

# Diet composition and feeding habits of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) from the Bay of Bengal

Silambarasan Krishnan<sup>1</sup> , Tiburtius Antony Pillai<sup>1</sup>, John Chembian Antony Rayappan<sup>1</sup>, Tharumar Yagappan<sup>1</sup> and Jeyabaskaran Rajapandian<sup>2</sup>

<sup>1</sup> Fishery Survey of India, Royapuram, Chennai, Tamil Nadu, India

<sup>2</sup> Fishery Survey of India, New Fishing Jetty, Sasson Dock, Colaba, Mumbai, India

Received 13 March 2023 / Accepted 22 June 2024

Handling Editor: Dr. François LE LOC'H

**Abstract** – Though yellowfin tuna (*Thunnus albacares*) is one of the important fishery resources in the Bay of Bengal, knowledge on its ecology, diet composition and feeding habits are limited from this area. In view of that, present study focuses on the diet composition and feeding habits of yellowfin tuna (YFT) hooked during exploratory longline survey conducted in the Indian EEZ of the Bay of Bengal during 2019–2021. A total of 213 specimens in the length range of 42.0 to 171.0 cm fork length (FL) were examined, of which 28.2% were empty while the remaining 71.8% contained at least one prey item. The modified Costello graphical method shows a wide range of prey items, with a few prey species that are dominant and can be found in high densities in the Bay of Bengal. Due to the fact that this apex predator is a generalist feeder, this might be the case. Cluster analysis based on the %IRI (Index of relative importance) identified two size groups. YFT with smaller (<80 cm FL) is one group. Crustaceans was the most frequently eaten prey in that group followed by cephalopods and teleostea. The second group consists of two length groups medium (81–120 FL), and larger (>120 FL), Cephalopods were the dominant prey items of this group and accounts for 62.0% in %IRI followed by teleostea 31.3% of the diet. Cephalopods (*Sthenoteuthis oualaniensis*) were the primary food consumed in all the size groups, followed by crustaceans (*Charybdis smithii*) and Teleost fishes (*Cubiceps pauciradiatus*). The dietary breadth and the occurrence of empty stomachs were significantly related to size of the yellowfin tuna. With increasing body size, diet breadth gradually increased while the percentage of empty stomachs declined. The yellowfin tuna diet does not vary significantly during the seasons. However, cephalopods were found in 53.5% of the IRI in their diet. Furthermore, there were notable seasonal changes in the percentage of empty stomachs, with the highest percentage observed during the monsoon season (38.3%).

**Keywords:** Feeding ecology / tuna / exploratory survey / diet breadth / seasonality

## 1 Introduction

Diet information is essential to our understanding of the concepts of ecology, trophic interrelationships, food webs, and ultimately, energy transfer through ecosystems. Stomach content analysis is an important technique for universally sampling the diets of fish, and these studies provide large amounts of species-specific data for potential use in trophic ecosystem modelling that contributes to ecosystem based fishery management advice (Ainsworth et al., 2010). These supporting ecosystems incorporate ecological interactions to assess the potential flows of biomass among interacting populations within an exploited ecosystem (Pauly et al., 2002).

Further, the importance of ecosystem based fishery management is demonstrated by the fact that studies of the diet of fish are essential for understanding spatial, temporal and ontogenetic changes of trophic interactions (Hollowed et al., 2000) as well as feeding regimes, food preferences, migrations, growth and breeding patterns (Varghese and Somvanshi, 2016).

With annual catches of 7.8 million metric tonnes, tuna and tuna-like species are one of the most important marine resources on the planet and are estimated to contribute at least USD 14.6 billion to the global economy (FAO, 2022). Despite their importance, there is still scope for improvement in our understanding of this key group's ecology. The Bay of Bengal Large Marine Eco-system (BOBLME) is one of the most productive ecosystems (>300 g C cm<sup>-2</sup> y<sup>-1</sup>) in the northeastern Indian ocean (Dwivedi and Choubey, 1998). It is surrounded by the India in the west, Bangladesh in the north,

\*Corresponding author: [silambuplankton@hotmail.com](mailto:silambuplankton@hotmail.com)

Myanmar and the Andaman Nicobar Islands in the east and Sri Lanka and Indonesia at both ends in the south (Dwivedi and Choubey, 1998). Fishery in this region is a multi-species and multi gears nature. In the Bay of Bengal, small pelagic finfish and shrimp have lower trophic levels and are mainly targeted species in nearshore waters. Subsequently, the deeper water catches are dominated by oceanic tunas and other allied resources having higher trophic levels, and the mean trophic level of the oceanic tunas is greater than 3 (Ullah et al., 2012). Major catches of larger pelagic tunas are landed in the Bay of Bengal using longlining, drift-net and gillnetting. Yellowfin tuna is an important export commodity in India, with a total production of 0.31 million metric tonnes from 2019 to 2020 (DoF, 2020). In spite of its commercial importance, very few studies have attempted to examine the feeding habits of yellowfin tuna (YFT) in the Indian Ocean region (Kornilova, 1981; Maldeniya, 1996).

Yellowfin tuna is an epi-pelagic species and one of the most important widespread species; it is distributed in the tropical and subtropical waters of all the oceans (Carpenter and De Angelis, 2016). This species is considered as a valuable fishery resource worldwide, and its management is a major concern for international levels, fishery managers and fishery scientists. In fact, from the ecological point of view, Yellowfin tuna plays an important role of apex predator in the pelagic trophic web, regulating and controlling the ecosystem balance and prey biomass by a constant predation, assuring a positive control on biodiversity by contributing to maintain its natural level (Battaglia et al., 2013). Yellowfin tuna is a voracious feeder and feeds on a broad spectrum of prey; he has been described as a non-selective generalist feeder (Rohit et al., 2010). To study Yellowfin tuna diet composition and feeding habits is critical not only for using the data to develop an improved exploitation strategy but also for understanding the significant structural changes brought about in the ecosystem when they are removed by fishing (Cox et al., 2002; Watters et al., 2003).

Several studies attempted to examine the food and feeding habits of yellowfin tuna from Indian waters (Vijayakumaran et al., 1992; Pillai et al., 1993; John, 1995; Govindaraj et al., 2000; Rohit et al., 2010; Abdussamad et al., 2012; Varghese and Somvanshi, 2016; Kumar and Ghosh, 2020). However, only two studies (Rohit et al., 2010; Kumar and Ghosh, 2020) were carried out from Western Bay of Bengal (Andhra Pradesh) based on the tuna landings in the fisheries harbour. However, none of the studies carried out in the Indian Exclusive Economic Zone (EEZ) came from the Bay of Bengal. Based on the exploratory fishery resources survey, this study made a preliminary attempt to analyze the diet composition, size, and seasonality of feeding strategies, considering the role of *T. albacares* in the ecosystem within the Indian Exclusive Economic Zone (EEZ) of the Bay of Bengal.

## 2 Materials and methods

### 2.1 Study area

The present study was conducted as an exploratory tuna and allied fishery resources survey by the departmental survey vessel Matsya Drushti (Over All Length: 37.5 m), attached to the Chennai Base of Fishery Survey of India, Govt. of India,

Ministry of Fisheries, Animal Husbandry & Dairying, Dept. of Fisheries. The tuna and allied fishery resources survey was carried out during 2019–span>2021 at (Lat. 10°–21°N; Long. 80°–90°E) and a depth of operation beyond 500 m from the Indian EEZ of the Bay of Bengal, which is the northeastern part of the Indian Ocean (Fig. 1).

### 2.2 Sample collections

In the present study yellowfin tuna samples were collected during the regular exploratory fishery resources survey cruises using Monofilament longline gear. The survey cruises were normally of 20 days duration and about 15 longline operations (sets) were conducted in each voyage (Tab. 1). The general method of operation was that the shooting of the line commences before sunrise and is completed in about 2–2.5 h. On average, 575–630 hooks are operated per set. Immersion time of 5–6 h is allowed, and hauling is done in the afternoon. A wide variety of baits, including mackerels, scads, sardines, squids etc., were utilized during the study. An immersion time of six hours is allowed, and the gear is retrieved at around 1400 h. All the fish samples were caught, measured for morphometric measurements ( $\pm 0.5$  cm), weighed ( $\pm 100$  g) the body cavity was cut open, sex was recorded macroscopically, and stomachs were removed and put in plastic bags with proper labelling and kept frozen at  $-20^{\circ}\text{C}$  onboard the vessel.

### 2.3 Identification of gut contents

A total of 213 yellowfin tuna (*T. albacares*) samples were caught during the survey. Further, examinations of the stomachs were transported to the shore laboratory, where they were thawed and opened, and prey species were weighed and counted to the lowest possible taxonomic level using a stereoscopic microscope. Food items that were considered bait were not included in the analysis because the stomachs that contained baits were treated as empty. When prey found advanced digestion status i.e., typical jaws of tetraodontiformes, *Alepisaurus*, the photophores of Myctophidae, otoliths, gladius and cephalopods lower beaks were considered hardparts remains and identified using available guides (Clarke, 1986; Harvey et al., 2000).

### 2.4 Data analysis

The proportion of empty stomachs in a sample and the mean stomach repletion can be used as indicators of relative foraging success. These indices were computed for each size class of yellowfin tuna and used to distinguish changes in foraging success based on predator size. The volume of the prey in milliliters, as a gram of stomach content per kilogram of body weight, was used to calculate the stomach Repletion Index (RI). Empty stomachs were characterized as having less than 0.1 ml of prey per kg of body weight.

Mean cumulative curves showing the relationship between the number of prey taxa detected and the number of stomach samples (refraction curves) were constructed using the Vegan package (Oksanen et al., 2010) in R statistical software (R Core Team, 2015). It was based on the assumption that an

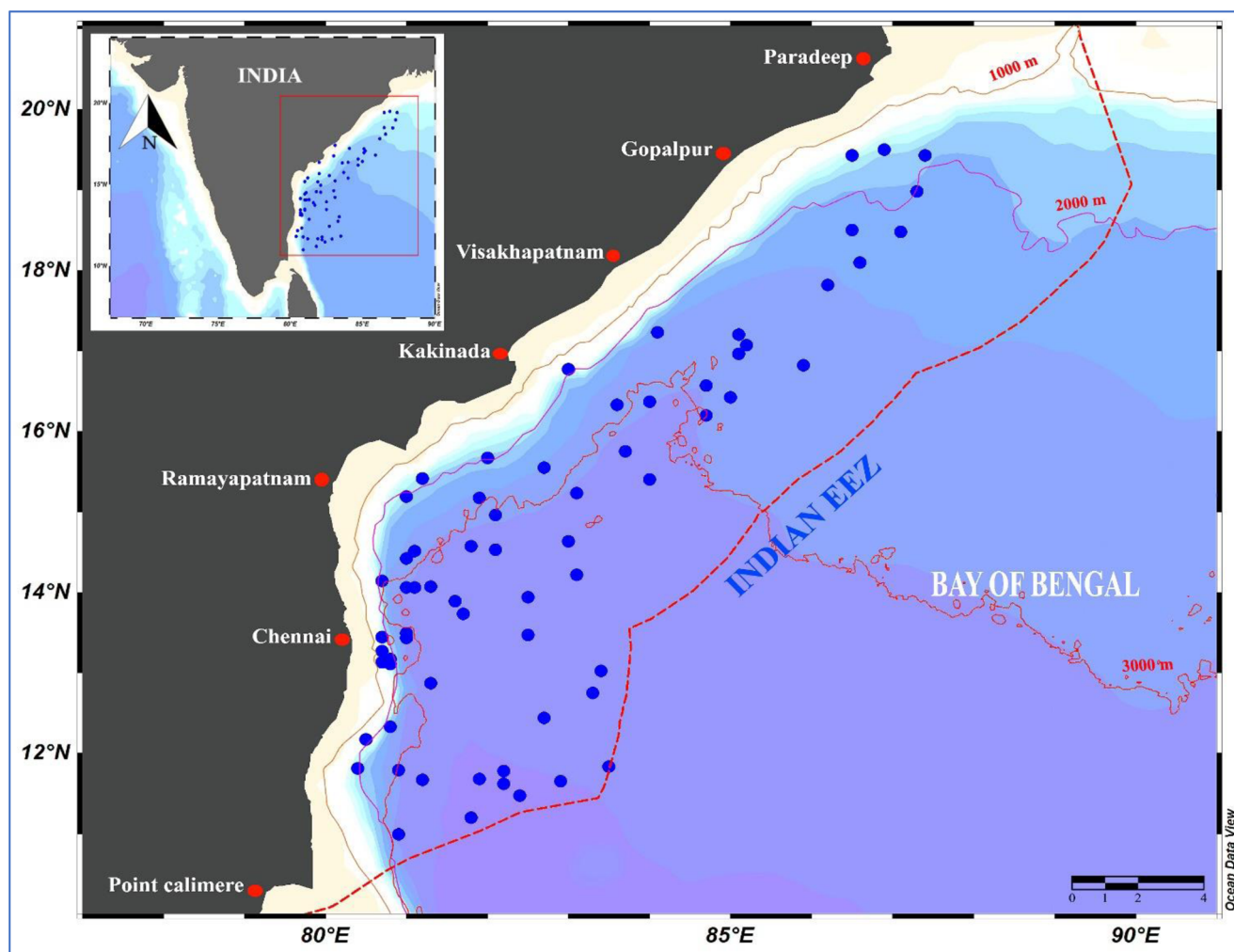


Fig. 1. Map showing the sampling stations.

**Table 1.** Number of sets operated, stomach samples by yellowfin tuna size and year.

| Size                  | Number of sets operated | Number of all stomachs | Number of stomachs with at least one prey item | % of stomachs with at least one prey item |
|-----------------------|-------------------------|------------------------|------------------------------------------------|-------------------------------------------|
| 80 cm Fork Length     | –                       | 43                     | 33                                             | 76.7                                      |
| 80–120 cm Fork Length | –                       | 50                     | 38                                             | 76.0                                      |
| >120 cm Fork Length   | –                       | 120                    | 82                                             | 68.3                                      |
| <b>Total</b>          |                         | 213                    | 153                                            | 71.8                                      |
| <b>Year</b>           |                         |                        |                                                |                                           |
| 2019                  | 120                     | 59                     | 38                                             | 64.0                                      |
| 2020                  | 105                     | 50                     | 42                                             | 84.0                                      |
| 2021                  | 165                     | 104                    | 73                                             | 70.1                                      |
| <b>Total</b>          | 390                     | 213                    | 153                                            | 71.8                                      |

asymptote is achieved when the slope of the line generated from the mean values of the last four endpoints is not statistically different from zero, and then the species accumulation curve was inferred to have reached an asymptote (Bizzarro et al., 2007). The importance of the different prey items in the diet was quantified by calculating the following dietary indexes:

Abundance percentage:  $(\%N = N_i/N_{\text{total}} \times 100)$ ,  
 Weight percentage:  $\%W = W_i/W_{\text{total}} \times 100$ ,  
 Frequency of occurrence:  $\%F = A_i/N \times 100$ .

where  $A_i$  is the number of fish preying species  $i$ ,  $N$  is the total number of fish examined (excluding individuals with empty stomachs),  $N_i$  ( $W_i$ ) is the number (dry weight) of prey individuals  $i$ , and  $N_{\text{total}}$  ( $W_{\text{total}}$ ) is the total number (dry weight) of prey individuals.

