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Ontogenetic and seasonal variations in the feeding ecology of Indo-Pacific sailfish, *Istiophorus platypterus* (Shaw, 1792), of the eastern Arabian Sea

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Present study consists the studies on the stomach contents of Indo-Pacific sailfish, *Istiophorus platypterus* (Shaw, 1792), caught during tuna longline survey conducted in the western Indian EEZ (eastern Arabian Sea) between 2006 and 2009 to investigate the sexual, ontogenetic and seasonal effects in the diet. Stomachs of 290 specimens in the forklength range of 101-261 cm were examined, of which 38 (13.10%) were empty. Prey composition was assessed in terms of occurrence by number, frequency of occurrence, weight and Index of Relative Importance. Quantile regression techniques were used to determine the mean and upper and lower bounds of the relation between prey size and sailfish length. Diet was dominated by teleost fishes, followed by cephalopods while crustaceans were represented in limited instances. Purpleback flying squid, *Sthenoteuthis oualaniensis*, was the most preferred prey species. Other important prey species identified were *Euthynnus affinis, Cubiceps pauciradiatus, Gempylus serpens* and *Onychoteuthis banksii*. Diet did not varied by sex, but the ontogenetic and seasonal variations in diet were significant. The maximum and mean size of prey increased with length of sailfish. However, relatively smaller prey constituted bulk of sailfish diet and even large specimens consumed small prey.

[**Keywords:** Indo-Pacific sailfish *Istiophorus platypterus* (Shaw, 1792), Eastern Arabian Sea, Feeding ecology, *Sthenoteuthis oualaniensis,* Ontogenetic and seasonal differences in diet, Predator-prey relationship]

Introduction

The Indo-Pacific sailfish, *Istiophorus platypterus* (Shaw, 1792), is a highly migratory large oceanic teleost, widely distributed in the tropical and temperate waters of Pacific and Indian Oceans[1]. The species constitutes a major bycatch component of the gillnet and longline fishery in the Indian waters[2,3] and the reported annual catch of this species from India during 2010 was 6890.44 t[4]. It is an ecologically important species as it functions as apex predator in oceanic pelagic ecosystems. Recent emphasis on Ecosystem Approach to Fisheries management (EAF) necessitates more information on the biological interactions, energy transfer, consumption and production among different trophic levels in the ecosystems[5,6]. Therefore, a thorough understanding on the effects of predation by apex predators like *I. platypterus* is a prerequisite for developing ecosystem based models. Analysis of stomach contents is a direct method of investigating food and feeding habits, which can yield valuable information on the prey species and feeding habits of the predator.

Studies on the diet composition of *I. platypterus* have been undertaken by many workers from different areas[1,7,8,9,10,11,12,13,14,15,16]. In Indian waters, Balan[17] studied the diet composition of sailfish *I. gladius* (Broussonet), caught by the driftnet along Calicut coast, while Varghese ***et al.*** studied the stomach contents of 501 specimens of sailfish caught by exploratory longlining from the northwest coast of India. However, there is a dearth of information on the comprehensive description of species-wise number, weight and frequency of occurrence of different food items of sailfish of the eastern Arabian Sea. In this perspective, the present study was undertaken to thoroughly investigate the feeding ecology of *I. platypterus* caught from the oceanic waters of the western Indian EEZ (eastern Arabian Sea).

Materials and Methods

Our study was carried out in the oceanic waters of western Indian Exclusive Economic Zone (eastern Arabian Sea, Fig. 1) between 2006 and 2009. One of the important characteristics of the Arabian Sea is the regular oscillation of monsoonal atmospheric conditions during the Southwest and Northeast monsoons[18]. The reversal of the monsoons has a

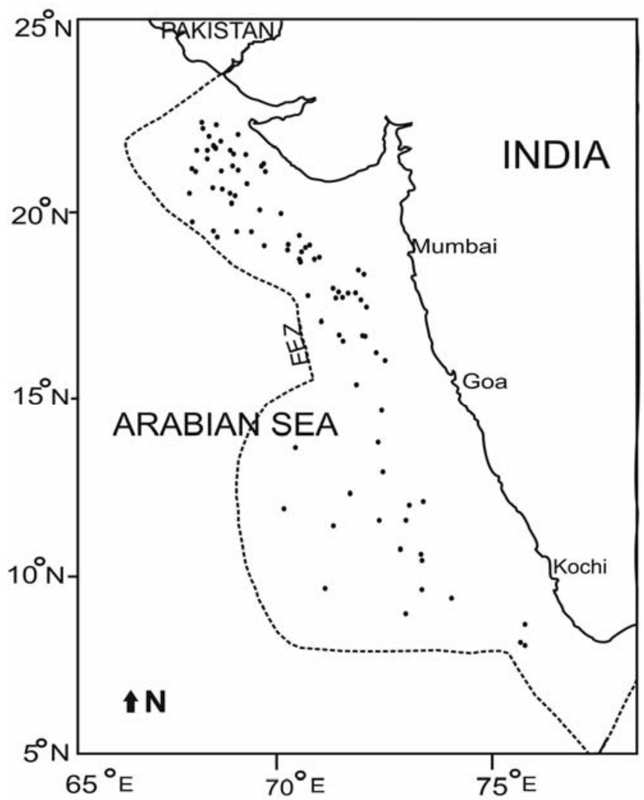

Fig. 1—Map showing the areas of sample collection

major influence on mixed-layer dynamics[19] and nutrient cycle of the Arabian Sea[20,21]. Additionally, a well-pronounced Oxygen Minimum Zone (OMZ) exists in the northern Arabian Sea[22,23] and the presence of this perennial OMZ is having pronounced effects on the distribution and abundance of marine organisms including fishery resources of the Arabian Sea[22,24,25,26].

