



## Feeding ecology and consumption rates of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) in the eastern Arabian Sea

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### ABSTRACT

Diet composition, predator-prey relationships and consumption rates of yellowfin tuna *Thunnus albacares* in the western Indian Exclusive Economic Zone (eastern Arabian Sea) were studied by stomach content analysis. Stomachs of 406 specimens in the fork length range of 48 to 165.5 cm caught during exploratory longlining conducted in the eastern Arabian Sea during 2006 to 2009 were examined, of which, 15.52% were empty. Purple back flying squid (*Sthenoteuthis oualaniensis*) was the dominant prey species, followed by the swimming crab (*Charybdis smithii*), bigeye cigarfish (*Cubiceps pauciradiatus*) and flyingfishes (family Exocoetidae). Diet breadth index and the modified Costello diagram showed dominance of few prey species which are available in high densities in the Arabian Sea, indicating opportunistic feeding nature of this apex predator. Diet did not significantly differ between sexes and size groups. Higher food intake during premonsoon and winter monsoon indicated a seasonal variation in diet. A steady increase in the abundance of *C. smithii* and a decrease in the proportion of *S. oualaniensis* in the diet were observed from premonsoon to winter monsoon seasons. Yellowfin tuna in the Arabian Sea consume an average of 545.65 g of food in a day and require daily ration of 1.95% body weight per day.

Keywords: Consumption rates, Daily ration, Diet breadth index, Diet composition

### Introduction

Changes in the structure and function of marine ecosystems due to industrial fishing (Pauly *et al.*, 1998) have prompted policy makers to adopt ecosystem approach to fisheries management (EAF) (Botsford *et al.*, 1997). The EAF models incorporate ecological interactions to evaluate the potential flows of biomass among interacting populations within exploited ecosystem (Pauly *et al.*, 2002). Food and feeding data are integrated into conceptual models in the EAF, allowing a better understanding of the structure and function of diverse aquatic ecosystems. In addition to the importance in developing an EAF, diet studies of fishes are also essential to understand the temporal, spatial and ontogenetical nature of trophic interactions (Walters *et al.*, 1999; Hollowed *et al.*, 2000), as well as the feeding regimes, food preference, migrations, growth and breeding patterns (Rao, 1974).

The yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) is an economically important apex predator distributed in the tropical and subtropical waters of the world oceans. Several studies on the food and feeding habits of yellowfin tuna in different oceans (Reintjes and King, 1953; King and Ikehara, 1956; Watanabe, 1960; Alverson, 1963; Dragovich and Potthoff, 1972; Kornilova, 1980; Bashmakov *et al.*, 1991; Zamorov *et al.*, 1992; Roger, 1994; Maldeniya, 1996; Bard *et al.*, 2002; M'énard

and Marchal, 2003; Potier *et al.*, 2004, 2007; Menard *et al.*, 2006; Young *et al.*, 2010) as well as in the Indian seas (Silas *et al.*, 1985; Sudarsan *et al.*, 1991; Vijayakumaran *et al.*, 1992; John and Sudarsan, 1993; Sudarsan and John, 1993, 1994; John, 1995; Govindaraj *et al.*, 2000; Rohit *et al.*, 2010) have been reported. However, none of the studies from the Indian Exclusive Economic Zone (EEZ) of the Arabian Sea, comprehensively described the species-wise number, weight and frequency of occurrence of different prey items. Further, there is a dearth of information on the daily ration and food consumption rates of yellowfin tuna from Arabian Sea. Our study was aimed to thoroughly understand the trophic ecology of yellowfin tuna and to calculate its consumption rate in the oceanic waters of the western Indian EEZ (eastern Arabian Sea).

### Materials and methods

This study was carried out in the area beyond the 500 m depth contour of the Indian EEZ part of the eastern Arabian Sea (Fig. 1) during 2006 to 2009. Yellowfin tuna samples for the study were collected during the survey voyages of two tuna longliners of the Fishery Survey of India (FSI) viz., *Matsya Vrushti* and *Yellow Fin*. Regular surveys were conducted in the Indian EEZ along the west coast (lat. 5°-23°N; long. 66-76°E) for oceanic tunas and allied resources employing pelagic longline gear. The fishing gear used and survey strategies adopted for

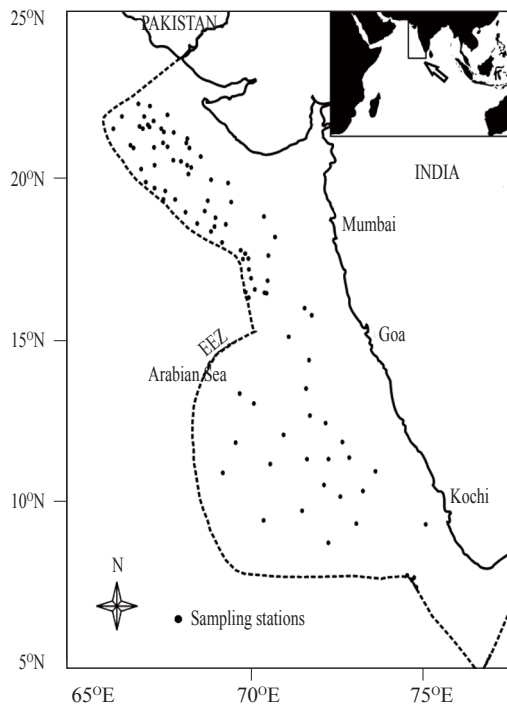


Fig. 1. Map showing sampling stations

collection, storage and analysis of stomach contents were as described previously (Somvanshi *et al.*, 2008; Varghese *et al.*, 2013).