These values were combined to calculate the index of relative importance (IRI) for each prey and expressed as a percentage ( $\%IRI$ ) (Pinkas et al., 1971; Hyslop, 1980; Hacunda, 1981):  $IRI = (\%N + \%W) \times \%F$ , and  $\%IRI_i = (IRI_i / \sum IRI) \times 100$ .

The 95% confidence limits for each prey category were calculated using the boot and boot.ci commands in the package boot (Canty and Ripley, 2011) in R statistical software (R Core Team, 2015). We performed 1000 replicates of random samples, with replacement, from the original data set, which included both empty and non-empty stomachs. We used the percentile bootstrap method to construct  $100 \times (1 - \alpha)\%$  confidence intervals (Davison and Hinkley, 1997). This method discards the  $100 \times \alpha/2\%$  smallest and  $100 \times \alpha/2\%$  highest values of the estimated parameter among the 1000 bootstrap resamples, thereby representing the level of uncertainty associated with these indices (Tirasin and Jorgensen, 1999).

The dietary breadth index ( $B$ ) was assessed by Levin's standardized index (Krebs, 1989), which is calculated by the following formula:  $B_i = (1/n - 1) \times (1 / \sum P_{ij}^2 - 1)$ . Where,  $B_i$  is Levin's standardized index for predator  $i$ ,  $P_{ij}$  is the proportion of the diet of predator  $i$  that is made up of prey  $j$ , and  $n$  is the number of prey categories. This index value ranged from 0 to 1, with lower values representing diets dominated by a few prey items (specialist predator) and higher values representing a generalist diet (Gibson and Ezzi, 1987; Krebs, 1989).

The analysis of niche overlap was calculated using Pianka's index (Pianka, 1973), which is derived from the composition of the diet (%) of the different species:  $O_{ij} = \sum p_{ij} p_{ik} / \sqrt{(\sum p_{ij}^2 \sum p_{ik}^2)}$ . Where,  $O_{ij}$  = Pianka's index of niche overlap between species  $j$  and  $k$ ,  $p_{ij}$  = the proportion of the  $i$ th resources in the diets of the species  $j$ ,  $p_{ik}$  = the proportion of the  $i$ th resource in the diet of species  $k$ , and  $n$  = the total number of items. Pianka's index values were interpreted according to Grossman (1986) and Novakowski et al., (2008) which follow the same boundaries as those of Levin's index.

## 2.5 Feeding strategies

The feeding strategy was assessed by Costello's theoretical diagram, which was developed by Costello (1990) and later modified by Amundsen et al. (1996), which consists of a scatter diagram composed of each prey-specific abundance ( $P_i$ )

relative to its occurrence, which is calculated by the formula:  $P_i = (\sum S_A / \sum S_{tA}) \times 100$ , where  $P_i$  = prey specific-abundance;  $\sum S_A$  = sum of prey  $A$  in weight or number;  $\sum S_{tA}$  = sum of total prey in weight or number only in the stomachs where prey  $A$  was found. For this analysis, the authors chose to work with the weight of the prey.

## 2.6 Ontogenetic and seasonal changes in diet

Size-related variations in diet composition were analysed in the yellowfin tuna specimens and classified into three groups: 1. Smaller (<80 cm FL), 2. Medium (81–120 cm FL) and 3. Larger (>120 cm FL). Similarly, seasonal variations of diet composition were divided into four seasons: (1) Postmonsoon (January–March), (2) Summer (April–June), (3) Premonsoon (July–September) and (4) Monsoon (October–December). Statistical differences by size-class and season in the dietary composition of each food item and the percentage of empty stomachs were tested using a chi-square test. A one-way analysis of variance was used to determine size class and seasonal variations in dietary breadth. Statistical analysis was calculated by SPSS for windows, version 16.0. Bray-curtis similarity based on the hierarchical cluster analysis  $\%IRI$  was used for classification and ordination of size classes and seasonality into groups. By employing the group average cluster mode, diet similarities were used to associate different size classes of fish with four different seasons. It was applied using the PRIMER v6 (Clarke and Gorley, 2006). By employing the group average cluster mode, diet similarities were used to associate each size class with various seasons. It was utilized for applying PRIMER v6. A Principal component analysis (PCA) was used to evaluate possible differences between all the categories-this test was carried out in PAST 4.13 (Hammer et al., 2001).

## 3 Results

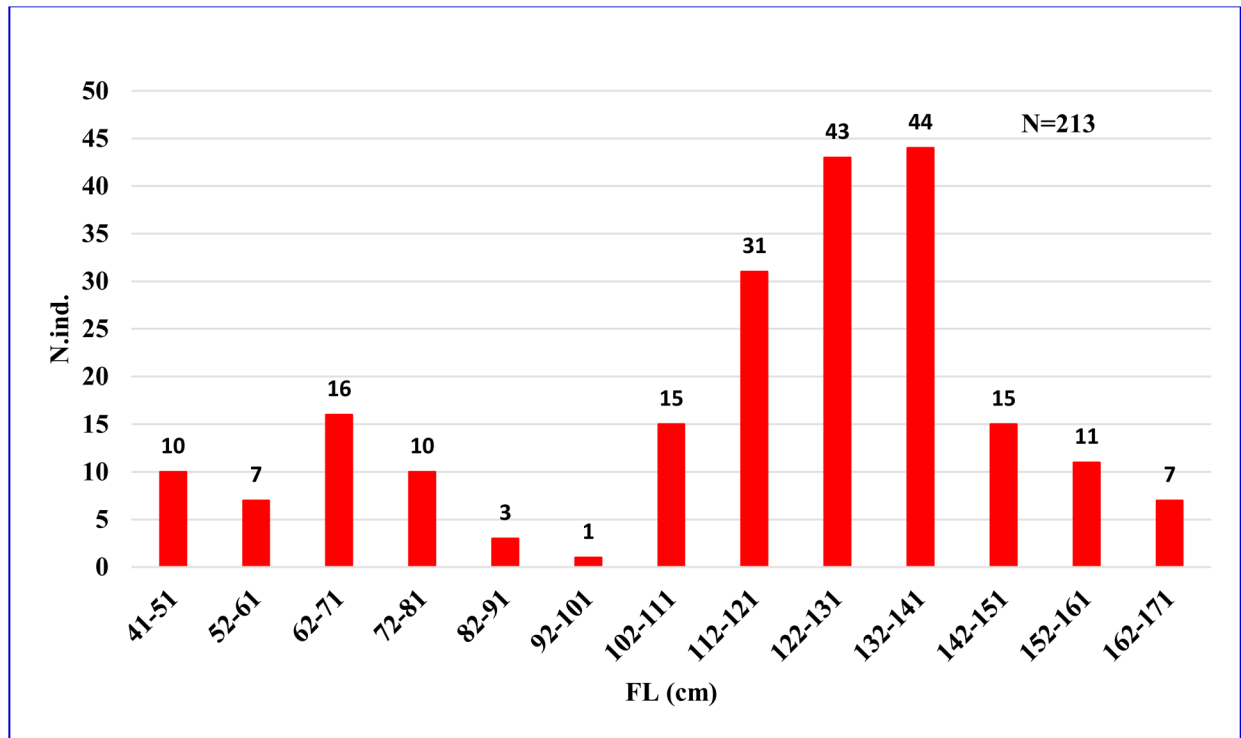
### 3.1 Feeding intensity

The yellowfin tuna fork length ranged from 42.0 to 171.0 cm  $L_F$  (mean FL =  $111.0 \pm 171.0$  cm) and weighed 1.0 to 75.0 kg (mean WT =  $26.2 \pm 15.8$  kg). The length-frequency distribution of the sampled yellowfin tuna specimens is shown in Figure 2. Of the 213 stomachs examined, 60 were empty (28.2%), while the remaining 153 (71.8%) contained at least one prey item. The weight of the stomach contents varied from 0 to 600 g, with a repletion index (RI) of 2.072 g per kg body weight for 213 samples. The cumulative prey curve did not approach an asymptote for the yellowfin tuna stomachs analysed (Fig. 3). The last four stomachs of the terminal curve exhibited a slope that significantly deviated from zero ( $p = 0.01713$ ). However, the indication that the curve begins to asymptote indicates that the majority of prey taxa found in the diet of yellowfin tuna are likely represented in this analysis.

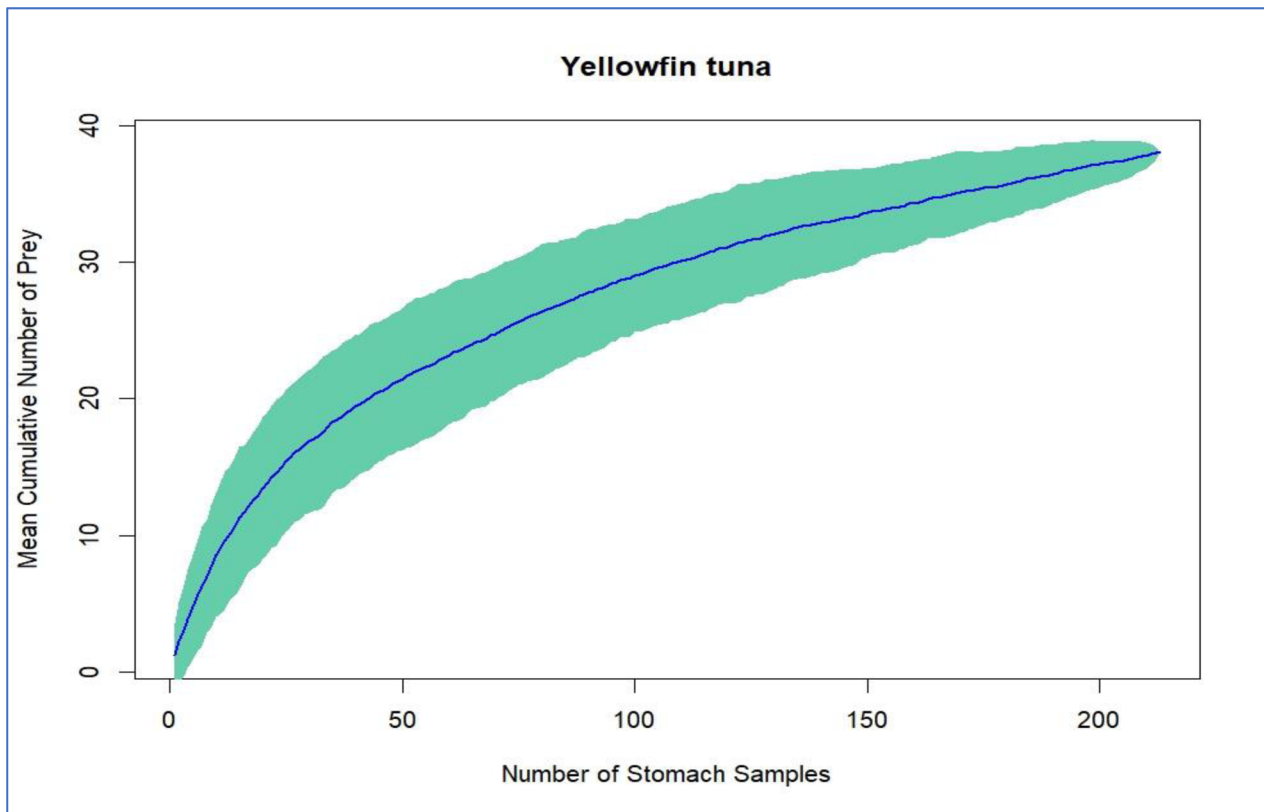
### 3.2 Diet composition

Overall, 53 taxa of prey items were identified in the stomach content of the yellowfin tuna, mostly belonging to Teleostea (30), followed by Cephalopoda (12), Crustacea (07),





**Fig. 2.** Fork length frequency distribution of yellowfin tuna specimens collected from Bay of Bengal based on the exploratory tuna longline surveys.



**Fig. 3.** Cumulative prey curve (refraction curve) for yellowfin tuna.

and others (04). The differences in diet composition between males and females there is no significant ( $\chi^2 = 3.932$ ,  $P > 0.05$ ) variations. Diet composition of yellowfin tuna and dietary indexes (abundance percentage, weight percentage, frequency of occurrence, *IRI* and %*IRI*) calculated for each prey item are presented in Table 2. The percentage of *IRI* indicates the highest values for *Sthenoteuthis oualaniensis* (%*IRI* = 59.825) and *Charybdis smithii* (%*IRI* = 13.541), followed by *Histioteuthis* sp., (%*IRI* = 6.079), and Teleostea unid. (%*IRI* = 6.615). However, an elevated contribute in terms of the number of prey (%*N*) was given by *Sthenoteuthis oualaniensis* (%*IRI* = 18.87) and Teleostea unid. (%*IRI* = 8.451), while *Sthenoteuthis oualaniensis* (%*W* = 24.32), *Charybdis smithii* (%*W* = 24.32) and *Solenocera hextii* (%*W* = 5.256) represented 40.0% of prey biomass. Furthermore, the most frequently consumed prey were *Sthenoteuthis oualaniensis* (%*F* = 18.87), *Charybdis smithii* and Teleostea unid, which recorded the same value of %*F* = 8.451.

The Amundsen plot depicts the frequency of occurrence (%*F*) plotted against prey-specific abundance ( $P_i$ ), expressed in weight and number. The explanatory theoretical Costello diagram (modified from Amundsen et al., 1996) for interpreting feeding strategy is provided. Most of the food categories are located in the lower left corner of the diagrams or close to the vertical axis, which indicates low prey importance. As suggested by the low values of frequency of occurrence, all these species are rare or unimportant prey, being consumed by a low percentage of predators. It is therefore inferred that some prey items resulted in being most frequently eaten by yellowfin tuna (*Sthenoteuthis oualaniensis*, *Charybdis smithii* and *Histioteuthis* sp.). Apart from few other prey species; *Argonauta hians*, *Cupiceps pauciradiatus*, *Decapterus macrosoma*, the rest exhibited low occurrences, indicating them to be an occasional prey (Fig. 4).

### 3.3 Variation in stomach contents by fish size

Size-related variation in dietary composition was significant ( $\chi^2 = 98.9$ ,  $P < 0.01$ ; Fig. 5). Cephalopods were the most dominant prey item in all size classes, representing 55.4% of the diet; teleost fishes contributed 24.2% followed by crustaceans (20.1%) and others (0.17%). Bray-curtis similarity based on the cluster analysis indicated two yellowfin tuna size groups below 50% similarity (Fig. 6). The first group of smaller (<80 cm FL) crustaceans was the most frequently eaten prey, followed by cephalopods. The second group consists of two length groups: medium-sized (81–120 cm FL) cephalopods were the dominant prey items; they comprised 78.9% of the *IRI*, and large-sized (>120 cm FL) cephalopods were the dominant prey items, which contributed 45.0% of the *IRI*.

