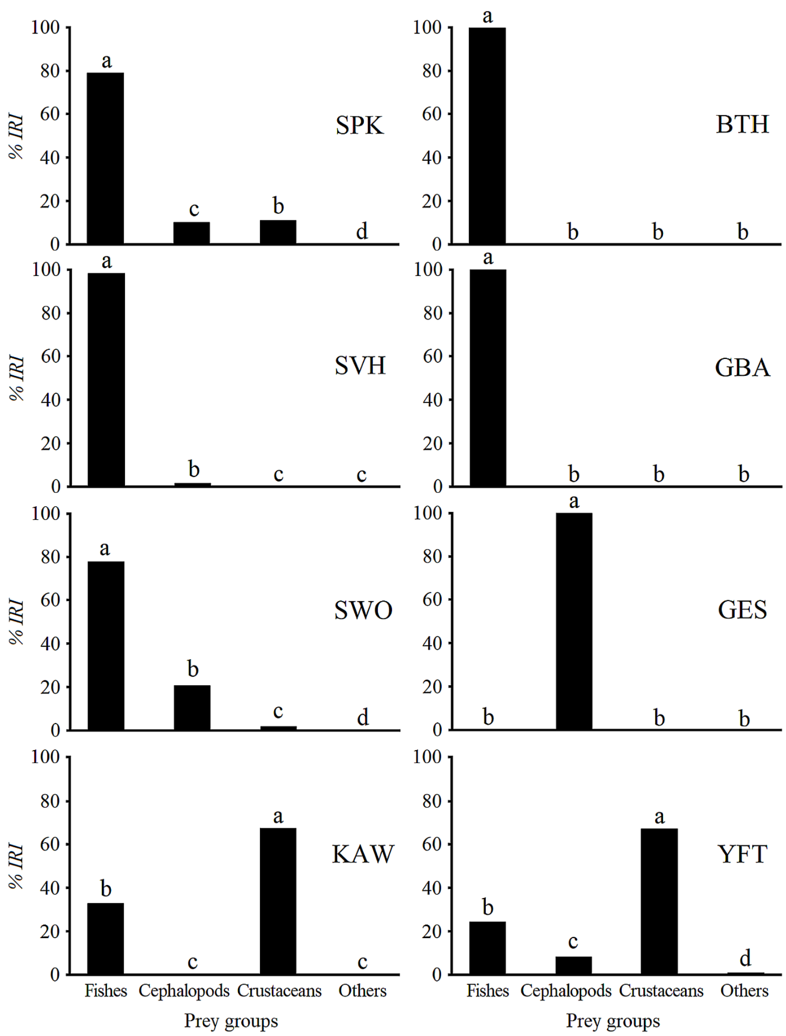


**Figure 2.** Percentage of the index of relative importance (% *IRI*) of each prey group found in the stomachs of eight predatory fish species caught from Thai waters in the Andaman Sea during 2010–2011. Different letters among four prey groups in each predatory fish species indicate a significant difference of % *IRI* between prey groups ($p < 0.05$). (SPK: great hammerhead (*Sphyrna mokarran*), BTH: bigeye thresher (*Alopias superciliosus*), SVH: savalai hairtail (*Lepturacanthus savala*), GBA: great barracuda (S*phyraena barracuda*), SWO: swordfish (*Xiphias gladius*), GES: snake mackerel (*Gempylus serpens*), KAW: kawakawa (*Euthynnus affinis*), YFT: yellowfin tuna (*Thunnus albacares*)).

