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Biological Aspects of Swordfish, *Xiphias gladius* Linnaeus, 1758, Caught During Tuna Longline Survey in the Indian Seas

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Abstract

Distribution, abundance and biology of swordfish, *Xiphias gladius*, of the Indian seas were investigated by analyzing the data gathered during tuna longline surveys conducted by the Fishery Survey of India (FSI). Study undertaken during the period from 2004 to 2010 revealed swordfish Catch Per Unit Effort of 0.02 numbers in 100 hooks from the Arabian Sea; 0.01 from Bay of Bengal and 0.02 form the Andaman and Nicobar waters. About 16% of the specimens caught were juveniles and the sex ratio of smaller fishes was in favour of males, whereas, larger specimens were mostly females. Length-weight relationship established indicated slightly positive allometric growth of the species and length based models revealed difference in growth between sexes. The growth parameters estimated for females were: asymptotic length ($L\infty$) = 311.11 cm, growth coefficient (K) = 0.17/yr and age at zero length (t_0) = –0.53 yr, whereas, the growth parameters estimated for males were: $L\infty$ = 243.79 cm, K = 0.22/yr and t_0 = –0.37 yr. Diet was dominated by finfishes and cephalopods, while crustaceans were recorded rarely. *Sthenoteuthis oualaniensis* was the dominant prey species, followed by *Paralepis* sp. Spawning area was identified in the Lakshadweep waters from where mature females with hydrated oocytes were caught during December to April. Size at 50% maturity for females was estimated at 164.03 cm, which is reached at about four years of age. Mean batch fecundity was 4.5 million, while the relative fecundity was 37.5 hydrated oocytes per gram of body weight and the diameters of mature oocytes were in the range of 0.9-1.6 mm. Our results provide preliminary information on the abundance, growth and biology of this species in the Indian seas which should be useful to fishery managers.

Keywords: Swordfish, longline bycatch, growth parameters, stomach contents, fecundity, Indian Ocean.

Introduction

Swordfish or broadbill, *Xiphias gladius*, the only living species of the family Xiphiidae, is a highly migratory apex predator distributed between latitudes 45°N to 45°S, ranging from tropical to temperate waters of the world oceans (Carey and Robinson, 1981; Palko *et al.*, 1981; Nakamura, 1985; Sagakawa and Bell, 1980). It is a large oceanic species of high commercial value, reaching a maximum length of 445 cm and weighing up to 540 kg. This epi and meso-pelagic species, usually found in surface waters warmer than 13°C, but can tolerate temperature 5 to 27°C, is able to migrate to a maximum depth of 1000 m (Nakamura, 1985).

Presently, majority of commercial swordfish are caught using pelagic longlines, with smaller catches from driftnets, harpoons and occasionally hand line, troll line, trap, purse seine and pole and line (Folsom *et al.*, 1997). In the Indian Ocean, this fish has been commercially exploited since 1952 and now the fishery in the high seas is managed by the Indian Ocean Tuna Commission (IOTC). Swordfish fishery from the Indian Ocean gained momentum during 1990s, with an increase in the overall catch from <10,000 tons before 1990s to 20835.19 tons in 2010, with a peak of 36795.57 tons in 2004. Fishing fleets of Distant Water Fishing Nations (DWFN), mainly from Taiwan Province of China and European Union (Spain, United Kingdom, France and Portugal) are leading in the exploitation of swordfish in the Indian Ocean. Swordfish fishery in the Indian Ocean was concentrated in the southwest Indian Ocean, however, in the recent years, it has extended eastward due to the increased piracy threats in the western Indian Ocean (IOTC–SC14, 2011).

India's contribution to swordfish fishery is meager 3.71% from the Indian Ocean catch and the reported catch of swordfish from India during 2010 was 773.75 t (Vijayakumaran and Varghese, 2011). Although there are reports of large scale swordfish exploitation from Indian seas, especially Bay of

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Bengal and northern Arabian Sea (Palko *et al.*, 1981), no serious efforts had been taken by India to develop a domestic fishery targeting swordfish. However, India adopts a precautionary approach and has been practicing total fishing ban in its Exclusive Economic Zone (EEZ) for a period of 45 days coinciding the monsoon season.

Biology of swordfish has been studied in detail from numerous locations (Yabe *et al.*, 1959; Kume and Joseph, 1969; Palko *et al.*, 1981; Toll and Hess, 1981; Stillwell and Kohler, 1985; Taylor and Murphy, 1992; Clarke *et al.*, 1995; De la Serna *et al.*, 1996; Hinton *et al.*, 1997; DeMartini *et al.*, 2000; Wang *et al.*, 2003; Poisson and Fauvel, 2009[a,b]). However, published information on the distribution, abundance and biology of this ecologically and commercially important species is lacking for the eastern Arabian Sea, western Bay of Bengal and Andaman and Nicobar waters. In this perspective, the present study was undertaken to contribute to our understanding of the abundance and biology of this species in oceanic waters around India.

Materials and Methods

Data on the nominal catch of swordfish caught during tuna longline survey conducted by four research vessels (*Matsya Vrushti*, *Yellow Fin*, *Matsya Drushti* and *Blue Marlin*) of Fishery Survey of India (FSI) during the period from January 2004 to December 2010 are used in this study. These four vessels were deployed for operation from Mumbai, Mormugao, Chennai and Port Blair to study the distribution, abundance and biology of oceanic tunas and allied resources in the Indian seas (Figure 1). While conventional Japanese multifilament longline with five hooks per basket was operated from the vessels *Yellow Fin* and *Blue Marlin*, the other two vessels operated monofilament longline gear with seven hooks per basket. Every month, these vessels are deployed for trips of 20 days duration, and about 15 longline operations are conducted in each trip, operating an average of 9,000 hooks. In a day's operation, the shooting of the line begins before sunrise and is completed in about 2 – 2.5 hours. Frozen Indian mackerel, nemipterids, sciaenids, round scads, sardines and occasionally squids were used as bait. Immersion time of six hours is allowed and the line is hauled in the afternoon, starting from the initially shot end.