Sailfish samples for our study were collected during the survey voyages of two research longliners of Fishery Survey of India (FSI), *viz., Matsya Vrushti* (OAL 37.5 m, GRT 465 t), and *Yellow Fin* (OAL 36.0 m, GRT 290 t). Regular surveys were conducted during the study period in the Indian EEZ along the west coast (Lat. 5°-23°N; 66-76°E) for oceanic tunas and allied resources using pelagic longline. Both monofilament longline (onboard *Matsya Vrushti*) and multifilament longline (onboard *Yellow Fin*) gears were used for collection of samples. The gear is set in the survey area before sunrise deploying 675 hooks in a day's operation. A wide variety of baits including squids, sardines, mackerels, scads, etc. were utilized during the study. An immersion time of six hours is allowed and the gear is retrieved at around 1400 hrs. All the fish samples caught were subjected for different morphometric measurements (±0.5 cm), weighed (±100 g) and body cavity is cut open, sex is recorded and stomachs were put in plastic bags with proper labeling and kept frozen at –20°C onboard the vessels.

Further examinations of the stomachs were carried out at the shore laboratory, where, each stomach was first thawed, drained, weighed and dissected to retrieve its contents. Accumulated items such as bones, eyeballs, squid beaks, gladius, etc. and bait were discarded. Preys were identified to the lowest possible taxa using taxonomic keys and descriptions from literature and online resources[27,28,29,30,31,32,33,34]. Length and weight of each food item was measured with maximum precision (±0.1 cm; ±0.01g). Prey items that were identifiable, but could not be measured due to partial digestion, were grouped together and weighed. Preys that could not be identified, but could be categorized as teleosts, invertebrates etc. were recorded as fish not identified (n.i.), squids n.i. etc. and weighed.

Stomach content data collected during the study period were pooled and analysed. Intensity of feeding was expressed by fullness index or Repletion Index (RI)[35]. The diet was assessed using percent occurrence by number (%N), percent frequency of occurrence (%F), and percent occurrence by weight (%W) of prey items[36]. Weight was the actual weight of the prey remains, not the reconstituted weight of prey at ingestion. Quantitative importance of each prey was determined by the Index of Relative Importance (IRI)[37] and to facilitate diet comparison, IRI was standardized to %IRI. To test for ontogenetic shifts in the diet, sailfish samples were categorised into six groups (<125, 125-150, 150-175, 175-200, 200-225 and >225 cm) according to their Fork Length (L_F) and the stomach contents were analysed for each size group. To test for seasonal differences in the diet, the stomach samples collected were segregated into four seasons of collection, *viz*., Pre monsoon (April-May); Southwest monsoon (June-September); Inter monsoon (October-November) and Northeast monsoon (December-March).

To investigate the trophic diversity and relative level of dietary specialization of *I. platypterus*, the diet breadth was assessed by calculating the Shannon-Wiener index (H')[38]. Feeding strategy of sailfish and prey importance were visually explored by applying the modified Costello graphical method[39,40] to the dataset of the major prey taxa. Information about prey importance, niche width and feeding strategy of the predator is given by the distribution of the points along the diagonals and the axes of the diagram[40].

Patterns of relative prey size use by sailfish were examined by plotting relative frequency histogram of prey-predator size ratios. Changes in prey size with increasing sailfish size were estimated by plotting an absolute prey size-predator size diagram. Standard Length (L_S) for finfish prey, Dorsal Mantle Length (DML) for cephalopod prey and Carapace Width (CW) for crabs were considered for the analysis. Quantile regression techniques[41,42,43] were used to determine the mean (50th quantile) and upper and lower bounds (95th and 5th quantiles) of the relation between prey size and sailfish length. Ontogenetic shifts in trophic niche breadth were quantified by examining the slopes of lower and upper bounds of relative prey size versus sailfish length scatter. Significant divergences of slopes indicate increase of ratio based trophic niche breadth[42]. Following Menard *et al.*[44], the software package 'quantreg' of R was used for estimation of the regression parameters and their standard errors.

Feeding similarities between length groups and seasons were assessed by plotting dendrograms of cluster analysis (paired group) using the Bray–Curtis similarity index[45] of %IRI of different food items. Kruskal-Wallis tests were performed to test the effect of sex, ontogenetic stage and seasons on the %IRI of prey. Software package PAST v. 2.00[46] was used for these statistical analyses. Matrix of Morisita–Horn index (C_{mh})[47,48] calculated using the percentage wet weight of prey items also were used for this purpose. Value greater than 0.6 were considered to indicate a significant overlap[49] indicating significant similarity of diets.

Results

The stomach contents of 290 specimens of *I. platypterus* were a analyzed in our study. Of these, 38 specimens (13.10%) were having empty stomachs. The sampled specimens were in the forklength (L_F) range of 101-261 (186.02 ± 31.60) cm, weighing 4-53 (26.84 ± 9.14) kg. Mean wet weight of stomach contents recovered from the stomachs was 111.66 (±118.84) g, and the average RI was 4.57 (±5.19) g per kg. Diet was dominated by finfishes in terms of weight, frequency of occurrence and IRI, while cephalopods dominated the diet in terms of number (Table 1). Contribution of the crustaceans, represented by *Charybdis smithii* and *Acanthosquilla* sp. and an unidentified isopod, to the diet was marginal. *Sthenoteuthis oualaniensis* was the most preferred prey species of sailfish in the Arabian Sea. *Euthynnus affinis*, *Cubiceps pauciradiatus*, *Gempylus serpens*, *Onychoteuthis banksii* and *Vinciguerria attenuata* were the other dominant prey species.

