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Studies on length frequency distribution, length - weight relationship and some aspects of reproductive biology of *Katsuwonus pelamis* (Linnaeus, 1758) off north Andhra Pradesh, central eastern coast of India

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Present paper deals with biological parameters such as length groups represented in the catches, Length-Weight Relationship studies and some aspects of reproductive biology such as maturity stages, ova diameter frequency studies, Gonado Somatic Index, size at first maturity and fecundity of skipjack tuna of size range 25.7 cm to 69.8 cm FL caught by troll line, gillnet, hook and line and long line during the period January 2007 to December 2010. Fecundity ranges between 1,24,247 to 9,08,013 in the specimens of size range 430 to 648 mm FL.

[**Key words**: skipjack tuna, LWR, maturity stages, GSI, size at first maturity, fecundity]

Introduction

Skipjack tuna (SKJ) (*Katsuwonus pelamis*, Scombridae) forms one of the most important commercially exploited oceanic tuna species in world waters. In Indian Ocean SKJ constituted about 38% of total tuna catch followed by yellowfin 26%, kawakawa 10%, big eye 9%, albacore 3% and bluefin 1% [1.] In the upper Bay of Bengal waters adjoining north Andhra Pradesh about (16º57'N; 82 º 11'E and 18 º 18'N; 83 º 54'E) tuna fishery has not received the attention it deserves till last decade. Only from mid 2002 fishermen have been venturing to go into deeper waters off this region to capture skipjack and yellowfin tunas from oceanic schools. Until then there are no authoritative reports of the commercial catches of SKJ from this region [2,3]. The total tuna catches in this region have been showing increasing trend and they are in great demand in top world markets due to their excellent meat quality[4]. Average annual tuna production during the period 2004 to 2007 ranged from 700 to 1000 tonnes from this region. Andhra Pradesh is one of the major contributors forming 18.3% of total landings of SKJ tuna from Indian waters [5]. Motorization of country crafts has resulted in increased mobility to offshore tuna fishing grounds which has contributed significantly to the increased tuna landings in this region. As tunas are being increasingly exploited in north Andhra region, information on length groups represented in the catches, Length Weight Relationship (LWR) studies and various aspects of reproductive biology are extremely important for proper management of this fishery.

Several authors carried out length frequency studies of SKJ from different regions of world waters [6-12] and in Indian waters [13,14]. Earlier investigations on various aspects of reproductive biology of SKJ have been carried out in Indo- Pacific region[13, 15-22]. Detailed studies on reproductive biology of male SKJ was carried out in western and central Pacific Ocean [23]. In Indian waters, studies on fishery, spawning, recruitment and several aspects of biology of SKJ were studied by some authors [5,14,24-31].

From the literature it is evident that the studies on length groups, LWR and reproductive biology of SKJ from waters of mainland of India are very meager. This is the first study to report these parameters in SKJ taken by traditional catches from waters of mainland of India. SKJ constituted the largest tuna fishery in the Indian

Ocean and are currently managed as a single stock [32]. Phylogenetic reconstruction of mt DNA and microsatellite marker studies revealed two coexisting divergent clades in north western Indian Ocean. It's stock structure is more complex than had originally been thought, i.e. that SKJ populations within ocean basins are not necessarily homogeneous. However results of latter studies showed that recoveries are well spread in the Indian Ocean and seem to indicate a good mixing of the tagged population with the wild population, this confirms the one stock hypothesis in the Indian Ocean [33]. Under such circumstances the biology of the stocks also must be studied carefully and for this thorough regional study is necessary to understand the behaviour, ecology, biology, spatial and seasonal distribution, migration of fish for the better management of fisheries. Present study was undertaken to understand some complex issues pertaining to reproduction, particularly spawning potential (fecundity), spawning period, maturity of gonads in relation to size of the fish, ova diameter measurements, gonado somatic indices in addition to length frequency and LWR studies of SKJ.

