

**POPULATION DYNAMICS OF *Sepioteuthis lessoniana* (CEPHALOPODA
LOLIGINIDAE) FROM THE JAFFNA LAGOON**

By

GNANAMUTHU ANTON CHARLES, B.Sc (Hons.)

**THESIS SUBMITTED TO THE UNIVERSITY OF JAFFNA THROUGH THE
FACULTY OF GRADUATE STUDIES FOR THE AWARD OF THE DEGREE OF
MASTER OF PHILOSOPHY IN ZOOLOGY**

**DEPARTMENT OF ZOOLOGY
FACULTY OF SCIENCE
UNIVERSITY OF JAFFNA
THIRUNELVELY, JAFFNA
SRI LANKA**

2010

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M .Phil

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SRI LANKA

2010



UNIVERSITY OF JAFNA, SRI LANKA

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CANDIDATE'S DECLARATION

I hereby declare that the entire work embodied in this thesis has been carried out by me. The extent of this information derived from the existing literature has been documented and fully acknowledged at the appropriate places, the work is original and has not been submitted in part or full for any Diploma or Degree in this or any other University.

[Handwritten Signature]

14.08.2010

Signature of the candidate

Date



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Certificate

This is to certify that the thesis entitled "Population dynamics of *Sepioteuthis lessoniana* (Cephalopoda: Loliginidae) from the Jaffna lagoon" submitted to the University of Jaffna in fulfilment of the requirements for the award of the Degree of Master of Philosophy in Zoology is a record of original research work done by the candidate Mr. Gnanamuthu Anton Charles under my supervision.

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List of publications arose from the project

Charles, G. A. and Kuganathan. S. (2011). Population dynamics of squid *Sepioteuthis lessoniana* (Lesson, 1830) from the Northern coast of Sri Lanka. *Journal of Fisheries and Aquatic Science*, 6(1): 74-84. ISSN 1816-4927; DOI: 10.3923/jfas.2011.74-84.

Charles, G. A. and Kuganathan. S. (2008). Preliminary studies on length - weight parameters of *Sepioteuthis lessoniana* (Cephalopoda:Teuthida) from the Jaffna lagoon, Sri Lanka. **Proceedings of Jaffna Science Association.** Fifteenth Annual Session (07-09 May 08), Vol 15(1): 20 (Abstract). (ISSN 1800-1289).

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Gnanamuthu Anton Charles

(Gnanamuthu Anton Charles)

Abstract

The present investigation was carried out from June 2007 to May 2009 in order to understand the population dynamics covering aspects such as length weight relationship, length at first maturity, total annual fecundity, spawning frequency, peak season of breeding, synchronous or asynchronous spawning, growth parameters, mortality parameters and exploitation rate of *Sepioteuthis lessoniana* from the Jaffna lagoon, Sri Lanka. The 'b' values 2.2205, 2.1137 and 2.396 obtained for male, female and indeterminate respectively indicate that the fish doesn't follow the cube law. Histological analysis of gonads showed male and female were categorized into immature, maturing, fully maturing and matured. High occurrence of spawning stage in squids observed in August 2007, November 2007, April 2008 and October 2008 suggests that the peak spawning period is in the said months even though it spawns throughout the year. Presence of all stages of macroscopic eggs in the same ovaries confirms that it spawns more than once and said to be asynchronous. Fecundity varied from 20 to 852 and a significant correlation was obtained with mantle length. Size at maturity curves indicated male reached maturity at 16 cm mantle length while female reached maturity at 17.0 cm mantle length. The optimized values for K and L_{∞} obtained by the ELEFAN I was 0.83 year^{-1} and 31.10 cm. The estimated t_0 value was -0.191. The length-converted catch curve gave a Z value of 3.75 year^{-1} . The natural mortality coefficient (M) obtained through Pauly's empirical model was 1.64 year^{-1} . The computed instantaneous fishing mortality coefficient (F) is 2.11. The predicted exploitation rate is 0.501. The computed exploitation rate of 0.56 is significantly above the predicted E_{\max} express that the stock is slightly overexploited. Thus, the fishing pressure on the stock has to be reduced. More capture should be prohibited by a reasonable decrease in the effort or by modifying the mesh size of the net for *S. lessoniana*. The suggested recommendation would also be either banning the catch of cephalopods during the peak spawning period or imposing restriction on the size of squids during certain months based on the findings in this study.

1. General introduction

1.1. World cephalopod fishery

Cephalopods are considerably important as a food resource as well as in scientific investigations (Ngoile 1987). Issues of squid growth and population dynamics are increasing in prominence and importance. Increased fishing pressure is hanging the trophic structure in many marine environments around the world (Pauly *et al.* 1998). As a result of this phenomenon, a greater emphasis is being placed on new fisheries and on cephalopod stocks in many parts of the world (Rodhouse 1997). The over-fishing of longer lived finfish has resulted in a shift to squid fishing (O'Dor *et al.* 1997). There is a significant worldwide commercial interest in cephalopods for human consumption.

Squids, cuttlefish and octopuses are important species yielding 1.4 million tonnes to the total world production in 2005 and 2006 (Anonymous 2008) (Table 1). The share of cephalopods in world trade in fish was 4.2 percent in 2006. Thailand is the largest exporter of squid and cuttlefish, followed by Spain, China and Argentina. Morocco is the principal octopus exporter. Spain, Italy and Japan are the largest importers of these species. Total annual catches of cephalopods are fairly stable at about 3.6–3.8 million tonnes. Squid prices plummeted in 2007 as traders in Argentina sold at prices much below those of the previous season. On the other hand, octopus production and trade declined in 2007 as a result of limited catches by the Mauritanian fleet. Demand for octopus in Japan improved, and lower imports resulted in an important price hike of US\$ 2.00 per kg in the course of 2007. It's obvious that separate statistics for squids is not available, so far.