Table 1—Prey species consumed and their percentage contribution to the diet of *I. platypterus*

Prey family	Prey species	%N	%W	%F	%IRI
Argonautidae	*Argonauta hians*	0.944	0.531	3.968	0.138
	Argonauta bottgeri	0.42	0.221	1.587	0.024
Bolitaenidae	*Japetella diaphana*	0.21	0.443	0.794	0.012
Cranchiidae	*Liocranchia reinhardti*	0.525	0.173	2.381	0.039
	Megalocranchia abyssicola	0.315	0.12	0.794	0.008
Enoploteuthidae	*Abralia andamanica*	2.728	1.317	3.968	0.378
	Abralia marisarabica	1.364	0.257	2.381	0.091
	Abraliopsis lineata	0.63	0.312	1.587	0.035
Histioteuthidae	*Histioteuthis hoylei*	0.105	0.063	0.794	0.003
	Histioteuthis sp	2.099	0.709	8.73	0.577
Ommastrephidae	*Sthenoteuthis oualaniensis*	34.627	29.566	52.381	79.122
Onychoteuthidae	*Onychoteuthis banksii*	3.987	1.805	9.524	1.298
Lepidoteuthidae	*Pholidoteuthis boschmai*	0.105	1.314	0.794	0.027
Tremoctopodidae	*Tremoctopus violaceus*	0.21	0.081	1.587	0.011
	Squids n.i.	3.568	0.454	9.524	0.901
	Cephalopods Total	**51.836**	**37.367**	**73.81**	**42.221**
Nannosquillidae	*Acanthosquilla* sp	0.105	0.003	0.794	0.002
Portunidae	*Charybdis (Goniohellenus) smithii*	2.099	1.603	3.175	0.277
	Isopod n.i.	0.105	0.002	0.794	0.002
	Crustaceans Total	**2.308**	**1.608**	**4.762**	**0.12**

(*Contd.*)

Table 1—Prey species consumed and their percentage contribution to the diet of *I. platypterus*—(*Contd.*)

Prey family	Prey species	%N	%W	%F	%IRI
Acropomatidae	*Acropoma japonicum*	0.525	0.501	1.587	0.038
Alepisauridae	*Alepisaurus ferox*	0.315	0.486	2.381	0.045
Apogonidae	Apogonidae n.i.	0.315	0.044	1.587	0.013
Balistidae	*Canthidermis maculata*	0.21	0.915	1.587	0.042
	Odonus niger	0.21	0.037	0.794	0.005
	Sufflamen sp	0.315	0.13	0.794	0.008
Berycidae	*Beryx splendens*	0.735	0.277	1.587	0.038
Bramidae	*Brama* sp	0.105	0.29	0.794	0.007
Carangidae	*Decapterus macrosoma*	1.049	1.02	2.381	0.116
	Decapterus kurroides	0.105	0.633	0.794	0.014
	Elagatis bipinnulata	0.315	0.526	1.587	0.031
Centrolophidae	Centrolophidae n.i.	0.21	0.056	0.794	0.005
Stomiidae	*Chauliodus sloani*	0.105	0.025	0.794	0.002
Coryphaenidae	*Coryphaena equiselis*	0.105	1.769	0.794	0.035
	Coryphaena sp	0.105	0.617	0.794	0.013
Diretmidae	*Diretmus* sp	0.105	0.011	0.794	0.002
Engraulidae	Engraulidae n.i.	4.827	0.653	5.556	0.716
Exocoetidae	*Cheilopogon nigricans*	0.105	0.399	0.794	0.009
	Cheilopogon furcatus	0.105	0.36	0.794	0.009
	Cheliopogon sp	0.21	0.333	0.794	0.01
	Exocoetus monocirrhus	2.728	2.784	3.175	0.412
Gempylidae	*Gempylus serpens*	6.191	1.938	11.905	2.277
	Lepidocybium flavobrunneum	0.42	1.49	3.175	0.143
	Neoepinnula orientalis	0.105	0.088	0.794	0.004
	Ruvettus pretiosus	0.105	0.13	0.794	0.004
	Rexea prometheoides	0.21	0.261	1.587	0.018
	Gempylidae n.i.	0.105	0.035	0.794	0.003
Microstomatidae	*Nansenia macrolepis*	0.21	0.228	1.587	0.016
	Nansenia obscura	0.105	0.06	0.794	0.003
Monacanthidae	*Thamnaconus modestoides*	1.784	0.215	3.175	0.149
	Monacanthidae n.i.	1.469	0.672	5.556	0.28
Muraenesocidae	*Gavialiceps taeniola*	0.42	0.963	1.587	0.052
Myctophidae	*Lampanyctodes* sp	0.315	0.038	0.794	0.007
	Diaphus sp	2.938	0.461	3.175	0.254
Nomeidae	*Cubiceps pauciradiatus*	6.716	3.58	15.873	3.845
	Cubiceps capensis	1.049	0.059	0.794	0.021
Omosudidae	*Omosudis* sp	0.21	0.017	0.794	0.004
Paralepididae	*Paralepis* sp	0.735	0.335	3.175	0.08
Phosichthyidae	*Vinciguerria attenuata*	2.728	4.166	7.937	1.288
Scombridae	*Auxis rochei*	0.21	0.818	0.794	0.019
	Auxis thazard	1.259	6.884	3.968	0.76
	Auxis sp	0.105	0.988	0.794	0.02
	Euthynnus affinis	2.728	12.817	14.286	5.226
	Katsuwonus pelamis	0.525	7.878	2.381	0.471
	Thunnus tonggol	0.21	2.617	1.587	0.106
	Tunas n.i.	0.315	0.669	1.587	0.037
	Scombridae n.i.	0.105	0.195	0.794	0.006
Tetraodontidae	*Lagocephalus lagocephalus*	0.21	0.717	1.587	0.035
Trichiuridae	*Trichiurus auriga*	0.105	0.216	0.794	0.006
	Finfish n. i.	1.469	0.625	7.143	0.352
	Finfishes total	**45.855**	**61.025**	**84.127**	**57.659**

n.i. – not identified

Modified Costello diagram constructed (Fig. 2) established the importance of *S. oualaniensis* as the main food item of sailfish of eastern Arabian Sea. The species appears in the upper right area of the modified Costello diagram, whereas, most of the other prey species are located in the left corner or close to the vertical axis, indicating low values for prey importance. As suggested by low values of frequency of occurrence, almost all other species are rare or unimportant prey, being consumed by few specimens. Majority of the specimens had been feeding on *S. oualaniensis*, while a large number of other prey species were included occasionally in the diets contributing small proportion of diet of sailfish of Arabian Sea. Diet breadth index (H') calculated (2.896) indicates a moderately wide spectrum of prey species in the diet of *I. platypterus* of the Arabian Sea.