Similarities were found in the diet for all categories recorded above and confirmed by the principal component analysis (PCA). The first PCA axis (horizontal) explains 88.8% of the total variance (eigen value = 3.46), while the second PCA axis (vertical) explains 6.1% of the total variance (eigen value = 0.24); thus, the first two PCA accounted for 94.9% of the total variance, providing a good representation of the data structure for yellowfin tuna diets. Generally, larger (>120 FL) specimens of yellowfin tuna highly consume

cephalopod prey. But the medium-sized (80–120 FL) specimens consumed six prey taxa, namely carangidae, trichiuridae, tetraodontidae, exocoetidae, balistidae and nomeidae. In small sized (<80 FL), there were five prey taxa, such as myctophidae, priacanthidae, pyrosomatidae, crustaceans and fish larvae.

The dietary breadth levin's index revealed there is no significant variations among the length groups ( $\chi^2 = 0.3679$ ,  $P > 0.05$ ), and the values ranged from 0.32 to 0.56 (Fig. 7), with the lowest value in size class (medium sized 80–120 FL) being 0.32 and the highest value being observed in 0.56 (large sized >120 FL). Similarly, the niche overlap-Pianka's index was applied to the %*IRI* of prey and revealed no significant differences between diets of different length groups ( $\chi^2 = 0.9407$ ,  $P > 0.05$ ). The diet of the size class <80 FL did not overlap significantly with the diet of other groups, while significant overlap in diets was observed between size groups 80–120 FL. However, the percentage of empty stomachs exhibited an opposite tendency to dietary breadth ( $\chi^2 = 6.54$ ;  $P < 0.05$ ), with the highest value (51.7%) recorded in larger fish size classes (>120 FL) and the lowest values (21.7%) recorded in smaller fish size classes (<80 FL).

Quantile regression parameters and their standard errors were calculated for a range of quantiles between 0.0014 and 0.02336 for yellowfin tuna. The 5th and 95th quantiles were selected to estimate the lower and upper bounds of prey size distribution (Fig. 8). The present study demonstrated that yellowfin tunas of Bay of Bengal consumed a broad range of prey sizes, with the size of prey proportionally increasing with predator size. Maximum and median prey size increased with predator size (50th quantile,  $y = 0.02522x + 3.66930$ ; 95th quantile,  $y = 0.11364x + 5.74545$ ), whereas minimum prey size remained fairly stable (5th quantile,  $y = 0.00665x + 1.28218$ ). However, 5th quantile, indicating a significant relationship between predator size and minimum prey size ( $P < 0.001$ ).

### 3.4 Seasonal variation in feeding habits

Seasonal changes in dietary composition there were no significant variations between the seasons ( $\chi^2 = 0.325$ ;  $P > 0.05$ ; Fig. 9). In all seasons, cephalopods were the most dominant prey items, occupying 49% in %*IRI*, the highest value was recorded during postmonsoon (Jan–Mar) season (53.5 %*IRI*). The second most dominant food item is teleost fish, it accounts for 34% in %*IRI*, which was elevated during monsoon (Oct–Dec) season (41.9%*IRI*). Third, crustaceans contributed 17% in %*IRI* which was dominated during the summer (Apr–Jun) season. Cluster analysis indicated three groups of yellowfin tuna with 50% similarity (Fig. 10). The first group indicated summer (April–June) and did not overlap with another season; similarly, the second group indicated monsoon season (October–December). The third group consist of the postmonsoon (January–March) and premonsoon (July–September) seasons, which significantly overlap in the cluster.

The yellowfin tuna diet exhibits significant seasonal fluctuation, as indicated by the first two primary axes (PCA 1 and PCA 2), which together account for 96.1% of the total variability (91.3% and 4.8%, respectively). During the summer and monsoon seasons, there are higher contributions from

**Table 2.** Diet composition of *T. albacares* and dietary indexes calculated for each prey item: abundance percentage (%N), weight percentage (%W), frequency of occurrence (%F), index of relative abundance (IRI), IRI percentage (%IRI), and (LCL) and (UCL) limits of 95% confidence intervals calculated by bootstrapping, as outlined in text.

| Class                              | Order          | Family          | Species                              | %N   | LCL | UCL | %W   | LCL | UCL | %F   | LCL | UCL | IRI   | LCL  | UCL  | %IRI | LCL | UCL |
|------------------------------------|----------------|-----------------|--------------------------------------|------|-----|-----|------|-----|-----|------|-----|-----|-------|------|------|------|-----|-----|
| <i>Hydrozoa</i><br><i>Decapoda</i> | Siphonophora   | Diphyidae       | Diphyidae unid.                      | 0.1  | 0.0 | 0.0 | 0.2  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                | Solenoceridae   | <i>Solenocera hexti</i>              | 4.6  | 0.2 | 0.4 | 5.3  | 0.3 | 0.7 | 2.8  | 0.1 | 0.2 | 27.7  | 1.0  | 2.5  | 1.8  | 0.0 | 0.2 |
|                                    | Portunidae     |                 | Shrimp larva                         | 0.6  | 0.0 | 0.1 | 0.2  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.2   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | Shrimps unid.                        | 2.5  | 0.1 | 0.2 | 1.3  | 0.1 | 0.2 | 2.3  | 0.1 | 0.1 | 8.7   | 0.3  | 0.8  | 0.6  | 0.0 | 0.1 |
|                                    |                |                 | <i>Charybdis smithii</i>             | 14.2 | 0.7 | 1.3 | 10.2 | 0.6 | 1.3 | 8.5  | 0.4 | 0.5 | 205.7 | 7.3  | 18.3 | 13.5 | 0.2 | 1.2 |
|                                    |                |                 | Brachyuran Megalopa                  | 4.6  | 0.2 | 0.4 | 0.5  | 0.0 | 0.1 | 3.1  | 0.2 | 0.2 | 15.6  | 0.6  | 1.4  | 1.0  | 0.0 | 0.1 |
|                                    |                |                 | <i>Squillaoides leptosquilla</i>     | 1.1  | 0.1 | 0.1 | 1.5  | 0.1 | 0.2 | 1.7  | 0.1 | 0.1 | 4.4   | 0.2  | 0.4  | 0.3  | 0.0 | 0.0 |
| <i>Cephalopoda</i>                 | Squilloidea    | Squillidae      | <i>Squilla</i> unid.                 | 0.3  | 0.0 | 0.0 | 0.2  | 0.0 | 0.0 | 0.6  | 0.0 | 0.0 | 0.3   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Abralia</i> sp.,                  | 0.1  | 0.0 | 0.0 | 0.1  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Abraliopsis</i> sp.,              | 0.8  | 0.0 | 0.1 | 0.6  | 0.0 | 0.1 | 0.8  | 0.0 | 0.0 | 1.1   | 0.0  | 0.1  | 0.1  | 0.0 | 0.0 |
|                                    |                |                 | <i>Onychoteuthidae</i>               | 0.3  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.2   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Histioteuthis</i> sp.,            | 5.8  | 0.3 | 0.5 | 5.9  | 0.3 | 0.8 | 7.9  | 0.4 | 0.5 | 92.3  | 3.3  | 8.2  | 6.1  | 0.1 | 0.5 |
|                                    | Teuthida       | Enoploteuthidae | <i>Benthoteuthis</i> sp.,            | 0.4  | 0.0 | 0.0 | 0.4  | 0.0 | 0.1 | 0.6  | 0.0 | 0.0 | 0.4   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Sthenoteuthis oualaniensis</i>    | 23.8 | 1.2 | 2.2 | 24.3 | 1.4 | 3.2 | 18.9 | 1.0 | 1.1 | 908.7 | 32.3 | 80.7 | 59.8 | 0.9 | 5.4 |
|                                    |                |                 | Teuthidae unid.,                     | 1.9  | 0.1 | 0.2 | 2.1  | 0.1 | 0.3 | 2.8  | 0.1 | 0.2 | 11.2  | 0.4  | 1.0  | 0.7  | 0.0 | 0.1 |
|                                    |                |                 | <i>Loligo vulgaris</i>               | 0.9  | 0.0 | 0.1 | 1.6  | 0.1 | 0.2 | 1.7  | 0.1 | 0.1 | 4.2   | 0.2  | 0.4  | 0.3  | 0.0 | 0.0 |
|                                    |                |                 | <i>Loligo</i> sp.,                   | 0.9  | 0.0 | 0.1 | 1.2  | 0.1 | 0.2 | 1.4  | 0.1 | 0.1 | 2.9   | 0.1  | 0.3  | 0.2  | 0.0 | 0.0 |
|                                    | Octopoda       | Argonautidae    | <i>Argonauta</i> hians               | 3.5  | 0.2 | 0.3 | 2.2  | 0.1 | 0.3 | 2.5  | 0.1 | 0.1 | 14.5  | 0.5  | 1.3  | 1.0  | 0.0 | 0.1 |
|                                    |                |                 | <i>Argonauta</i> sp.,                | 0.9  | 0.0 | 0.1 | 0.3  | 0.0 | 0.0 | 0.8  | 0.0 | 0.0 | 1.0   | 0.0  | 0.1  | 0.1  | 0.0 | 0.0 |
|                                    |                |                 | Cephalopoda unid.                    | 2.5  | 0.1 | 0.2 | 2.0  | 0.1 | 0.3 | 3.4  | 0.2 | 0.2 | 15.3  | 0.5  | 1.4  | 1.0  | 0.0 | 0.1 |
|                                    |                |                 | Salpidae unid.                       | 0.1  | 0.0 | 0.0 | 0.0  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.0   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Pyrosoma atlanticum</i>           | 0.8  | 0.0 | 0.1 | 0.7  | 0.0 | 0.1 | 1.1  | 0.1 | 0.1 | 1.6   | 0.1  | 0.1  | 0.1  | 0.0 | 0.0 |
| <i>Tunicata</i>                    | Salpida        | Pyrosomatidae   | <i>Doliolum</i> sp.,                 | 0.9  | 0.0 | 0.1 | 0.3  | 0.0 | 0.0 | 1.1  | 0.1 | 0.1 | 1.3   | 0.0  | 0.1  | 0.1  | 0.0 | 0.0 |
|                                    |                |                 | <i>Sardinella</i> sp.,               | 0.1  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Acropoma lacrima</i>              | 0.1  | 0.0 | 0.0 | 0.2  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Acropoma argentistigma</i>        | 0.3  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Decapterus macrostoma</i>         | 3.2  | 0.2 | 0.3 | 5.5  | 0.3 | 0.7 | 4.8  | 0.2 | 0.3 | 41.4  | 1.5  | 3.7  | 2.7  | 0.0 | 0.2 |
| <i>Clupeiformes</i>                | Perciformes    | Carangidae      | <i>Selar crumenophthalmus</i>        | 0.1  | 0.0 | 0.0 | 0.4  | 0.0 | 0.1 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Caranx</i> spp.,                  | 0.6  | 0.0 | 0.1 | 0.6  | 0.0 | 0.1 | 0.6  | 0.0 | 0.0 | 0.7   | 0.0  | 0.1  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | Carangidae unid.                     | 0.1  | 0.0 | 0.0 | 0.1  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Sphyræna barracuda</i>            | 0.3  | 0.0 | 0.0 | 0.5  | 0.3 | 0.7 | 0.6  | 0.0 | 0.0 | 3.3   | 0.1  | 0.3  | 0.2  | 0.0 | 0.0 |
|                                    |                |                 | <i>Cubiceps pauciradiatus</i>        | 2.2  | 0.1 | 0.2 | 3.0  | 0.2 | 0.4 | 3.1  | 0.2 | 0.2 | 15.9  | 0.6  | 1.4  | 1.0  | 0.0 | 0.1 |
|                                    | Sphyrænaeidae  | Nomeidae        | <i>Diaphus</i> sp.,                  | 0.6  | 0.0 | 0.1 | 0.3  | 0.0 | 0.0 | 1.1  | 0.1 | 0.1 | 1.0   | 0.0  | 0.1  | 0.1  | 0.0 | 0.0 |
|                                    |                |                 | <i>Diaphus fragilis</i>              | 0.3  | 0.0 | 0.0 | 0.2  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Vinciguerrita attenuate</i>       | 0.1  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Katsuwonus pelamis</i>            | 0.1  | 0.0 | 0.0 | 1.4  | 0.1 | 0.2 | 0.3  | 0.0 | 0.0 | 0.4   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Trichiurus lepturus</i>           | 0.9  | 0.0 | 0.1 | 1.4  | 0.1 | 0.2 | 0.8  | 0.0 | 0.0 | 1.9   | 0.1  | 0.2  | 0.1  | 0.0 | 0.0 |
|                                    | Phosichthyidae | Scombridae      | <i>Hirundichthys coromandelensis</i> | 1.9  | 0.1 | 0.2 | 3.7  | 0.2 | 0.5 | 1.4  | 0.1 | 0.1 | 7.9   | 0.3  | 0.7  | 0.5  | 0.0 | 0.0 |
|                                    |                |                 | <i>Hirundichthys</i> sp.,            | 0.1  | 0.0 | 0.0 | 0.1  | 0.0 | 0.0 | 0.3  | 0.0 | 0.0 | 0.1   | 0.0  | 0.0  | 0.0  | 0.0 | 0.0 |
|                                    |                |                 | <i>Cheilopogon furcatus</i>          | 0.9  | 0.0 | 0.1 | 1.4  | 0.1 | 0.2 | 0.8  | 0.0 | 0.0 | 1.9   | 0.1  | 0.2  | 0.1  | 0.0 | 0.0 |
|                                    |                |                 |                                      |      |     |     |      |     |     |      |     |     |       |      |      |      |     |     |
|                                    |                |                 |                                      |      |     |     |      |     |     |      |     |     |       |      |      |      |     |     |

Table 2. (continued).

