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Feeding strategies and diet composition of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) caught along Andhra Pradesh, east coast of India

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ABSTRACT

The food of yellowfin tuna, *Thunnus albacares* caught by longlines off the east coast of India was studied in detail. Contents of 146 non-empty stomachs were analysed for the Index of relative importance (IRI) and prey specific abundance. *T. albacares* caught by the longline were found to be non-selective generalist feeders, foraging on micronektonic, pelagic or benthic organisms available in the epipelagic waters. Teleost fish, crabs, squids and shrimps were the major component of food items. *Priacanthus hamrur* was the most preyed upon fish with a high IRI (40.5%) followed by the swimming crab *Charybdis smithii* (23.9%), the squid *Sthenoteuthis oualaniensis* (15.5%) and prawn *Solenocera hextii* (10.3%). Being a large pelagic predator, it formed an important link in the food chain of the ocean system and also formed a good collector of the less exploited micronekton organisms of the deep scattering layer (DSL).

Keywords: Deep scattering layer (DSL) Diet, Food, Index of relative importance (IRL), Predator, Prey, *Thunnus albacares*, Yellowfin tuna

Introduction

Yellowfin tuna *Thunnus albacares,* considered as an apex predator, is a large pelagic fish residing in the oceanic columnar waters and actively hunting for its prey. Tunas are voracious feeders and actively prey on fishes, crustaceans and molluscs. The survival of these apex predators depends on their efficiency to locate prey-rich areas in the vicinity of their environment (Sund *et al*., 1981; Bertrand *et al*., 2002). The ecological role of apex predators in marine food webs is of interest because it is critical in the assessment of the impact of fishing on ecosystems (Kitchell *et al*., 1999; Essington *et al*., 2002; Schindler *et al*., 2002; Cox *et al*., 2002; Watters *et al*., 2003). The study of food and feeding in yellowfin tuna thus becomes very important not only in using the data to evolve improved exploitation strategy but also to understand the substantial structural changes brought about in the ecosystem when they are removed by fishing.

Studies have been carried out on the diet of *T. albacares* in the tropical Atlantic and Pacific oceans by several workers (Perrin *et al*., 1973; Matthews *et al.,* 1977; Pelczarski, 1990; Valere, 2005). Vaske *et al*. (2003) studied the food composition and feeding strategy of yellowfin tuna caught off Brazil. The diet composition and feeding habits of yellowfin tuna caught from the Indian Ocean cleary indicate the opportunistic behaviour of tunas which adapt their feeding to the available prey (Bashmakov *et al*., 1992; Roger, 1994; Potier *et al*., 2002). Somvanshi (2002) reviewed studies on the biological aspects of *T. albacares* from the Indian Ocean. Reports on the food and feeding of *T. albacares* from Indian waters were mostly based on specimens collected onboard exploratory research cruises and generally confined to the fishes from island systems of India (Silas *et al*., 1985; Sudarshan *et al*., 1991; Vijaykumaran *et al*., 1992; John and Sudarshan, 1993; Pillai *et al*., 1993; John, 1995, 1998; Govindraj *et al*., 2000; Premchand and Chogale, 2003, Sivaraj *et al*., 2003). General fishery and biology of *T. albacares* caught by traditional fishermen operating hooks and line along the Andhra Coast have been studied. (Rao and Rohit, 2007; Rohit and Rammohan, 2007; Vivekanandan *et al*., 2008; Rohit *et al*., 2008). However, detailed studies on the prey contents and feeding behaviour of *T. albacares* especially those landed by the commercial units are lacking. This paper discusses in detail the feeding and the different prey items constituting the food of *T. albacares* landed by commercial fishermen operating hooks and line in the oceanic waters along the east coast of India.