Proportion of specimens with empty stomachs was more in females than males. Diets of both the sexes were dominated by finfishes, followed by cephalopods and crustaceans (Table 2). *S. oualaniensis* was

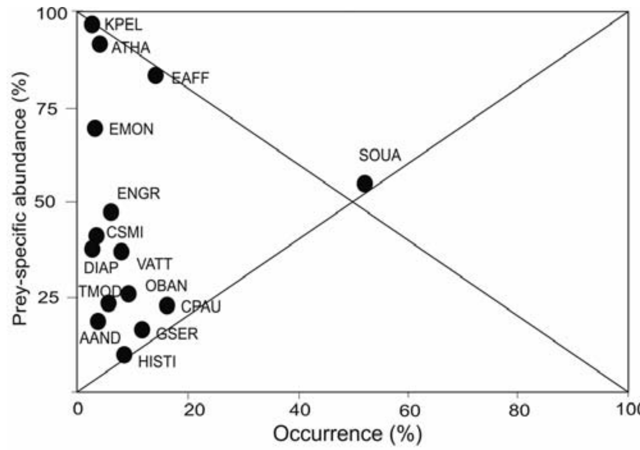

Fig. 2—Modified Costello diagram showing the relative importance of important food items to the diet of *I. platypterus* (SOUA - *Sthenoteuthis oualaniensis*; EAFF-*Euthynnus affinis;* CPAU - *Cubiceps pauciradiatus*; GSER-*Gempylus serpens;* OBAN - *Onychoteuthis banksii;* VATT - *Vinciguerria attenuata;* ATHA - *Auxis thazard;* ENGR–Engraulidae n.i.; HISTI - *Histioteuthis* sp; KPEL-*Katsuwonus pelamis;* EMON-*Exocoetus monocirrhus;* AAND-*Abralia andamanica;* TMOD-*Thamnaconus modestoides;* CSMI-*Charybdis smithii;* DIAP - *Diaphus* sp)

Table 2—Sex-wise and seasonal differences in the %IRI of different food items of *I. platypterus* of eastern Arabian Sea—(*Contd.*)

Prey family	Prey species	Females	Males	Pre monsoon	SW monsoon	Inter monsoon	NE monsoon
Argonautidae	*Argonauta hians*	0.321	0.073	0.035	0.316	2.296	
	Argonauta bottgeri	0.131			0.126		
Bolitaenidae	*Japetella diaphana*		0.036		0.064		
Cranchiidae	*Liocranchia reinhardti*	0.016	0.061	0.289			0.026
	Megalocranchia abyssicola		0.024	0.114			
Enoploteuthidae	*Abralia andamanica*	0.22	0.533	2.398			0.373
	Abralia marisarabica	0.056	0.076		0.293		0.026
	Abraliopsis lineata		0.106		0.014		0.146
Histioteuthidae	*Histioteuthis hoylei*	0.017		0.045			
	Histioteuthis sp	0.487	0.5	0.982	0.951		0.032
Ommastrephidae	*Sthenoteuthis oualaniensis*	77.26	77.156	51.178	83.679	17.955	76.248
Onychoteuthidae	*Onychoteuthis banksii*	0.852	1.626	0.5	0.684		2.252
Lepidoteuthidae	*Pholidoteuthis boschmai*	0.144					0.258
Tremoctopodidae	*Tremoctopus violaceus*	0.015	0.008	2.438		7.252	
	Squids n.i.	0.708	1.168		0.068		1.266
	Cephalopods Total	**44.95**	**38.02**	**28.411**	**55.064**	**20.997**	**42.155**
Nannosquillidae	*Acanthosquilla* sp		0.006			1.67	
Portunidae	*Charybdis (Goniohellenus) smithii*	0.117	0.431				3.389
	Isopod n.i.		0.006		0.011		
	Crustaceans Total	**0.042**	**0.197**		**0.004**	**0.471**	**0.946**
Acropomatidae	*Acropoma japonicum*	0.078	0.015	0.208			0.048
Alepisauridae	*Alepisaurus ferox*		0.134		0.021		0.214
Apogonidae	Apogonidae n.i.	0.012	0.014				0.132
Balistidae	*Canthidermis maculata*	0.229				2.789	0.132
	Odonus niger		0.014		0.024		
	Sufflamen sp		0.025		0.044		
Berycidae	*Beryx splendens*	0.047	0.031	0.376			
Bramidae	*Brama* sp	0.04			0.039		

(*Contd.*)

Table 2—Sex-wise and seasonal differences in the %IRI of different food items of *I. platypterus* of eastern Arabian Sea—(*Contd.*)