Materials and Methods

Specimens of SKJ were obtained from traditional fish landing centers (Lawson's Bay, Bheemunipatnam, Pudimadaka) and fisheries harbour of Visakhapatnam, where tunas caught by surface trolling from 40 m to 110 m depth regions are brought for sale. Samples were also collected from Kakinada and Srikakulam along east coast of India. For length frequency and Length - Weight Relationship (LWR) studies a total of 1134 specimens of SKJ (233 males, 354 females and 547 juveniles) of length range 278 to 698 mm FL and weight 330 to 5420 g were collected during the period January 2007 to December 2010. Determination of the relationship between length and weight was based on the combined data regardless of time of capture, sex and stage of maturity for the species. Relationship between the length and weight of a fish is usually expressed by the equation, $W = aL^b$ Where W - body weigth (g); L - total length (mm); *a* - coefficient related to body form and b- exponent. The parameters *a* and *b* of LWR were estimated by the least-square method from logarithmically transformed data, and the association degree between length-weight variable was calculated (r^2). For estimating LWR and parameters a and b standard methodology followed [34].

Methods employed for investigating some aspects of reproduction are briefly described below. The maturity stages of gonads were classified based on morphological features of the ovary/testes as well as on microscopic examinations. During the present study, a total of 497 specimens (286 females and 211 males) of length range 34.7 to 66.5 cm FL were examined for studying various aspects of reproductive biology. The methods adopted for studying several aspects of reproduction in general namely maturity stages of gonads, Gonadosomatic Index, size at first maturity and fecundity follows [35-38]. A scale of five stages where first and second stages includes two sub stages (primitive and advanced) has been adopted for determining maturity stages of SKJ. Differentiation of various stages of maturity and terminology for maturity stages also follows standard procedures [39, 41]. GSI was calculated by the following formula: GSI = (gonad weight / body weight) x 100. Mean GSI values were calculated by pooling the month wise data. Fecundity to fork length (FL), body weight (W) and gonad weight (O) showed relations in the form: $F = a L^b$ where L = fork length, W = fish weight/ovary weight, a and b constants.

Results and Discussion

Length frequency distribution and Length-Weight Relationship (LWR)

Month wise pooled length frequency distribution given in Fig. 1. A total of 1134 fish of which 233 males, 354 females and 547 juveniles were analysed for this study. Males ranged in length from 35 to 69 cm FL and females ranged in length from 38 to 66 cm FL Juveniles of size range 25 to 35 cm FL were represented in the catches only in May. Length groups 250-350 mm FL represented in hook and line, 300 – 500 mm FL in troll line and more than 500 mm FL in long line catches.

The length weight relationship for males, females, juveniles and pooled data as below and the equivalent relation in $W = a L^b$ form given in Table 1. Males: Log W = -5.6336 + 3.166Log L;
Females: Log W = -5.3756 + 3.12 Log L
Juveniles: Log W =- 6.1448 + 3.1555 Log L
Pooled : Log W = - 5.2825 + 3.1869 Log L .
The calculated value of regression coefficient (b) for SKJ is 3.1869 for pooled data and the same for males, females and juveniles also given in Table 1. As the estimated value of b slightly more than 3 it may be inferred that this species shows positive allometric growth.

Table 1: Length range and Length-Weight relationship of skipjack tuna represented in the catches of north Andhra Pradesh

Skipjack	n	L, mean±S.D. (Lmin-Lmax)	W, mean±S.D. (Wmin-Wmax)	Log a	B	*W-L* equation	Determination Coefficient (r) original data	Determination Coefficient (r) log transformed data	Growth Type
Male	233	44.6±7.286 (44.6-69.8)	3690±1423.74 (720-5420)	-5.6336	3.166	$W=0.0001660L^{3.1666}$	0.89	0.89	Allometric (+)
Female	354	50.82±3.936 (42.5-56.5)	2424.68±989.24 (720-3880)	-5.3756	3.12	$W=0.00001846L^{3.222}$	0.87	0.85	Allometric (+)
Juvenile	547	41.74±3.323 (25.7-46.0)	1612.79±708.97 (330-4550)	-6.1448	3.555	$W=0.00002216L^{3.555}$	0.89	0.92	Allometric (+)
Pooled	1134	50.78±7.532 (25.7-69.8)	2402.83±1211.83 (330-5420)	-5.2825	3.1869	$W=0.00001834L^{3.186}$	0.87	0.91	Allometric (+)