Materials and methods

Samples (165 numbers) were collected from the different yellowfin tuna landing centres along Andhra Pradesh coast during 2007-2009. The fork length (cm) and wet weight (kg) of the fishes were noted which were then cut open and the entire stomach was carefully removed for further detailed analysis. Stomach fullness was visually classified into five categories as full, three-fourth full, half full, one-fourth full and empty, based on the distension of the stomach due to the presence or absence of food. The average intensity of feeding was evaluated by point's method (Hynes, 1950; Bapal and Bal, 1958). Sex and stage of gonad maturity were also recorded for each fish. The collected stomachs were kept frozen at -20 ^{o}C until further analysis. During analysis, each stomach sample was thawed and drained. The total weight of the stomach content was taken and the contents were divided into broad prey classes sorted by large categories (fish, mollusc, crustacean, others) and the weight of each category was noted.

Different items constituting one category were sorted and counted. For each item, identifiable organs were used to determine the number of prey present in the stomach. Prey items if consumed just before capture could be easily identified up to species level. In case of partially digested fish, the number of mandibles, parasphenoids or the maximum number of either right or left otoliths was assumed to reflect the total number of prey. For partially digested cephalopods, the number of either upper or lower beak was taken into account. In the case of partially digested crustaceans, telsons, cephalo-thorax or claws were counted. Prey was identified up to genus level and further to species level whenever possible using keys and as per descriptions in Smith and Heemstra (1986); Fischer and Whitehead (1974) and also by comparison with the material available in the reference collection of the Central Marine Fisheries Research Institute.

Trophic and similarity indices of the different items in the diet of tuna were determined using the modified Costello diagram (Costello, 1990; Amundsen *et al*., 1996) as described by Potier *et al*. (2004). Here the abundance of prey taxon is replaced by a new parameter, the prey specific abundance. The prey specific abundance is given by the formula: $P_1 = (\Sigma S_A/\Sigma S_1 A) \times 100$ with ΣS_A = Total of prey A (expressed in number or weight) in the stomachs with prey A and $\Sigma S_1 A$ = Total of prey (expressed in number or weight) in the stomachs with prey A. Information about prey importance and feeding strategy of the predator is given by the distribution of the points along the diagonals and the axes of the diagram (Fig. 1)

The importance of each food item in the diet was determined by Index of relative importance (IRI) (Pinkas *et al*., 1971), modified to weight percentage:

$IRI_i = (\% N_i = \% W_i) \% FO_{i,}$

where $\% N_i$ = number of taxon i percentage, $\% W_i$ = weight of taxon i percentage

$\% FO_i$ = frequency of occurrence of taxon i percentage.

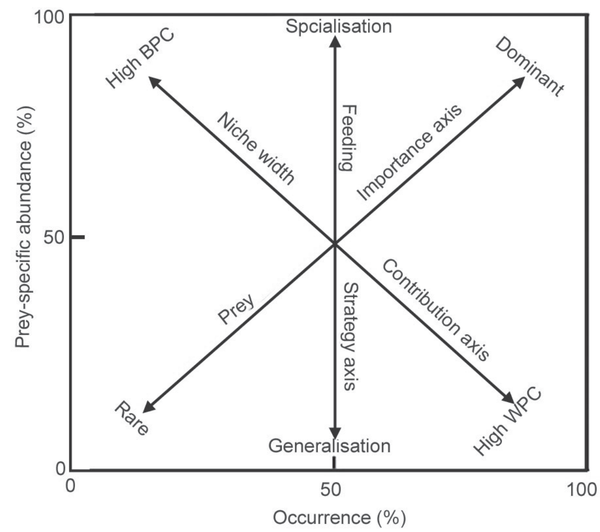

Fig. 1. The theoretical Costello diagram and its interpretation indicating feeding strategy. (BPC= between phenotype component; WPC = within phenotype component).

Results

The size distribution of yellowfin tuna whose stomachs were examined ranged from 67cm to 174 cm with mode at 130 cm and mean length at 135.3 cm. In all the 165 tuna stomachs analysed, 19 (11.6%) were empty. Analysis was based on 146 stomachs containing prey items. Visual observation of the distension of tuna stomach indicated that proportion of full, three-fourth full, half full and one-fourth full was 19.5%, 7.3%, 26.2%, and 35.4% respectively (Fig. 2). The food contents formed 0.1 to 1.4% of the wet body weight. The prey items were grouped into fishes, crustaceans and molluscs (Fig. 3) and in wet mass, fishes formed the bulk of the diet (47.1%).