Prey family	Prey species	Females	Males	Pre monsoon	SW monsoon	Inter monsoon	NE monsoon
Carangidae	Decapterus macrosoma	0.014	0.217	0.412			0.204
	Decapterus kurroides		0.041		0.072		
	Elagatis bipinnulata		0.141				0.307
Centrolophidae	Centrolophidae n.i.	0.027			0.026		
Stomiidae	Chauliodus sloani		0.007				0.024
Coryphaenidae	Coryphaena equiselis		0.104		0.183		
	Coryphaena sp		0.04		0.071		
Diretmidae	Diretmus sp		0.007				0.021
Engraulidae	Engraulidae n.i.		1.418	1.08	1.226		0.043
Exocoetidae	Cheilopogon nigricans		0.028		0.049		
	Cheilopogon furcatus		0.026	0.137			
	Cheliopogon sp	0.055			0.053		
	Exocoetus monocirrhus	0.057	1.051	0.165	1.463		
Gempylidae	Gempylus serpens	2.727	1.875	1.691	4.409	2.061	0.261
	Lepidocybium flavobrunneum	0.082	0.185		0.079	4.308	0.056
	Neoepinnula orientalis		0.011		0.019		
	Ruvettus pretiosus		0.013				0.043
	Rexea prometheoides	0.02	0.031	0.052	0.027		
	Gempylidae n.i.	0.014				1.789	
Microstomatidae	Nansenia macrolepis	0.034	0.006		0.011		0.06
	Nansenia obscura		0.009	0.044			
Monacanthidae	Thamnaconus modestoides	0.17	0.025		0.103		0.304
	Monacanthidae n.i.	0.371	0.208		1.201		0.021
Muraenesocidae	Gavialiceps taeniola	0.282		0.364	0.014		
Myctophidae	Lampanyctodes sp		0.02	0.088			
	Diaphus sp		0.767		0.012		2.41
Nomeidae	Cubiceps pauciradiatus	3.269	4.512	12.961	1.548	2.39	1.174
	Cubiceps capensis	0.114					0.204
Omosudidae	Omosudis sp		0.013				0.042
Paralepididae	Paralepis sp	0.025	0.14	0.364		2.127	0.026
Phosichthyidae	Vinciguerria attenuata	0.295	1.565	0.906	0.09		5.279
Scombridae	Auxis rochei		0.057	0.305			
	Auxis thazard	0.837	0.672	2.508			2.151
	Auxis sp		0.061				0.199
	Euthynnus affinis	10.36	2.633	17.757	2.863	6.583	0.94
	Katsuwonus pelamis		1.4	0.909		48.779	
	Thunnus tonggol	0.141					1.029
	Tunas n.i.		0.08				0.087
	Scombridae n.i.	0.031	0.11		0.05		0.055
Tetraodontidae	Lagocephalus lagocephalus	0.095					0.338
Trichiuridae	Trichiurus auriga	0.033			0.031		
	Finfish n. i.	0.203	0.484	1.693	0.065		0.181
	Finfishes total	55.01	61.783	71.589	44.932	78.532	56.899
Predator information							
	Total stomachs analysed	172	118	66	88	16	120
	% of empty stomachs	18.64	9.3	6.06	2.27	12.5	25
	Mean (± SD) predator Forklength (cm)	191.5 (± 31.31)	182.27 (± 31.43)	188.90 (± 34.30)	175.86 (± 38.51)	196.88 (± 14.44)	188.78 (± 27.10)
	Mean (± SD) predator weight (kg)	28.89 (± 9.81)	25.24 (± 8.25)	28.92 (± 12.09)	23.09 (± 10.96)	23.25 (± 6.61)	28.1 (± 4.79)
	Mean (± SD) food wt (g)	112.78 (± 115.23)	110.89 (± 121.92)	136.49 (± 14.21)	129.73 (± 115.15)	167.9 (± 189.74)	83.25 (± 100.77)
	Mean (± SD) Repletion Index (g/kg)	4.47 (± 4.69)	4.68 (± 5.52)	8.30 (± 20.88)	5.48 (± 4.24)	7.90 (± 9.38)	3.29 (± 4.33)

n.i. – not identified

dominating in the cephalopods consumed by males, *Charybdis smithii* dominated among the crustaceans, while *C. pauciradiatus*, *E. affinis*, *G. serpens* and *V. attenuata* were dominating among the finfish components. *S. oualaniensis* was dominating in the diet of females, followed by *E. affinis*, *C. pauciradiatus* and *G. serpens*. Though there were differences in the RI of the male and female sailfish, the Bray-Curtis similarity index calculated (0.891) and Kruskal-Wallis test performed (H=2.30, P=0.13) did not revealed any significant differences in the diet components of both the sexes.

Among the size groups of sailfish studied, maximum number of stomachs (104) examined was from the size class 175-200 cm, while the minimum (10) was from the class 125-150 cm. Percentage of specimens with empty stomachs increased with the length of specimens upto the size class 200-225 cm. The average RI was maximum in the smallest size class (<125 cm), thereafter decreasing with increasing size up to the size class 200-225 cm. Major food components of smaller size groups were finfishes, whereas, the larger specimens slowly shifted their food preference to cephalopods. However, the most dominant prey species (in terms of %IRI) was *S. oualaniensis* in all the size classes. Kruskal-Wallis test performed on the %IRI of individual food items revealed significant variations among the diet of different ontogenetic groups (H=15.65, P<0.01). Dendrogram constructed indicated maximum similarity between the diet of the size class 175-200 and >225 cm (Fig. 3). The diet composition of the size class <125 cm and 125-150 cm clustered separately from those of other species groups (similarity index <0.5) indicating significant variations in the diets of juveniles and adults. Morisita–Horn indices (C_{mh}) calculated also indicated significant variations among the diet of different size groups. Maximum value for C_{mh} (0.937) was recorded for the size group pair 150-175 and 175-200 cm, while the size group pair <125 and >225 cm recorded minimum value (0.375).

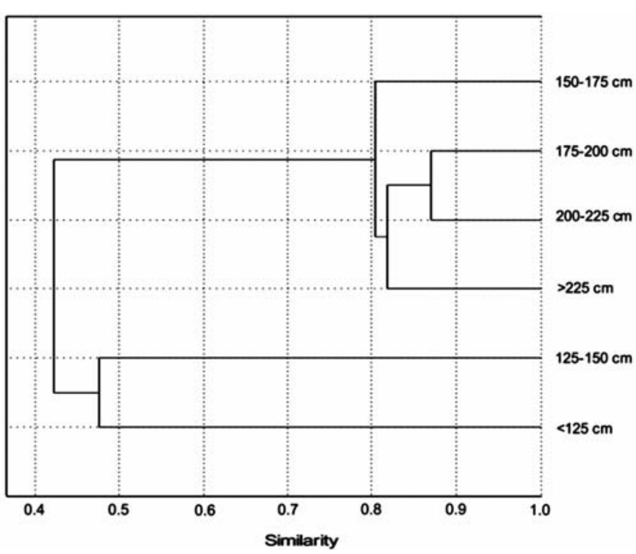

Fig. 3—Dendrogram of Cluster analysis (paired group) showing Bray-Curtis similarity index of %IRI values of food items of different length classes of *I. platypterus*