| Class | Order | Family          | Species                               | %N  | LCL | UCL | %W  | LCL | UCL | %F  | LCL | UCL | IRI   | LCL | UCL | %IRI | LCL | UCL |
|-------|-------|-----------------|---------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|-----|-----|------|-----|-----|
|       |       |                 | <i>Cheilopogon spilopterus</i>        | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1   | 0.0 | 0.0 | 0.0  | 0.0 | 0.0 |
|       |       |                 | <i>Cheilopogon sp.</i>                | 0.3 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1   | 0.0 | 0.0 | 0.0  | 0.0 | 0.0 |
|       |       |                 | <i>Exocoetus sp.</i>                  | 1.1 | 0.1 | 0.1 | 1.4 | 0.1 | 0.2 | 1.7 | 0.1 | 0.1 | 4.3   | 0.2 | 0.4 | 0.3  | 0.0 | 0.0 |
|       |       |                 | Flying fishes unid.                   | 0.6 | 0.0 | 0.1 | 0.7 | 0.0 | 0.1 | 1.1 | 0.1 | 0.1 | 1.5   | 0.1 | 0.1 | 0.1  | 0.0 | 0.0 |
|       |       |                 | <i>Priacanthus hamrur</i>             | 1.6 | 0.1 | 0.1 | 1.4 | 0.1 | 0.2 | 1.7 | 0.1 | 0.1 | 5.1   | 0.2 | 0.5 | 0.3  | 0.0 | 0.0 |
|       |       | Priacanthidae   | <i>Bregmaceros maclellandi</i>        | 0.4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.6   | 0.0 | 0.1 | 0.0  | 0.0 | 0.0 |
|       |       | Bregmaceroidae  | <i>Aulotrachichthys sp.</i>           | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1   | 0.0 | 0.0 | 0.0  | 0.0 | 0.0 |
|       |       | Trachichthyidae | <i>Canthichthys maculatus</i>         | 0.4 | 0.0 | 0.0 | 0.6 | 0.0 | 0.1 | 0.6 | 0.0 | 0.0 | 0.6   | 0.0 | 0.0 | 0.0  | 0.0 | 0.0 |
|       |       | Balistidae      | <i>Pseudobalistes flavimarginatus</i> | 0.4 | 0.0 | 0.0 | 1.6 | 0.1 | 0.2 | 0.8 | 0.0 | 0.0 | 1.7   | 0.1 | 0.2 | 0.1  | 0.0 | 0.0 |
|       |       |                 | <i>Arothron spp.</i>                  | 1.3 | 0.1 | 0.1 | 1.4 | 0.1 | 0.2 | 1.7 | 0.1 | 0.1 | 4.6   | 0.2 | 0.4 | 0.3  | 0.0 | 0.0 |
|       |       | Tetraodontidae  | <i>Lagocephalus lagocephalus</i>      | 0.5 | 0.0 | 0.0 | 1.5 | 0.1 | 0.2 | 0.8 | 0.0 | 0.0 | 1.7   | 0.1 | 0.1 | 0.1  | 0.0 | 0.0 |
|       |       |                 | Fish larva                            | 2.3 | 0.1 | 0.2 | 0.2 | 0.0 | 0.0 | 2.3 | 0.1 | 0.1 | 5.6   | 0.2 | 0.5 | 0.4  | 0.0 | 0.0 |
|       |       |                 | Teleostea unid.                       | 7.4 | 0.4 | 0.7 | 4.5 | 0.3 | 0.6 | 8.5 | 0.4 | 0.5 | 100.5 | 3.6 | 8.9 | 6.6  | 0.1 | 0.6 |

taxa such as crustacea, carangidae, pyrosomatidae, and exocoetidae. However, during the premonsoon and postmonsoon seasons, the contribution of cephalopods, priacanthidae, tetraodontidae, myctophidae, and balistidae increases.

The dietary breadth, assessed by levin's index, revealed no significant variations between the seasons (*ANOVA*,  $F = 0.325$ ;  $P > 0.05$ ); the maximum value was recorded during the summer (Apr–Jun) (0.720), and the minimum value was recorded in the Postmonsoon (Jan–Mar) season (0.662). The niche overlap, evaluated using Pianka's index, indicated no significant variations between the seasons ( $\chi^2 = 0.20$ ,  $P > 0.05$ ). However, there was significant overlap between the summer and postmonsoon, as well as between the premonsoon and postmonsoon seasons; the other seasons did not show overlap. Seasonal changes in the percentage of empty stomachs were significant ( $\chi^2 = 20.8$ ;  $P < 0.05$ ; Fig. 11), with the maximum percentage of empty stomachs observed during the monsoon season (38.3%) and minimum during the summer season (13.3%).

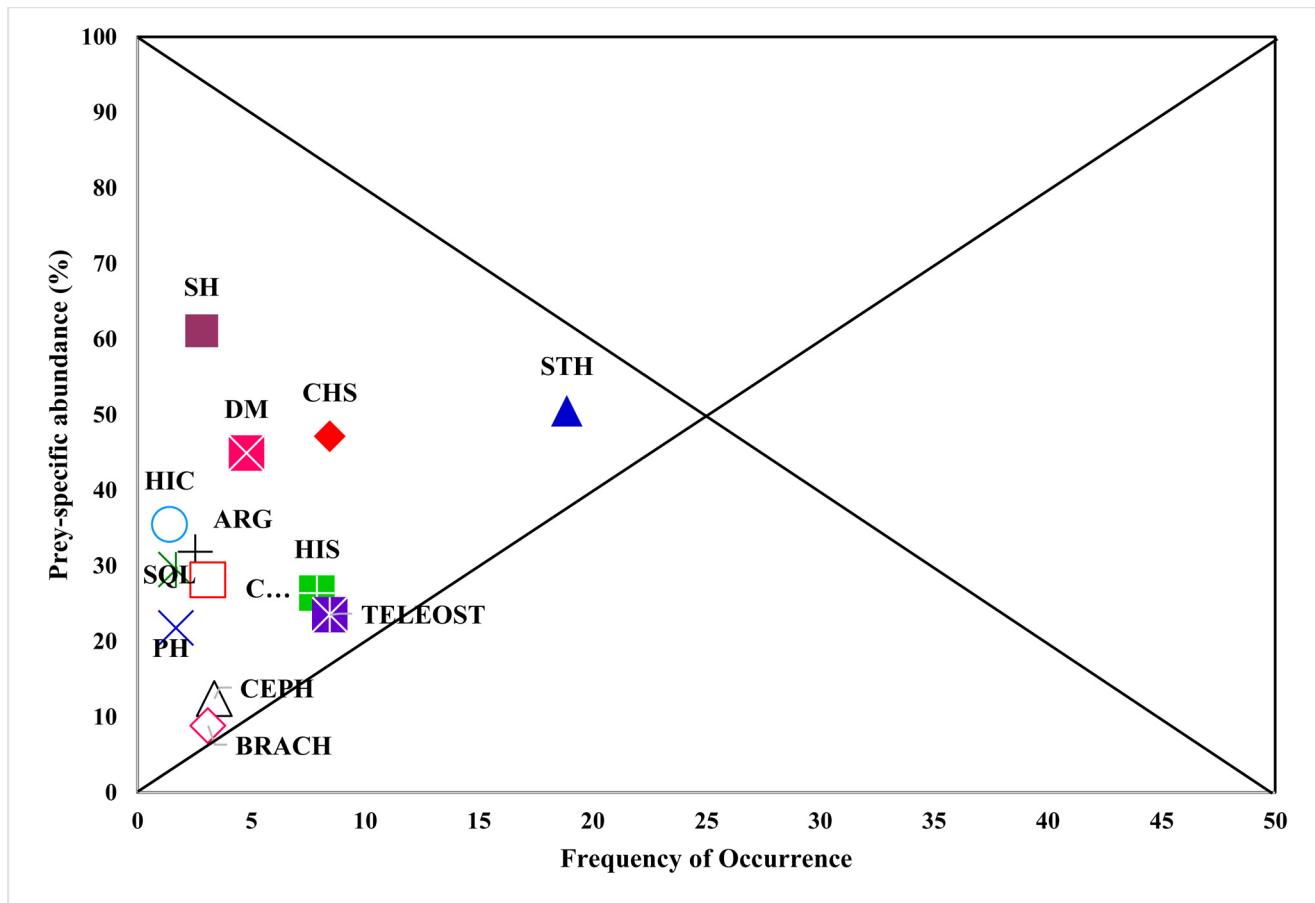
## 4 Discussion

The analysis of diet composition and feeding habits of yellowfin tuna has revealed that cephalopods constitute the primary fraction of food items in the diet, followed by teleost fishes and crustaceans. Other systematic taxa such as Hydrozoa and Tunicata have negligible impact on the diet. This finding aligns with earlier studies conducted in Indian waters (Kumar and Ghosh, 2020; Varghese and Somvanshi, 2016; and Rohit et al., 2010).

In the present investigation, 28.2% of empty stomachs were noticed. Our studies conclusions are less significant than those of prior research in Indian waters. Kumar and Ghosh (2020) found that 34.6% had empty stomachs in the Western Bay of Bengal. Similar observations were made by Maldeniya (1996), who found 37% of empty stomachs in Sri Lankan waters. The repletion index of yellowfin tuna was ( $2.072 \text{ g kg}^{-1}$ ) in the present study; this value contrasts to other investigations at a lower level ( $3.74 \text{ g kg}^{-1}$ ) (Varghese and Somvanshi, 2016). These variations could be due to the difference in mode of capture and method of preservation of stomach contents (Yesaki, 1983). Further, the abundance and distribution of prey items in the Bay of Bengal is one of the reasons for the variations.

The data from this study is consistent with earlier studies of yellowfin tuna diet composition (Rohit et al., 2010; Varghese and Somvanshi, 2016; Kumar and Ghosh, 2020). It indicates that the yellowfin tuna is a relatively non-selective, opportunistic feeders that consumes diverse prey items (Laptikhovskiy et al., 2020; Poitier et al., 2007). As a consequence of their concept, the yellowfin tuna diet is influenced by prey availability in the different habitats rather than prey selection and therefore might be similar to that of other non-selective predators (Ruderhausen et al., 2010). However, the yellowfin tuna diet changes in different oceanic areas; it might be dominated by cephalopods, teleost fishes, or crustaceans. According to similar observations made by Silva et al. (2019); Varghese and Somvanshi, (2016); and Rohit et al. (2010), the yellowfin tuna demonstrates a diverse range of prey items (53). This suggests a generalist behavior in this predator,





**Fig. 4.** Graphical representation for the relationship between prey-specific abundance ( $P_i$ ), expressed as weight, and frequency of occurrence (% F) of prey items in the diet of yellowfin tuna (*Thunnus albacares*), in the Bay of Bengal. The graph was developed in this study by using the Amundsen graphical method. Each dot represents a different prey species. The diagonal axes represent the importance of prey and the contribution to the niche width and the vertical axis defines the predator feeding strategy. Where, STH – *Sthenoteuthis oualaniensis*, CHS – *Charybdis smithii*, SH – *Solenocera hextii*, DM – *Decapterus macrosoma*, HIC – *Hirundichthys coromandelensis*, ARG – *Argonauta hians*, SQL – *Squilla leptoquilla*, CUB – *Cubiceps pauciradiatus*, PH – *Priacanthus hamrur*, CEPH – Cephalopoda unid., BRACH – Brachyuran megalopa, HIS – *Histioteuthis sp.*, and TELEOST – Teleostea unid.

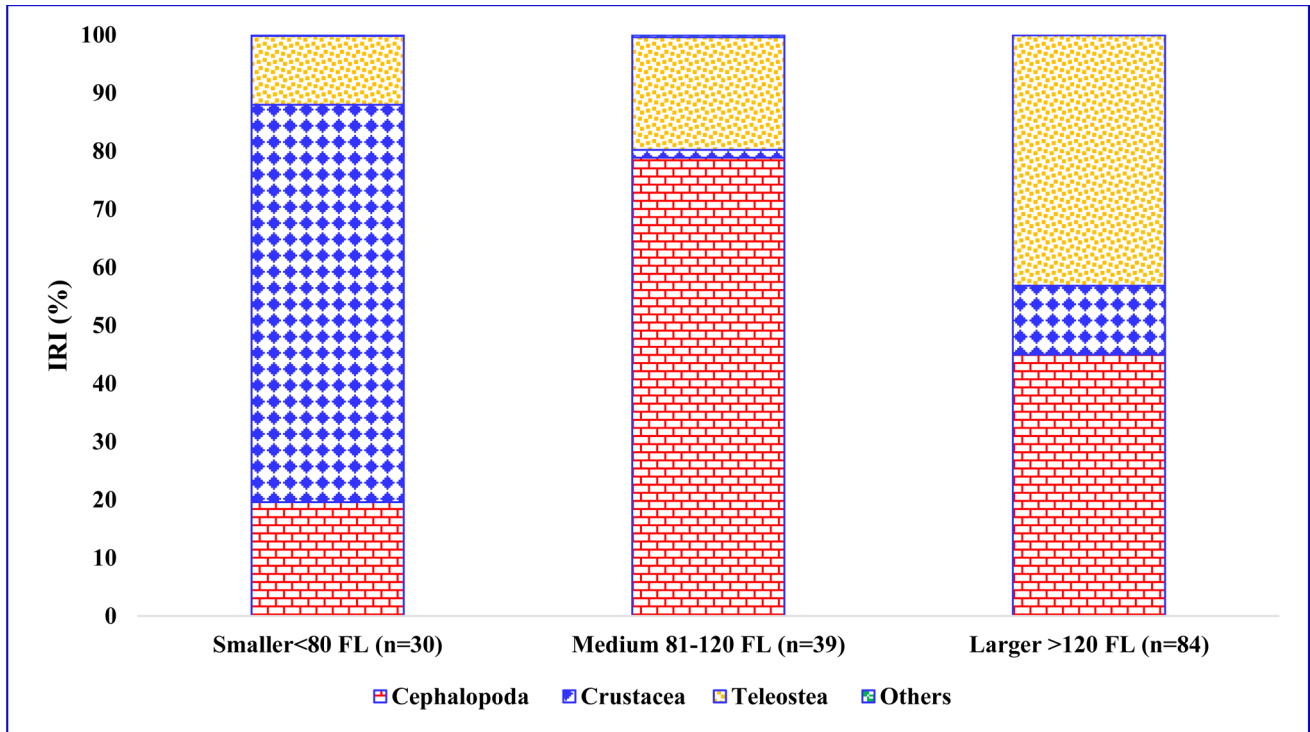
with numerous species that occasionally appear in its diet, as also indicated by the application of the Costello graphical method modified by Amundsen et al. (1996).

Cephalopods (69.2% IRI) play a major role in the yellowfin tuna diet in the Bay of Bengal. The present study contributed a higher percentage of cephalopods compared to other investigations in Indian waters (Govindaraj et al., 2000; Rohit et al., 2010). Most of the cephalopod prey from the Bay of Bengal was dominated by mesopelagic squids i.e., *Sthenoteuthis oualaniensis*, *Histioteuthis sp.*, *Abralia sp.*, and *Onychoteuthis sp.* In addition, the epipelagic octopod *Argonauta hians* was very common in the diet of yellowfin tuna in the Bay of Bengal and other tropical waters (Ruderhausen et al., 2010; Varghese and Somvanshi, 2016).