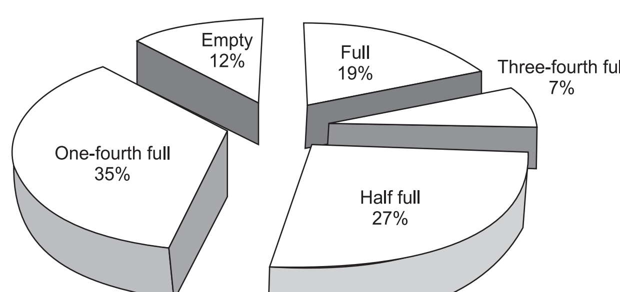

Fig. 2. Proportion of full, three-fourth full, half full and one-fourth full stomachs in *T. albacares*.

Prey species composition

The results of the analysis of the 146 yellowfin tuna stomachs are summarised in Table 1. A total of 1656 prey items belonging to 17 families were identified, which included 11 families of fish, 5 families of crustaceans and

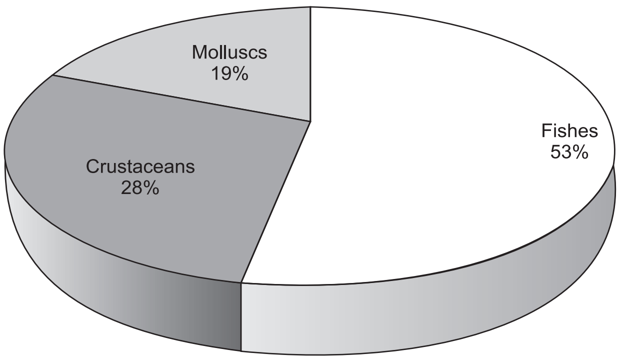

Fig. 3. Major prey groups constituting the diet of *T. albacares*.

a single family of cephalopods. Fishes were the most dominant prey item by mass (52.9%) followed by crustaceans (27.3%) and cephalopods (19.3%). The fully digested unrecognisable food content comprised the remaining 0.6%. On an average, 97 g of prey were found per stomach. Fish dominated the diet by occurrence (65.1 %), and crustaceans by number (47.2 %). The Costello diagram (Fig. 4) showed that tuna fed within a specific niche width. *Priacanthus hamrur* followed by the deep water squid *Sthenoteuthis oualaniensis* and the swimming crab *Charybdis smithii* were the most dominant prey species and occupied the upper location in the plot. These prey items also occupied a higher level on the feeding strategy axis. The deepsea shrimp *Solenocera hextii* had a medium prey importance in the food of yellowfin tuna. Brachyuran megalopa and squilla occupied a very low level on the prey importance axis indicating that they may have been consumed when they were found in association with other more popular larger prey items.

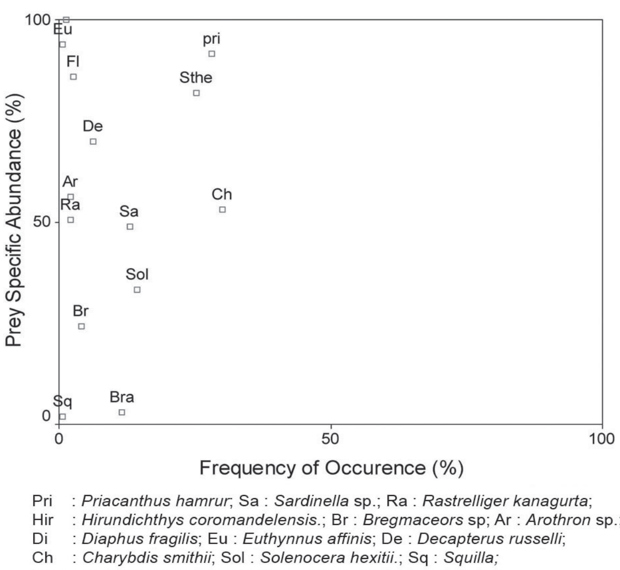

Fig. 4. The Costello diagram depicting the importance of different prey groups in the diet of *T. albacares*.