Our study revealed significant variations in the diet of *I. platypterus* according to seasons prevailed. Proportion of specimens with empty stomachs was maximum during Northeast monsoon season (25.0%), whereas it was minimum during Southwest monsoon (2.27%). During monsoon seasons, the food weight per unit body weight was low, in comparison with non-monsoon seasons. Teleost fishes were the dominant prey group during the seasons Pre monsoon, Inter monsoon and Northeast monsoon, whereas the cephalopods were the dominant prey group during Southwest monsoon season (Table 2). Ranked by %IRI, *S. oualaniensis* was the dominant prey species during Pre monsoon, Southwest monsoon and Northeast monsoon, while *Katsuwonus pelamis* was predominating in the diet of samples collected during the Inter monsoon season. Swimming crab, *C. smithii* was recorded among the prey species during Northeast monsoon season only. Bray-Curtis similarity indices (Fig. 4), Morisita–Horn indices (C_{mh}) calculated and Kruskal-Wallis test performed (H=11.50, P<0.01) indicated very significant seasonal variation in the diet of *I. platypterus* of eastern Arabian Sea.

Diet of *I. platypterus* in the Arabian Sea consists of relatively small prey. Relative frequency distribution of prey size-predator size ratios revealed that 68.45% of all prey consumed by the species of the area were less than 5% of the predator length, 92.26% less than 10% and 98.81% were less than 15% of the sailfish forklength (Fig 5). Despite extensive variation between specimens, maximum and median prey size increased significantly with sailfish size (Fig. 6, 50th quantile, y=0.02369x + 5.39145 (SEs = 0.0613; SEi = 0.0248) 95th quantile, y=0.06468x + 9.12154 (SEs = 0.26932; SEi = 0.39242). Predation on minimum-sized prey did not significantly increase with predator size (5th quantile, y=0.00084x + 4.70753; (SEs = 0.0000; SEi = 0.66752). There was a significant negative relationship between prey length-predator length ratios and predator forklength. Examination of scatter diagram of relative prey size (prey: predator size ratio) as a function of predator size (Fig. 7) indicated no significant changes in trophic niche breadth.

Table 3—Ontogenetic differences in the %IRI of different food items of *I. platypterus* of eastern Arabian Sea—(*Contd.*)

Prey family	Prey species	<125 L_F	125-150 L_F	150-175 L_F	175-200 L_F	200-225 L_F	>225 L_F
Argonautidae	*Argonauta hians*			0.755	0.022	0.086	0.185
	Argonauta bottgeri			0.201			0.2
Bolitaenidae	*Japetella diaphana*			0.263			
Cranchiidae	*Liocranchia reinhardti*				0.021	0.122	0.207
	Megalocranchia abyssicola					0.133	
Enoploteuthidae	*Abralia andamanica*		7.278	0.064	0.066	1.764	
	Abralia marisarabica	4.833		0.053	0.021		
	Abraliopsis lineata				0.28		
Histioteuthidae	*Histioteuthis hoylei*					0.052	
	Histioteuthis sp		2.845	0.319	1.171	0.202	0.192
Ommastrephidae	*Sthenoteuthis oualaniensis*	30.19	37.78	69.906	79.08	78.498	72.45
Onychoteuthidae	*Onychoteuthis banksii*	0.562		0.056	2.059	0.682	6.352
Lepidoteuthidae	*Pholidoteuthis boschmai*					0.463	
Tremoctopodidae	*Tremoctopus violaceus*				0.022		0.197
	Squids n.i.	0.933		1.403	0.594	0.458	2.22
	Cephalopods Total	**27.57**	**25.41**	**38.85**	**43.77**	**41.61**	**48.79**
Nannosquillidae	*Acanthosquilla* sp					0.032	
Portunidae	*Charybdis (Goniohellenus) smithii*	28.32				0.355	
	Isopod n.i.			0.045			
	Crustaceans Total	**9.526**		**0.014**		**0.222**	
Acropomatidae	*Acropoma japonicum*			0.31	0.039		
Alepisauridae	*Alepisaurus ferox*					0.76	
Apogonidae	Apogonidae n.i.					0.216	
Balistidae	*Canthidermis maculata*					0.726	
	Odonus niger			0.101			
	Sufflamen sp						0.6
Berycidae	*Beryx splendens*					0.744	
Bramidae	*Brama* sp			0.158			
Carangidae	*Decapterus macrosoma*			0.615	0.166		
	Decapterus kurroides						0.908
	Elagatis bipinnulata		2.92		0.075		
Centrolophidae	Centrolophidae n.i.		2.483				
Stomiidae	*Chauliodus sloani*			0.053			
Coryphaenidae	*Coryphaena equiselis*						2.272
	Coryphaena sp						0.889
Diretmidae	*Diretmus* sp					0.035	
Engraulidae	Engraulidae n.i.	0.418	7.557	1.806		1.091	0.799
Exocoetidae	*Cheilopogon nigricans*			0.202			
	Cheilopogon furcatus					0.149	
	Cheliopogon sp				0.08		
	Exocoetus monocirrhus			0.825		2.798	
Gempylidae	*Gempylus serpens*	1.303		10.153	1.674	0.532	
	Lepidocybium flavobrunneum			0.563	0.06	0.26	
	Neoepinnula orientalis			0.079			
	Ruvettus pretiosus				0.035		
	Rexea prometheoides			0.113	0.028		
	Gempylidae n.i.					0.043	0.275
Microstomatidae	*Nansenia macrolepis*	0.382			0.049		
	Nansenia obscura			0.067			
Monacanthidae	*Thamnaconus modestoides*	0.418			0.522		0.17
	Monacanthidae n.i.		3.442	0.779	0.017	0.242	0.333
Muraenesocidae	*Gavialiceps taeniola*		1.318		0.184		
Myctophidae	*Lampanyctodes* sp				0.052		
	Diaphus sp	2.476			0.77	0.037	

(*Contd.*)

Table 3—Ontogenetic differences in the %IRI of different food items of *I. platypterus* of eastern Arabian Sea—(*Contd.*)