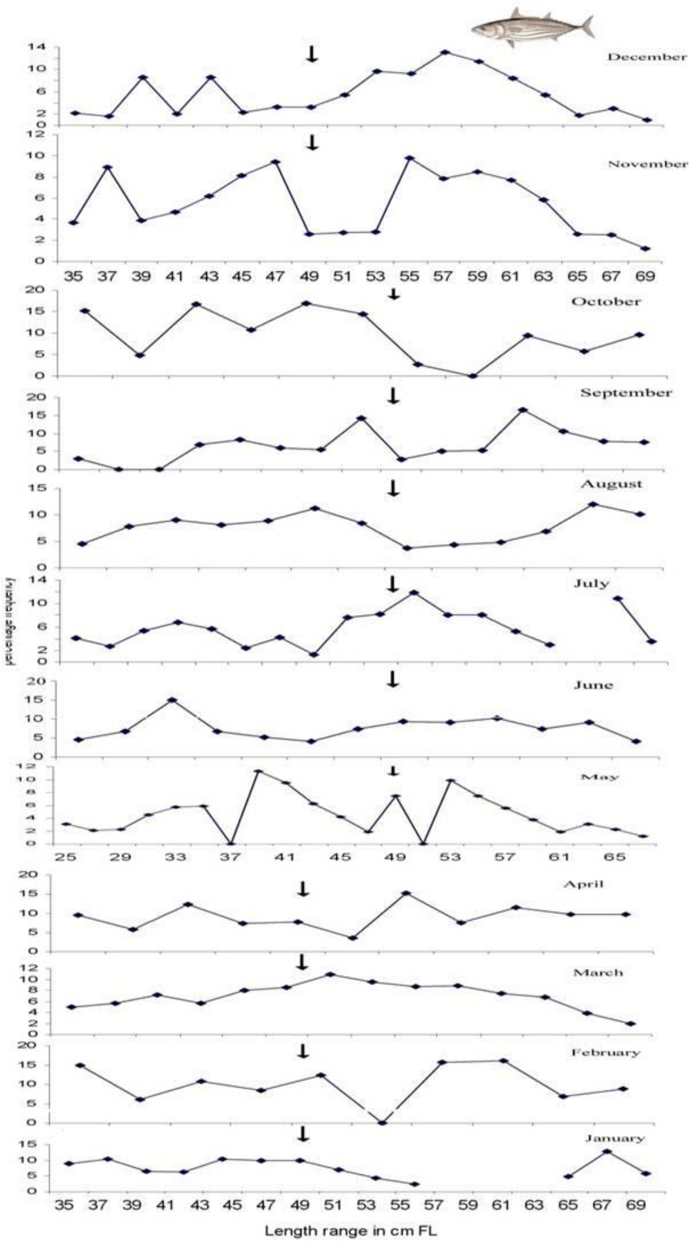

Fig. 1. Monthly length frequency distribution of *Katsuwonus pelamis* (↓ represents size at first maturity)