A total of 213 swordfish were sampled during the study period. All the swordfish specimens caught were subjected for various morphometric measurements (±1.0 cm) using a measuring tape and weighed (±500 g). Total weight and Lower Jaw Fork Length (LJFL) were used for further analyses. Length-weight relationship and condition factor separately for males, females and all specimens were calculated following Le Cren (1951). Length frequency data were pooled by sex into 20 cm size classes, and these pooled data were used in ELEFAN (Electronic Length Frequency Analysis) routine of FiSAT (Fish Stock Assessment Tools, Ver. 1.2.2). Powell–Wetherall plots were used to estimate asymptotic length ($L\infty$) separately for males and females and the asymptotic length estimated were then used as fixed values in subsequent ELEFAN scans for growth coefficient (K). Age at zero length (t_0) was estimated using the empirical equation derived by Pauly (1979). Growth performance index

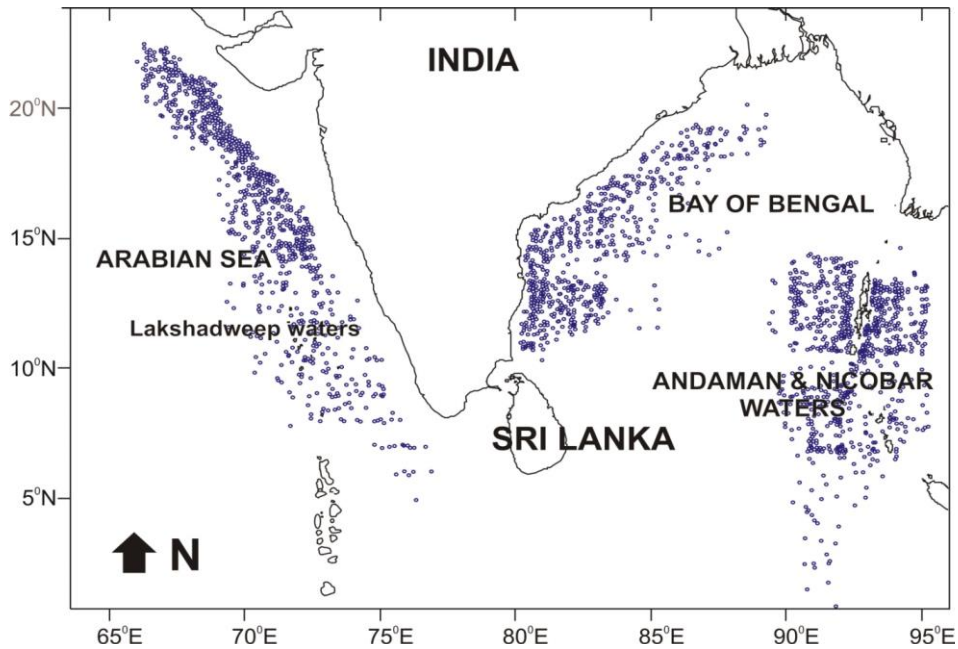

Figure 1. Map showing the longline stations surveyed during the study.

value (ϕ′) was calculated following Pauly and Munro (1984).

For biological studies, body cavities of sampled specimens were cut opened to visually examine the gonads and stomachs by the scientist onboard. The gonads and stomachs of samples collected from the eastern Arabian Sea were removed, placed in separate plastic bags with proper labeling and were frozen at –20°C onboard. Further examinations of the stomachs and ovaries were carried out at the shore laboratory. For diet studies, each stomach was first thawed, drained, weighed and dissected to retrieve its contents. Accumulated items were discarded and preys were identified to the lowest possible taxa. Repletion Index (RI) was calculated for studying intensity of feeding and expressed as gram prey items per kilogram body weight of predator. The diet was assessed using percentage occurrence by number (%N), percentage frequency of occurrence (%F), and percentage occurrence by weight (%W) of prey items. Quantitative importance of each prey was determined by calculating the Index of Relative Importance (IRI) (Pinkas *et al.*, 1971). Weight was used in calculation of IRI, and the IRI values were standardized to %IRI enabling diet comparison. Trophic niche breadth was assessed by calculating the Shannon-Weiner index (H') (Krebs, 1999) using biomass of different food items. Trophic level was calculated based on the proportion (by weight) of each prey component in the diet following Pauly and Palomares (2005).

For studying the maturity of female swordfish of Indian seas, a five stage maturity scale was adopted, following Qasim (1973) and Griggs *et al.* (2005). Maturity stages were assigned to the females by eye observation of the ovaries (for all specimens) and microscopic observation of oocytes (for specimens collected from eastern Arabian Sea). Gonadal index, calculated following Hinton *et al.* (1997) also was used to quantitatively ascertain the reproductive status of females. Fecundity and oocyte diameter studies were attempted on ripe ovaries of five female specimens collected from the eastern Arabian Sea. For these studies, ripe ovaries brought to shore laboratory were thawed, adhering excess connective tissue and moisture from the surface of ovaries were removed and then weighed with a precision of ±0.1 g. For oocyte diameter studies, three each subsample, of about 0.2 g were collected from each ovary lobes. Oocytes from each sub sample were detached from the ovarian tissue using needles and a fine brush and diameters of minimum 200 randomly selected hydrated oocytes were measured with an ocular micrometer at 10x magnification. The ovaries used for oocyte diameter studies, after fixing, were utilized for fecundity studies also. For fecundity studies, from each lobe of ovary, 12 sub samples (of about 0.05 g), six each from various locations of dorsal and ventral sides were collected and weighed with a precision of ±0.001 g. In total, 120 subsamples were collected from five ripe ovaries. These subsamples were carefully transferred to plastic vials with proper labeling and preserved in modified Gilson's fluid for separating the oocytes from the ovarian tissue (Lowerre-Barbieri and Barbieri, 1993). The vials were shaken periodically and after allowing a minimum fixation time of one month, the oocytes, liberated from ovarian tissue were washed, decanted and transferred to a counting chamber. Total number of hydrated oocytes from each subsample was counted under the light microscope at 10x magnification. Number of oocytes was then raised to the total weight of the ovary to estimate the batch fecundity, the number of oocytes released per spawning. Relative fecundity, the number of hydrated oocytes per gram body weight was estimated by dividing the batch fecundity by the weight of swordfish. Size at first maturity, the length at which 50% of all individuals are mature, was estimated by adopting the logistic model of King (1995). Proportions of mature females in 20 cm length class were calculated and a logistic curve was fitted to the proportion of sexually mature females by length. Parameters were estimated using a least square method applied to a non-linear fit.