According to the IRI, the main food item of *T. albacares* was fishes (47.07%), of which the bull's eye *P. hamrur* was the most preyed species representing 28.1 % of the total occurrence of the food items with IRI of 40.5% (Table 1). The other significant prey fish by occurrence were *Sardinella* spp., *Decapterus russelli*, *Bregmaceros* sp. *Rastrelliger kanagurta*, *Hirundichthys coromandelensis*, *Arothron* sp. *Balistes* sp. and *Aluterus* sp. (Fig. 5). Occurrence of *Diaphus* sp., *Balistes* sp. and tuna (*Euthynnus affinis*) as food content was marginal. Numerically, crustaceans were the most abundant (47.2%) prey in the stomach. These were represented by the swimming crabs *C. smithii,* the deep water shrimp *S. hextii*, brachyuran megalopa, isopods and squilla. The IRI of total crustaceans was 35.7%. Though shrimps were more numerically abundant (25.8%), crabs were more prominent in the diet forming 20.4% of total prey wet weight with an IRI of 23.9. Deep water flying squid, the ommastrephid *S. oualaniensis* represented the cephalopods prey composition with an IRI of 15.5%.

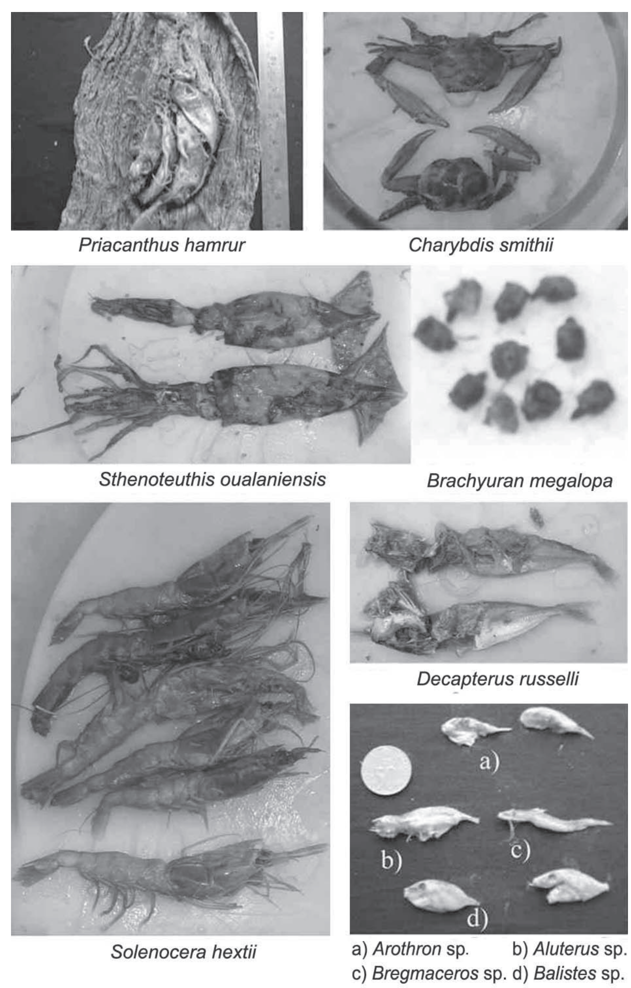

Fig. 5. Dominant prey species observed in the stomach contents of *T. albacares*.

Table 1. Results of stomach content analysis of yellowfin tuna, *Thunnus albacares*