Generally, under the condition of isometric growth, the weight of the fish is considered as an exponential function to length and their relationship could be expressed by the cube-law, i.e., $W = a\ l^3$. The exponent value 3 is being applied only to an ideal fish under favorable conditions of growth. The value (3.1869) of regression coefficient (exponent) obtained in the present study for SKJ, is significantly very near to the hypothetical value ($P<0.01$); hence, cube-law could be applicable. Previous studies reveal that the regression coefficient exhibits inter and intra specific variations. Following Bayesian approach in SKJ of Indian Ocean, regression coefficient was estimated as 3.1530 [11], from Minicoy waters regression coefficient estimated as 3.3930 [14]. Exploited size of SKJ ranged from 120 to 820 mm FL and that the length distribution from different regions – east and west coasts and from Lakshadweep showed marked differences [5]. The difference may be due to the change in distribution pattern of fishes in different areas, gears employed and other environmental parameters. LWR estimated as $W=0.0109L^{3.147}$.The results in the present study are in agreement with that of Minicoy waters and all length groups from juveniles to adults ranging from 257 to 698 mm FL are represented in the catches unlike those from south China Sea [41] where juveniles of length range 305 to 345 mm FL are said to be missing.

Maturation of gonads, gonado somatic index, size at first maturity and fecundity estimates of Katsuwonus pelamis

A. Ovarian morphological studies: Based on the characteristics of several developmental groups of ova present in the ovaries of SKJ five stages with two sub stages in first and second stage. Ova diameter frequency polygon of different maturity stages of SKJ are given in Fig. 2.

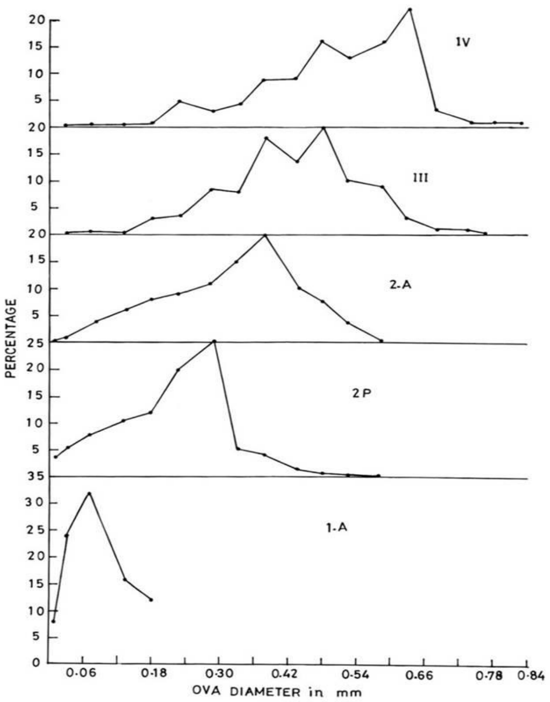

Fig. 2. Ova diameter frequency polygon of skipjack tuna off north Andhra Pradesh

Stage 1 Immature: ovaries are slender and ribbon like; not possible to determine the sex

a) Primitive: ova not visible to the naked eye.
In the present study regenerating ovaries were observed, the condition of the ovary is macroscopically similar to Immature - Primitive stage.

b) Advanced: sex could be determined by gross examination; a large vesicular nucleus occupies major part of the ovum; yolk deposition starts in this stage

Stage 2 Developing: ovaries enlarged, light pinkish

a) Primitive: several small nuclei present around the periphery of nucleus; thick deposition of yolk is seen in this stage.

b) Advanced: ovaries occupy almost half the length of the body cavity; as the ova advance towards maturity they become opaque and yellowish in colour due to the presence of yolk granules (Fig. 5a)

Stage 3 Spawning Capable: ovaries occupy 2/3rds of the body cavity and appear reddish due to increased blood supply; mature ova spherical and easily dislodged from follicles (Fig. 5b).

Stage 4 Spawning: ovary greatly enlarged and fully turgid occupying almost the entire body cavity; mature ova large, spherical and easily separable; the ova are round and translucent with a large oil globule.

Stage 5 Regressing: during the present study specimens with ovaries in Regressing (Spent) stage were not encountered in the catches of this region.

B. Testicular morphological studies:

In SKJ, the following stages were identified based on the morphological features and microscopic examination of small sections taken from different regions of the testes.