Table 1. World fish capture production by groups of species (in tonnes)								
Type	Group	1999	2000	2001	2002	2003	2004	2005
Finfish	Sturgeons, paddlefishes	2 851	2 603	2 313	1 908	1 628	1 450	1 333
Finfish	Salmons, trouts, smelts	913 327	805 154	891 042	809 873	966 097	880 261	1 031 141
Migratory fish	Shads	788 770	860 346	665 284	589 692	524 800	569 160	605 548
Finfish	Miscellaneous migratory fishes	75 921	83 328	75 650	79 538	79 465	68 077	65 817
Demersal fish	Flounders, halibuts, soles	956 926	1 009 253	948 427	915 177	917 326	862 162	900 012
Finfish	Cods, hakes, haddocks	9 431 141	8 695 910	9 304 922	8 474 044	9 385 328	9 398 780	8 964 873
Finfish	Miscellaneous coastal fishes	6 119 412	6 112 189	6 310 904	6 315 752	6 789 732	7 002 006	6 640 784
Demersal fish	Miscellaneous demersal fishes	2 955 849	3 033 384	3 008 283	3 062 222	3 059 707	3 163 050	2 986 081
Pelagic fish	Herrings, sardines, anchovies	22 671 427	24 919 239	20 640 734	22 289 332	18 840 389	23 047 541	22 404 769
Pelagic fish	Tunas, bonitos, billfishes	5 943 593	5 816 647	5 782 841	6 138 999	6 197 087	6 160 868	6 243 122
Pelagic fish	Miscellaneous pelagic fishes	10 712 994	10 654 041	12 332 170	11 772 320	11 525 390	11 181 871	11 179 641
Sharks etc	Sharks, rays, chimaeras	858 007	870 455	845 854	845 820	880 785	819 012	771 105
Other fish	Marine fishes not identified	10 721 534	10 736 398	10 599 122	10 513 550	9 714 669	9 747 625	9 565 512
Crustacean	Freshwater crustaceans	494 111	563 641	626 407	816 405	366 117	353 446	391 526
Crustacean	Crabs, sea spiders	1 061 042	1 101 880	1 093 256	1 122 414	1 334 001	1 332 932	1 323 616
Crustacean	Lobsters, spiny rock lobsters	229 179	227 950	222 138	225 646	225 793	233 825	231 233
Crustacean	King crabs, squat lobsters	77 644	67 932	46 382	41 853	43 993	36 457	52 064
Crustacean	Shrimps, prawns	3 028 171	3 089 755	2 957 730	2 969 311	3 545 309	3 542 438	3 416 533
Crustacean	Krill, planktonic crustaceans	101 957	114 425	104 216	125 989	117 981	118 164	127 034
Crustacean	Miscellaneous marine crustaceans	1 293 164	1 372 858	1 427 312	1 359 158	449 711	486 249	470 568
Mollusc	Freshwater molluscs	552 452	595 286	628 205	631 444	435 668	427 843	415 105
Mollusc	Abalones, winkles, conchs	121 414	120 190	131 429	112 798	121 844	133 240	120 400
Mollusc	Oysters	158 196	249 675	198 132	185 122	196 424	150 088	166 145
Mollusc	Mussels	207 470	261 635	240 718	224 741	186 062	188 359	143 182
Mollusc	Scallops, pectens	609 418	665 569	702 382	750 445	804 349	790 887	711 342
Mollusc	Clams, cockles, ark shells	841 658	798 069	822 520	799 336	899 362	835 150	705 649
Mollusc	Squids, cuttlefishes, octopuses	3 602 711	3 679 332	3 348 493	3 261 615	3 612 308	3 807 189	3 892 145
Mollusc	Miscellaneous marine molluscs	1 562 141	1 509 752	1 505 608	1 486 114	936 169	988 220	1 049 731
Other	Frogs and other amphibians	1 807	2 328	2 486	2 463	2 917	2 836	2 845
Other	Turtles	1 243	1 010	818	1 444	1 498	408	422
Other	Sea squirts and other tunicates	3 905	3 858	2 427	2 320	2 951	2 496	2 735
Other	Horseshoe crabs and other arachnoids	2 397	1 696	1 299	1 387	1 190	519	732
Echinoderm	Sea urchins and other echinoderms	121 567	122 480	107 460	123 955	107 109	115 831	100 063
Other	Miscellaneous aquatic invertebrates	542 659	556 787	475 045	454 572	521 855	278 097	360 679
	World total	93 623 912	95 609 607	93 045 815	93 197 994	90 353 972	94 363 635	93 253 346

Source:

http://en.wikipedia.org/wiki/World_fish_production#Capture_production_by_species

Squids play an important role not only as human food equipped with protein and fat but also used as animal feeds, particularly as fishmeal. Another emerging application of squids is as a source of bioactive molecules for the pharmaceutical industry (Lee *et al.* 1994).

There are large variations across countries and regions of the world in the amount of total fish supply for human consumption, reflecting different eating habits and traditions, availability of fish and other foods, prices, socio-economic levels and seasons. Per capita apparent fish consumption can vary from less than 1 kg per capita in one country to more than 100 kg in another. Differences are also evident within countries, with consumption usually higher in coastal areas (Anonymous, 2008).

Of the 16.4 kg of fish per capita available for consumption in 2005, about 74 percent came from finfish. Shellfish supplied 26 percent or about 4.1 kg per capita which could be subdivided into 1.6 kg of crustaceans, 0.5 kg of cephalopods and 2.0 kg of other molluscs. Freshwater and diadromous species accounted for about 32 million tonnes of the total supply (about 4.9 kg per capita). Marine finfish species provided more than 47 million tonnes, of which 20.0 million tonnes were demersal fish, 19.9 million tonnes were pelagic species and 7.6 million tonnes were unidentified marine fish. The remaining share of the total food supply consisted of shellfish, of which 10.5 million tonnes were crustaceans, 3.5 million tonnes cephalopods and 12.9 million tonnes other mollusks (Anonymous 2008).

Sepioteuthis lessoniana (big fin reef squid) is a commercially important squid throughout the Indo-West Pacific and is a useful species in biomedical research. It has now been cultured through seven successive generations in closed, recirculating seawater systems (Walsh *et al.* 2002a). World catches of cephalopods have increased steadily throughout the last 50 years with annual landings increasing from 0.5 million tonnes in 1950 to over 4.3 million tonnes in 2006 (Anonymous, 2008).