Prey family	Prey species	<125 L_F	125-150 L_F	150-175 L_F	175-200 L_F	200-225 L_F	>225 L_F
Nomeidae	*Cubiceps pauciradiatus*	2.653		5.199	3.174	3.469	2.727
	Cubiceps capensis					0.331	
Omosudidae	*Omosudis* sp				0.034		
Paralepididae	*Paralepis* sp			0.1	0.369		
Phosichthyidae	*Vinciguerria attenuata*	10.64		0.106	1.36	1.457	
Scombridae	*Auxis rochei*		7.419			0.331	
	Auxis thazard			0.734	1.217		1.603
	Auxis sp				0.162		
	Euthynnus affinis	16.87	24.16	3.218	4.22	1.498	7.199
	Katsuwonus pelamis			1.186	1.605		
	Thunnus tonggol					1.845	
	Tunas n.i.					0.095	
	Scombridae n.i.			0.203	0.071	0.095	
Tetraodontidae	*Lagocephalus lagocephalus*					0.298	
Trichiuridae	*Trichiurus auriga*		2.797				
	Finfish n. i.			0.347	0.707	0.193	0.222
	Finfishes total	**62.91**	**74.59**	**61.14**	**56.24**	**58.17**	**51.21**
Predator information							
	Total stomachs analysed	18	10	56	104	76	26
	% of empty stomachs	0	0	7.14	15.38	23.68	0
	Mean (± SD) predator Forklength (cm)	104.78 (± 11.11)	144 (± 4.30)	161.75 (± 6.84)	187.38 (± 6.56)	208.71 (± 5.83)	238.69 (± 12.22)
	Mean (± SD) predator weight (kg)	11.56 (± 1.88)	12.80 (±1.30)	17.96 (± 3.78)	26.72 (± 5.08)	32.95 (± 4.68)	39.38 (± 6.54)
	Mean (± SD) food wt (g)	121.44 (± 147.96)	122.98 (± 102.67)	117.52 (± 113.32)	92.02 (± 115.08)	111.76 (± 126.36)	145.94 (± 99.12)
	Mean (± SD) Repletion Index (g/kg)	11.98 (± 14.95)	9.51 (± 8.28)	6.37 (± 5.80)	3.50 (± 4.81)	3.38 (± 3.69)	3.90 (± 2.88)

n.i. – not identified

Discussion

Sailfish in eastern Arabian Sea consumed many epi- and meso-pelagic prey items including cephalopods and teleosts, while crustaceans were represented in limited instances. Samples for our study were collected using pelagic longline operated in the early morning and forenoon hours. As the longlines, being a passive gear, generally captures predators which are in a state of active feeding[50], our results showed that sailfish feed actively during morning hours. This is further established while considering that majority of the preys in our study was in undigested condition.

In our study, the contribution of finfishes to the sailfish diet was higher in terms of %W and %F and %IRI, while the cephalopods were dominating the diet by number. Many studies, conducted in different regions of the world oceans had revealed the greater importance of fish over the cephalopods in the diet of sailfish[14,7,10,11,9]. Varghese ***et al.***[2], while studying the stomach contents of sailfish caught by longlining from the northwestern Indian EEZ also reported that, the diet of this species is dominated by bony fishes, closely followed by cephalopods and crustaceans. Studies on the stomach contents of sailfish ***I. gladius***

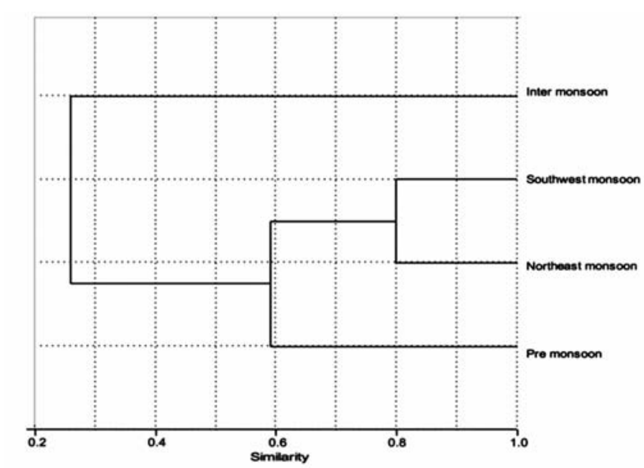

Fig. 4—Dendrogram of Cluster analysis (paired group) showing Bray-Curtis similarity index of %IRI values of food items of *I. platypterus* during different seasons

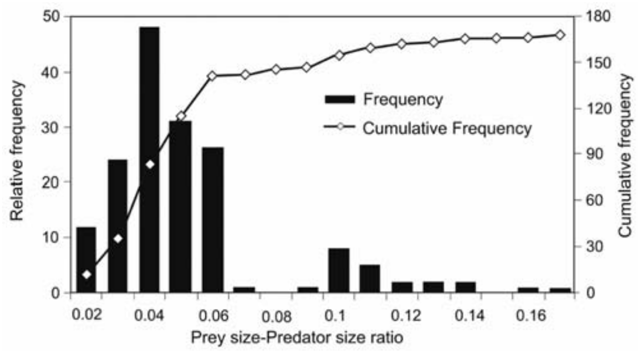

Fig. 5—Relative frequency distributions of prey size-predator size ratios for *I. platypterus* in the eastern Arabian Sea

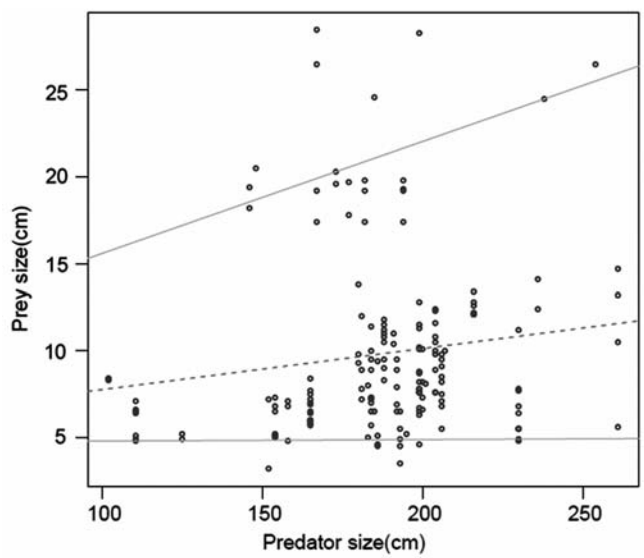

Fig. 6—Scatter diagrams showing the relationship of length of *I. platypterus* and its preys in the eastern Arabian Sea. Quantile regression lines (Continuous lines) indicate upper (95th) and lower (5th) boundaries used to describe predator and prey size relationships. Least squares regression lines (dashed line) estimates rate of change in mean prey size as a function of predator size.