Stage 1 Immature: very slender, elongated; each cell possesses a large nucleus with eccentric nucleus

Stage 2 Developing: enlarged testes; size of lobules increases; the spermatogonia and spermatocytes start developing in this stage revealing spermatogenic activity (Fig. 5c)

Stage 3 Spawning Capable: spermatozoa can be seen upon microscopic examination; testis turgid occupying ¾th of body cavity; lobular wall becomes thin and volume increases (Fig. 5d)

Stage 4 Spawning: testis occupies entire length of body cavity and under close examination some empty lobules also appear.

Stage 5 Regressing: specimens with testis in spent condition were not encountered in the catches of this region

Several authors from various regions reported that SKJ is a multiple spawner. From Minicoy waters it was noted that immature, maturing (=Developing stage) and mature (=spawning capable) groups of ova are clearly separated from each other and as the ripe group of ova is spawned out its place is soon taken by the maturing group of ova [14, 27]. Therefore when mature ova are spawned out maturing ova will grow and may be ready for spawning soon, thus having more than one spawning in an year. The present observations are in conformity with the above findings as multiple modes were observed in SKJ of this region also. Moreover there are no significant differences in the distributions of ova diameter between right and left ovaries for the same fish. During the entire study period, specimens with ovaries in recently spawned and post spawning stages were not encountered in the catches. This may probably be either due to the reason that SKJ being a multiple spawner matured ova released are continuously replaced by maturing group of are females move into deeper waters for spawning which generally are not fishing grounds. In males and females five maturity stages were identified based on the morphological features and microscopic examination of small sections taken from different regions of testes and ovaries. Photograph showing different oocyte maturity stages based on microscopic examination given in Fig. 6. In the present study, specimens in maturity stages I to IV were encountered in the catches. However specimens in stage V corresponding to regressing condition were not encountered in the catches.

C. Gonado somatic index (GSI): Monthly trends in GSI values obtained from pooled data of male and female SKJ were represented in Fig. 3. The peak period of occurrence of mature fish from March to May, again in August and from November to December suggests that this species spawns almost throughout the year with peak months of spawning from March to April.

Various studies carried out on spawning period of SKJ from Pacific, Atlantic and Indian Oceans which suggested that SKJ spawns throughout the year although there may be identifiable peak periods. According to them with the increase in distance from the equator, the season becomes progressively shorter and spawning occurs during the summer months. Based on larval collections from Laccadive Archipelago it was stated that spawning of SKJ takes place over an extended period from January to April and then from June to early September based on larval collections[24]. Spawning of SKJ takes place over an extended period in Minicoy waters with the peaks in January and June [27]. In Minicoy waters, occurrence of mature fish in almost all months except from July to August and occurrence of young fishes of about 300 mm FL during January to May and September to December clearly indicates that SKJ spawns throughout the year [14]. SKJ spawns round the year with peak from December to March and minor during June to August [5]. Observations in the present study are in coincidence with observations from Minicoy waters.

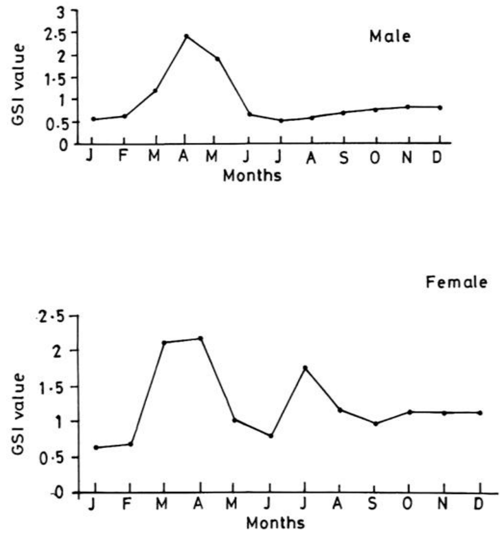

Fig. 3. Gonado-somatic index of male and female skipjack tuna off north Andhra Pradesh

D. Size at first maturity: The size at first maturity has been estimated from a plot of percentage of mature fish in the sample against fork length. From the maturity curve (Fig. 4) it was estimated that size at first maturity in female SKJ is 490 mm FL and in male 478 mm FL.