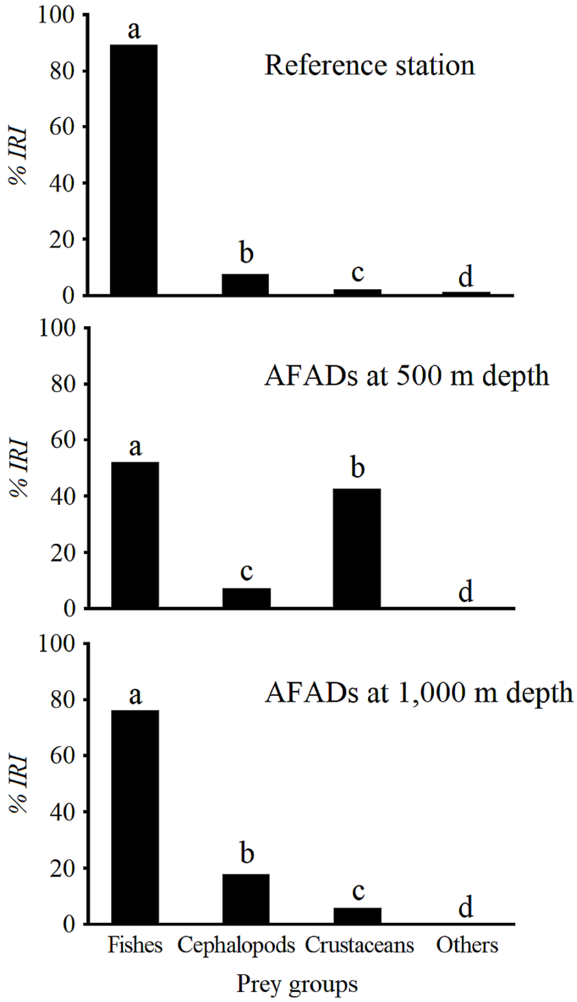


**Figure 3.** Percentage of the index of relative importance (% *IRI*) of each prey group found in the stomachs of predatory fish species caught from three study areas during 2010–2011. Different letters among four prey groups in each area indicate a significant difference of % *IRI* between prey groups ($p < 0.05$).

**Feeding relationship**

To comparatively describe the feeding habits of the predatory fishes among the three areas, a feeding relationship map was illustrated using the data on predatory fishes, preys, and secondary preys that occurred in each area (Fig. 4). There were several taxa of the four prey groups available for the eight predatory fish species in the three areas; nevertheless, the feeding relationship among predatory fishes, preys, and secondary preys in the areas of AFADs at 500 m depth and AFADs at 1,000 m depth were more complex than in the area of reference station. Preys of the predatory fishes caught in the areas of AFADs, particularly at 500 m depth, were more diverse than those caught in the area of the reference station. It should be noted that bramids, stomatopods, shrimps, and crabs were found as preys of the predatory fishes caught in the two areas of AFADs. For the secondary preys, they were diverse in the areas of AFADs than in the area of the reference station. The results indicated that preys and secondary preys were more available in the areas of AFADs than in the area of the reference station.