To determine whether the sample size of stomachs analysed was sufficient to describe their diet diversity and breadth, cumulative prey curve was constructed by plotting the cumulative number of unique prey species (y axis) against the number of non-empty stomachs (x axis). Stomach content data, collected during the study period were pooled and analysed. Further, the data were analysed separately by sex, size and season. Intensity of feeding was expressed by repletion index (RI), expressed as gram of stomach content per kilogram body weight of yellowfin tuna (Potier *et al.*, 2004). The diet was assessed using percent occurrence by number (%N), percent frequency of occurrence (%F), and percent occurrence by weight (%W) of prey items (Hyslop, 1980). Actual weight of the prey remains was considered and not the reconstituted weight of prey at ingestion. Quantitative importance of each prey was determined by the index of relative importance (IRI) (Pinkas *et al.*, 1971) and to facilitate diet comparison, IRI was standardised to %IRI. Trophic diversity and relative level of dietary specialisation of yellowfin tuna was assessed by calculating the Levin's standardised index (Krebs, 1989). Feeding strategy of yellowfin tuna and prey importance were visually explored by applying the modified Costello graphical method (Costello, 1990; Amundsen *et al.*, 1996) to the dataset of the major prey taxa.

To test ontogenetic shifts in the diet, yellowfin tuna samples were categorised into five groups, (<80, 80-100, 100-120, 120-140, and >140 cm) according to their fork lengths ( $L_F$ ) and the stomach contents were analysed for each size group. For testing seasonal diet differences, the year was divided into four seasons namely, premonsoon (March-May), summer monsoon (June-September), intermonsoon (October-November) and winter monsoon (December-February) and the stomach samples collected during these seasons were pooled and analysed separately. Feeding similarities between sexes, length groups and seasons were measured using the Bray-Curtis similarity index (Bray and Curtis, 1957) based on %IRI of different food items. Similarity values among clusters that were >0.6 were considered to indicate major divisions. Kruskal-Wallis tests were performed to test the effect of sex, ontogenetic stage and seasons on the %IRI of prey. The software package PAST v. 2.00 (Hammer *et al.*, 2001) was used for these statistical analyses. Morisita-Horn index ( $C_{mh}$ ) of overlap (Krebs, 1998) calculated using the percentage wet weight of prey items were used for examining the diet overlap among sexes, size groups and seasons. Values greater than 0.6 were considered as significant overlap (Hyndes *et al.*, 1997), thereby indicating significant similarity of diets.

Data on the average wetweight of prey items were used for estimating the preliminary consumption rates and daily ration of yellowfin tuna of the Arabian Sea. Stomach evacuation model of Olson and Mullen (1986) was used to predict feeding rate of a predator by dividing the mean actual weight of stomach contents by the average time required to evacuate the average proportion of all meals present in the stomach at any given time ( $A_i$ ), which was adopted for estimating food consumption rates. Actual wet weight of food ingested by *T. albacares* was estimated from the weight of food recovered from the stomach using the linear relationship between the amount of food remaining in the stomach and the assumed time elapsed since feeding (Olson and Boggs (1986). We assigned the  $A_i$  values and parameters of linear relationship estimated by Olson and Boggs (1986) to the prey items of yellowfin tuna of eastern Arabian Sea based on their similarity of digestibility. Accordingly,  $A_i$  values and parameters of linear relationship established by Olson and Boggs (1986), for *Scomber japonicus* were assigned to all prey items of the Scombridae family; for *Stolephorus purpureus* to other epipelagic, mesopelagic and unidentified fish prey; for *Loligo opalescens* to cephalopod prey and the mean of all the above experimental food species to crustaceans and the remaining prey. Since yellowfin tuna feed mainly during the daylight hours (Reintjes and King, 1953; King and Ikehara, 1956; Watanabe, 1958, 1960), the daily food intake (daily meal) was calculated by multiplying the

feeding rate by 12 h, and the daily ration by daily meal divided by average body weight times 100.

The relationship between size of yellowfin tuna and prey size was studied by quantile regression analysis of yellowfin tuna size ( $L_F$ ) and dominant prey length. Standard length ( $L_S$ ) for finfish prey, dorsal mantle length (DML) for cephalopod prey and carapace width (CW) for crabs were considered for these analyses. The software packages ‘vegan’ and ‘quantreg’ of R was used for cumulative prey curve and quantile regression respectively.

## Results

Stomach contents of 406 specimens of yellowfin tuna, having  $L_F$  ranging from 48.0 to 165.5 cm and weight ranging from 2.3 to 88.0 kg, were analysed in this study (Table 1). Altogether, 63 (15.52%) specimens had empty stomachs. Weight of the stomach contents ranged from 0 to 1105 g and the repletion index (RI) ranged from

0-35.65 g per kg body weight. The cumulative prey curve constructed (Fig. 2) reached an asymptote, indicating the sample size of stomachs analysed was sufficient to describe the entire breadth of the diet. Cephalopods were the dominant prey group, followed by teleosts and crustaceans. Purpleback flying squid (*Sthenoteuthis oualaniensis*) was the dominant prey species contributing maximum to the diet in terms of %IRI, followed by the swimming crab (*Charybdis smithii*). *Cubiceps pauciradiatus*, *Onychoteuthis banksii* and *Hirundichthys coromandelensis* were the other important prey species. In addition to the above mentioned prey species, a variety of epipelagic and mesopelagic cephalopods and teleosts were also identified among the stomach contents (Table 2). The estimated diet breadth index (Levin’s standardised index,  $B_i$ ) of yellowfin tuna was 0.106, indicating maximum contribution to the diet by a few prey items.