Name of prey speceis	Prey number	Prey number (%)	Prey weight (g)	Prey weight (%)	Frequency of occurrence (%)	Index of Relative Importance (IRI) (%)	Prey specific abundance (%)
Priacanthus hamrur	432	26.1	5569.3	39.3	28.1	40.5	91.5
Sardinella spp.	27	1.6	407.6	2.9	13.0	1.3	48.9
Rastrelliger kanagurta	3	0.2	74	0.5	2.1	0.0	50.5
Hirundichthys coromandelensis	7	0.4	391.3	2.8	2.7	0.2	85.8
Bregmaceros sp.	21	1.3	50.5	0.4	4.1	0.1	24.2
Arothron sp.	5	0.3	9	0.1	2.1	0.0	56.3
Diaphus fragilis	30	1.8	121	0.9	1.4	0.1	100.0
Euthynnus affinis	1	0.1	290.4	2.0	0.7	0.0	93.8
Balistes sp.	3	0.2	4	0.0	1.4	0.0	57.1
Decapterus russelli	25	1.5	569.4	4.0	6.2	0.8	69.8
Aluterus sp.	1	0.1	0.9	0.0	0.7	0.0	18.4
Fish remains	0	0.0	2	0.0	2.7	0.0	3.3
Charybdis smithii	258	15.6	2885	20.4	30.1	23.9	53.0
Solenocera hextii	428	25.8	955.5	6.7	14.4	10.3	33.2
Squilla	1	0.1	1	0.0	0.7	0.0	1.8
Brachyuran megalopa	90	5.4	17.6	0.1	11.6	1.4	2.9
Isopod	5	0.3	3.1	0.0	0.7	0.0	23.7
Crustacean remains	0	0.0	0	0.0	1.4	0.0	0.0
Sthenoteuthis oualaniensis	142	8.6	2703.4	19.1	25.3	15.5	82.0
Squid beaks	177	10.7	25.2	0.2	24.0	5.7	0.9
Molluscan remains	0	0.0	0	0.0	0.7	0.0	0.0
Fully digested	0	0.0	87.8	0.6	2.1	0.0	0.0

Discussion

Observations on the food composition of *T. albacares* as revealed from the stomach contents analysis showed that teleost fish, crabs, squids and shrimps were the major component of food items. Squid beaks were found in stomachs of *T. albacares* and were useful in determining the food item diversity. Generally, beaks resist digestion by top predators for longer periods and continue to get accumulated in the stomach much after the muscle tissues have been digested. If these are included in number and weight estimations of IRI, it could lead to an overestimation of the importance of cephalopods in the diet (Vaske and Rincon, 1998). Hence as suggested by Bigg and Fawcett (1985), the presence of only beaks was not considered as component of stomach diet for the day. Kornilova (1981) observed that fishes were the most important prey by weight for yellowfin tuna in the equatorial zone of the Indian Ocean. Similarly, Alverson (1963) too reported that the major food items in the stomach contents of yellowfin tuna from the eastern tropical Pacific was fish (46.9% of total volume) and crustaceans (45.4%) with cephalopods forming only 7.6% of the volume. He also reported on a wide variety of food items and changes in species composition from area to area and concluded that yellowfin tuna are non-selective feeders, foraging on whatever pelagic or benthic organisms that are locally available. Roger (1994) and Ménard and Marchal (2003) also recorded such non-selective foraging and suggested that once the prey concentration of one target species is detected, tuna can feed on this concentration until satiation. Abundance of a single species (*P. hamrur*, *C. smithii* or *S. hextii*) in the stomachs (full and three-fourth full condition) of well fed yellowfin tuna during the present study is indicative of such a feeding behaviour. The diversity observed in the food consumed by yellowfin tuna in the present study is indicative of a non-selective feeding nature and the difference in the percentage composition of food items could be inferred as the availability of particular prey species rather than selection of preferred food items. Numerically, crustaceans dominated yellowfin tuna diet. In the tropical eastern Pacific Ocean (Alverson, 1963), the tropical eastern Atlantic Ocean (Dragovich and Potthoff, 1972) and western tropical Indian Ocean (Potier *et al.*, 2004) the diet of yellowfin tuna exhibited similar pattern.