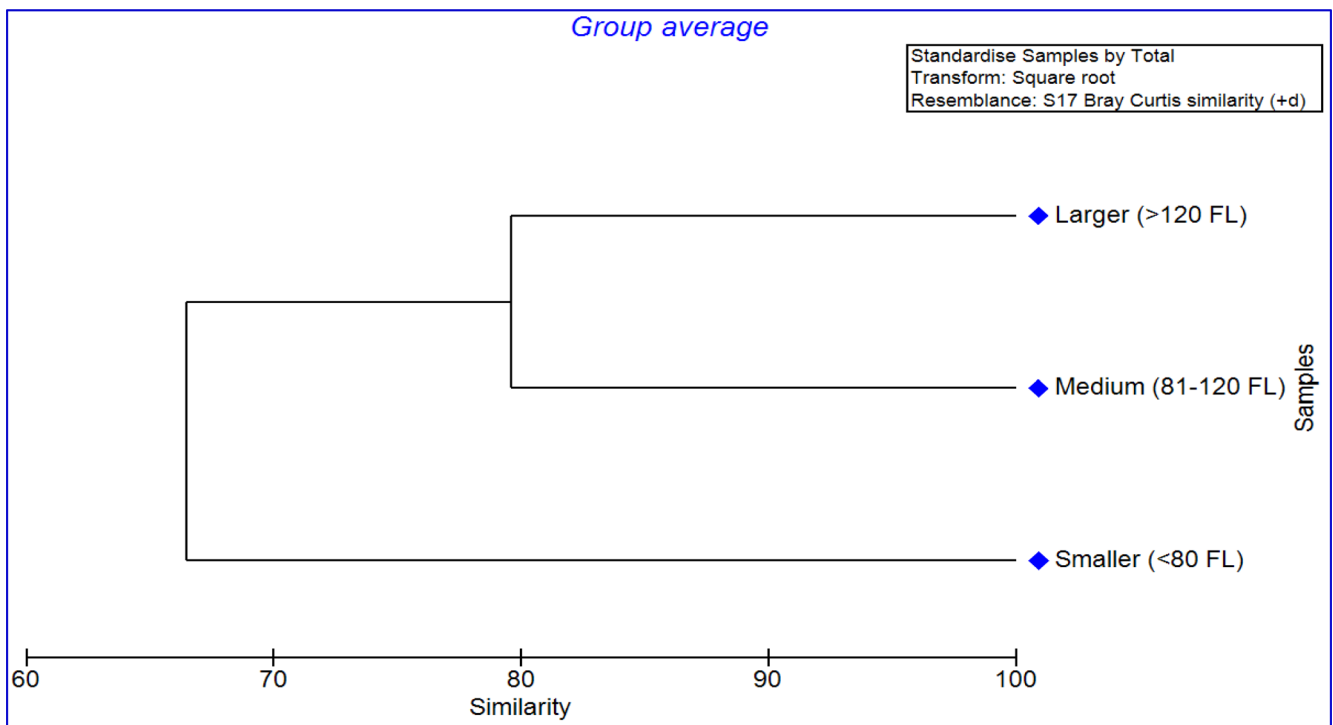
Crustaceans were the second most important prey of yellowfin tuna in the Bay of Bengal, accounting for 17.2% IRI. In the present observation, *Charybdis smithii* the main crustacean prey, contributed 13.5% of the IRI. Further, megalopa larvae and shrimp larvae contributed at a high level; they might be shallow water taxa, hence they may be present at high densities in the Bay of Bengal, or alternately

they may be aggregated by local climatic conditions such as water temperature, salinity and turbulent kinetic energy (Laptikhovsky et al., 2020). The findings of the diet dominated by portunid swimming crab *C. smithii* are not exceptional; it has been documented in large fish (mean tuna FL of 120 cm), during the winter season in Sri Lankan waters (Dassanayake et al., 2008). *C. smithii* is an ecologically important species and comprises a significant component of the diets of numerous larger pelagic species, including yellowfin tuna and plays a critical role in the trophic connection in the open ocean ecology of the western Indian Ocean (Romanov et al., 2009). A similar observation of seasonality and predominance of this species (64% numbers, 55% by weight), was noticed in the Seychelles (Potier et al., 2007).

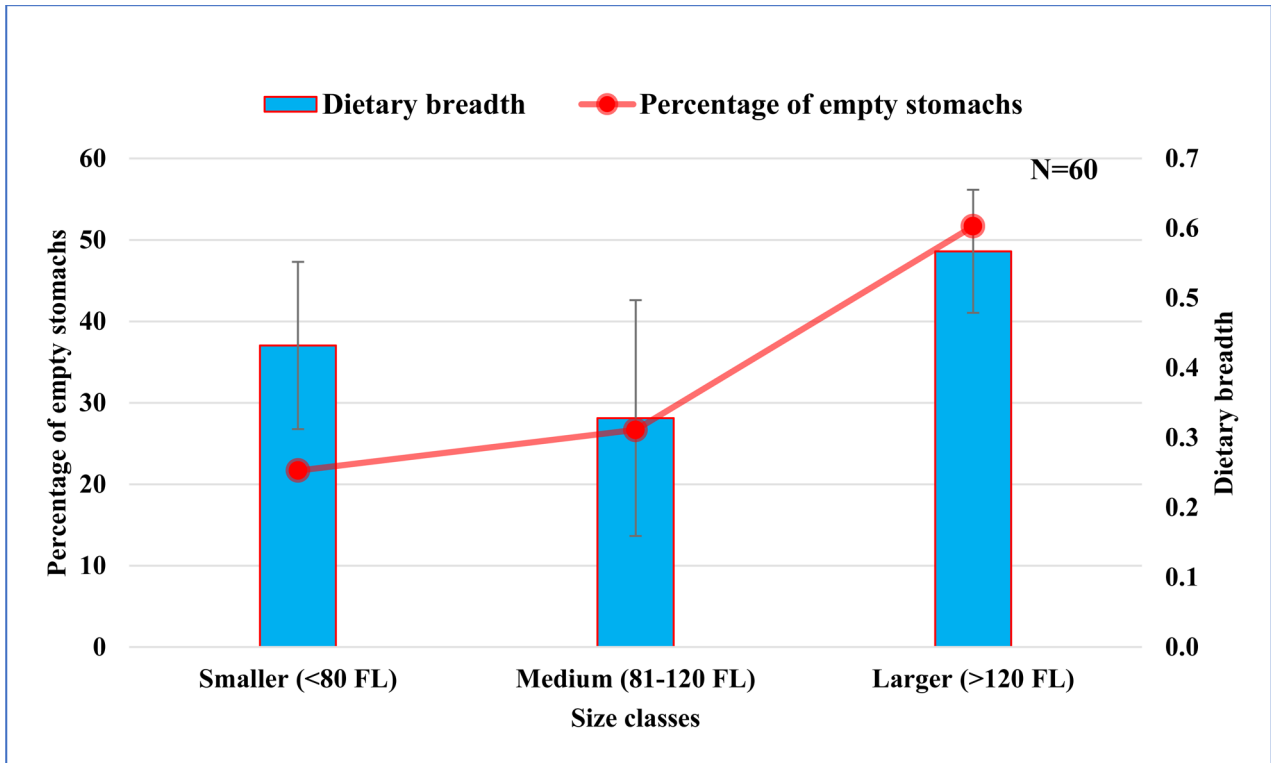
Teleost fishes also one of the important prey of yellowfin tuna diet in the Bay of Bengal accounting for 38.4 %IRI by weight with the rest represented mostly cephalopods and crustaceans. Similar observations with the predominance of the aforementioned teleost fishes, cephalopods and crustaceans were found in the Bay of Bengal and Arabian sea (Rohit et al., 2010; Varghese and Somvanshi, 2016). Furthermore, the



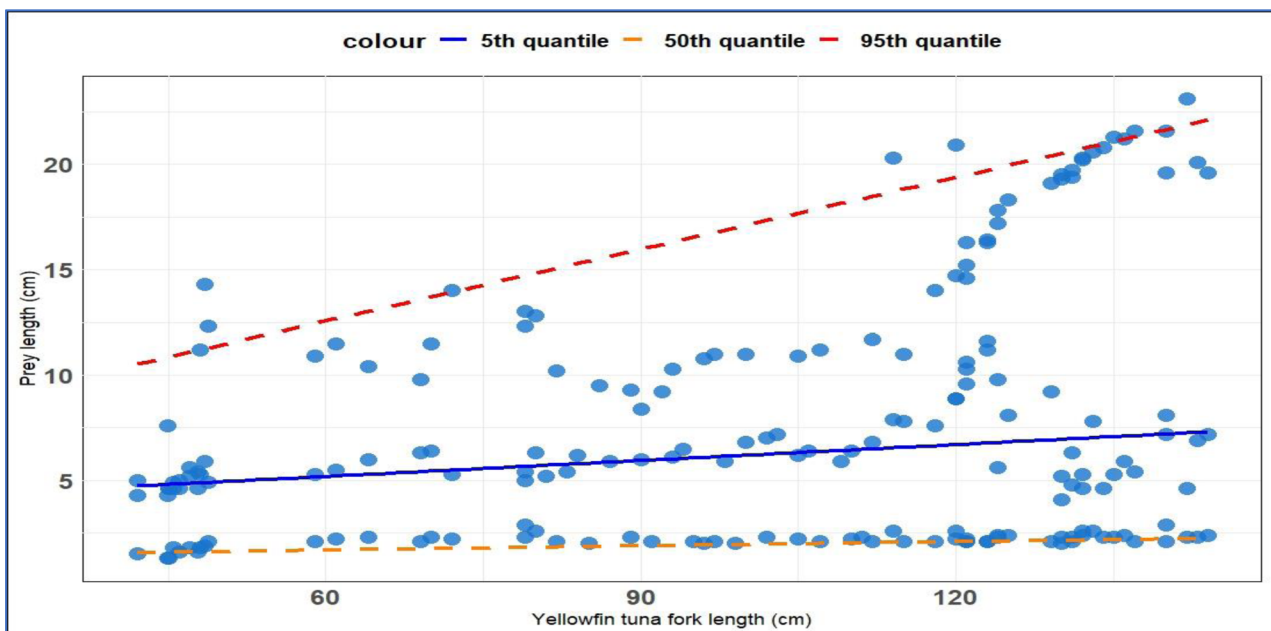
**Fig. 5.** Ontogenetic changes in composition of *T. albacares* diets based on %IRI in relation to Fork length.



**Fig. 6.** Cluster analysis based on %IRI values of food items of different size classes (Smaller <80 FL, 81–120 FL, >120 FL) in *T. albacares* from Bay of Bengal.



**Fig. 7.** Size-wise variation in diet breadth and percentage of empty stomachs of *T. albacares*.



**Fig. 8.** Predator-prey size scatter diagrams of *Thunnus albacares* and its prey items Cephalopods, Crustaceans and Teleostea. Quantile regression lines (continuous lines) indicate upper (95th) and lower (5th) boundaries used to describe predator and prey size relationships. Least squares regression line (dashed line) estimates rates of change in mean prey size as a function of predator size.

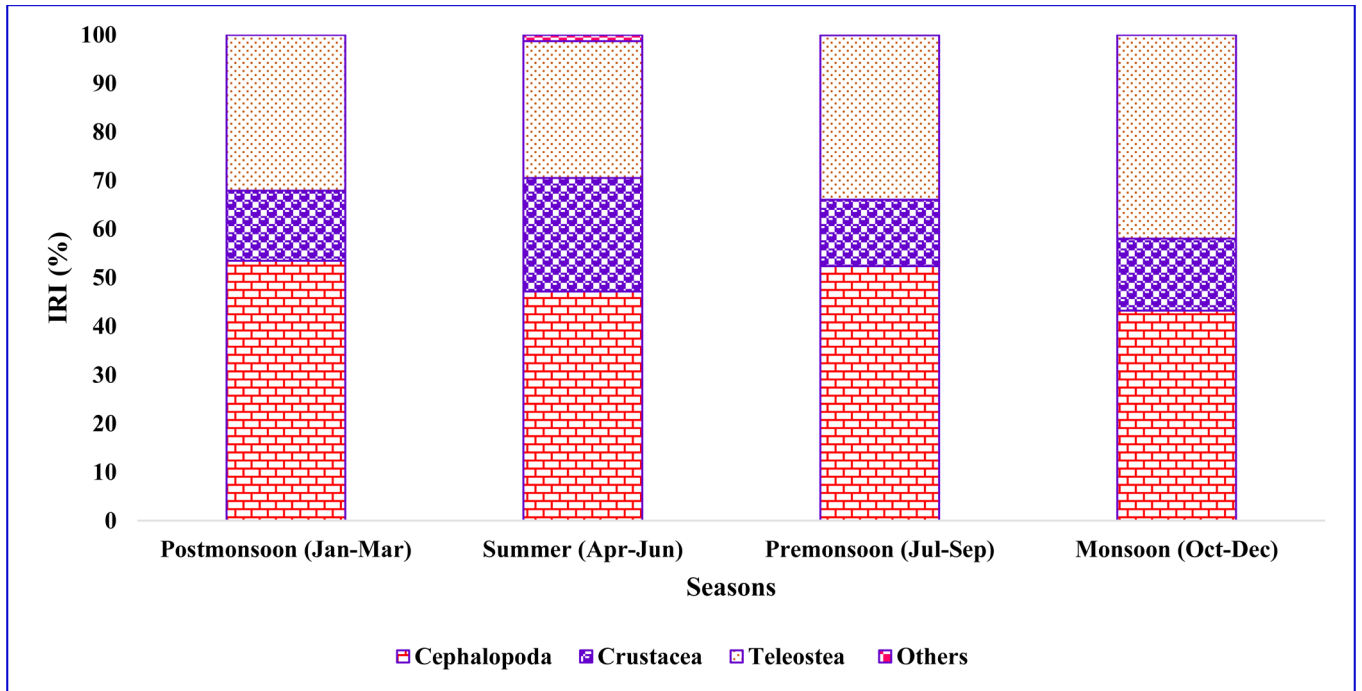


Fig. 9. Season wise diet composition of *T. albacares*.

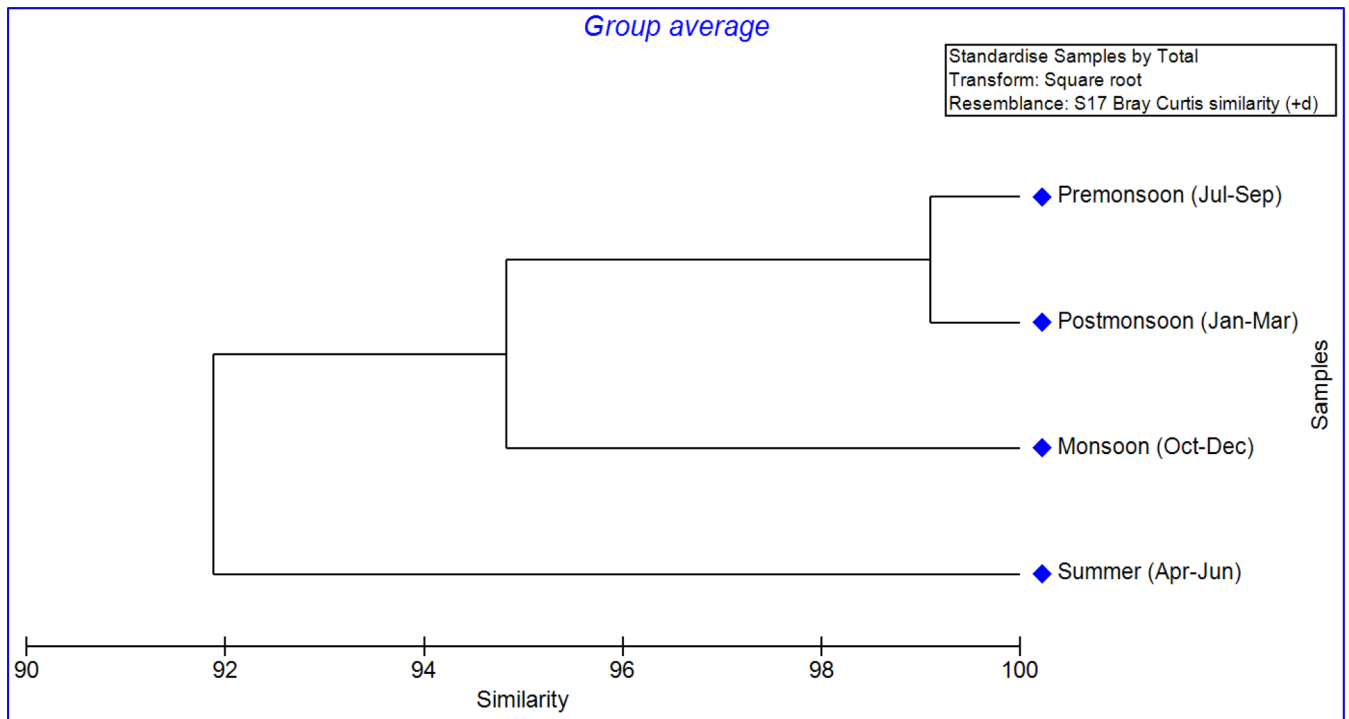


Fig. 10. Cluster analysis based on %IRI values of food items of different seasons in *T. albacares* from Bay of Bengal.