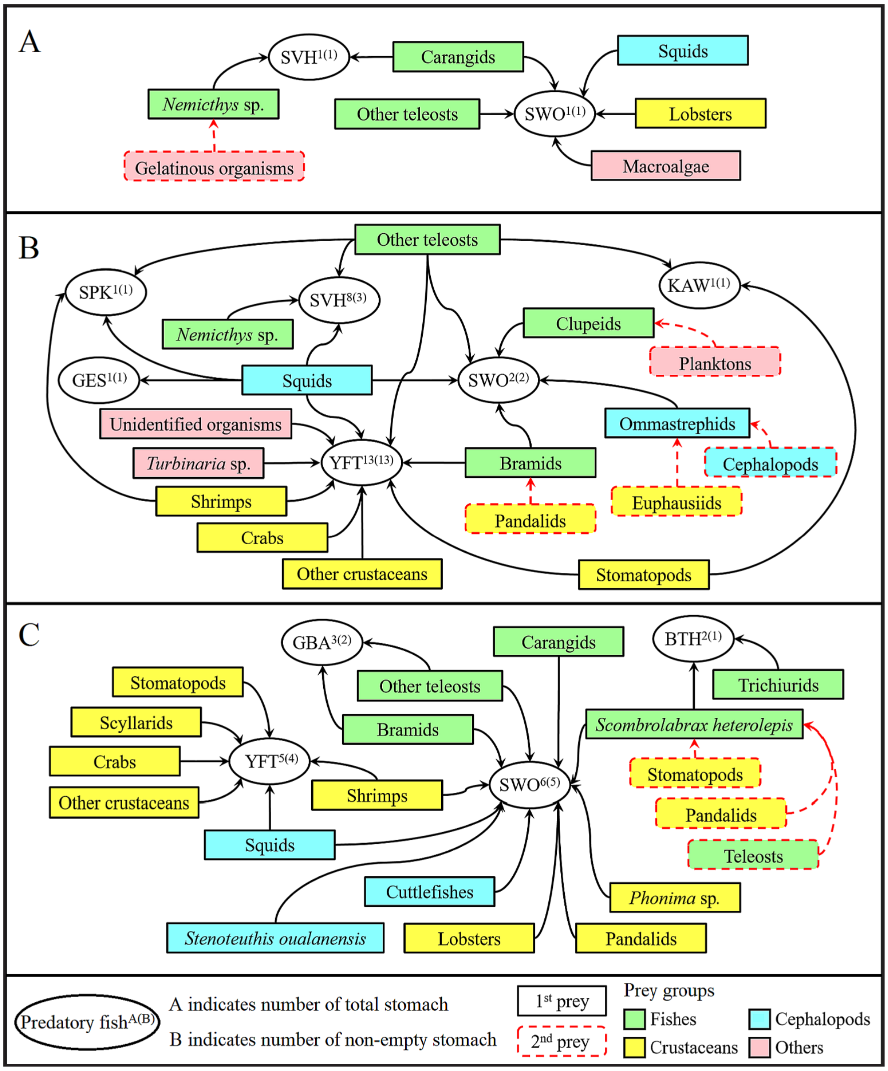


**Figure 4.** Feeding relationship map among predatory fishes, primary preys (1st preys), and secondary preys (2nd preys) in three areas (A: reference station, B: AFADs at 500 m depth, and C: AFADs at 1,000 m depth) in Thai waters in the Andaman Sea. (SPK: great hammerhead (*Sphyrna mokarran*), BTH: bigeye thresher (*Alopias superciliosus*), SVH: savalai hairtail (*Lepturacanthus savala*), GBA: great barracuda (*Sphyraena barracuda*), SWO: swordfish (*Xiphias gladius*), GES: snake mackerel (*Gempylus serpens*), KAW: kawakawa (*Euthynnus affinis*), YFT: yellowfin tuna (*Thunnus albacares*)).

## DISCUSSION

This study provided information on the diet and feeding habits of the eight predatory fish species caught from Thai waters in the Andaman Sea. The eight predatory fish species found in this study have been also reported to be distributed in Thai waters in the Andaman Sea (Nakamura and Parin 1993; Satapoomin 2011). Regarding the standardized CPUEs from the three fishing gears, it was confirmed that there was more abundant predatory fishes in the two areas of AFADs (at 500 m and 1,000 m depth) than in the area of the reference station. Though there were only three fishing operations in the reference station (*i.e.*, one fishing operation for each fishing gear), the standardized fishing efforts from the three fishing gears were assumed to be sufficient for catching predatory fishes. According to the cruise report of SEAFDEC (2010), the fishing efforts in the reference station were able to catch only two individuals of fish (standardized CPUE of 3.11 individuals/1,000 hooks), while Darumas and Chumchuen (2019) reported that the CPUE of large predatory fishes (tunas, billfishes, and sharks) from pelagic longline fishing in the Andaman Sea was 7.47 individuals/1,000 hooks. This supported the low abundance of predatory fishes in the reference station in our study. Besides, the higher abundance of predatory fishes in the two areas of AFADs may be due to the effectiveness of AFADs in attracting predatory fishes (Pillai and Mallia 2007; Fréon and Dagorn 2000). Sukramongkol *et al*. (2014) reported that a higher abundance of fish larvae of scombrids, particularly yellowfin tuna, were found in the area of AFADs in comparison to the area without AFAD. Aprieto (1991) also supported that the juvenile tunas and small pelagic fishes were distributed under the AFADs deployed in the upper layer of the water column, and the larger predators were in the deeper water.