Previous studies on size at first maturity from Pacific, Atlantic and Indian Oceans including Minicoy from Indian waters revealed that size at first maturity in SKJ ranges from 400 to 450 mm FL. From Tuticorin waters it was reported that the size at first maturity in SKJ was 430 mm in males and 465 mm in females[43], from south west coast, Minicoy and Lakshadweep size at first maturity estimated as 41 cm [5]. However in the present study size at first maturity observed to be slightly higher than previous studies. A review on reproduction of Mediterranean fishes was carried out and it was noted that the differences in hydrography, topography and species composition and fisheries exploitation affect certain aspects of fish biology including onset and duration of spawning. Intense fishing pressure affects the maturation of fish stocks with those suffering higher fishing mortality rates maturing earlier[44]. These may be the reasons for variation in size at first maturity of this region also when compared to that from Tuticorin and Minicoy waters. As exploitation of these oceanic species started since 2002, this is still developing fishery, size at first maturity may be higher than reported earlier.

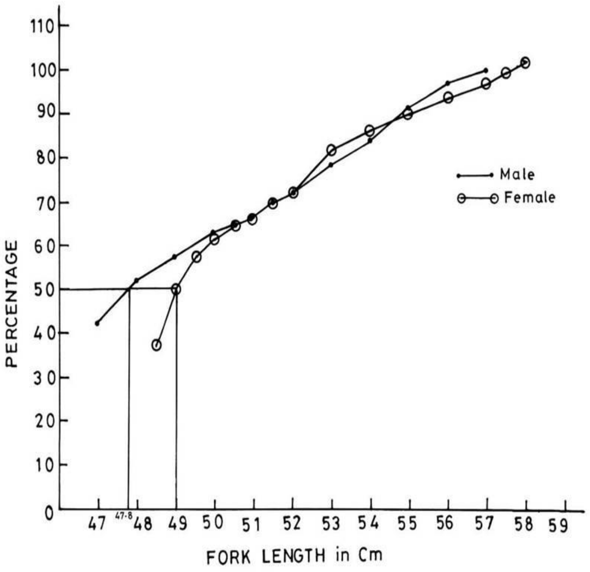

Fig. 4. Size at first maturity of male and female skipjack tuna off north Andhra Pradesh

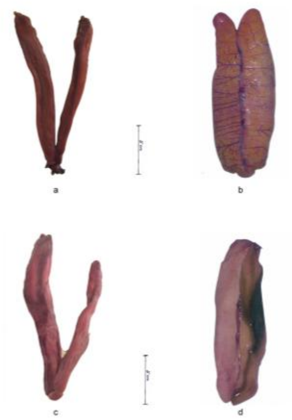

Fig. 5: Female and male gonads of skipjack tuna
a - Satge 2 (Developing-advanced) ovary b - Stage 3 (mature) ovary
c - Stage 2 (Developing-advanced) testis d - Stage 3 (mature) testis

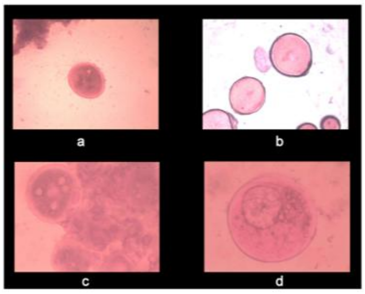

Fig. 6: Photograph showing different maturity stages of oocytes of skipjack tuna observed under microscope
a - Stage 2 Developing-primitive b - Stage 2 Developing-adavance
c - Stage 3 Spawning capable d - Stage 4 Spawning

E. Fecundity: Fecundity studies in SKJ were made on 21 specimens of length range 498 mm to 648 mm FL. Number of ova ranged from 124,247 to 1,378,230. Highest fecundity observed in fish measuring 665 mm FL with gonad weight of 115 g.