For abundance data analysis, seas around India were segregated into three regions, the eastern Arabian Sea, the western Bay of Bengal, and Andaman and Nicobar waters. Data gathered from these areas during January 2004 to December 2010 were pooled by regions and latitudes and analyzed for studying the spatial distribution and abundance of swordfish. Nominal Catch Per Unit Effort (CPUE) is expressed in terms of Hooking rate (HR), the number of fish caught in 100 hooks operated.

Results

During the period 2004-2010, the seas around India were surveyed for oceanic tuna and allied resources by operating 1.2 million longline hooks. Of this, 0.43 million hooks were operated in the eastern Arabian Sea; 0.37 million in the western Bay of Bengal while 0.40 million were operated in the Andaman and Nicobar waters. From the eastern Arabian Sea (5-22°N of west coast of India), swordfish were recorded at a hooking rate of 0.02 numbers in 100 hooks (Table 1). Swordfish from the eastern Arabian Sea were caught between latitudes 8°-21°N. Latitude 10°N registered maximum CPUE (HR - 0.05) whereas the average weight of swordfish caught was maximum in the latitude 11°N (40 kg). In the western Bay of Bengal (east coast of India), swordfish were recorded from all the latitudes surveyed (8-19°N) except latitude 9°N. Hooking Rate of swordfish from this area ranged between 0.003 registered in the latitude 17°N to 0.046 numbers in 100 hooks registered from the latitude 10°N. In the Andaman and Nicobar waters, swordfish were caught at a hooking rate of 0.018 numbers in 100 hooks form the area between latitudes 6 and 16°N except latitude 15°N. Maximum hooking rate was observed in the

Table 1. Latitude–wise details of swordfish caught during the fishing trips of tuna longline vessels of FSI between 2004 and 2010

Latitude (˚N)	Hooking Rate (Number/100 hooks operated)			Average weight (kg)		
	EAS	WBoB	AandN	EAS	WBoB	AandN
6			0.017			2
7			0.035			11.6
8	0.027	0.027	0.027	2.667	60	7.667
9	0.011		0.041	1.5		19.75
10	0.053	0.046	0.026	10.611	2.833	26.462
11	0.034	0.007	0.009	40	4	15.714
12	0.051	0.007	0.01	17.5	3	13.714
13	0.069	0.015	0.01	19.231	17.786	19.5
14	0.063	0.022	0.034	5.674	2.7	47
15	0.041	0.008		5.969	12.5	
16	0.006	0.019	0.053	4	52.6	40
17	0.007	0.003		35	30	
18	0.007	0.004		2.333	70	
19	0.009	0.025		2.375	46	
20	0.008			4		
21	0.005			18		
22						
Average	0.022	0.012	0.018	11.135	17.856	18.375

latitude 16°N, followed by latitude 9°N. Average weight of swordfish caught from this area was 18.375 kg.

The swordfish samples collected during the study period were in the LJFL range of 53 to 301 (102.90±38.16) cm (Figure 2), weighing 1 to 340 (15.90±31.18) kg. About 16% of the specimens caught were juveniles and the global sex ratio of specimens collected was 1:0.47 (M : F). While sex ratio of small fish indicated predominance of males, females were dominating in larger specimens (>160 cm) and all the specimens above 190 cm LJFL were females in our study (Figure 3). The female specimens were in the length range of 66-301 (129.28 ±48.94) cm, with an average weight of 34.31 (±52.11) kg, whereas, the LJFL of males were in the range of 60-185 (96.55±29.80) cm, and their weight ranged between 1.5 to 80 (10.92±14.59) kg. Significant differences in the average sizes were observed between sexes (ANOVA, $F_{1,202} = 34.75$; $p<0.001$).

Length-weight relationships of the males, females and pooled samples showed positive allometric growth for this species in the study area (Figure 4). Slight difference in the 'b' values of the formula indicates that the females were heavier than the males of same length. The mean condition factors were 0.82 (all specimens); 0.89 (females) and 0.85 (males) which indicated that swordfish samples collected in our study were in good condition. Growth parameters of Von Bertalanffy growth equation for female specimens were estimated as $L\infty = 311.11$ cm, $K = 0.17$, $t_0 = -0.53$ and $\phi' = 4.22$, whereas, those for male specimens were $L\infty = 243.79$ cm, $K = 0.22$, $t_0 = -0.37$ and $\phi' = 4.12$. The analysis of growth curves, prepared by fitting growth parameters to the swordfish length-at-age data by sex using the Von Bertalanffy equation revealed that female swordfish grow larger and faster than males, with the growth curves diverging after about 2 years (Figure 5).