1.2. Marine Fishery in Sri Lanka

Sri Lanka is a coastal state located in the Indian Ocean to the south of India, between latitudes 6 – 10 degrees north and longitudes 80 - 82 degrees east. The fishing industry of the island has a long history. According to the Mahawamsa (the historical record of the island), a coastal fishery existed even prior to 190 B.C. The fishery plays an important role in the island's economy. Catches of cephalopods, mainly octopus (*Octopus vulgaris* Cuvier, 1797), cuttlefish (*Sepia officinalis hierredda* Linnaeus, 1758) and squid (*Loligo vulgaris* Lamarck, 1798), were very small until the 1960s when a spectacular increase was observed in their landings, inducing boats already operating in the area to shift their fishing strategy (Anonymous 2007).

Though, the share of fisheries sector in Gross Domestic Production (GDP) is less than 2%, the sector provides about 600,000 employment opportunities directly and indirectly in Sri Lanka, in 2006 (Anonymous 2006). Food security is the availability of food primarily carbohydrates for human consumption without shortage. Fish is also an

essential food item providing high nutritional value. Medical Research Institute (MRI) recommends the increase the per capita consumption of fish to 21 kg. However, the per capita availability of fish was about 15.7 kg in 2006. This dropped to 11.38 kg in 2005 due to decline in local production. About 18.9 per cent of per capita availability of fish is provided by imports. Although, per capita availability of fish was 15.7 kg, the per capita net availability for consumption was 12.03 kg after adjustment is made for wastages. There is no separate statistics for squid production in Sri Lanka; apparently the category ‘others’ includes the squids also (Table 2).

Species group	1995	2000	2002	2003	2004
Spanish mackerel	2 990	3 130	3 920	6 290	5 260
Trevally	8 910	10 450	10 760	14 940	13 580
Skipjack tuna	33 550	49 110	54 640	42 810	43 830
Yellowfin tuna	26 050	29 320	38 430	27 620	32 870
Other species	17 640	27 890	27 540	35 210	36 830
Shark and skate	22 120	28 790	25 340	26 590	21 320
Rockfish	10 450	14 910	16 320	19 980	17 540
Shore seine species	60 610	76 250	72 910	50 310	54 410
Prawns	8 000	7 540	9 820	10 190	9 730
Lobster	950	1 150	1 860	2 530	1 590
Others	26 230	15 140	13 220	18 210	16 230
Total	217 500	263 680	274 760	254 680	253 190

Source: http://www.fao.org/fishery/countrysector/FI-CP_LK/en

1.3. Cephalopod Fishery in Jaffna

Specifically, *Sepioteuthis lessoniana* (big fin reef squid) is an important species for human consumption in Jaffna, Sri Lanka. Among the total fish catch, cephalopods contribute 17.1 % for the year 2007, 10.9 % for the year 2008 and 26.4 % for the year 2009 (Data gathered from statistical unit, Department of Fisheries, Jaffna, Sri Lanka)

from the waters surrounding Jaffna peninsula. Marine fish catch by main species in Jaffna is tabulated in Table 3 (Statistical unit, Department of Fisheries, Jaffna, Sri Lanka).

Squids captured by sirahu valai made up of 12 mm mesh size net wing, trawls, pots, traps, lures, hook-and-lines etc. Usually they are captured along with other fish and fish related organisms. Due to the significance of the common squid fishery and the declining trend in landings during the last decades, there is increasing interest in managing and conserving common squid stocks. Currently, squid stocks in Northern region of Sri Lanka are not assessed and managed.

Table 3. Jaffna Marine fish catch by main species groups (in kg)			
Type of fish	2007	2008	2009
Seer	80808	8380	181620
Parawa	77741	120924	1532428
Balaya	3880	0	0
Kelawa	0	0	0
Other blood fish	408076	433206	1508117
Shark	86275	36601	218256
Rock fish	498567	496354	2458054
Shoe siene variety	375076	221193	816318
Prawns	359968	415960	979266
Lobsters	0	222	708
Kumbala	21825	23920	20996
Sparts	0	0	0
Crabs	102133	95758	572162
Beach De mer	2400	9380	266561
Cuttlefish, Squids	44336	25150	205920
Skate	43159	28433	763442
Valai	3800	17560	12192
Salai	16860	8694	47351
Soodai	254212	186202	369375
Others	665747	537820	1538620
Total	3044863	2665757	11491386

Source: Statistical unit of Department of Fisheries, Jaffna, Sri Lanka.

1.4. Fishing gear and crafts

Mainly sirahu valai (Fig. 1; Plate 1) is the major gear used to catch the cephalopods like squids, cuttle fish and octopi in the study area. But these types of fish were also caught along with other food fish in trawl nets, cast nets and seines.

Sirahu valai is a deep water trap net set at depths of 4-6 m. It is fixed by fishermen on a semi-permanent basis. Every three to four months the damaged nets are removed and replaced with those that had been repaired before. Fishermen drive long timber poles about 4-5 m in length into the lagoon bed every 2-3 m. These poles are fixed as framework on to which net walls are fixed. The components of the gear generally are a long leader, a "C" shaped play ground and a trap.

The length of the leader depends on the side of the installation and extends up to about 100 m. The webbing used is 12 mm mesh of 12 ply. The leader which guides the fish into the playground area is usually positioned perpendicular to the length of the shore. In very large traps there can be more than one playground. From the playground area there are guides leading to the trap which is the cod end. Trap is generally in the form of a semi circle having a radius of about 6-8 m, while the distance between the two widest points in the playground could be 10-12 m. The webbing for the playground and for the cod end is 12 to 16 mm mesh of 12 to 15 ply. All the nets are usually treated with the extract of mangrove bark to reduce rotting. Each morning the catch is collected. About 3-4 persons are engaged in this operation who dive into the trap area and in the playground area wearing a mask. The catch is scooped out or if there are bigger fish, they are harpooned.

The main craft used in the study area were wooden canoes. These are fashioned by 3-5 curved logs of wood measuring 3-5 m in length and 0.5 m in girth. These are extensively used to operate gill nets and boat seines. These are also used for transport the materials for gear installation, the gear that has to be repaired and the catch.