The results revealed that preys found in the stomachs of both swordfish and yellowfin tuna had high taxa richness and value of *H* index. Although preys found in the stomachs of great barracuda and savalai hairtail had low taxa richness and value of *H* index, the value of *J* index was higher than preys found in the stomachs of swordfish and yellowfin tuna. This indicated that swordfish and yellowfin tuna consumed numerous prey species; however, some prey species were in high proportion but some were in low proportion. In contrast, great barracuda and savalai hairtail consumed lesser diverse prey species; however, proportions among prey species were equal for great barracuda and similar for savalai hairtail.

For the higher taxa richness and value of *H* index in the two areas of AFADs in comparison to the area of non-AFAD, we assumed that AFADs had a function to attract marine organisms for the food sources of predatory fishes. This was supported by Fréon and Dagorn (2000) that AFADs served as shelter from predators, concentration of food supply, spatial reference, and meeting point.

Moreover, the results also indicated that the most available prey group for the predatory fishes was fishes followed by crustaceans and cephalopods. This may be due to the availability of prey fishes in the study areas. Satapoomin (2011) reported that there were 1,746 species under 198 families of fishes found in the Andaman Sea coast of Thailand. Sukramongkol *et al.* (2014) also reported that 49 families of fish larva were found around AFADs in the same period of our study. For other prey groups, the occurrence rate was very low; besides, macroalgae and *Turbinaria* sp. might have been accidentally consumed together with other prey taxa which were targeted by the predatory fishes as their prey. This phenomenon was reported by Manooch and Hogarth (1983) that sargassum, eelgrass, and a piece of plastic were probably only eaten accidentally, which were found in the stomach of a predatory fish, wahoo (*Acanthocybium solanderi* (Cuvier, 1832)). Furthermore, it should be noted that only one prey group and a few pray taxa were found in the stomachs of bigeye thresher (three taxa), great barracuda (two taxa), and snake mackerel (one taxon) in this study. This might be due to the small number of stomach samples for these species. This was supported by the study of Hammerschlag *et al*. (2010) that the number of prey taxa found in the three stomach samples of great barracuda (same number of stomach samples as in this study) was between two and four taxa; additionally, the number of prey taxa increased when the number of stomach samples increased (eight taxa from nine stomach samples and nine taxa from 24 stomach samples). Preti *et al*. (2008) also supported that 20 prey taxa were found from 23 non-empty stomach samples of bigeye thresher. Therefore, further studies with more samples of bigeye thresher, great barracuda, and snake mackerel around AFAD are needed in order to provide more information to prove the feeding habit of these species from our study.

For the feeding habits of the eight predatory fish species, our results were similar to other studies. Great hammerhead consumed mainly fishes followed by crustaceans and cephalopods (Cliff, 1995). Bigeye thresher fed dominantly on fishes (% *IRI* > 90) (Preti *et al*. 2008). Savalai hairtail consumed a variety of fishes and crustaceans (Lalitkumar 2014). Great barracuda was piscivorous (Hammerschlag *et al*. 2010). Swordfish took fishes as the main diet (% *IRI* > 87) followed by cephalopods and crustaceans (Varghese *et al*. 2013). Snake mackerel fed primarily on fishes and cephalopods (Choy *et al*. 2013). Kawakawa had a variety of preys but the most important prey group was crustaceans (% *IRI* > 60) (Vigneshwaran *et al*. 2018). Yellowfin tuna fed mainly on crustaceans followed by cephalopods, fishes, and others (Chumchuen *et al*. 2017).