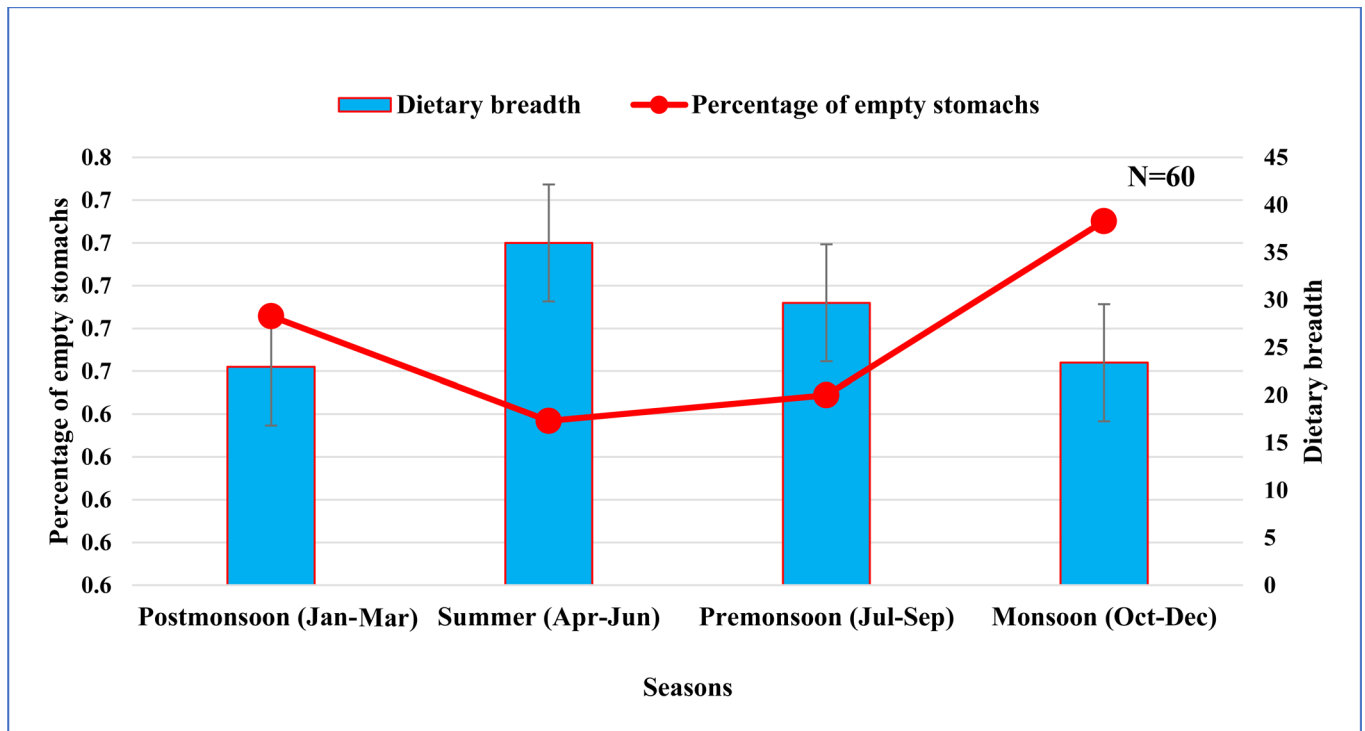


Fig. 11. Seasonal variations in diet breadth and percentage of empty stomachs of *T. albacares*.

predominance of prey is probably to offshore, epi-pelagic, oceanic species. This ecological group, which included flying fishes and Scombrids, contributed only slightly to the mesopelagic fauna and accounted for 90% of food consumed by yellowfin tuna on the east coasts of the United States (Ruderhausen et al., 2010) and year-round at the remote South Atlantic archipelago of St Peter and St Paul, Brazil (Vaske et al., 2003) with a minor role for the mesopelagic fauna. In addition, the dominance of fish species, and in particular the abundance of cigarfish (*Cubiceps pauciradiatus*) in the diet of spawning females in yellowfin tuna, may be related to this species group energy content and the high energy demands generated during the spawning phase (McBride et al., 2013). The aggregation of cigarfish associated with large concentrations of tuna has been investigated previously in the Western Indian Ocean (Fonteneau et al., 2008), the Atlantic Ocean (Bard et al., 2002) and the Pacific Ocean (Flynn and Paxton, 2013). The present study has been supported by an aggregation of cigarfish interaction with yellowfin tunas in the Bay of Bengal. Fish diet variations in connection to seasonal or inter-annual shifts in oceanic productivity, might have an impact on a species ability for reproduction. As a result, female yellowfin tuna appears to be able to quickly change (i.e. within days to weeks) their investment in reproduction based on food availability, and furthermore, to take advantage of areas of high food abundance to improve their reproductive capacity (Zudaire et al., 2015). Cigarfish are an essential component of these dynamics in the Bay of Bengal.

Weng et al. (2015) reported yellowfin tuna above 50 cm fork length to be piscivorous, with maximum consumption of cephalopods and crabs between 80 and 129 cm fork length, and a switch on the diet to teleost fish at sizes greater than 50 cm fork length. In the present study, with the increase in fish size,

feeding intensity also increased. Fish measuring 120 cm or above in fork length were found to have full and gorged stomachs. Subsequently, the ratio of prey weight to fish weights also increased. This could be attributed to the increase in mouth and body size of the fish; ontogenetic shifts in diet contents permits it to catch a wide range of prey sizes and types (Labropoulou and Eleftheriou, 1997). In the present study, feeding preferences were established and there were no significant variations between the sexes, it could depend on prey availability and yellowfin tuna is a non-specific predator feeding in both sexes. Further interesting aspects of the yellowfin tuna are their mostly epipelagic habitat and not their vertical migration pattern, which constitutes the deep scattering layer (DSL) (Grandperrin, 1976; Potier et al., 2004). Previous study by Varghese and Somvanshi (2016) also reported no significant differences in diet between the sexes.

The swim bladder of the yellowfin tuna plays a crucial role between yellowfin tuna and dolphins. Larger yellowfin tunas actively seek out dolphins to boost their likelihood of inhabiting a habitat with abundant food (Fiedler et al., 1998), or yellowfin tuna can detect dolphin sonar echolocation (Au, 1993). It is tempting to speculate on the potential range at which yellowfin tuna could become aware of dolphins, prey, predators, or conspecifics through sound reception and detectability as an auditory target (Blaxter, 1980). This is because swim bladders may improve yellowfin tuna hearing.

Food composition and dietary overlap reveal significant changes in the diets of yellowfin tuna as they grow, although cephalopods are the most important prey in all size classes. Smaller individuals feed mainly on small prey such as fish larvae, megalopa larvae and small shrimps, whereas larger individuals prefer large cephalopods, shrimps, teleost fishes and crabs. Many yellowfin tuna stomachs show ontogenetic

**Table 3.** Comparison with other studies on the diet of yellowfin tuna. The quoted families were found either in this study or in at least one other study where one of the main taxa were identified.

| Taxon             | This study, Bay of Bengal<br>FL range (cm) = 42.0–171.0<br>No. of fish examined = 213<br>No. of non-empty<br>stomachs = 153 |    |      |      | Varghese and Somvanshi,<br>2016, Arabian sea,<br>FL range (cm) = 48.0–165.0<br>No. of fish examined = 406<br>No. of non-empty<br>stomachs = 343 |      |      |      | Rohit et al., 2010<br>Andhra Pradesh coast<br>FL range (cm) = 67.0–174.0<br>No. of fish examined = 165<br>No. of non-empty<br>stomachs = 146 |      |      |      | Kumar and Ghosh (2020),<br>Western Bay of Bengal<br>FL range (cm) = 18.0–186.0<br>No. of fish examined = 1412<br>No. of non-empty<br>stomachs = 923 |     |     |      |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------|----|------|------|-------------------------------------------------------------------------------------------------------------------------------------------------|------|------|------|----------------------------------------------------------------------------------------------------------------------------------------------|------|------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|------|
|                   | %N                                                                                                                          | %W | %F   | %N   | %W                                                                                                                                              | %F   | %N   | %W   | %F                                                                                                                                           | %N   | %W   | %F   | %N                                                                                                                                                  | %W  | %F  | %N   |
| Diphyidae         | 0.1                                                                                                                         |    | 0.2  | 0.3  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                          | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Solenoceridae     | 4.5                                                                                                                         |    | 5.2  | 2.8  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                          | 0.0  | 25.8 | 6.7  | 14.4                                                                                                                                                | 0.0 | 0.0 | 0.0  |
| Shrimps unid.     | 2.5                                                                                                                         |    | 1.3  | 2.2  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                          | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Portunidae        | 18.8                                                                                                                        |    | 10.7 | 11.6 | 13.1                                                                                                                                            | 10.7 | 13.4 | 15.6 | 20.4                                                                                                                                         | 13.4 | 15.6 | 30.1 | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Squillidae        | 1.4                                                                                                                         |    | 1.7  | 2.3  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.1  | 0.0                                                                                                                                          | 0.0  | 0.1  | 0.7  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Nanosquillidae    | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.1                                                                                                                                             | 0.0  | 0.6  | 0.0  | 0.0                                                                                                                                          | 0.6  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Squilla unid.     | 0.2                                                                                                                         |    | 0.2  | 0.5  | 3.0                                                                                                                                             | 0.1  | 7.0  | 0.0  | 0.0                                                                                                                                          | 7.0  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Total crustaceans | 27.4                                                                                                                        |    | 19.1 | 19.4 | 16.2                                                                                                                                            | 10.8 | 19.2 | 41.5 | 27.1                                                                                                                                         | 19.2 | 41.5 | 45.2 | 18.4                                                                                                                                                | 0.0 | 0.0 | 18.4 |
| Ancistrocheiridae | 0.0                                                                                                                         |    | 0.0  | 0.0  | 1.0                                                                                                                                             | 2.7  | 1.7  | 0.0  | 0.0                                                                                                                                          | 1.7  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Bolitaenidae      | 0.0                                                                                                                         |    | 0.0  | 0.0  | 1.0                                                                                                                                             | 0.5  | 4.7  | 0.0  | 0.0                                                                                                                                          | 4.7  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Cranchiidae       | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.5                                                                                                                                             | 0.2  | 3.5  | 0.0  | 0.0                                                                                                                                          | 3.5  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Enoploteuthidae   | 0.9                                                                                                                         |    | 0.7  | 1.1  | 1.1                                                                                                                                             | 1.2  | 5.8  | 0.0  | 0.0                                                                                                                                          | 5.8  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Onychoteuthidae   | 0.3                                                                                                                         |    | 0.3  | 0.3  | 1.8                                                                                                                                             | 3.0  | 10.5 | 0.0  | 0.0                                                                                                                                          | 10.5 | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Histioteuthidae   | 5.8                                                                                                                         |    | 5.9  | 7.9  | 0.1                                                                                                                                             | 0.2  | 0.6  | 0.0  | 0.0                                                                                                                                          | 0.6  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Octapodiidae      | 0.4                                                                                                                         |    | 0.4  | 0.6  | 0.1                                                                                                                                             | 0.1  | 0.6  | 0.0  | 0.0                                                                                                                                          | 0.6  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Ommastrephidae    | 25.7                                                                                                                        |    | 26.4 | 21.7 | 27.5                                                                                                                                            | 39.4 | 53.5 | 8.6  | 19.1                                                                                                                                         | 53.5 | 8.6  | 25.3 | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Spirulidae        | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.1                                                                                                                                             | 0.1  | 0.6  | 0.0  | 0.0                                                                                                                                          | 0.6  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Loliginidae       | 1.8                                                                                                                         |    | 2.8  | 3.1  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                          | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Thysanoteuthidae  | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.3                                                                                                                                             | 1.3  | 1.7  | 0.0  | 0.0                                                                                                                                          | 1.7  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Tremoctopodiidae  | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.2                                                                                                                                             | 0.1  | 1.7  | 0.0  | 0.0                                                                                                                                          | 1.7  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Argonautidae      | 4.4                                                                                                                         |    | 2.5  | 3.3  | 0.5                                                                                                                                             | 0.3  | 4.7  | 0.0  | 0.0                                                                                                                                          | 4.7  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Cephalopoda unid. | 2.5                                                                                                                         |    | 2.0  | 3.4  | 5.1                                                                                                                                             | 2.3  | 14.6 | 10.7 | 0.2                                                                                                                                          | 14.6 | 10.7 | 24.0 | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Total cephalopods | 41.8                                                                                                                        |    | 41.0 | 41.4 | 41.1                                                                                                                                            | 51.9 | 59.3 | 0.0  | 0.0                                                                                                                                          | 59.3 | 0.0  | 0.0  | 44.9                                                                                                                                                | 0.0 | 0.0 | 44.9 |
| Pyrosomatidae     | 1.7                                                                                                                         |    | 1.0  | 2.2  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                          | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Salpidae unid.    | 0.1                                                                                                                         |    | 0.0  | 0.3  | 1.1                                                                                                                                             | 0.0  | 2.9  | 0.0  | 0.0                                                                                                                                          | 2.9  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Total tunicates   | 1.8                                                                                                                         |    | 1.0  | 2.5  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                          | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Clupeidae         | 0.1                                                                                                                         |    | 0.3  | 0.3  | 0.0                                                                                                                                             | 0.0  | 0.0  | 1.6  | 2.9                                                                                                                                          | 0.0  | 1.6  | 13.0 | 4.6                                                                                                                                                 | 0.0 | 0.0 | 4.6  |
| Acropomatidae     | 0.4                                                                                                                         |    | 0.5  | 0.6  | 0.6                                                                                                                                             | 0.1  | 1.7  | 0.0  | 0.0                                                                                                                                          | 1.7  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Acanthuridae      | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.2                                                                                                                                             | 0.3  | 0.6  | 0.0  | 0.0                                                                                                                                          | 0.6  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Berycidae         | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.7                                                                                                                                             | 1.3  | 59.7 | 0.0  | 0.0                                                                                                                                          | 59.7 | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Bramidae          | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.6                                                                                                                                             | 0.1  | 0.6  | 0.0  | 0.0                                                                                                                                          | 0.6  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Carangidae        | 3.9                                                                                                                         |    | 6.1  | 5.4  | 0.5                                                                                                                                             | 4.7  | 2.9  | 1.5  | 4.0                                                                                                                                          | 2.9  | 1.5  | 6.2  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Carangidae unid.  | 0.1                                                                                                                         |    | 0.1  | 0.3  | 0.0                                                                                                                                             | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                          | 0.0  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |
| Centrolophidae    | 0.0                                                                                                                         |    | 0.0  | 0.0  | 0.9                                                                                                                                             | 0.6  | 2.9  | 0.0  | 0.0                                                                                                                                          | 2.9  | 0.0  | 0.0  | 0.0                                                                                                                                                 | 0.0 | 0.0 | 0.0  |