The relation between fecundity (F) and fork length (L) given in Fig.7.a is:

$F = 0.007L^{5.3094}$; correlation coefficient r = 0.8614

The relation between fecundity (F) and body weight (W) given in Fig 7.b is :

$F = 21.26W^{2.4137}$; correlation coefficient r = 0.8509

The relation between fecundity (F) and ovary weight (O) given in Fig.7.c is:

$F = 2.0164O^{1.3511}$; correlation coefficient r = 0.8698

In the present study it was inferred from the above graphs that fecundity increases with increase in fork length, fish weight and ovary weight.

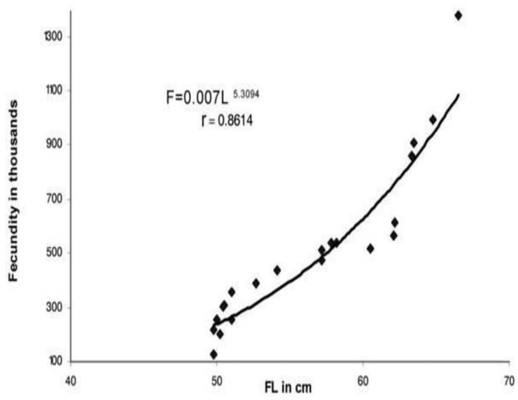

Fig. 7a. Relation between fecundity and fork length in skipjack tuna

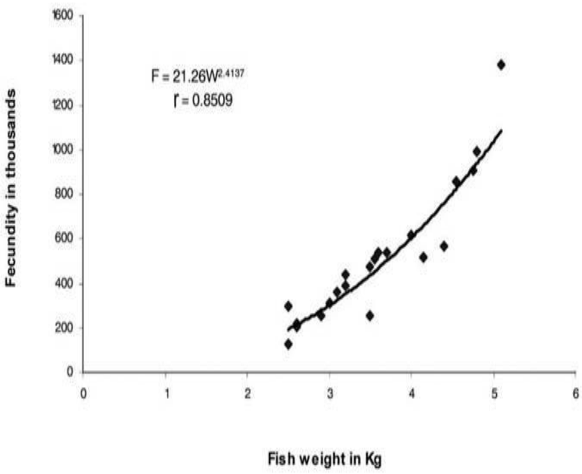

Fig.7b. Relation between fecundity and body weight in skipjack tuna

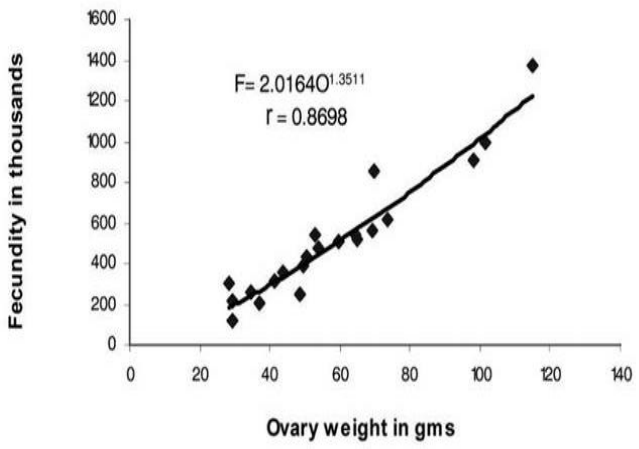

Fig. 7c. Relation between fecundity and gonad weight in skipjack tuna

Studies on fecundity from different regions in Pacific, Atlantic and Indian Oceans showed that fecundity ranged from 100,000 to 1.25 million. In Indian waters, fecundity ranges from 0.8 to 1.9 million ova in specimens of length range 410 mm to 703 mm[27] in Minicoy waters. Fecundity ranged from 2,11,410-29,52,253[8] in Srilankan waters. Fecundity estimated as 3,00,718 per kg body weight[5]. Fecundity estimated in the present study is coinciding with that estimated from Ryuku Islands and Hawaiian waters.

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