Only 24 specimens of *X. gladius*, in the LJFL range of 66-211 (110±54.78) cm, weighing 2-120 (37.29±24.68) kg could be attended for diet analysis during the period of investigation. None of the stomachs analysed were empty. The average food weight was 99.79 (±89.16) g while the average Repletion Index calculated was 16.78 (±14.44) g per kg body weight. The diet was dominated by finfishes, contributing 83.70% (by number), 79.57% (by weight), and 91.677% (by frequency of occurrence), and the percentage Index of Relative Importance was 87.76. Cephalopods contributed 15.22 (%N), 20.40 (%W) and 58.33 (%F) to the diet, while the %IRI calculated for this group of prey items was 12.18. Crustaceans, represented by *Acanthosquilla* sp. only, contributed 1.09 (%N), 0.04 (%W) and 8.33 (%F) and 0.06 (%IRI) respectively to the diet (Table 2). *Sthenoteuthis oualaniensis* was the dominant prey species, followed by *Paralepis* sp., *Myctophum* sp., *Carcharhinus falciformis*, *Alepisaurus ferox* and *Decapterus macrosoma* (Figure 6). Other cephalopods and finfishes recorded among the food contents had %IRI <5. Diet breadth index (Shannon-Weiner index, H') estimated was 1.85 and the trophic level calculated was 4.34.

Studies on the reproduction of the samples revealed that, mature females having Gonadal Index (GI) greater than 1.375 are appearing in the catch in Lakshadweep and Andaman and Nicobar waters during December to April. Analysis of maturity stages at an interval of three months revealed that proportion of ripening (stage III) and ripe (stage IV) specimens is maximum during the quarters October-December and January-March (Figure 7).

Size at first maturity was estimated by

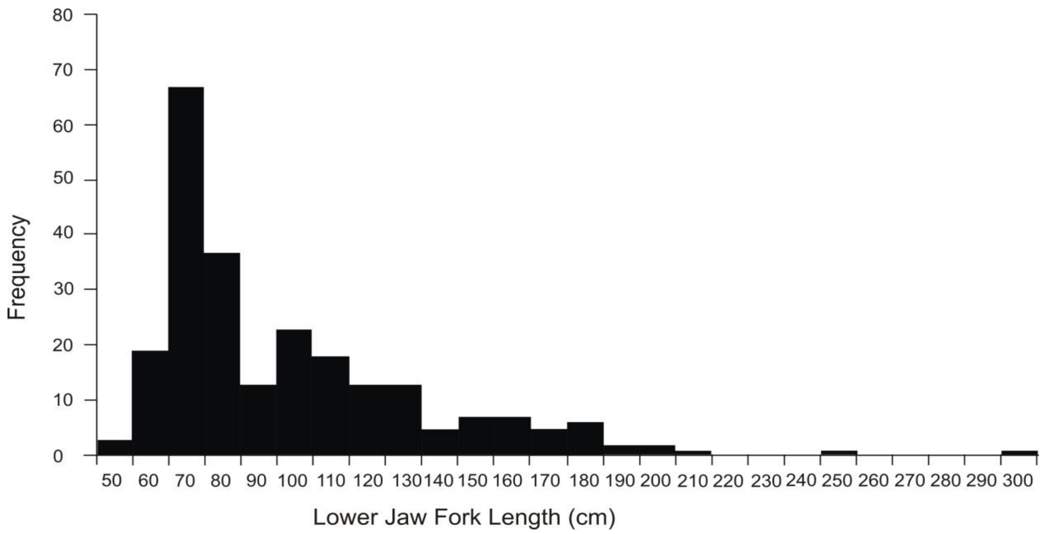

Figure 2. Length frequency distribution of *X. gladius* of the Indian seas.

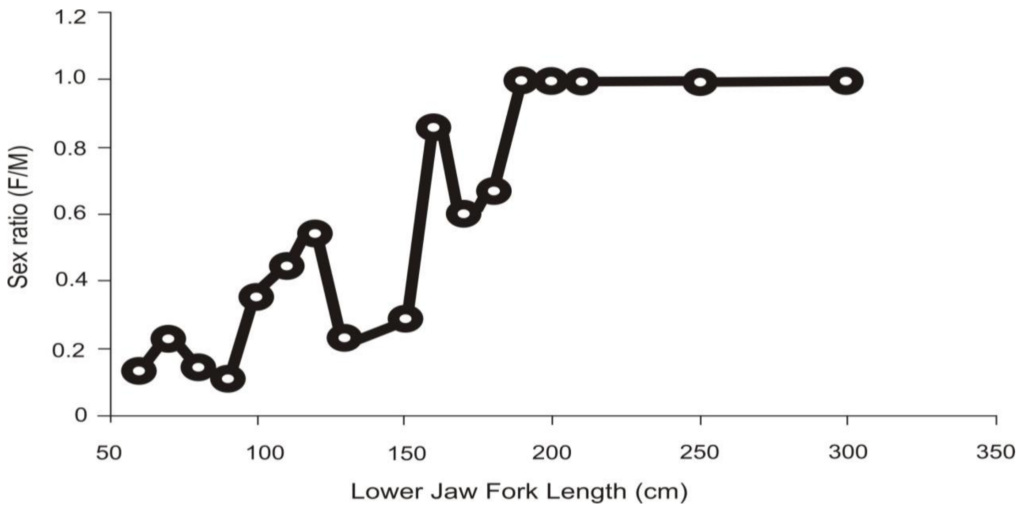

Figure 3. Relationship between sex ratio and LJFL of *X. gladius* of the Indian seas.

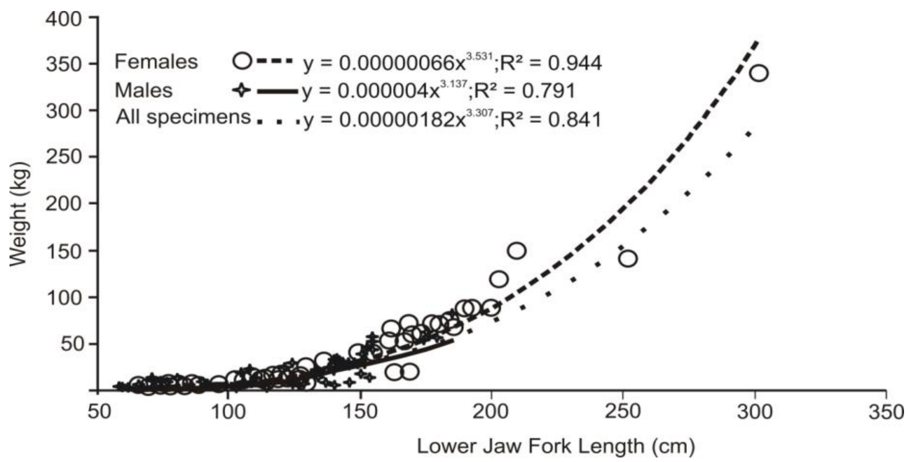

Figure 4. Length-weight relationship of *X. gladius* of the Indian seas.