Table 1. Length, weight, food weight and repletion index (RI) of *T. albacares* sampled from the eastern Arabian Sea

Predator group	No. of specimens	No. of empty stomachs	Fork length (cm)		Weight (kg)		Food weight (g)		Repletion index (g kg <sup>-1</sup> )	
			Range	Mean (±SD)	Range	Mean (±SD)	Range	Mean (±SD)	Range	Mean (±SD)
All specimens	406	63	48-165.5	113.27 (±26.21)	2.3-88	27.96 (±16.01)	0-1105	104.74 (±181.02)	0-35.65	3.75 (±5.27)
Females	204	32	60-150	112.02 (±24.09)	4.0-56	26.62 (±13.25)	0-1105	121.04 (±211.66)	0-35.65	4.55 (±7.18)
Males	202	31	48-165.5	114.52 (±28.26)	2.3-88	29.31 (±18.36)	0-861	88.27 (±142.83)	0-21	3.01 (±4.43)
<80 $L_F$	53	13	48-79	64.92 (±7.12)	2.3-10	5.75 (±1.77)	0-153	23.10 (±39.82)	0-19.13	4.02 (±5.75)
80-100 $L_F$	55	9	80-99	89.44 (±5.51)	7.5-22	12.87 (±3.89)	0-425	82.13 (±117.84)	0-23.61	6.38 (±7.08)
100-120 $L_F$	80	15	100-119	107.61 (±6.63)	8-36	21.79 (±6.04)	0-445.4	93.95 (±119.04)	0-19.37	4.31 (±5.06)
120-140 $L_F$	173	15	120.5-138	128.87 (±5.01)	25-46	34.86 (±5.21)	0-1105	126.84 (±218.00)	0-35.65	3.64 (±6.51)
>140 $L_F$	45	11	140-165.5	150.39 (±8.77)	43-88	57.68 (±11.95)	0-888	164.87 (±244.64)	0-16.15	2.86 (±4.06)
Pre-monsoon	251	29	65-144	124.1 (±20.28)	4-88	33.04 (±13.81)	0-1105	126.44 (±211.90)	0-35.65	3.99 (±6.33)
Summer monsoon	27	2	48-160	90.2 (±38.71)	4.5-70	19.35 (±21.22)	0-164.6	45.82 (±63.10)	0-6.85	1.91 (±2.00)
Inter-monsoon	60	13	60-164	89.9 (±23.77)	2.3-36	15.78 (±10.09)	0-425	54.67 (±92.78)	0-23.61	3.52 (±5.40)
Winter monsoon	68	19	62-165.5	105.9 (±25.71)	4-74	23.19 (±17.54)	0-405.2	95.33 (±125.57)	0-19.6	5.11 (±6.14)

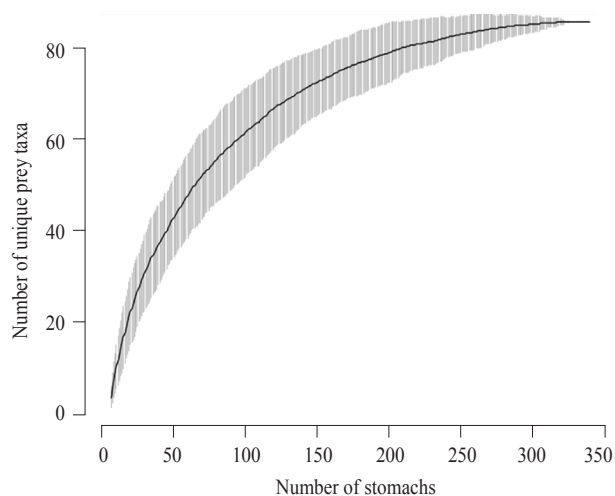


Fig. 2. Cumulative prey curve of yellowfin tuna in the eastern Arabian Sea

Modified Costello diagram (Fig. 3) revealed that, except *S. oualaniensis* which appears in the upper right area of the diagram and *C. smithii*, appearing in the upper left area, most of the other prey species or categories are located in the left corner of the diagram or close to the vertical axis indicating low values for prey importance. It is therefore inferred that *S. oualaniensis* and *C. smithii* are the prime prey species of yellowfin tuna in the Arabian Sea. As suggested by the low values of frequency of occurrence, almost all other species are rare or not important prey, being consumed by few specimens.

Among the 406 specimens sampled, 202 were males and 204 were females. Thirty one males (15.35%) and 32 females (15.69%) had empty stomachs. Contribution of cephalopods was important in the diet in females than in males, while males consumed more crustaceans and teleosts. Though there were marginal differences in the RI

Table 2. Prey species consumed and their percentage contribution to the diet of *T. albacares*