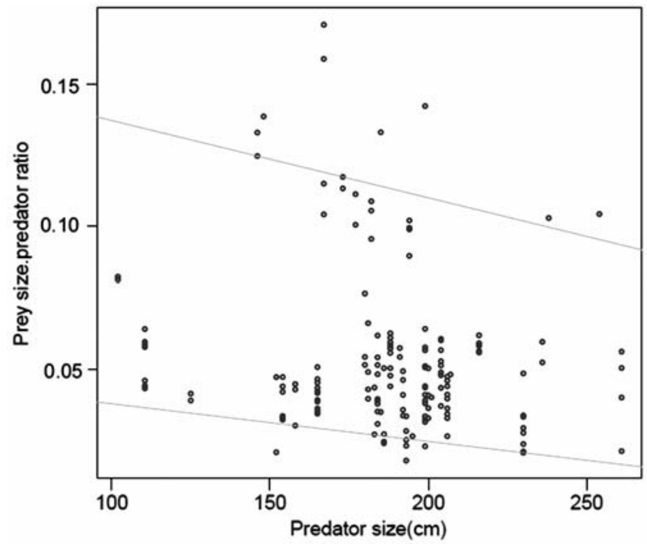

Fig. 7—Scatter diagram of relative prey size (prey: predator size ratio) as a function of predator size. Fifth and 95th quantile regression lines showing potential changes in trophic-niche breadth

(Broussonet) by the driftnet unit along Calicut coast by Balan[17] revealed that this species feeds mainly on teleost fish and cuttlefish. However, studies conducted in Pacific Ocean reported that the cephalopods are dominating in the diet of sailfishes[8,13,15,16]. Although the finfishes were dominating the diet in our study, the importance of *S. oualaniensis* as the main food item of the sailfish in this area, as reflected in the highest values of %N, %W, %F and %IRI for this species is highlighted.

Varghese *et al.*[2] identified the bony fishes in the diet of sailfish as pufferfish, flyingfish, snake mackerels, dolphinfish, filefish, horse mackerel and juveniles of a number of fish species while the dominant cephalopod species was identified as *Loligo* sp. Our study revealed that the diet of sailfish in the eastern Arabian Sea includes a wide spectrum of prey species, since the diet is composed of 14 taxa of cephalopods, 2 crustacean taxa and 47 teleost taxa. High diversity of prey taxa suggests that the sailfish are opportunistic predators, feeding on variety of available prey. However, high consumption of *S. oualaniensis, E. affinins* and *C. pauciradiatus* by sailfish in the study area resulted in a moderate value for Shannon-Wiener index. These dominant prey species are available in high density in the Arabian Sea[51,52,53,54,55] and the sailfish, instead of restricting its diet to preferred food, may feed on the most profitable food source at a particular time, leading to moderate value for diet breadth index.

Studies conducted in Mexico[15] indicated that male and female sailfish fed largely on the same prey. In our study, contribution of cephalopod prey was more to the diet of females than males. However, *S. oualaniensis* remained the most preferred food item of both the sexes and the Bray-Curtis similarity index calculated and Kruskal-Wallis test performed did not revealed any significant differences in the diet of both sexes.

In our study, the Repletion Indices of smaller size classes were very high in comparison with that of specimens in larger size classes. Specimens of small size class require more food for meeting the high energy requirements for rapid growth. Specimens in smaller size class ate more finfishes than those of large size class, while large size group ate more cephalopods in comparison with smaller size groups. This shift in the diet as fish grow will help to reduce intraspecific competition between juveniles and adults. Our study further indicates that the sailfish of Arabian Sea most likely school by size and feed separately, as reported earlier[1].

Seasonal differences in the diet were also significant in our study. The maximum RI recorded during Inter monsoon season can be related to requirement of more food to meet higher metabolism as a result of increased water temperatures during summer months. Finfishes remained the preferred food item of sailfish of Arabian Sea in all the seasons except Southwest monsoon, during which the cephalopods were the dominant diet group. This further establishes the opportunistic feeding habit of *I. platypterus* of eastern Arabian Sea. The sailfish, instead of selecting any particular food item, would ingest any available species of consumable size and therefore, differences in diet reflect differences in availability of prey species in the surroundings during different seasons.

Diet of *I. platypterus* in the Arabian Sea consists of relatively smaller prey. The maximum size of the prey increased with predator length, whereas, minimum prey size remained fairly stable. Large pelagic predators like sailfish are generally non-selective, as the waters they reside are mostly oligotrophic. Thus the individuals of the species eat whatever prey are available in the surroundings, irrespective of their types and size. The only limitation to eat larger prey species will be the gape size, as established in the study by Menard *et al.*[44] on the prey species of tunas caught from French Polynesia.

Our study provides basic information on the food and feeding habits of *I. platypterus* essential for ecological modeling and for understanding the relationship between different trophic levels in the oceanic waters of eastern Arabian Sea. Our results will help the fishermen in deriving fishing strategies for selection of appropriate baits, scheduling of operation, targeting specific stocks and temporal preferences. However, the sailfish samples for present study were collected using pelagic longlining. Longlines, being a passive gear, generally captures specimens who are in a state of active feeding[50] and therefore there is a chance of inadequate sampling of satiated sailfish in our study.

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