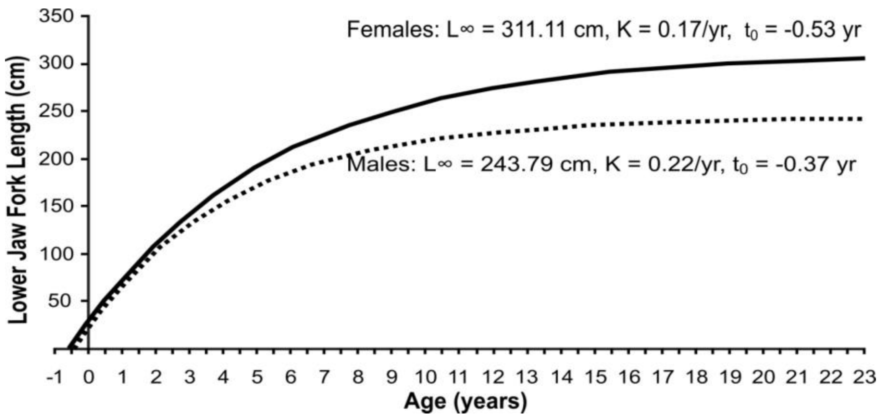

Figure 5. Von Bertalanffy growth curves for male (dashed line) and female (continuous line) *X. gladius* in the Indian seas.

Table 2. Prey species consumed, and their percentage contribution to the diet of *X. gladius*

Prey family	Prey species/group	%N	%W	%F	%IRI
Histioteuthidae	*Histioteuthis hoylei*	1.087	0.925	8.333	0.552
Histioteuthidae	*Histioteuthis* sp	2.174	0.578	16.667	1.509
Ommastrephidae	*Sthenoteuthis oualaniensis*	8.696	15.995	41.667	33.855
Thysanoteuthidae	*Thysanoteuthis rhombus*	1.087	2.436	8.333	0.966
	Unidentified squids	2.174	0.463	8.333	0.723
	Total Cephalopods	15.217	20.397	58.333	12.183
Nannosquillidae	*Acanthosquilla* sp	1.087	0.039	8.333	0.309
	Total Crustaceans	1.087	0.039	8.333	0.055
Alepisauridae	*Alepisaurus ferox*	1.087	19.425	8.333	5.625
Berycidae	*Beryx splendens*	4.348	1.21	16.667	3.048
Bramidae	*Brama* sp	1.087	1.549	8.333	0.723
Bramidae	*Brama brama*	2.174	2.521	16.667	2.575
Carangidae	*Decapterus macrosoma*	2.174	7.847	16.667	5.496
Carcharhinidae	*Carcharhinus falciformis*	1.087	21.969	8.333	6.323
Diretmidae	*Diretmus* sp	2.174	1.179	8.333	0.92
Exocoetidae	*Exocoetus monocirrhus*	1.087	4.109	8.333	1.425
Gempylidae	*Gempylus serpens*	3.261	1.287	16.667	2.495
Gempylidae	*Rexea prometheoides*	6.522	3.415	8.333	2.725
Myctophidae	*Lampanyctodes* sp	3.261	0.578	8.333	1.053
Myctophidae	*Myctophum* sp	41.304	1.84	8.333	11.832
Omosudidae	*Omosudis* sp	2.174	2.081	16.667	2.334
Paralepididae	*Paralepis* sp	10.87	6.159	25	14.01
Scombridae	*Euthynnus affinis*	1.087	4.394	8.333	1.503
	Total Finfishes	83.696	79.565	91.667	87.762

examining the maturity stages of 73 female specimens, of which, 20 were mature. The minimum size of mature female was 109 cm and the logistic curve fitted to the proportion of sexually mature females by LJFL (Figure 8) was given by the equation

Proportion of mature females = 1/[1+(exp(5.870361-(0.03579*LJFL)))], r^2 = 0.982.

The estimated length at first maturity was 164.03 cm.

Average batch fecundity of females hooked from the Lakshadweep waters was estimated to 4.5 million (coefficient of variation – 12.9). Fecundity was observed to have strong correlation with LJFL (R^2 = 0.82). Average relative fecundity was 37.5 hydrated oocytes per gram of body weight. Diameter of matured oocytes was in the range of 0.9-1.6 mm, of which 83% were in the range of 1.1-1.3 mm (Figure 9).

Discussion

Abundance indices of swordfish in our study are considerably lower than the CPUE recorded from many areas of Indian Ocean (IOTC–WPB10, 2012). Targeted survey for swordfish using longline with light sticks may result in better catch rates in the study area. Our observations on the length and weight of swordfish in the Indian seas revealed that, the specimens collected were in the LJFL range of 53-301 cm, weighing 1-340 kg. This indicates that, most of