Prey family	Prey species/group	%N	%W	%F	%IRI
Ancistrocheiridae	<i>Ancistrocheirus lesueurii</i>	0.973	2.67	1.74	0.144
Argonautidae	<i>Argonauta hians</i>	0.389	0.21	3.49	0.047
Argonautidae	<i>Argonauta</i> sp.	0.13	0.05	1.16	0.005
Bolitaenidae	<i>Japetella diaphana</i>	0.973	0.54	4.65	0.16
Cranchiidae	<i>Liocranchia reinhardti</i>	0.195	0.08	1.74	0.011
Cranchiidae	<i>Megalocranchia abyssicola</i>	0.259	0.11	1.74	0.015
Enoploteuthidae	<i>Abralia marisarabica</i>	0.13	0.05	1.16	0.005
Enoploteuthidae	<i>Abraliopsis lineata</i>	1.102	1.18	5.81	0.301
Histioteuthidae	<i>Histioteuthis</i> sp.	0.13	0.17	0.58	0.004
Histioteuthidae	<i>Histioteuthis hoylei</i>	1.556	0.56	2.91	0.14
Histioteuthidae	<i>Histioteuthis bonnellii</i>	0.195	0.08	0.58	0.004
Octopodidae	<i>Benthoctopus behni</i>	0.13	0.11	0.58	0.003
Ommastrephidae	<i>Sthenoteuthis oualaniensis</i>	27.5	39.4	53.5	81.23
Onychoteuthidae	<i>Onychoteuthis banksii</i>	1.816	2.95	10.5	1.136
Spirulidae	<i>Spirula spirula</i>	0.065	0.09	0.58	0.002
Thysanoteuthidae	<i>Pholidoteuthis</i> sp.	0.324	1.3	1.74	0.064
Tremoctopodidae	<i>Tremoctopus violaceus</i>	0.195	0.11	1.74	0.012
	<i>Octopus</i> n.i.	0.713	1.39	4.07	0.194
	Squids n.i.	4.345	0.91	10.5	1.252
	Cephalopods total	41.12	51.9	59.3	51.18
Portunidae	<i>Charybdis smithii</i>	13.1	10.7	13.4	7.238
Nannosquillidae	<i>Acanthosquilla</i> sp.	0.065	0.01	0.58	0.001
	Megalopa larva	2.789	0.09	5.23	0.342
	Squilla n.i.	0.195	0.01	1.74	0.008
	Crustaceans total	16.15	10.8	19.2	4.801
Acanthuridae	<i>Naso</i> sp.	0.195	0.31	0.58	0.007
Acropomatidae	<i>Acropoma japonicum</i>	0.13	0.01	0.58	0.002
Acropomatidae	Acropomatidae n.i.	0.454	0.08	1.16	0.014
Balistidae	Balistidae n.i.	0.13	0.03	1.16	0.004
Balistidae	<i>Odonus niger</i>	0.389	0.17	2.91	0.037
Berycidae	<i>Beryx splendens</i>	0.649	0.08	1.74	0.029
Berycidae	<i>Beryx</i> sp.	0.065	1.17	0.58	0.016
Bramidae	<i>Brama</i> sp.	0.584	0.07	0.58	0.009
Carangidae	<i>Decapterus macrosoma</i>	0.065	0.45	0.58	0.007
Carangidae	<i>Elagatis bipinnulata</i>	0.065	0.14	0.58	0.003
Carangidae	<i>Selar crumenophthalmus</i>	0.324	4.12	1.74	0.176
Centrolophidae	Centrolophidae n.i.	0.908	0.63	2.91	0.102
Chauliodontinae	<i>Chauliodus sloani</i>	0.324	0.16	1.16	0.013
Champsodontidae	<i>Champsodon capensis</i>	2.529	0.56	6.98	0.489
Coryphaenidae	<i>Coryphaena equiselis</i>	0.065	0.05	0.58	0.002
Diretmidae	<i>Diretmoides pauciradiatus</i>	0.259	0.16	1.16	0.011
Diretmidae	<i>Diretmus</i> sp.	0.065	0.04	0.58	0.001
Engraulidae	Engraulidae n.i.	0.519	0.14	0.58	0.009
Exocoetidae	<i>Cheilopogon furcatus</i>	1.232	1.39	4.65	0.277
Exocoetidae	<i>Exocoetus monocirrhus</i>	0.389	1.35	2.91	0.115
Exocoetidae	<i>Exocoetus</i> sp.	0.13	0.04	0.58	0.002
Exocoetidae	<i>Hirundichthys coromandelensis</i>	1.427	3.95	4.07	0.497
Exocoetidae	<i>Hirundichthys</i> sp.	0.13	0.33	1.16	0.012
	Flying fish n.i.	0.065	0.02	0.58	0.001
Gempylidae	<i>Gempylus serpens</i>	1.427	0.45	5.81	0.248
Gempylidae	<i>Lepidocybium flavobrunneum</i>	0.195	3.35	1.74	0.14
Gempylidae	<i>Neoepinnula orientalis</i>	0.065	0.06	0.58	0.002
Microstomatidae	<i>Nansenia macrolepis</i>	1.038	0.12	0.58	0.015

Prey family	Prey species/group	%N	%W	%F	%IRI
Microstomatidae	<i>Nansenia obscura</i>	1.297	0.04	0.58	0.018
Monacanthidae	<i>Aluterus monoceros</i>	0.778	0.03	0.58	0.011
Monacanthidae	<i>Thamnaconus modestoides</i>	2.01	0.67	2.33	0.142
Monacanthidae	Monacanthidae n.i.	0.065	0.01	0.58	0.001
Muraenesocidae	<i>Gavialiceps taeniola</i>	0.195	0.48	0.58	0.009
Myctophidae	<i>Diaphus</i> sp.	1.621	0.15	1.74	0.07
Myctophidae	<i>Lampanyctus</i> sp.	5.772	0.66	1.16	0.169
Nomeidae	<i>Cubiceps pauciradiatus</i>	5.837	3.41	16.9	3.547
Omosudidae	<i>Omosudis</i> sp.	0.778	0.58	1.16	0.036
Ostraciidae	<i>Lactoria diaphana</i>	0.065	0	0.58	0.001
Paralepididae	<i>Paralepis</i> sp.	1.621	0.24	1.74	0.073
Phosichthyidae	<i>Vinciguerrria attenuata</i>	0.454	0.34	2.33	0.042
Scombridae	<i>Auxis rochei rochei</i>	0.13	1.39	1.16	0.04
Scombridae	<i>Auxis</i> sp.	0.065	0.1	0.58	0.002
Scombridae	<i>Auxis thazard</i>	0.13	1.04	1.16	0.031
Scombridae	Neritic tuna n.i.	0.065	1.04	0.58	0.015
Scombridae	<i>Euthynnus affinis</i>	0.584	5.53	2.33	0.323
Scombridae	Scombridae n.i.	0.13	0.79	1.16	0.024
Scopelarchidae	<i>Scopelarchus analis</i>	0.13	0.04	0.58	0.002
Scopelarchidae	<i>Scopelarchus guentheri</i>	0.065	0.03	0.58	0.001
Sternoptychidae	Hatchetfish n.i.	1.362	0.3	5.81	0.219
Sternoptychidae	<i>Argyropelecus gigas</i>	0.065	0.02	0.58	0.001
Sternoptychidae	<i>Sternoptyx diaphana</i>	0.065	0.03	0.58	0.001
	Teleosts n.i.	1.946	0.81	7.56	0.473
	Fish larva	0.713	0.03	2.33	0.039
	Teleosts total	39.69	37.2	61.6	43.92
	Salpa n.i.	1.102	0.04	2.91	0.075
	Chaetognatha n.i.	1.946	0.03	1.74	0.078
	Other organisms total	3.048	0.07	3.49	0.101