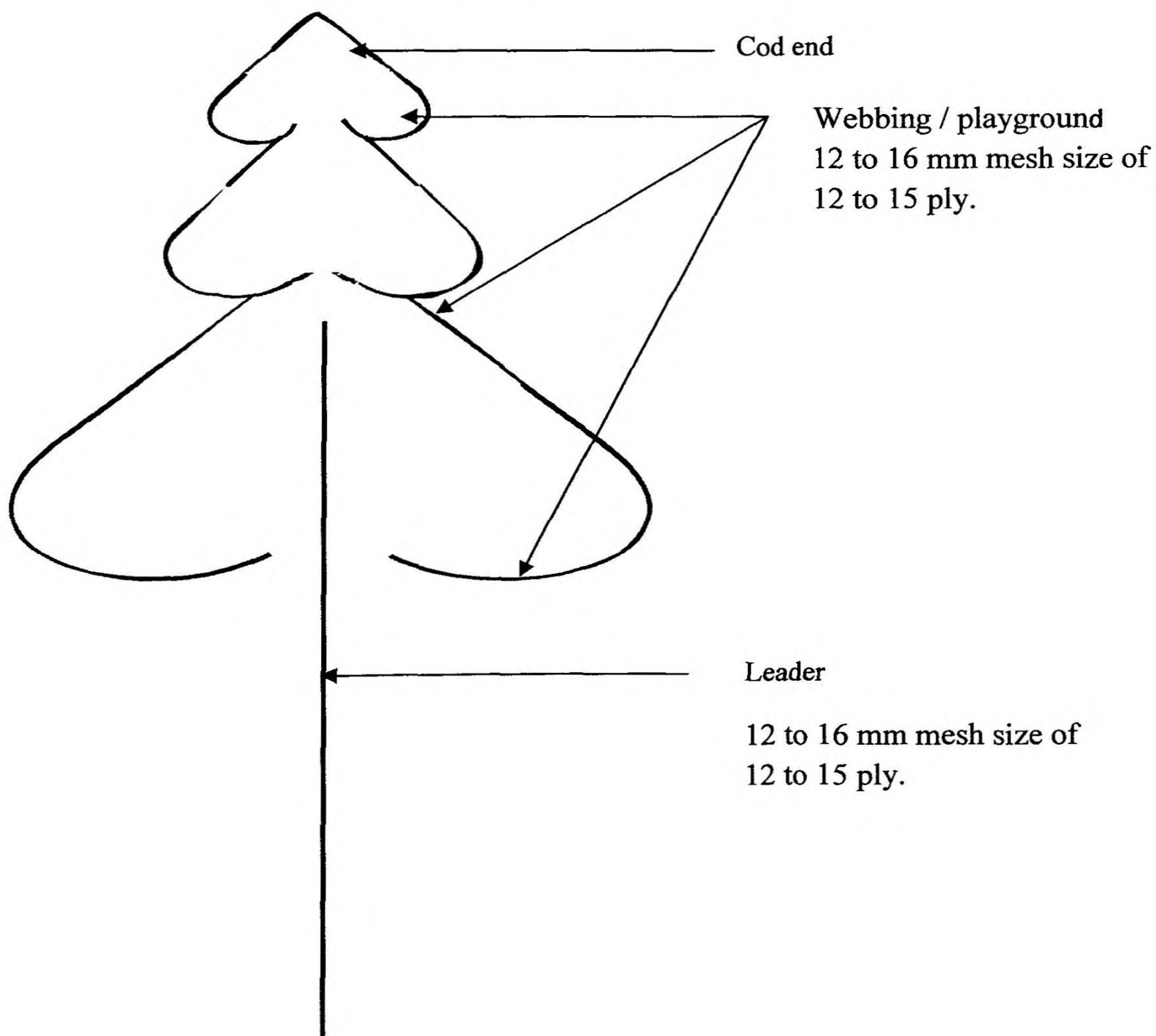


Fig. 1. Diagram of Sirahu valai



Plate 1. Sirahu valai operating in Jaffna lagoon

1.5. Period of abundance

This species available throughout the year, the major season is November to March. Large numbers of squids were observed during this season.

1.6. Study Area

The study area was Jaffna lagoon in the northern part of Sri Lanka. Jaffna lagoon is situated 79° 52'E to 80° 38'E longitude and 9° 26'N to 9° 46'N latitude and has an area of about 412 km² (160 square miles) and the depth does not exceed 4 m (Chitravadivelu 1987). The Jaffna lagoon is the largest shallow water body located in the northern province of Sri Lanka. The Jaffna lagoon extends from the fort Hammenhill in the east to the Elephant pass and in the west as a narrow body of water separating the Jaffna peninsula from the main land and a few neighboring islands. The length of the coast is 140 km where there are more fishery resources and thus fishing villages are found all along the coast line (Fig. 2).

None of the waterways in the Jaffna lagoon has any significant freshwater input except during heavy rains when salinity gradients develop and the stream assumes estuarine characteristics. On the seaward side, immediately adjacent to the mangrove vegetation, the lagoon opens up to less intertidal flats which are covered by a mixed assemblage of sea grasses and algae. Fishing activities are conducted near the reef.

The local climate in Northern waters is dominated by monsoons, which prevails from north-east monsoon rains that occur in the northern and eastern regions in December and January. The climate is cool from November to March with average temperature of 28.5°C and hot from May to August with average temperature of 31.2°C (data from meteorological station, Thirunelvely). Heavy rains (long rains) coupled with thunderstorms, occur from November to January and light rains (short rains) occur from April to June. Samples for research were collected from fishermen at fish landing stations at Paasaiyoor, Gurunagar, Kakkaitivu, and Ponnalai (Fig. 2) between June 2007 and May 2009.