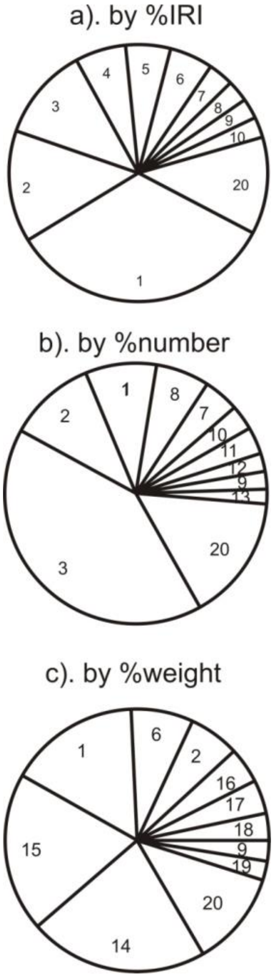

Figure 6 a-c. Prey species dominating the diet of *X. gladius* of eastern Arabian Sea (1- *Sthenoteuthis oualaniensis*; 2. *Paralepis* sp; 3. *Myctophum* sp; 4. *Carcharhinus falciformis*; 5. *Alepisaurus ferox*; 6. *Decapterus macrosoma*; 7. *Beryx splendens*; 8. *Rexea prometheoides*; 9. *Brama brama*; 10. *Gempylus serpens*; 11. *Lampanyctodes* sp 12. *Decapterus macrosoma*; 13. *Omosudis* sp 14. *Carcharhinus falciformis*; 15. *Alepisaurus ferox*; 16. *Euthynnus affinis*; 17. *Exocoetus monocirrhus* 18. *Rexea prometheoides*; 19. *Thysanoteuthis rhombus*; 20. other prey).

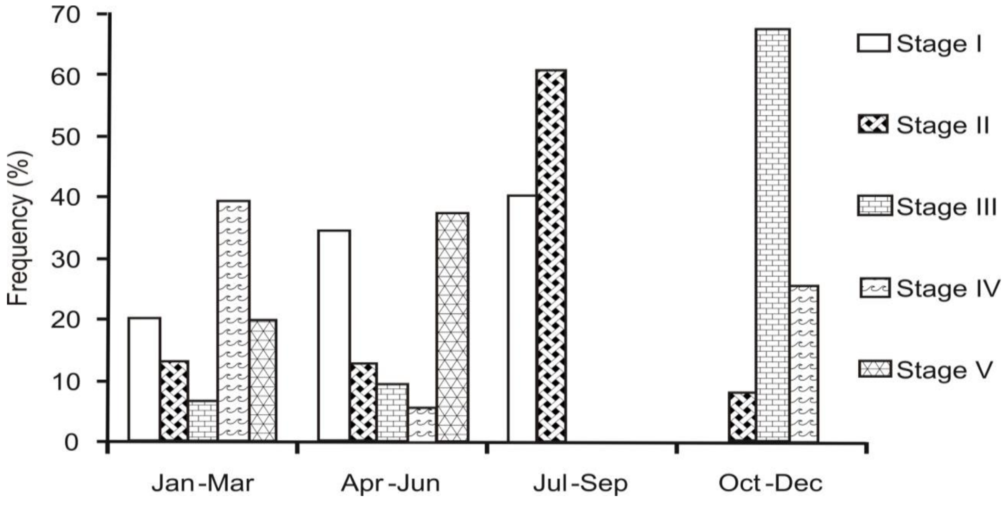

Figure 7. Quarterly percentage frequency of maturity stages (female) of *X. gladius* of eastern Arabian Sea.

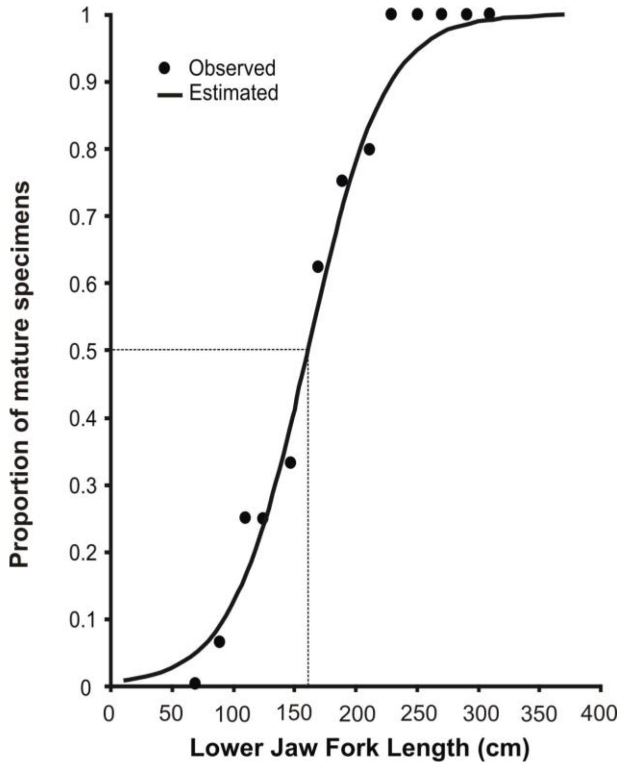

Figure 8. Logistic curve fitted to the proportion of mature females in relation to LJFL of *X. gladius* of Indian seas. Dashed line indicates the length at first maturity.

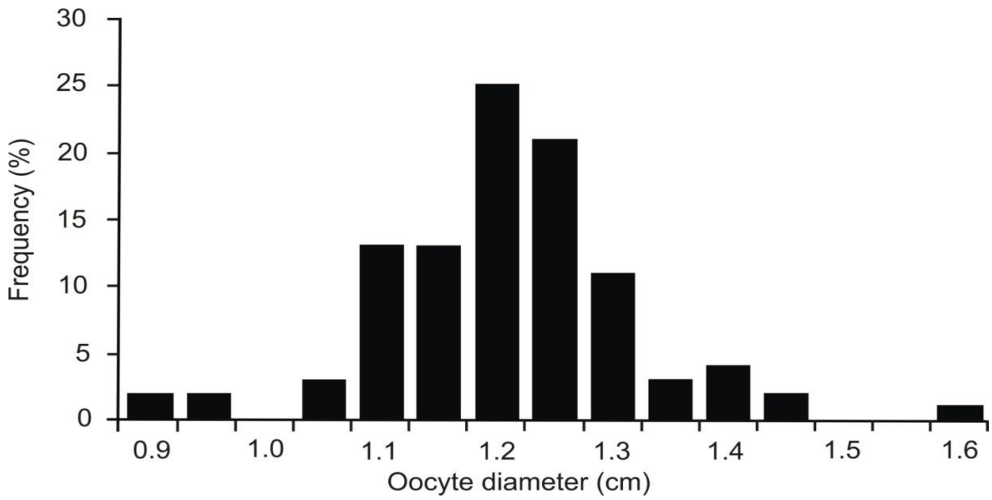

Figure 9. Oocyte diameter frequency distribution in ripe ovaries of *X. gladius* of eastern Arabian Sea