n.i. – not identified

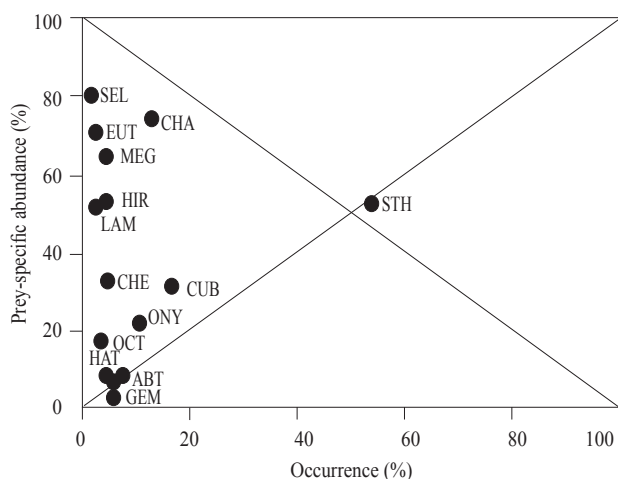


Fig. 3. Modified Costello diagram showing relative importance of main food items of *T. albacares* in the eastern Arabian Sea (STH – *Sthenoteuthis oualaniensis*; CHA - *Charybdis smithii*; CUB – *Cubiceps pauciradiatus*; ONY – *Onychoteuthis banksii*; HIR – *Hirundichthys coromandelensis*; CHA – *Champsodon capensis*; MEG - Megalopa larva; EUT – *Euthynnus affinis*; ABR – *Abraliopsis lineata*; CHE – *Cheilopogon furcatus*; GEM – *Gempylus serpens*; HAT – Hatchet fish n.i.; Oct - Octopus n.i.; SEL – *Selar crumenophthalmus*; LAM – *Lampanyctus* sp.)

of the males and females, the Bray-Curtis similarity index calculated (0.782) and Kruskal-Wallis test performed ( $H=1.21$ ,  $p=0.29$ ) did not reveal significant differences between the sexes. Further, Morisita–Horn index (0.851) revealed overlap of diets of males and females.

Feeding activity of yellowfin tuna, as indicated by the number of empty stomachs varied by ontogenetic stage. Percentage of empty stomachs was marked in juveniles (<80 cm) and very large (>140 cm) adults (Table 1) while the specimens in the size class 120-140 cm had minimum proportion of empty stomachs. Average RI also varied among the size groups, maximum recorded being for the size group 80-100 cm and minimum for specimens of >140 cm size group. Major constituents in the diet of the size class <80 cm were macroplankton and micronekton. Groupwise, juveniles and larvae of teleosts were dominant prey, followed by cephalopods and crustaceans, whereas, megalopa larvae of crabs were dominant prey. Teleosts were the dominating prey group in the size class 80 - 100 cm and >140 cm, whereas, cephalopods dominated the diets of size classes 100-120 cm and 120-140 cm. Further, *S. oualaniensis* was the

most important prey species of all the above size classes. Kruskal-Wallis test performed on the %IRI of prey revealed no significant variation among the diet of different ontogenetic groups ( $H=7.02$ ,  $p=0.13$ ). Dendrogram constructed based on Bray-Curtis similarity indices calculated for different size classes indicated maximum similarity between the diet of the size classes 100-120 and 120-140 cm (Fig. 4a). The diet of fish of size classes <80 cm and >140 cm clustered separately from those of other size groups (similarity index <0.6). Morisita-Horn indices ( $C_{mh}$ ) calculated also resulted in similar inferences. The diet of size class <80 did not overlap significantly with diet of other groups, while significant overlap of diets were observed between size group pairs 80-100 and 100-120 ( $C_{mh} = 0.74$ ); 80-100 and 120-140 ( $C_{mh} = 0.73$ ); 100-120 and 120-140 ( $C_{mh} = 0.93$ ); 100-120 and >140 ( $C_{mh} = 0.77$ ); 120-140 and >140 ( $C_{mh} = 0.76$ ).