From the results of the three areas, we considered that AFADs were effective in attracting preys and predatory fishes for the enhancement of pelagic fish resources (*e.g*., yellowfin tuna and swordfish) which could be captured using trolling line, pelagic longline, and drifting vertical line. This may be supported by the function of AFAD which serves as the area with a high concentration of food supply for pelagic fish (Fréon and Dagorn, 2000). Babaran *et al*. (2009) found that there were at least 24 prey categories available in the area of AFADs and 19 prey categories available in the areas of non-AFAD for bigtooth pomfret (*Brama orcini* Cuvier, 1831), one of the bramids; in addition, crustaceans were the major prey group for this bramid, which was similar to the secondary prey, *i.e*., pandalid shrimps, that were eaten by bramids found in the stomach of predatory fishes in AFADs area in our study. Sukramongkol *et al*. (2014) emphasized that a total of 49 families of fish larva were found in FADs areas; moreover, the larvae of yellowfin tuna and other scombrids in the areas of AFADs had higher abundance than in the area of non-AFAD. Chumchuen *et al*. (2021) studied pelagic fishes captured by pelagic longline in the periods of pre- and post-deployment AFADs in the same areas of the present study and reported that the diversity of pelagic fishes caught during the period of post-deployment of AFADs (including four species of tunas and billfishes) was higher than during the period of pre-deployment (including three species of tunas and billfishes).

In terms of the enhancement of pelagic fish resources using AFADs, our results were supported by Pillai and Mallia (2007) that deep water AFADs (500–1,500 m depth) were successful in attracting tunas, as well as by Beverly *et al*. (2012) that tunas and billfishes were the target species in AFAD fishery. Karama and Matsushita (2019) emphasized that the introduction of AFADs has been promoted throughout the world to assist small-scale fishers. AFADs, therefore, can be considered as an effective tool for fishery resources enhancement and utilization. For a successful case of AFAD fishery of the Maldives, the number of AFADs increased from an initial of 10 AFADs in the late 1980s to 55 AFADs in 2019, which were deployed and managed by the government; consequently, both artisanal and commercial pole-and-line vessels across the Maldives had equal accessibility to all AFADs and contributed to nearly one-third of tuna production caught by pole-and-line in the Maldives (Jauharee *et al*. 2021). We suggest that the expansion of the AFADs network would help further enhance the large pelagic fish resources in order to support the enhancement of fishing ground for tunas and billfishes in Thai waters in the Andaman Sea. In addition, the AFADs management (*i.e*., number, deployment area, ownership, and registration) for fisheries purposes is needed to support sustainable resource utilization.

## CONCLUSION

The CPUE in the three areas revealed that the abundance of predatory fishes in the two areas of AFADs was higher than in the area of reference station; therefore, AFADs were believed to be effective in attracting the large predatory fishes, particularly tunas and billfishes in Thai waters in the Andaman Sea. The comparison of % *IRI* for each predatory fish revealed that there were different major food sources among the eight predatory fish species. The most important prey group was fishes for great hammerhead, bigeye thresher, savalai hairtail, great barracuda and swordfish, cephalopods for snake mackerel, and crustaceans for kawakawa and yellowfin tuna. The comparison of % *IRI* among the four prey groups for the three areas indicated that fishes were the major food source and available for the eight predatory fish species. Besides, crustaceans were the potential important food source in the area of AFAD at 500 m depth. As a result of the feeding realtionship among the three areas, the preys and secondary preys found in the stomachs of the predatory fishes were more diverse in the areas of AFADs than in the area without AFAD.

As for recommendations, studies on marine organisms (*e.g*., planktons and fishes) in the areas of AFADs and non-AFAD along the stomach contents analysis of predatory fishes are necessary to confirm the food sources of the predatory fishes as well as the function of AFADs to serve as a foraging ground for the predatory fishes. For the prey availability around the areas of AFADs and non-AFAD, the different monsoons may have an influence, and further study is recommended to clarify this point.

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