the swordfish recorded as bycatch in the tuna longline fishery of Indian seas were juveniles, since the size at sexual maturity of this species are in the range of 112-129 for males and 142-189 cm for females (Yabe *et al.*, 1959; Kume and Joseph, 1969; Taylor and Murphy, 1992; De la Serna *et al.*, 1996; DeMartini *et al.*, 2000; Wang *et al.*, 2003; Poisson and Fauvel, 2009[a]). Kume and Joseph (1969) observed that juvenile swordfish are common in tropical and sub-tropical waters, migrating to higher latitudes as they mature.

The sex ratio of specimens collected in our study was 0.47:1 (F:M), whereas, most of the earlier studies reported the sex ratios of this species in the range of 1.06:1 to 2.94:1 (F:M) (Wang *et al.*, 2003; Weber and Goldberg, 1986). In our study, while sex ratio of smaller fishes was in favour of males, majority of the larger fishes above 160 cm were females. Since about 74% of the swordfish caught during the study were in the LJFL range of <160 cm, the sex ratio observed is not unreasonable. Generally, juvenile swordfish display a 1:1 sex ratio but in large swordfish (>200 cm) 90 to 100% are biased in favour of females i.e. 1 male: 9 females, since males have lower growth rate and shorter life span (Taylor and Murphy, 1992; Ward and Elscot, 2000).

Studies conducted in other locations indicated that, the swordfish can grow to enormous sizes, exhibiting phenomenal growth in the earlier years of their life (Ehrhardt, 1992). They have been estimated to attain 74 cm within six months (Megalofonou *et al.*, 1995) and 90 cm LJFL by the end of their first year (Sun *et al.*, 2002), thereafter growth rates declining (Ehrhardt, 1992). Growth rates of swordfish of Indian seas were lower than these earlier reports since in our estimation, female swordfish of Indian seas was observed to attain 50 cm in six months and 71 cm in one year. Kume and Joseph (1969) observed that males and females grow at different rates and after two or three years of life, female swordfish grow faster than males, attaining maximum size at about 15 years, while males reach their maximum size at 9 years. Growth parameters estimated in our study also revealed significant differences in growth of males and females indicating that females grow larger and faster than males. As revealed in most of the earlier studies, male swordfish of Indian seas have higher growth coefficient and lower asymptotic length than females. Growth parameters ($L\infty$ and K) estimated in our study was considerably higher than the estimations by Wang *et al.* (2010) for swordfish collected from northern Indian Ocean (Table 3). However, it was intermediate compared to the estimations from other regions (Montiel, 1996; Demartini *et al.*, 2007; Young and Drake, 2004; Griggs *et al.*, 2005). Growth parameters estimated in our study using length based models were not verified with more reliable method like counting of growth bands of anal fin ray. However, the ϕ' value in our study is similar to the values reported for this species earlier (Yabe *et al.*, 1959; Barbieri *et al.*, 1998; Uchiyama *et al.*, 1998; Tsimenides and Tserpes, 1989). Since the value of ϕ' will be constant for a species (Pauly and Munro 1984), it is used as an index of accuracy and reliability of the growth parameters estimated for a species using different methods (Bellido *et al.*, 2000).

The values of parameters in length-weight relationship (constant, a and exponent, b) calculated in the present study fall within the range of length-weight relationship parameters reported in the FishBase (Froese and Pauly, 2011) for this species. The length-weight relationship established in our study revealed slight difference between sexes indicating that the females were heavier than the males of same length.

Adult swordfish are aggressive predators, feeding throughout the water column as they follow the migration of the deep-scattering sound layer (Ward and Elscot, 2000). In oceanic waters, swordfish migrate to great depths during the day, possibly as deep as 1000 m (Ward and Elscot, 2000), rising to the surface waters to feed at night, when they are targeted by longliners (Carey and Robinson, 1981). Our study revealed that, the swordfish is an aggressive, voracious and opportunistic predator feeding mainly on pelagic teleosts as well as cephalopods. Finfishes were the primary dietary component of the swordfish in our study. Many of the earlier studies on the swordfish diet also had established the finfishes as the principal component of the swordfish diet (Tibbo *et al.*, 1961; Marsac and Potier 2001). However, Yabe *et al.* (1959), Ovchinnikov (1971), Toll and Hess (1981) and Stillwell and Kohler (1985) have reported the cephalopods as the main component of the diet of *X. gladius*. Our study revealed that many epi- and meso pelagic organisms are represented in the diet of *X. gladius*, suggesting that the swordfish in Arabian Sea feeds near surface as well as in deep waters. The state of digestion of the prey suggests that both nocturnal and diurnal feeding were important. However, Clarke *et al.* (1995) suggested that swordfish in Azorean

Table 3. Results of selected studies on the growth of *X. gladius*

$L\infty$ (cm)	K (1/y)	t_o (years)	Sex	Country/locality	Reference
310	0.124	-1.169	Pooled	Japan	Yabe *et al.*, 1959
282	0.293	0.1085	F	Chile	Montiel., 1996
250	0.322	-0.7545	M	Chile	Montiel., 1996
321	0.14	-1.3	Pooled	Central Pacific	Uchiyama *et al.*, 1998
300.66	0.04	-0.75	F	Taiwan	Sun *et al.*, 2002
213.05	0.086	-0.626	M	Taiwan	Sun *et al.*, 2002
296	0.08	-3.7	F	Australia	Young & Drake, 2004
224.2	0.13	-3	M	Australia	Young & Drake, 2004
434.7	0.053	-3.46	F	New Zealand	Griggs *et al.*, 2005
394.4	0.044	5.86	M	New Zealand	Griggs *et al.*, 2005
221	0.07	−0.15	M	Hawaii	DeMartini, 2007
227.2	0.524	−2.41	F	Hawaii	DeMartini, 2007
234.002	0.169	-2.181	M	Indian Ocean	Wang *et al.*, 2010
274.855	0.138	-1.998	F	Indian Ocean	Wang *et al.*, 2010
311.11	0.17	-0.53	F	Indian seas	Present study
243.79	0.22	-0.37	M	Indian seas	Present study

waters would forage at the surface by night but be inactive at depth by day. Diet breadth index (Shannon-Weiner index, H') indicated moderately wide spectrum of prey species of *X. gladius* in the Arabian Sea. High value (4.34) for trophic level calculated in our study established the status of *X. gladius* as an apex predator.