Seasonal variations in the diet of *T. albacares* of Arabian Sea revealed that the cephalopods, dominated

Length of prey items consumed by yellowfin tuna of Arabian Sea were small fraction of their fork length. The average prey-to-predator length ratio calculated was 7.71% ( $\pm 4.07$ ) and 32.12% of all prey consumed were less than 5% of the predator length, 73% less than 10% and 95.75% were less than 15% of the yellowfin tuna fork length (Fig. 5). While the maximum size of the prey species increased with predator length, minimum prey size remained fairly stable (Fig. 6). Despite extensive variation between specimens, the maximum (95<sup>th</sup> quantile), mean (50<sup>th</sup> quantile) and minimum size (5<sup>th</sup> quantile) of *S. oualaniensis* consumed by yellowfin tuna of eastern Arabian Sea significantly increased with its size. However, the maximum length of *C. smithii* (95<sup>th</sup> quantile) was observed to decrease with increase in size of yellowfin tuna. Regression analysis of lengths of all prey species except *C. smithii* indicated that the mean, maximum and minimum size of prey species consumed by yellowfin tuna of Arabian Sea increased with its size.

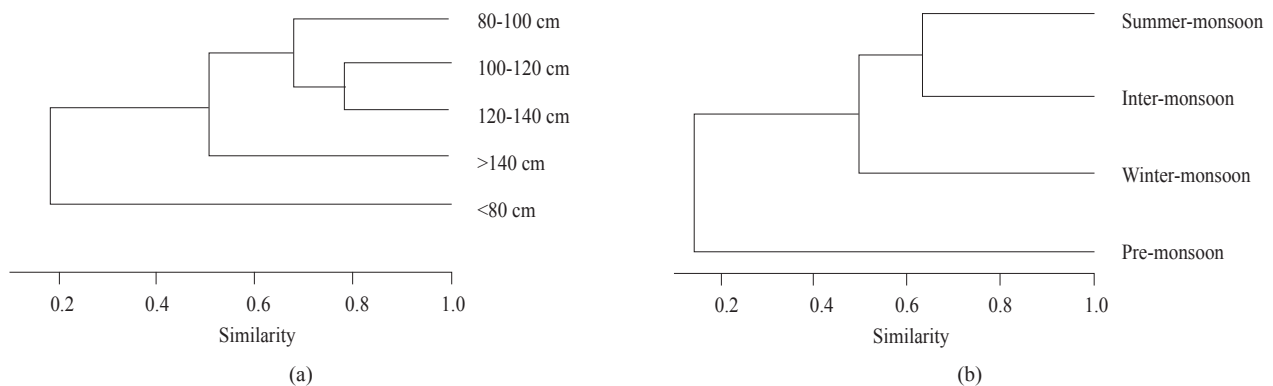


Fig. 4. Dendrogram of cluster analysis (paired group) showing Bray-Curtis similarity index of %IRI values of food items of different length classes (a) and different seasons of capture (b) of yellowfin tuna in the eastern Arabian Sea

by *S. oualaniensis* were the main prey item during premonsoon season, whereas during the remaining seasons, *C. smithii* was the dominant prey species. Interestingly, this study showed an increase in the proportion of *C. smithii* and a steady decrease in the proportion of *S. oualaniensis* from premonsoon to winter monsoon season through summer monsoon and inter monsoon. However, teleosts dominated by *E. affinis* was the main prey group during inter-monsoon season. Bray-Curtis similarity indices (Fig. 4b) and Morisita-Horn indices indicated significant overlap ( $C_{mh} = 0.69$ ) between summer monsoon and winter monsoon only. Kruskal-Wallis test ( $H= 33.72$ ,  $p<0.001$ ), showed marked variation in the diets of *T. albacares* during the four seasons.

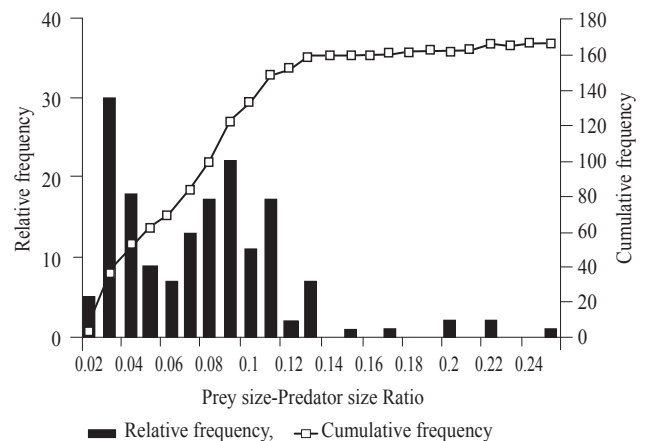


Fig. 5. Relative frequency distributions of prey-predator size ratios for yellowfin tuna in the eastern Arabian Sea