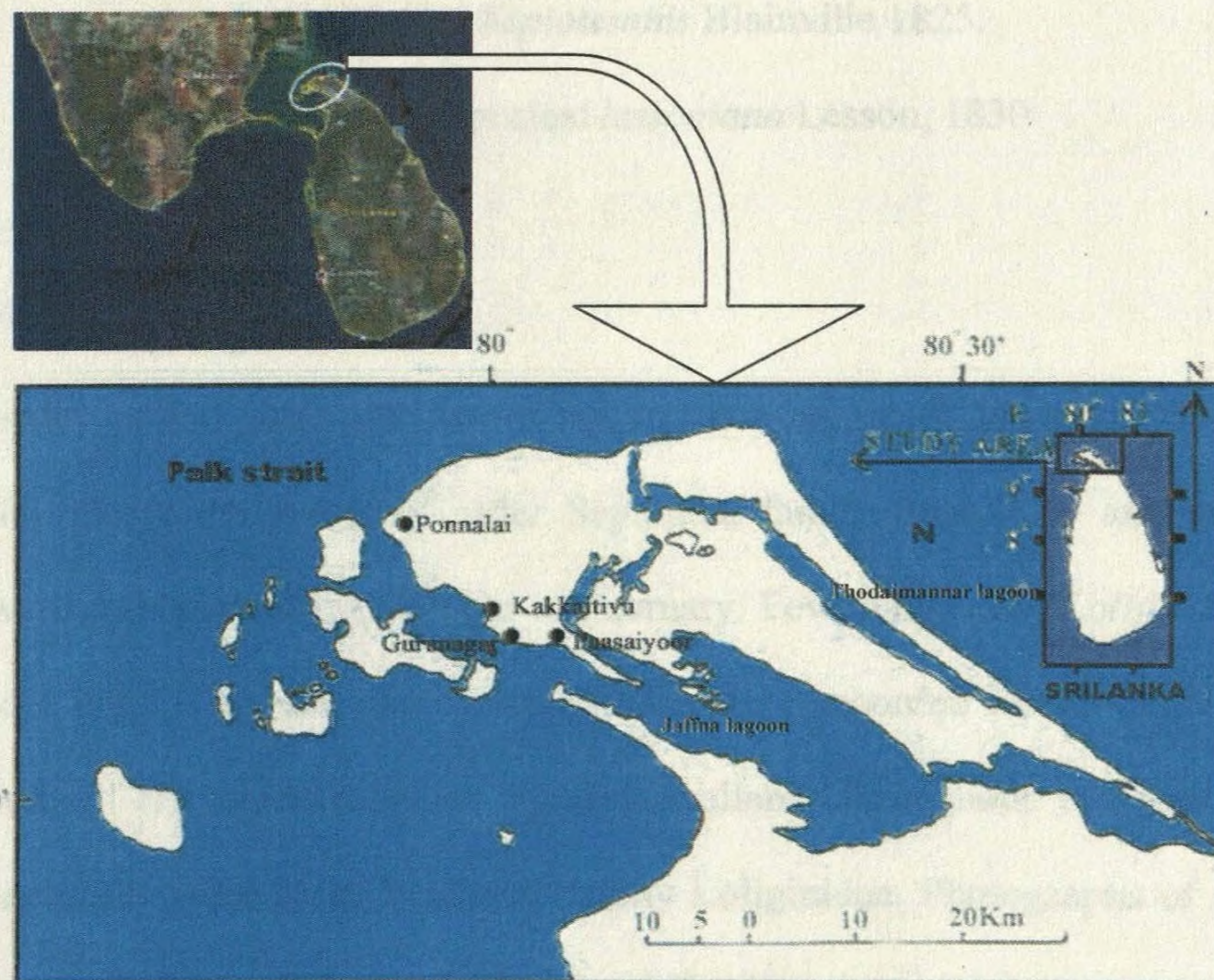


Fig. 2. Sampling sites of *Sepioteuthis lessoniana*

1.7. Taxonomy and classification

Source:(<http://www.Zipcode.com/Animals/s/Sepioteuthis lessoniana>)

Kingdom: Animalia

Phylum: Mollusca

Class: Cephalopoda

Subclass: Coleoidea

Superorder: Decapodiformes

Order: Teuthida

Suborder: Myopsina

Family:Loliginidae

Genus: *Sepioteuthis* Blainville 1825,

Species: *lessoniana* Lesson, 1830

1.8. Diversity

During the study period three species of squids were recorded. Moderate numbers of Bobtail squids *Euprymna berryi* of order Sepiolida, family Sepiolidae and subfamily Sepiolinae were collected during October to February. Few numbers of *Loligo duvauceli* included under order Teuthida, family Loliginidae were recorded intermittently during the study period. The most abundant species available throughout the year was *S. lessoniana* included under order Teuthida, family Loliginidae. Photographs of all three species are shown in Plates 2, 3 and 4. The population dynamics studies were undertaken only for *S. lessoniana* as it was the most abundant species throughout the year.

1.9. Description of species

Shell internal, usually thin, but well developed gladius - Order: Teuthidea. Marginal fin extends about 1-2 mm from the lateral margin of the mantle - *Sepioteuthis lessoniana*. The photograph of dorsal and ventral view of *Sepioteuthis lessoniana* is shown in Plate 5 and 6 respectively. Mantle is long and tubular, rounded posteriorly. Head is broad and stout, wider than the mantle, with prominent eyes, small olfactory crest below and ventral to the eyes. Eight arms are present. The arms are in the order 3, 4, 2, 1 and all the arms are somewhat flattened and keeled for at least part of their length. The sessile suckers are bordered on either side on all arms by protective membrane being largest and deepest on 3 where the dorsal membrane is much wider than the ventral one. In the males left ventral arm is hectocotylized by a modification of the distal 4th of the arm. Two non retractile tentacles are present. The tentacles are long and stout, with slightly expanded clubs and well developed protective membranes. The tentacular suckers are in four rows. The suckers of the dorsal and ventral marginal rows are two-third of the size of the median suckers. The horny rings present in the suckers consist of 14-15 teeth. Colour variable, chromatophores are large and very numerous dorsally in the mantle, fin, headed arm but absent ventrally. Internal shell chitinous, flexible and pen-shaped (De Bruin *et al.* 1995).