Table 3. (continued).

| Taxon                 | This study, Bay of Bengal  |                            |                                 |     | Varghese and Somvanshi, 2016, Arabian sea, |                            |                                 |      | Rohit et al., 2010         |                            |                                 |     | Kumar and Ghosh (2020), Western Bay of Bengal |                             |                                 |      |
|-----------------------|----------------------------|----------------------------|---------------------------------|-----|--------------------------------------------|----------------------------|---------------------------------|------|----------------------------|----------------------------|---------------------------------|-----|-----------------------------------------------|-----------------------------|---------------------------------|------|
|                       | FL range (cm) = 42.0–171.0 | No. of fish examined = 213 | No. of non-empty stomachs = 153 |     | FL range (cm) = 48.0–165.0                 | No. of fish examined = 406 | No. of non-empty stomachs = 343 |      | FL range (cm) = 67.0–174.0 | No. of fish examined = 165 | No. of non-empty stomachs = 146 |     | FL range (cm) = 18.0–186.0                    | No. of fish examined = 1412 | No. of non-empty stomachs = 923 |      |
| Chauliodontidae       | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.3                                        | 0.2                        | 1.2                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Champsodontidae       | 0.0                        | 0.0                        | 0.0                             | 0.0 | 2.5                                        | 0.6                        | 7.0                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Coryphaenidae         | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.1                                        | 0.1                        | 0.6                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Diretmidae            | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.3                                        | 0.2                        | 1.7                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Engraulidae           | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.5                                        | 0.1                        | 0.6                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Sphyraenidae          | 0.3                        | 5.6                        | 0.6                             | 0.0 | 0.0                                        | 0.0                        | 0.0                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Scopelacidae          | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.2                                        | 0.1                        | 1.2                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Sternoptychidae       | 0.0                        | 0.0                        | 0.0                             | 0.0 | 1.5                                        | 0.4                        | 7.0                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Nomeidae              | 2.2                        | 3.0                        | 3.1                             | 0.0 | 5.8                                        | 3.4                        | 16.9                            | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Monacanthida          | 0.0                        | 0.0                        | 0.0                             | 0.0 | 2.9                                        | 0.7                        | 3.5                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Myctophidae           | 1.0                        | 0.8                        | 1.7                             | 0.0 | 7.4                                        | 0.8                        | 2.9                             | 1.8  | 0.9                        | 1.4                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Microstomatidae       | 0.0                        | 0.0                        | 0.0                             | 0.0 | 2.3                                        | 0.2                        | 1.2                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Muraenesocidae        | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.2                                        | 0.5                        | 0.6                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Scombridae            | 0.1                        | 1.4                        | 0.3                             | 0.0 | 1.1                                        | 9.9                        | 7.0                             | 0.3  | 2.5                        | 2.8                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Trichiuridae          | 0.9                        | 1.4                        | 0.8                             | 0.0 | 0.0                                        | 0.0                        | 0.0                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Exocoetidae           | 4.4                        | 7.1                        | 4.8                             | 0.0 | 3.3                                        | 7.1                        | 13.4                            | 0.4  | 2.8                        | 2.7                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Flying fishes unid.   | 0.6                        | 0.7                        | 1.1                             | 0.0 | 0.1                                        | 0.0                        | 0.6                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Gempylidae            | 0.0                        | 0.0                        | 0.0                             | 0.0 | 1.7                                        | 3.9                        | 8.1                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Priacanthidae         | 1.6                        | 1.4                        | 1.7                             | 0.0 | 0.0                                        | 0.0                        | 0.0                             | 26.1 | 39.3                       | 28.1                       | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Paralepididae         | 0.0                        | 0.0                        | 0.0                             | 0.0 | 1.6                                        | 0.2                        | 1.7                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Phosichthyidae        | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.5                                        | 0.3                        | 2.3                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Bregmacrotidae        | 0.4                        | 0.4                        | 0.8                             | 0.0 | 0.0                                        | 0.0                        | 0.0                             | 1.3  | 0.4                        | 4.1                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Trachichthyidae       | 0.1                        | 0.3                        | 0.3                             | 0.0 | 0.0                                        | 0.0                        | 0.0                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Balistidae            | 1.3                        | 1.4                        | 1.7                             | 0.0 | 0.5                                        | 0.2                        | 4.1                             | 0.3  | 0.0                        | 2.1                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Omosudidae            | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.8                                        | 0.6                        | 1.2                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Ostraciidae           | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.1                                        | 0.0                        | 0.6                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Tetraodontidae        | 1.8                        | 2.9                        | 2.5                             | 0.0 | 0.0                                        | 0.0                        | 0.0                             | 0.3  | 0.1                        | 2.1                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Fish larva            | 2.3                        | 0.2                        | 2.3                             | 0.0 | 0.7                                        | 0.0                        | 2.3                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Teleostea unid.       | 7.4                        | 4.5                        | 8.5                             | 0.0 | 1.9                                        | 0.8                        | 7.6                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |
| Total fish            | 28.9                       | 38.1                       | 36.8                            |     | 39.7                                       | 37.2                       | 61.6                            | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 30.9                        | 30.9                            | 30.9 |
| Other organisms total | 0.0                        | 0.0                        | 0.0                             |     | 3.0                                        | 0.1                        | 3.5                             | 0.0  | 0.0                        | 0.0                        | 0.0                             | 0.0 | 0.0                                           | 0.0                         | 0.0                             | 0.0  |

diet changes and these changes show a general trend in the diets of other tuna species such as *K. pelamis*, *T. obesus*, *E. affinis* and *T. thynnus* (Battaglia et al., 2013). These could be associated with the optimization of energy acquisition (Kyne et al., 2008) i.e., larger fish prefer large prey because they provide more energy and reflect the improved mobility of yellowfin tuna (Stoner and Livingston, 1984).

As is the case the yellowfin tuna is an opportunistic predator (Menard et al., 2007; Potier et al., 2007), due to the considerable prey diversity and generally low abundance of each prey type in its diet. According to Van Valen (1965), yellowfin tuna is a Type A generalist, as opposed to a Type B generalist, where each individual specializes on a particular prey type. Yellowfin tuna have high energy demands (Olson and Boggs, 1986) because of their high metabolic rates (Stevens and Dizon, 1982), requirement for continuous swimming, and high rates of somatic and gonadal growth, digestion, and recovery from strenuous exercise (Brill, 1996). The Bay of Bengal has limited resources and patchy distributions of forage. When energy-consuming processes combine with an energetically expensive life cycle, a non-selective broad diet is essential.

Understanding biomass and energy flow in pelagic environments requires knowledge of the links and interaction rates in the food web. The bioenergetic effects of a change in diet for yellowfin tuna were not taken into account in our study, which analyzed qualitative and quantitative aspects of the stomach content examination of the yellowfin tuna. The focus of this study does not extend to a thorough examination of daily ration estimates based on stomach contents and gastric evacuation rates.

Seasonal changes in the feeding habits of fish are correlated to seasonality in food availability as a result of environmental changes and seasonal physiological changes (Wotton, 1990). Information on abundance, distribution and seasonal changes in yellowfin tuna in the Bay of Bengal was limited, so we did not explain the temporal predator relationships. In the present study, yellowfin tuna was a relative non-selective, opportunistic feeder that consumed a broad range of prey, and therefore few seasonal differences were found in its diet. In the present study, two peaks of feeding intensity was recorded, i.e., Postmonsoon (Jan–March) and Premonsoon (July–September); they could be related to the reproductive activity during the spawning period of fishes. The spawning season of yellowfin tuna in the north-west Indian EEZ reported to be during December–June (Govindaraj et al., 2000). Similarly, Varghese and Somvanshi (2016) noticed two peaks of spawning seasons in the Arabian Sea i.e. winter monsoon (December–February) and premonsoon (March–May). Gonad maturation and development in the species along the Bay of Bengal starts in March and continues until July, with a substantial energy demand for gonadal maturation apart from somatic growth.

Although seasonal changes in diet breadth and the percentage of empty stomach were significant, relatively low diet breadth and a high percentage of empty stomachs were found during the Monsoon season (38.3%); diets were consumed by cephalopods, which constituted 49% of the diet in %IRI. It could be a possible reason for starvation and the migration of fish. Furthermore, the monsoon brings rainy and cyclonic weather conditions to the Bay of Bengal; the surface

water is very cold, and it can restrict habitat range and food resources in the diet of yellowfin tuna, leading to a narrow range of food items and low feeding intensity.

Only three quantitative studies (Rohit et al., 2010; Varghese and Somvanshi, 2016; Kumar and Ghosh, 2020) are available for yellowfin tuna tropho-dynamics in the Indian waters (Tab. 3). In the exploratory tuna longline surveys conducted by Varghese and Somvanshi (2016) in the Arabian sea and the present study in the Bay of Bengal, yellowfin tuna samples were collected. However, a comparison of the results revealed that Varghese and Somvanshi (2016) identified more prey species than the present study. They reported the presence of several typically oceanic prey taxa, such as Nanosquillidae, Ancistrocheridae, Bolitaenidae, Cranchiidae, Thysanoteuthidae, Berycidae, Bramidae, Gempylidae, and Paralepididae. Nonetheless, their results were similar to ours in terms of diversity and the proportions of fish, crustaceans, and cephalopods.

The present study reported a wide range of prey in the diet of yellowfin tuna in the Bay of Bengal, in contrast to two previous studies (Rohit et al., 2010; Kumar and Ghosh, 2020). The study also identified epi- and mesopelagic prey such as Myctophidae, Phosichthyidae, Nomeidae, and Trachichthyidae in the Bay of Bengal. All four studies consistently showed cephalopods as the primary diet for yellowfin tuna, followed by fishes and crustaceans. In Indian waters, the diversity of prey was especially in the Arabian sea (17 cephalopod species, 42 fish species and 02 crustacean species) and the Bay of Bengal (12 cephalopod species, 30 fish species and 07 crustacean species in the present study). The variability of the species diversity, indicating the availability of prey, suggests a high diversity of prey and individual plasticity in foraging behaviour.

In comparison, studying the diet of yellowfin tuna and other large pelagic fishes coexisting in the Bay of Bengal can provide valuable insights into their trophic relationships. According to Johnson (1977), interspecific food competition occurs when a food item is present in more than 25% of two or more predators. We observed niche partitioning between yellowfin tuna and dolphinfish (*Coryphaena hippurus*), sailfish (*Istiophorus platypterus*), swordfish (*Xiphias gladius*), and lancetfish (*Alepisaurus ferox*) in both the Bay of Bengal and the Arabian Sea (Varghese et al., 2013; Ghosh et al., 2021). In the Bay of Bengal, yellowfin tuna and dolphinfish may compete for cephalopods and crustaceans (Ghosh et al., 2021). Additionally, Varghese et al. (2010) suggested that yellowfin tuna and lancetfish may compete for cephalopods, flying fishes, and crabs in the Indian EEZ.

## 5 Conclusion

As an apex predator, *Thunnus albacares* is crucial to the energy flow of pelagic ecosystems in the world's oceans. They are numerous and all-pervasive in the epipelagic ecology, and their removal by fishing causes significant structural changes in the ecosystems. This is the preliminary survey data on exploratory tuna and allied fishery resources survey from the Bay of Bengal, providing a basic understanding of its function in the food chain in this marine ecosystem. Further, information on size-wise, season-wise, dietary breadth and

dietary overlap is important globally. The present study suggests that this species shows different size-related dietary changes to occur at a smaller (<80 FL), medium sized (80–120 FL) and large sized (>120 FL). Despite the fact that cephalopods (*Sthenoteuthis oualaniensis*), Crustaceans (*Charybdis smithii*) and cigar fishes (*Cubiceps pauciradiatus*) appear to be the predominate prey species in the sampling area. Considering some physioc-chemical parameters, i.e surface water temperature and salinity are major factors that define fish habitats, this spatial variation may be related to the oceanographic features of the particular region. Finally, this base line information on diet derived from exploratory survey data along the Bay of Bengal would be essential in comprehending species ecology and trophic relationships needed for trophic ecosystem modelling, supporting ecosystem-based fishery management in the area.

## Acknowledgements

We thank the Director General, Fishery Survey of India, Mumbai, the Govt. of India, Ministry of Fisheries, Animal Husbandry and Dairying, Dept. of Fisheries for providing the necessary permission and facilities. The authors are grateful to the officers and staff of the vessels of the Matsya Drushti and all the scientists for their active participation and data collection during the cruise programmes at sea. Additionally, we wish to extend our thanks to Dr. Antonella Preti, Assistant Project Scientist, Institute of Marine Sciences, University of California Santa Cruz, NOAA Southwest Fisheries Science Center, California. Finally, we would like to acknowledge the Editor and the three anonymous reviewers for their valuable suggestions during the review process.