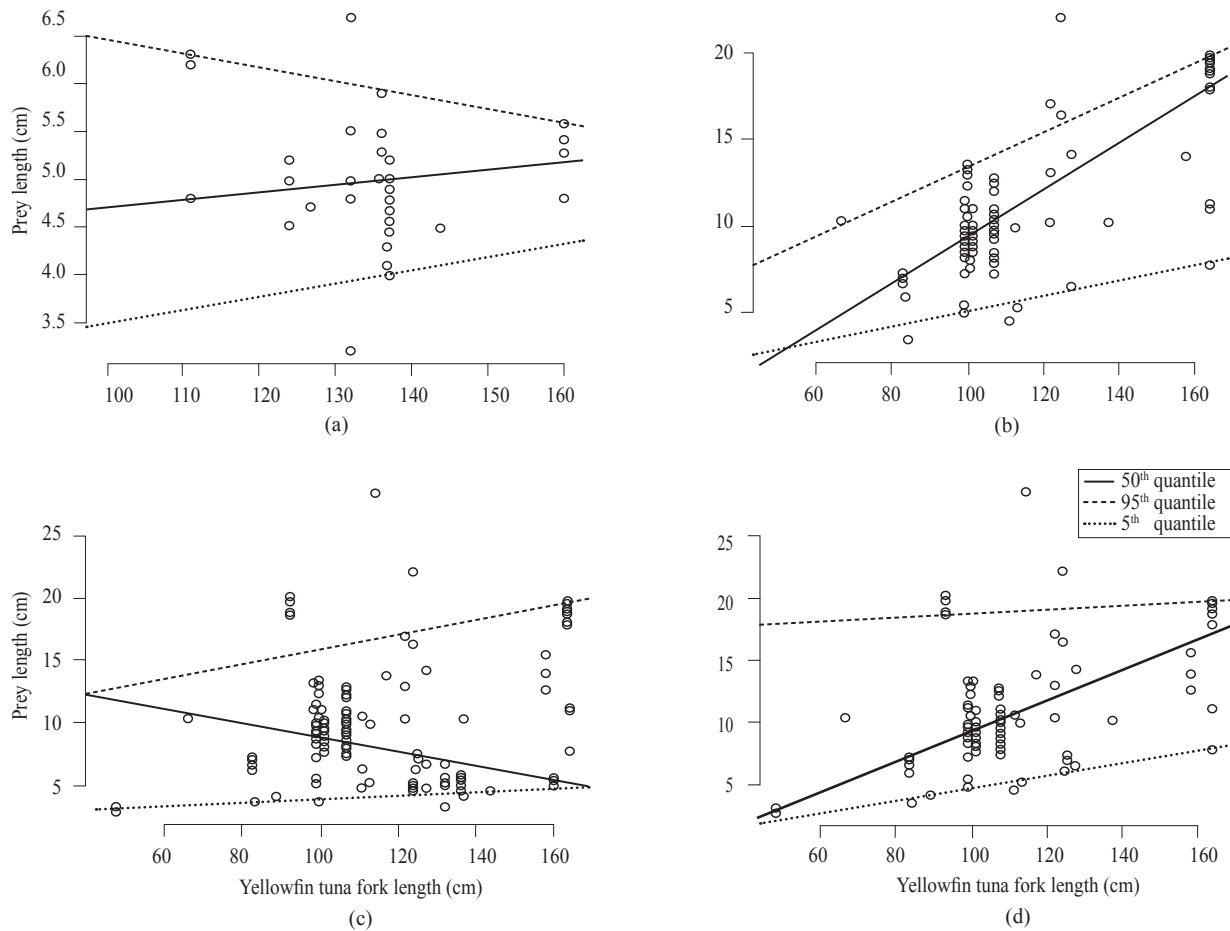


Fig. 6. Scatter diagrams showing the relationships of length of yellowfin tuna and its prey items (a) *Charybdis smithii*, (b) *Sthenoteuthis oualiansensis*, (c) all prey items and (d) all prey items except *C. smithii* in the eastern Arabian Sea. Quantile regression indicate upper (95<sup>th</sup>) and lower (5<sup>th</sup>) boundaries used to describe predator and prey size relationships. Least squares regression line (50<sup>th</sup> quantile) estimates rate of change in mean prey size as a function of predator size

Daily food consumption and daily ration (expressed as percentage of body mass) were estimated according to yellowfin tuna sex and size. The overall daily food consumption and daily ration estimated were 545.65 g and 1.95% body weight (BW) day<sup>-1</sup> respectively (Table 3). The study showed that for the male and female yellowfin tuna, the daily consumption is 482.68 g (male), 608.34 g (female) and the daily ration required are 1.63% BW day<sup>-1</sup> (male) and 2.29% BW day<sup>-1</sup> (female)

respectively. The present study showed considerable variations in the daily food consumption and daily ration requirement according to size of yellowfin tuna (Table 3). Annual prey consumption estimates for yellowfin tuna of Arabian Sea increased from 44.49 (<80 cm L<sub>F</sub>) to 367.68 kg (>140 cm L<sub>F</sub>), while the overall yearly food consumption was 199.16 kg. Annual average weight of major prey species consumed by yellowfin tuna was estimated as: *S. oualiansensis* - 64.82 kg,

Table 3. Average weight, adjusted weight and weight consumed of different prey items and daily ration of *T. albacares* in the eastern Arabian Sea

Prey category	Average wt. of food items (g)	Adjusted weight (g)	Food consumption (g)	Daily meal (g)	Daily ration (as % body mass)
Cephalopods	54.376	87.383	19.505	234.061	0.837%
Crustaceans	11.342	17.549	5.207	62.489	0.223%
Finfishes of family Scombridae	10.328	17.021	3.218	38.611	0.138%
Finfishes other than scombrids	28.578	39.221	17.509	210.112	0.751%
Other food items	0.068	0.105	0.031	0.373	0.001%
Total	104.692	161.278	45.47	545.646	1.952%

*C. smithii* - 22.59 kg, *S. crumenophthalmus* - 11.58 kg, *H. coromandelensis* - 11.09 kg and *C. pauciradiatus* - 9.58 kg.

## Discussion

Our study revealed that the diet of yellowfin tuna of the eastern Arabian Sea is very diverse, comprising a variety of cephalopods, crustaceans and teleosts and that the species feed mainly on *S. oualaniensis*, *C. smithii*, *C. pauciradiatus*, *O. banksii* and flying fishes. The percentage of empty stomachs in our study (15.52%) was lower than the value reported in many of the earlier works in the region (John, 1995; Maldeniya, 1996). The average weight of food per stomach for yellowfin tuna observed in the present study (104.69 g) was considerably lower than the value reported by Barut (1988), while it was higher than the value reported by John (1995). Our results were comparable to the value reported from Andaman waters (106 g, Vijayakumaran *et al.*, 1992). The repletion index of yellowfin tuna in our study (3.74 g kg<sup>-1</sup>) was higher than the earlier reported value of 3.5 (John, 1995; Barut, 1998). These variations in the RI values could be attributed to the difference in mode of capture and method of preservation of stomach contents (Yesaki, 1983), or to the abundance of prey species in the oceanic waters of the eastern Arabian Sea.