Roger and Grandperrin (1976) and Roger (1977; 1994) reported that longline tunas prey actively on micronektonic epipelagic fishes (0-450 m depth) and it accounted for 60% of their diet by volume, the remaining 40% being mainly cephalopods. It has been reported that the diet of surface caught fishes as is the case with tunas caught by purseseines is very homogenous between species and among individuals of the same species and the diversity of prey in terms of family remains low as compared to fishes that feed in deeper areas such as tunas caught by hooks and line (Ménard and Marchal, 2003; Potier *et al*., 2002; 2004). Samples for the present study were collected from tunas caught by longlines that were operated in the open oceanic environment. Sudarshan and John (1994) reported much higher species diversity in the diet of yellowfin tuna caught by longline as compared to the present study. This may be related to the fact that their study covered coastal regions, whilst the present collection was made from the open oceanic system (Potier *et al*., 2006).

As is the case with any apex predator, *T. albacares* hunts actively for its prey. The food chain and transfer of energy can be depicted as: phytoplankton→ small zooplankton→ euphausiids→ micronektonic fishes→ *T. albacares* from long line. This food chain has a food source restricted only to the biomass which stays between 0-450 m during daytime and often supplemented by the diurnally migrating deep scattering layer (DSL) organisms. The role and catchability of the vertically migrating mesopelagic fauna which are responsible for the DSL, by surface predators is not well understood. The micronekton defined as "assemblage of actively swimming crustaceans, cephalopods and fishes ranging from 1-10 cm in greatest dimension" form an integral part of the DSL and plays a great role as prey to oceanic pelagics (Menon, 2004). Research conducted by Inter American Tropical Tuna Commission (IATTC) indicate that yellowfin tuna are generalist feeders and do not seek out specific prey species. They generally feed during daytime, feeding primarily on near-surface fishes, squids, and swimming crabs (Buck, 1997) with intense predatory activity during the dawn and sunset (Roger and Grandperrin, 1976). Menon (2004) and Karuppasamy and Menon (2005) have reported that along the east coast of India, micronektonic biomass was abundant in the depth realm below 300 m with swarming crabs (*C. smithii*), shrimps (*S. hextii*), cephalopods (*S. oualaniensis*) and myctophids being more abundant at a depth of 0-100 m. However, Roger and Grandperrin (1976) and Potier *et al*. (2004) have reported that the micronektonic fish component preyed upon by longline yellowfin tuna are almost epipelagic fishes and not the vertically migrating micronektonic fishes which are the main constituents of the DSL. The rare occurrence of myctophids, *Bregmaceros* sp. and absence of other fishes/crustaceans (which constitute the DSL) among the diet components in the samples analysed during the present study is agreeable with the above observations. The occurrence of small prey such as brachyuran megalopa in the stomach of yellowfin tuna may be related to their availability in the vicinity and food selectivity of the gill rakers as suggested by Magnuson and Heitz (1971). Dragovich (1969) too has made similar observations and stated that *T. albacares* fed mainly on large surface organisms, but took macroplankton (megalopae) when it was abundant locally. Romanov *et al*. (2009) reported on the formation of "swarms" of the swimming crabs *C. smithii* in the open Indian Ocean and its significance as an important prey for more than 30 species of epipelagic top predators including yellowfin tuna. This crab in turn feeds on mesopelagic species and forms a major species of the intermediate trophic levels and represents a crucial seasonal trophic link in the open ocean ecosystem. Such indirect routes of energy transfer by species of the intermediate trophic levels (swimming crabs, cephalopods) allows the use of DSL by longline tuna to some extent.

It is difficult to infer real diet from stomach content analysis as there is insufficient published experimental background on prey specific transit and digestion times in tuna (Jobling and Breiby, 1986; Pierce and Boyle, 1991; Santos *et al*., 2001; Pusineri *et al.,* 2005). Therefore more such studies have to be carried out to establish the role of niche specific food groups in the diet of tunas. Apex predators like the yellowfin tuna play a very important role in the tropical open oceans. They are abundant and ubiquitous in the epipelagic ecosystem and produce substantial structural changes in the ecosystem when removed by fishing (Cox *et al*., 2002; Watters *et al*., 2003) and could have repercussions on the food web structure through top down, trophic cascades (Kitchell *et al*., 1999). The present study on the diet of *T. albacares* add to the knowledge on its role in the food web and aid in evolving improved exploitation strategies especially for an ecosystem based approach for fishery management of yellowfin tuna fisheries along the east coast of India.

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