## References

- Abdussamad EM, Koya KP, Rohit P, Joshi KK, Ghosh S, Elayathu MNK, Rao GS. 2012. Fishery of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) in the Indian EEZ with special reference to their biology and population characteristics. *Ind J Fish* 59: 43–51.
- Ainsworth CH, Kaplan IC, Levin PS, Mangel M. 2010. A statistical approach for estimating fish diet compositions from multiple data sources: Gulf of California case study. *Ecol Appl* 20: 2188–2202.
- Amundsen PA, Gabler HM, Staldvik FJ. 1996. A new approach to graphical analysis of feeding strategy from stomach contents data—modification of the Costello (1990) method. *J Fish Biol* 48: 607–614.
- Au WWL. 1993. The Sonar of Dolphins. New York: Springer-Verlag.
- Bard FX, Kouame B, Herve A. 2002. Schools of large yellowfin (*Thunnus albacares*) concentrated by foraging on a monospecific layer of *Cubiceps pauciradiatus*, observed in the eastern tropical Atlantic. *ICCAT Coll Vol sci pap* 54: 33–41.
- Battaglia P, Andaloro F, Consoli P, Esposito V, Malara D, Musolino S, Pedà C. 2013. Feeding habits of the Atlantic bluefin tuna, *Thunnus thynnus* (Linnaeus, 1758), in the central Mediterranean Sea (Strait of Messina). *Helgol Mar Res* 67: 97–107.
- Bizzarro JJ, Robinson HJ, Rinewalt CS, Ebert DA. 2007. Comparative feeding ecology of four sympatric skate species off central California, USA. *Environ Biol Fish* 80: 197–220.
- Blaxter JHS. 1980. The swim bladder and hearing. In Hearing and sound communication in fishes (W. N. Tavolga, A. N. Popper, R. R. Fay. eds. ), p. 61–71. Springer-Verlag, New York, NY.
- Brill RW. 1996. Selective advantages conferred by the high performance physiology of tunas, billfishes, and dolphin fish. *Comp Biochem Physiol A* 113: 3–15.
- Carpenter KE, De Angelis N. 2016. The living marine resources of the Eastern Central Atlantic. Volume 3: Bony fishes part 1 (Elopiformes to Scorpaeniformes). FAO Species Identification Guide for Fishery Purposes, Rome, FAO. pp. 1511–2350.
- Canty A, Ripley BD. 2011. Boot: bootstrap R (S-plus) functions. *R package version* 1. 3–3. Available at <http://CRAN.R-project.org/package=boot>.
- Clarke KR, Gorley RN. 2006. PRIMER v6: User Manual/Tutorial (Plymouth Routines in Multivariate Ecological Research). *PRIMER-E, Plymouth*.
- Clarke MR. 1986. A handbook for the identification of cephalopods beaks. Oxford: Clarendon Press, pp. 273.
- Costello MJ. 1990. Predator feeding strategy and prey importance: a new graphical analysis. *J Fish Biol* 36: 261–263.
- Cox SP, Essington TE, Kitchell JF, Martell SJ, Walters CJ, Boggs C, Kaplan I. 2002. Reconstructing ecosystem dynamics in the central Pacific Ocean, 1952–1998. II. A preliminary assessment of the trophic impacts of fishing and effects on tuna dynamics. *Can J Fish Aqua Sci* 59: 17361747.
- Dassanayake DCY, Samara Weera EKV, Amarasiri C. 2008. Fishery and feeding habits of yellowfin tuna (*Thunnus albacares*) targeted by coastal tuna longlining in the north western and north eastern coasts of Sri Lanka. *Sri Lanka J Aqua Sci* 13: 1–21.
- Davison, AC, Hinkley DV. 1997. Bootstrap methods and their application. Cambridge series in statistical and probabilistic mathematics. *Cambridge University Press*.
- DoF. 2020. Hand book of fisheries statistics. Dept. of Fisheries Ministry of Fisheries, Animal Husbandry & Dairying, Government of India, New Delhi, pp. 1–176.
- Dwivedi SN, Choubey AK. 1998. Indian Ocean Large Marine Ecosystems: need for national and regional framework for conservation and sustainable development. In: Sherman K., Okemwa E., Ntiba M. (Eds.), Large Marine Ecosystems of the Indian Ocean: assessment, sustainability and management. Cambridge: Blackwell Science Inc. pp. 361–368.
- FAO. 2022. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. <https://doi.org/10.4060/cc0461en>.
- Fiedler PC, Barlow J, Gerrodette T. 1998. Dolphin prey abundance determined from acoustic backscatter in eastern Pacific surveys. *Fish Bull* 96: 237–247.
- Flynn A, Paxton J. 2013. Spawning aggregation of the lanternfish *Diaphus danae* (family Myctophidae) in the north-western Coral Sea and associations with tuna aggregations. *Mar Freshw Res* 63: 1255–1271.
- Fonteneau A, Lucas V, Tewkai E, Delgado A, Demarcq H. 2008. Mesoscale 751 exploitation of a major tuna concentration in the Indian Ocean. *Aquat Living Resour* 21: 109–121.
- Ghosh S, Satishkumar M, Manas Hoshalli M, Prathibha R, Abdussamad EM, Gopalakrishnan A. 2021. Observations on feeding habits of the common dolphinfish, *Coryphaena hippurus* (Linnaeus 1758) from the Western Bay of Bengal. *Aquat Living Res* 34: 1–12.
- Gibson RN, Ezzi IA. 1987. Feeding relationships of a demersal fish assemblage on the west coast of Scotland. *J Fish Biol* 31: 55–69.
- Govindaraj K, John ME, Premchand, Unnikrishnan N, Thomas J, Somvanshi VS. 2000. Oceanic tuna resources in the north-west region of Indian EEZ. *Bull Fish Surv India* 27: 1–16.



- Grandperrin R. 1976. Structures trophiques aboutissant aux thons de Longue Ligne dans le Pacifique Sud-Ouest tropical. These de Doctorat d'Etat, Universite de Provence, *Marseille*. 296 pp.
- Grossman GD. 1986. Food resources partitioning in a rocky intertidal fish assemblage. *J Zool* 1: 317–355.
- Hacunda JS. 1981. Trophic relationships among demersal fishes in a coastal area of the Gulf of Maine *Fish Bull* 79: 775–788.
- Hammer O, Harper DAT, Ryan PD. 2001. PAST: paleontological statistics software package for education and data analysis. *Palaeo Elect* 4: 1–9.
- Harvey JT, Loughin TR, Perez MA, Oxman DS. 2000. Relationship between fish size and otolith length for 62 species of fishes from the eastern north Pacific Ocean. U.S. Dep. Commer. *NOAA Tech. Rept., NMFS circular* 150: 1–36.
- Hollowed AB, Bax N, Beamish R, Collie J, Fogarty M, Livingston P, Pope J, Rice JC. 2000. Are multispecies models an improvement on single-species models for measuring fishing impacts on marine ecosystems? *ICES J Mar Sci* 57: 707–719.
- Hyslop EJ. 1980. Stomach content analysis: a review of methods and their application. *J Fish Biol* 17: 411–422.
- Johnson FH. 1977. Response of walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*) population to the removal of white sucker *Catostomus commersonii* from a Minnesota Lake in 1966. *J Fish Res Board Can* 34: 1633–1642.
- Kornilova, G.N. 1981. Feeding of yellowfin tuna, *Thunnus albacares*, and bigeye tuna *Thunnus obesus*, in the equatorial zone of the Indian Ocean. *J Ichthyol* 20: 111–119.
- Krebs CJ. 1989. Ecological methodology. New York, NY: Harper and Row Publishers Inc. 654 p.
- Kumar SM, Ghosh S. 2020. Understanding the trophodynamics of yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788) from the western Bay of Bengal. *Turkish J Fish Aquat Sci* 20: 857–866.
- Kyne PM, Courtney AJ, Bennett MB. 2008. Aspects of reproduction and diet of the Australian endemic skate *Dipturus polyommata* (Ogilby) (Elasmobranchii: Rajidae), by-catch of a commercial prawn trawl fishery. *J Fish Biol* 72: 61–67.
- Labropoulou M, Eleftheriou A. 1997. The foraging ecology of two pairs of congeneric demersal fish species: importance of morphological characteristics in prey selection. *J Fish Biol* 50: 324–340.
- Laptikhovsky V, Naulaerts K, Clingham E, Collins MA, Cranfield M, Henry L, Small A, Stamford T, Xavier J Wright S. 2020. Comparative feeding strategies of yellowfin tuna around St Helena and adjacent seamounts of the South Atlantic Ocean. *J Appl Ich* 00: 1–15.
- Maldeniya R. 1996. Food consumption of yellowfin tuna, *Thunnus albacares*, in Sri Lankan waters. *Environ Biol Fish* 47: 101–107.
- McBride SR, Vidal TE, Cadrin SX. 2013. Changes in size and age at maturity of the northern stock of tilefish (*Lopholatilus chamaeleonticeps*) after a period of overfishing. *Fish Bull* 111: 161–174.
- Menard F, Marsac F, Bellier E, Cazelles B. 2007. Climatic Oscillations and tuna catch rates in the Indian Ocean: a wavelet approach of time series analysis. *Fish Oceanogr* 16: 95–104.
- Novakowski GC, Hahn NS, Fugi R. 2008. Diet seasonality and food overlap of the fish assemblage in a pantanal pond. *Neo Ich* 6: 567–576.
- Oksanen J, Blanchet F, Kindt R, Legendre P, O'Hara RG, Simpson G. 2010. Vegan: community ecology package. *R package*, version 1. 17–0. Accessible online: <http://CRAN.R-project.org/package=vegan>
- Olson RJ, Boggs CH. 1986. Apex predation by yellowfin tuna (*Thunnus albacares*): independent estimates from gastric evacuation and stomach contents, bioenergetics, and cesium concentrations. *Can J Fish Aquat Sci* 43: 1760–1775.
- Pauly DJ, Christensen V, Guenette S, Pitcher TJ, Sumaila UR, Walters CJ, Watson R, Zeller D. 2002. Towards sustainability in world fisheries. *Nature* 418: 689–695.
- Pianka ER. 1973. The structure of lizard communities. *Ann Rev Ecol Syst* 4: 53–74.
- Pillai PP, Said Koya KP, Pillai NGK, Jayaprakash AA. 1993. Fishery biology of yellowfin tuna occurring in oceanic fishing in Indian Seas. In: John, M. E., C & Sudarshan, D. (Eds). Tuna research in India. Fishery Survey of India.
- Pinkas L, Oliphant MS, Iverson ILK. 1971. Food habits of albacore, bluefin tuna and bonito in Californian waters. *Calif Fish Game* 152: 1–105.
- Potier M, Marsac F, Cherel Y, Lucas V, Sabatié R, Maury O, Ménard F. 2007. Forage fauna in the diet of three large pelagic fishes (lancetfish, swordfish and yellowfin tuna) in the western equatorial Indian Ocean. *Fish Res* 83: 60–72.
- Potier M, Marsac F, Lucas V, Sabatié R, Hallier JP, Ménard F. 2004. Feeding partitioning among tuna taken in surface and mid-water layers: the case of yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*) in the western tropical Indian Ocean. *West Ind Ocean J Mar Sci* 3: 51–62.
- R Core Team. 2015. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.
- Rohit P, Rao GS, Ram Mohan K. 2010. Feeding strategies and diet composition of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) caught along Andhra Pradesh, east coast of India. *Ind J Fish* 57: 13–19.
- Romanov E, Potier M, Zamorov V, Ménard F. 2009. The swimming crab *Charybdis smithii*: distribution, biology and trophic role in the pelagic ecosystem of the western Indian Ocean. *Mar Biol* 156: 1089–1107.
- Ruderhausen PJ, Buckel JA, Edwards J, Gannon DP. 2010. Feeding ecology of blue marlins, dolphinfish, yellowfin tuna, and wahoos from the North Atlantic Ocean and comparisons with other oceans. *Trans Ameri Fish Soci* 139: 1335–1359.
- Silva GB, Hazin HG, Hazin FHV, Vaske-Jr T. 2019. Diet composition of bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) caught on aggregated schools in the western equatorial Atlantic Ocean. *J Appl Ich* 35: 1111–1118.
- Stevens ED, Dizon AE. 1982. Energetics of locomotion in warm-bodied fish. *Annu Rev Physiol* 44: 121–131.
- Stoner AW, Livingston RJ. 1984. Ontogenetic patterns in diet and feeding morphology in sympatric sparid fishes from sea-grass meadows. *Copeia* 174–178.
- Tirasin EM, Jorgensen T. 1999. An evaluation of the precision of diet description. *Mar Ecolo Prog Ser* 182: 243–252.
- Ullah MH, Rashed-Un-Nabi M, Al-Mamun MA. 2012. Trophic model of the coastal ecosystem of the Bay of Bengal using mass balance Ecopath model. *Ecol Model* 225: 82–94.
- Van Valen L. 1965. Morphological variation and width of ecological niche. *Am Nat* 99: 377–390.
- Varghese SP, Somvanshi VS, Varghese S. 2010. Discontinuous distribution of *Alepisaurus ferox* Lowe, 1833 (Alepisauridae, Teleostei) in the Indian EEZ as revealed by the tuna longline survey. *Ind J Mar Sci* 39: 406–414.
- Varghese SP, Somvanshi VS. 2016. Feeding ecology and consumption rates of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) in the eastern Arabian Sea. *Ind J Fish* 63: 16–26.

- Varghese SP, Vijayakumaran K, Anrose A, Mhatre VD. 2013. Biological aspects of swordfish, *Xiphias gladius* Linnaeus, 1758, caught during longline survey in the Indian seas. *Turk J Fish Aqua Sci* 13: 529–540.
- Vaske T, Jr Vooren CM, Lessa RP. 2003. Feeding strategy of yellow fin tuna (*Thunnus albacares*) and wahoo (*Acanthocybium solandri*) in the Saint Peter and Saint Paul archipelago, Brazil. *Boletim do Instituto De Pesca, São Paulo* 29: 173–181.
- Vijayakumaran K, Parasuraman PS, Rajakumar SA, Nagarajan G. 1992. A study on the food and feeding habits of yellowfin tuna (*Thunnus albacares*) caught in Andaman waters of Indian EEZ by tuna long lining. *Bull Fish Surv India* 24: 40–44.
- Watters GM, Olson RJ, Francis RC, Fiedler PC, Polovina JJ, Reilly SB, Aydin KY, Boggs CH, Essington TE, Walters CJ, Kitchell JF. 2003. Physical forcing and the dynamics of the pelagic ecosystem in the eastern tropical Pacific: simulations with ENSO-scale and global warming climate drivers. *Can J Fish Aqua Sci* 60: 1161–1175.
- Weng JS, Lee MA, Liu KM, Hsu MS, Hung MK, Wu LJ. 2015. Feeding ecology of juvenile yellowfin tuna from waters southwest of Taiwan inferred from stomach contents and stable isotope analysis. *Mar Coast Fish* 7: 537–548.
- Wotton RJ. 1990. Ecology of teleost fishes. Chapman Hall, New York, USA, pp. 404.
- Yesaki M. 1983. Observations on the biology of yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) tuna in the Philippine waters. FAO, *Indo-Pacific Tuna Development and Management Programme*, IF'TP/ 83.
- Zudaire I, Murua H, Grande M, Goñi N, Potier M, Menard F, Chassot E, Bodin N. 2015. Variations in the diet and stable isotope ratios during the ovarian development of female yellowfin tuna (*Thunnus albacares*) in the western Indian Ocean. *Mar Biol* 162: 2363–2377.

**Cite this article as:** Krishnan S, Pillai TA, Rayappan JCA, Yagappan T, Rajapandian J. 2024. Diet composition and feeding habits of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) from the Bay of Bengal. *Aquat. Living Resour.* 37: 10