In the Reunion waters, swordfish with the greatest gonadal index are caught durung October to March (Poisson and Taquet, 2000). Yabe *et al.* (1959) reported the catch of females with ripe ovaries from equatorial Indian Ocean in April. Our results show that, mature females having ripe ovaries with hydrated oocytes are appearing in the catch in Lakshadweep waters during December to April. Jones (1958) and Jones and Kumaran (1964) reported collection of swordfish larvae from Laccadive (Lakshadweep) waters during the months February and April. This indicates that the swordfishes spawn in the Lakshadweep waters during December – April. Spawning in the North Atlantic occurs throughout the year with a peak from April to September in the Caribbean, the Gulf of Mexico and off Florida (Taylor and Murphy, 1992). In the central north Pacific spawning occurs in spring and summer (March through to July), during June to September in the Mediterranean (De Metrio and Megalofonou, 1987; Orsi Relini *et al.*, 1999; Tserpes *et al.*, 2008 Alıçlı *et al.*, 2012), in spring (September to December) in the western south Pacific and all year round in equatorial Pacific waters (Nakamura, 1985). Earlier reports suggest that swordfish spawn in warm, relatively close to coastal waters in the western parts of ocean basins (Taylor and Murphy, 1992; Arocha and Lee, 1995). Based on histological examination of ovaries, gonadal index and maximum oocyte size, Poisson and Fauvel (2009[a]) identified swordfish spawning site off Reunion Island, which is reported to be the only spawning site for swordfish in the Indian Ocean (Poisson and Fauvel, 2009[a]). Spawning site identified in Lakshadweep waters in our study will be an addition to this already reported swordfish spawning site of Indian Ocean.

Size at first maturity of female swordfish estimated in this study was 164.03 cm (LJFL). Our study reveals that the females of swordfish in the Indian seas become sexually mature at about 4th year of their life. De la Serna *et al.* (1996) estimated that 50% of female swordfish in the Mediterranean Sea mature at 142 cm. The size at first maturity of female swordfish in southwestern Indian Ocean was 170.4 cm (Poisson and Fauvel 2009[a]). Wang *et al.* (2003) estimated the size at first maturity of female swordfish from Taiwanese waters as 168.2 cm. Taylor and Murphy (1992) estimated size at first maturity of 182 cm for female swordfish of the Straits of Florida. Our estimation was comparable to the length at first maturity (144 cm, Eye Fork Length ~162.23 cm, LJFL) calculated by DeMartini *et al.* (2000) for female swordfish caught by the Hawaii-based pelagic longline fishery.

Average batch fecundity and relative fecundity of females hooked from the Lakshadweep waters was comparable with those reported from Reunion (Poisson and Fauvel, 2009[b]). Estimates of the number of eggs produced in earlier studies ranged from more than 1 million eggs for a 68 kg swordfish (Palko *et al.*, 1981) to 29 million for a 272 kg swordfish (Wilson, 1984). In our study, a strong correlation between fecundity and LJFL of females were established. Poisson and Fauvel (2009[b]) also made similar observation. Diameters of mature oocytes observed in our study were in the range of 0.9-1.6 mm. Poisson and Fauvel (2009[a]) reported that the hydrated oocyte diameters of swordfish sampled from Reunion Island was in the range of 1200 and 1550 μm.

Recent survey by the FSI vessels reveal availability of swordfish in Indian high seas and adjoining areas, especially western Bay of Bengal and adjoining Indian Ocean areas in the east coast and Lakshadweep waters in the west coast of India indicating scope for developing swordfish fishery in these areas. However, the development and expansion of swordfish fishery must be done with caution, since several swordfish fisheries in other parts of the world has shown initial, rapid expansion, and then declined and even collapse in many areas, prompting concern over the species' ability to support intensive harvesting (Ward and Elscot, 2000). The Scientific Committee of the Indian Ocean Tuna Commission (IOTC), during its annual Meeting in 2011 reviewed the stock status of *X. gladius* in the Indian Ocean and concluded that the present level of swordfish exploitation from the Indian Ocean is below Maximum Sustainable Yield (MSY) of 30,000 t. However, the assessments made by IOTC Working Party on Billfish indicated that the catch rate data from the Indian Ocean suggest overfishing of swordfish in localised areas, especially in the southwest Indian Ocean (IOTC–SC14, 2011). Genetic studies revealed that *X. gladius* stock of Bay of Bengal is genetically different from the stock of south-west Indian Ocean (Lu *et al.*, 2006). Bycacth in the targeted swordfish fishery especially that of sea turtles is another area of concern, which is to be addressed at the earliest. Further, the swordfish caught in longline in the Indian waters are prone to heavy depredation, mainly by the pelagic sharks (Varghese *et al.*, 2008).

In conclusion, our study revealed abundance of swordfish in Indian high seas. Further, this study provides some information on the growth and biology of *X. gladius* in the Indian seas essential for the management of these valuable resources. Our results may help fishermen in deriving fishing strategies for selection of fishing ground and appropriate baits. Intensive survey, targeting swordfish are to be conducted for gathering further information regarding the distribution, abundance and biology of this species.

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