Contribution of cephalopods to the total diet of yellowfin tuna was higher in our study than those reported earlier (Alverson, 1963; Dragovich and Potthoff, 1972; Kornilova, 1980; Silas *et al.*, 1985; Vijayakumaran *et al.*, 1992; John and Sudarsan, 1993; Sudarsan and John, 1993, 1994; John, 1995; Govindaraj *et al.*, 2000; Potier *et al.*, 2007; Rohit *et al.*, 2010). Low value for the diet breadth index (Levin's Standardised index, B<sub>i</sub>) for yellowfin tuna in our study (0.106) indicated that, although this species consumed a wide variety of prey items, maximum contribution to the diet was by few prey items including oceanic squids, swimming crabs and teleosts (bigeye cigarfish and flying fishes), which are available in high density in the Arabian Sea (Trotsenko and Pinchukov, 1994; Couwelaar *et al.*, 1997; Chesalin and Zuyev, 2002; Potier *et al.*, 2008; Romanov *et al.*, 2009), that could restrict yellowfin's feeding to most frequently available prey items in this area. Yellowfin tuna of Arabian Sea may be feeding mainly on these prey species, leading to low value for diet breadth index and hence showing an opportunistic feeding strategy. Similar observations were made for albacore tuna from the central Mediterranean Sea (Consoli *et al.*, 2008).

In our study, we could not establish any significant variations in the diets of males and females. While the consumption rates varied between sexes in our study, diet composition did not, as evidenced by the high value

for Bray-Curtis similarity index. Earlier study by Yesaki (1983) also showed no significant difference in diet between males and females.

Graham *et al.* (2006) reported rapid ontogenetic shift in the diet of juvenile yellowfin (L<sub>F</sub> - 45 and 50 cm) caught by rod and reel fishing from Hawaii. It was revealed in our study that the average weight of food increased with size from 23.10 g (<80 cm size class) to 164.96 g (>140 cm size class). However, as observed by John (1995), the food consumption per unit body weight was found to be decreasing (except a slight increase in the size class 80-100 cm) with increase in size. Although the ontogenetic difference in constituents of the diet was not statistically significant, it was evident from the Bray-Curtis similarity indices and Morisita-Horn indices (C<sub>mh</sub>) that yellowfin tuna juveniles (<80 cm) of Arabian Sea feed mainly on macrozooplankton and fish larvae and adults slowly shift their food preferences to *S. oualaniensis* and *C. smithii* while large adults (>140 cm) prefer teleosts.

Results of our study showed that season was the most important factor contributing to variation in diet of yellowfin tuna of the Arabian Sea. Higher food intake recorded during winter monsoon (December-February) and premonsoon (March-May) seasons could be related to the increased intake of food by the fish in order to meet the energy requirements for reproductive processes during the spawning period. The spawning season of yellowfin tuna in the north-west Indian EEZ is reported to be during December-June (Govindaraj *et al.*, 2000). Our study indicated the availability of a variety of prey species for yellowfin tuna in the Arabian Sea during different seasons. Our results further revealed that yellowfin tuna in the Arabian Sea, having teleosts as common food, enjoy succession in food preference from cephalopods to swimming crabs. Since yellowfin tuna are voracious feeders and are generally non-selective, occurrence of a particular prey species in large quantity in their stomach contents could be due to the availability of such prey species in abundance during a particular season. Swimming crabs occur in great densities in the pelagic waters of the Arabian Sea during July - January (Couwelaar *et al.*, 1997).

Diet of yellowfin tuna in the eastern Arabian Sea consists of relatively small prey. Relative frequency distribution of prey-predator size ratios revealed that 32.12% of all prey consumed by yellowfin tuna of the area were less than 5% of the predator length. Maximum size of the prey increased with predator length while the minimum prey size remained fairly stable. Menard *et al.* (2006) also made similar observations on the yellowfin tuna caught from French Polynesia.

Consumption rate and daily ration in yellowfin tuna estimated during the present study were considerably lower than many of the earlier estimations (Yesaki, 1983; Barut, 1988; Menard *et al.*, 2000), and higher than the estimation of Young *et al.* (2010) for yellowfin tuna (>100 cm length), while the results were comparable with the estimations of Vijayakumaran *et al.* (1992) and Maldeniya (1996). This difference in the estimated values of consumption rates and daily ration could be attributed to the presence of squids as the dominant food in the diet of yellowfin tuna of the Arabian Sea, as squids are easily digested and get evacuated faster.

The results of the present study provide basic information on the food and feeding habits of *T. albacares* for ecological modeling of oceanic waters and for understanding the relationship between different trophic levels in the eastern Arabian Sea. The study further revealed that there is huge potential for developing fisheries for underexploited resources in the Arabian Sea, in the form of oceanic squids (*S. oualaniensis*), swimming crabs (*C. smithii*), bigeye cigarfish (*C. pauciradiatus*), flying fishes and neritic tunas which form natural prey of large predatory fishes. Longline, being a passive gear, generally capture fishes which are in a state of active feeding and therefore there is a chance of inadequate sampling of satiated tunas in our study. Further, diet of small yellowfin tunas (<40 cm), which are not usually caught by pelagic longlines, could not be studied in the present study.

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