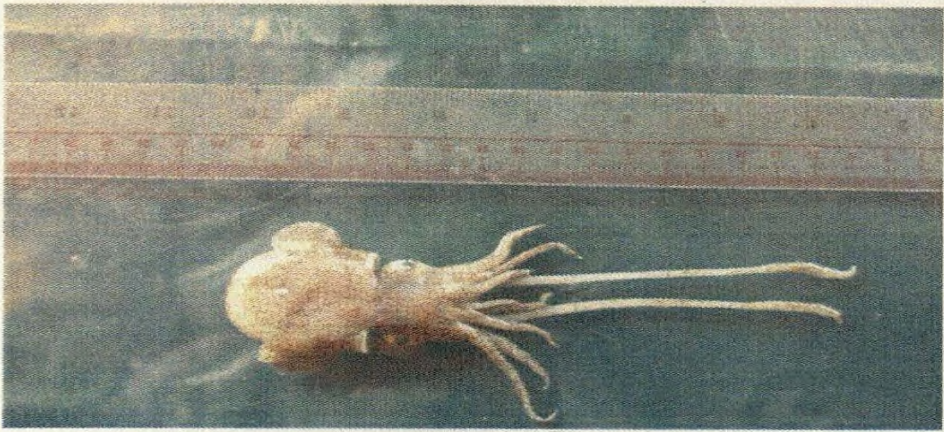


Plate 2. *Euprymna berryi*

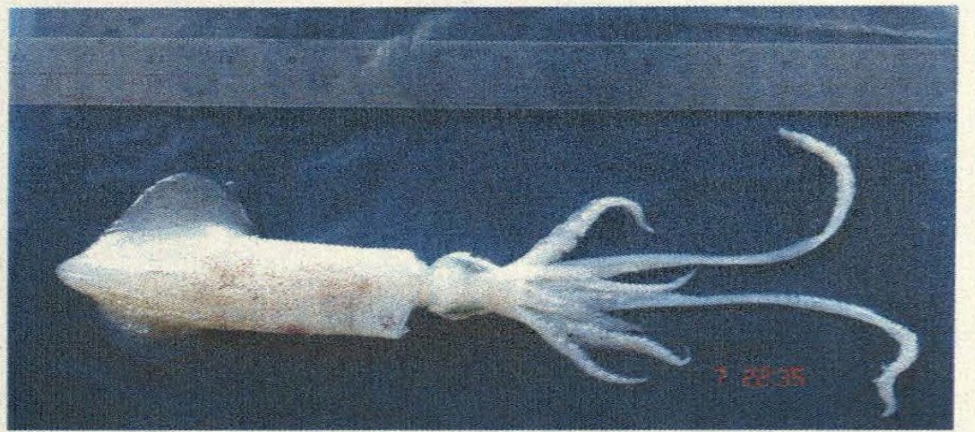


Plate 3. *Loligo duvauceli*



Plate 4. *Sepioteuthis lessoniana*

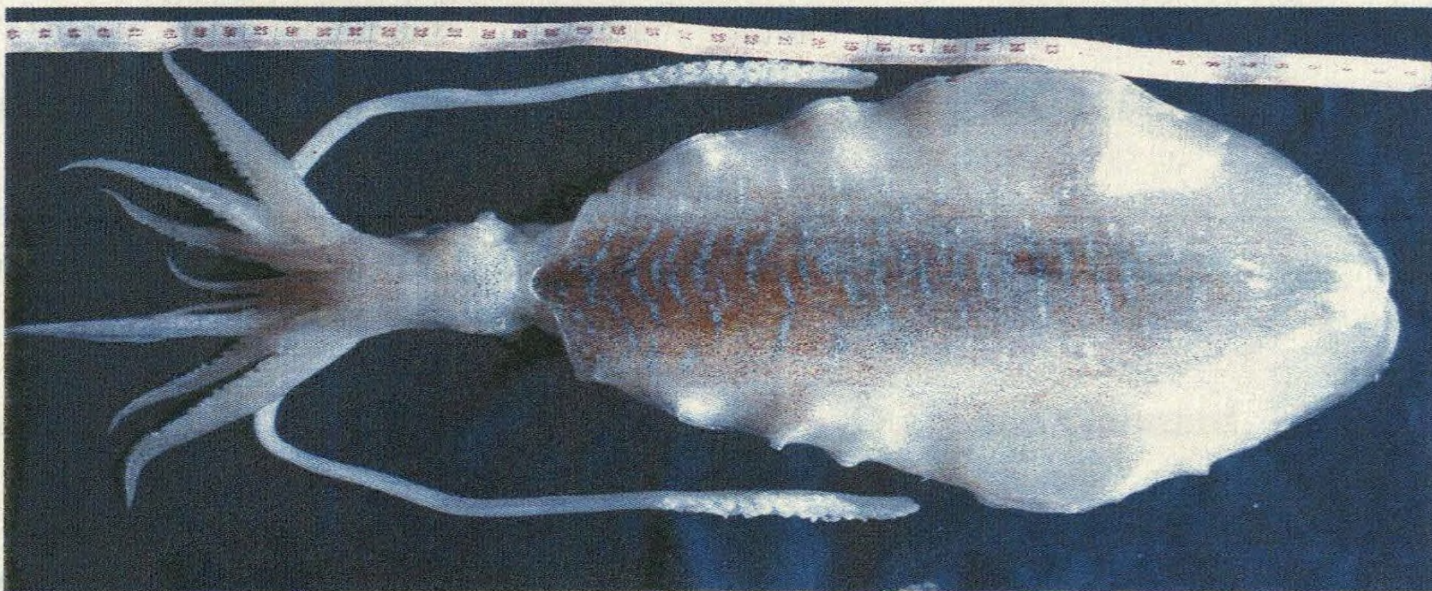


Plate 5. Dorsal view of *S. lessoniana*

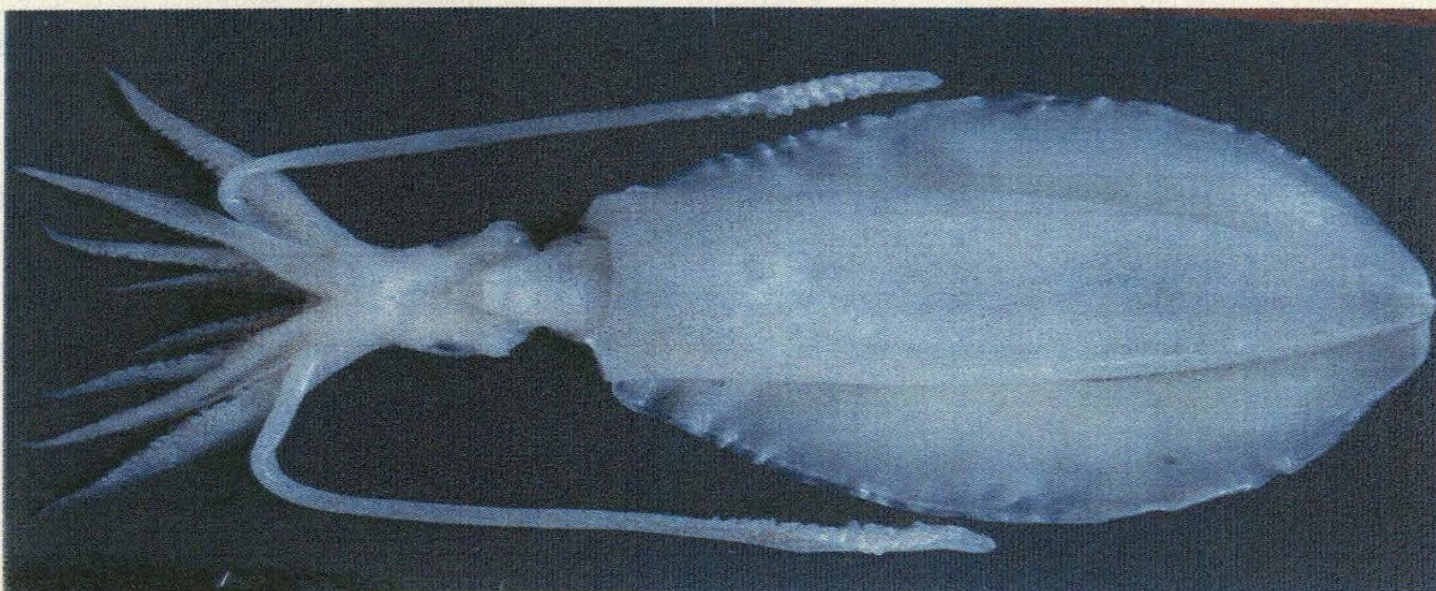


Plate 6. Ventral view of *S. lessoniana*

1.10. Synonyms

Synonym	Author
<i>Sepioteuthis hemprichii</i>	Ehrenberg, 1831
<i>Sepioteuthis guinensis</i>	Quoy and Gaimard, 1832
<i>Sepioteuthis lunulata</i>	Quoy and Gaimard, 1832
<i>Sepioteuthis mauritiana</i>	Quoy and Gaimard, 1832
<i>Sepioteuthis doreinsis</i>	Ferussac and d'Orbigny, 1835-1848
<i>Sepioteuthis arctipinnis</i>	Gould, 1852
<i>Sepioteuthis brevis</i>	Owen, 1881
<i>Sepioteuthis indica</i>	Goodrich, 1896
<i>Sepioteuthis krempfi</i>	Robson, 1928
<i>Sepioteuthis lunulata</i>	Quoy and Gaimard, 1832
<i>Sepioteuthis malayana</i>	Walker, 1913
<i>Sepioteuthis neoguinaica</i>	Pfeffer, 1884
<i>Sepioteuthis sieboldi</i>	Joubin, 1898
<i>Sepioteuthis sinensis</i>	Ferussac and D'orbigny, 1834-1848

1.11. Distribution

Most widely distributed loliginids in the Indo Pacific region and also reported in Eastern Indian Ocean, Japanese Islands to Australia and New Zealand. Worldwide distribution of *S. lessoniana* is shown in (Fig. 3).

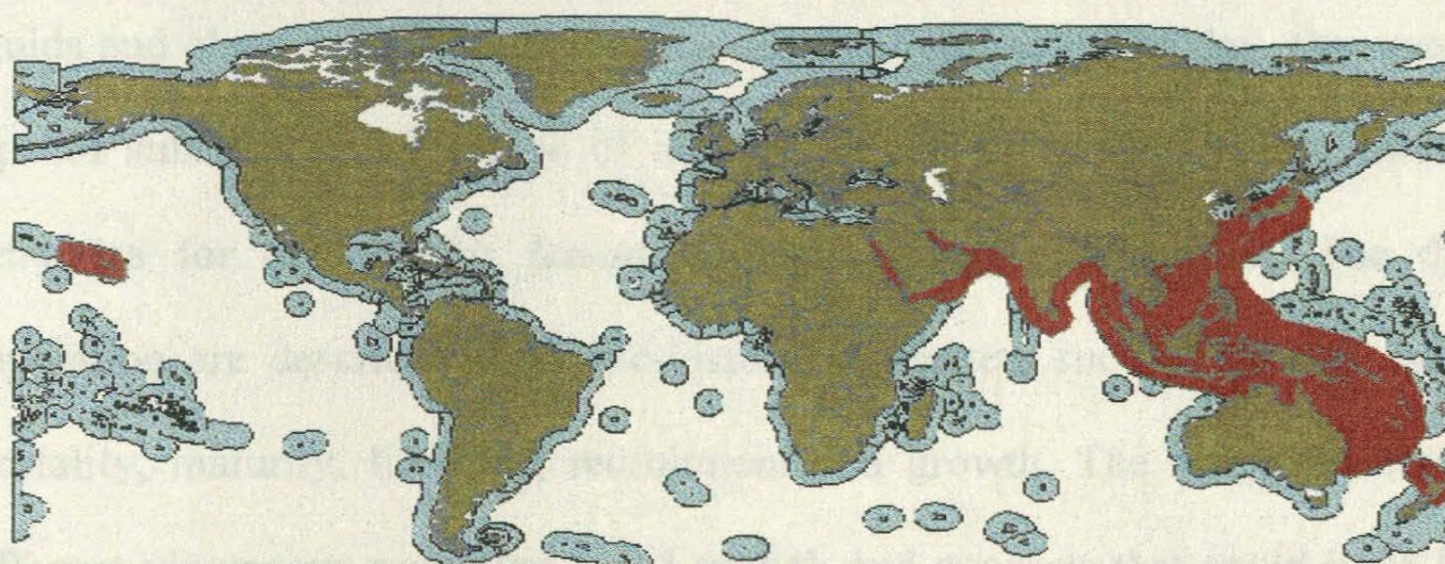


Fig. 3. Worldwide distribution of *S. lessoniana* (Red patches indicates the distribution areas of *S. lessoniana*) – Source: <http://www.cephbase.utmb.edu/bioge/bioge.cfm>

1.12. Habitat

Squids are the euryhaline, which can tolerate the water salinity, temperature and pH ranges 28 - 34 ppm, 28°- 30° C and 6.8 - 7.1 respectively. These are the quick moving predacious creatures which feed on crustaceans, fishes and worms (Pechenick, 2000).

1.13. Common names (Personal observation)

Tamil: Oosikanavai / Oolaikanavai

Sinhala: Thalilla

English: Big fin reef squid

1.14. Scope of the study

A detail understanding of biology and the variation of mortality rate is necessary for sustainable management of stocks. Demographic models are essential tools in that direction. The catching efficiency of these fishing gear is not highly size-selective for squids and also varies according to the season, the time of the day, the maturity stage, the type of substrate and the type of natural dens. Despite these recent studies, population dynamics for *Sepioteuthis lessoniana* remain largely unknown. The dynamics of a population are described from life-history parameters such as natural mortality, fishing mortality, maturity, life-span, recruitment and growth. The scientific literature presents different viewpoints regarding squid growth and suggests that squid have long life spans and asymptotic growth. This viewpoint exists primarily as a direct consequence of researchers fitting asymptotic growth curves to squid length-frequency data. By using the model, several life cycle parameters, necessary for developing a conservation policy were estimated and compared with the earlier more or less similar studies wherever applicable.

The present research thesis is arranged into 6 chapters. The first chapter gives a general introduction of the study, second chapter consist the overall literature review of the study, third chapter provides information about length - weight relationship of *S. lessoniana*, fourth and fifth chapters explain the reproduction and age and growth of *S. lessoniana* respectively and sixth chapter deals with stock assessment of *S. lessoniana*.

Cephalopods (Squid) play a significant worldwide commercial importance especially for human consumption. Population dynamics of squids in the northern region of Sri Lanka have not been reported so far. The present research is planned to,

- record biological parameters in detail
- estimate growth parameters, mortality parameters and exploitation rate
- indicate the fishing pressure
- recommend conservation and management measures of squid fishery
- provide suggestions to formulate laws and legislation for proper management of squid fishery.

2. Literature Review

The class Cephalopoda is the most highly evolved taxon within the Mollusca. The taxon Loliginidae is a commercially important group of neritic squids numbering 40 to 50 described species (Brakoniecki 1984; Nesis 1987). The Cephalopoda which includes the *Nautilus*, cuttlefishes, squids and octopods, is the most advanced class of the phylum Mollusca adapted to a swimming existence. The cephalopods are a class of marine mollusc that emerged approximately 500 million years ago at the end of the Cambrian era (Clarkson 1993) with two extant subclasses: the Nautiloidea represented by a single genus, *Nautilus*; and the Coleoidea, which is further divided into four orders: Sepiida (cuttlefishes), Teuthida (squid), Octopoda (octopuses) and Vampyromorpha (Nesis 1987). They are exclusively marine, diverse in form, size and nature and occupy littoral and benthic to pelagic environments of all oceans. Information on the identification of genera, species and brief descriptions on their biology, geographical distribution, habitat and fisheries are obtained from reviews and species catalogues (Voss 1973, 1977; Voss and Williamson 1971; Worms 1983; Boyle *et al* 1995; Caddy 1991; Voss 1983; Roper *et al.* 1984). In cephalopods secondary sexual characteristics primarily consists of difference in body size, body pattern, sucker size, gonad shape or colour and sometimes photophores (Hanlon and Messenger 1996). Spermatophores were generally found deposited in the buccal cavity of females, however, several females were observed with spermatophore capsules affixed to the head, arms, or dorsal mantle (Hanlon and Messenger 1996).

Members of the Coleoids inhabit a wide range of photic environments from the surface waters of the continental shelf to the bathypelagic depths (Nesis 1987). Cephalopods are characterized by rapid constant indeterminate growth throughout their life, with no asymptotic size limits being approached (Alford and Jackson 1993). Cephalopod reproductive strategies and life cycles are genetic adaptations to optimize the use of the ecological niches in direct competition with other species as responses to the environmental conditions (Rocha *et al.* 2001). The overall growth rates of squid exceed those of fish because growth continues during the adult phase (Moltschaniwskyj 1994). Recent age and growth studies, using daily statolith increments to determine age, and length as a measure of size, show that both exponential and linear growth patterns are common for squid (Bigelow 1994; Brodziak and Macy 1996).

In addition, several Loliginid species possess paired bacterial bioluminescent organs on the ventral surface of the ink sac (*Uroteuthis*) (Anderson 1996). Squids are dioecious mollusks, the gonads located most posterior in the mantle cavity. The female reproductive system is relatively simple consisting of an ovary lying posterior in the gonadocoel and from which arises an oviduct with its associated oviducal gland which produces albumin to coat the eggs. The oviduct opens into the mantle cavity to the left of the rectum. The eggs are coated with an outer gelatinous material secreted by nidamental glands of the oval outline. The gelatinous coating which hardens on exposure to sea water, may cement the eggs together in masses (Jantzen and Havenhand 2003; Parker and Haswell 1995).

The squids of the genus *Sepioteuthis*, belonging to the family Loliginidae, are characterized by wide oval fins that extend almost the entire perimeter of the mantle (Adam 1939). Loliginid squids display a diversity of morphology and body sizes. These exhibit complex behaviours and possess a sophisticated central nervous system with an extreme fusion of ganglia, so that their 'brain' is subdivided into numerous lobes interconnected by tracts and commissures. Four species are presently recognized (Adam 1939); *Sepioteuthis lessoniana* Lesson, 1830; *S. australis* Quoy and Gaimard, 1832; *S. sepioidea* Blainville, 1823 and *S. loliginiformis* Ruppel and Leuckart, 1828. Three species of squids *Loligo duvauceli*, *Loligo singhalensis* and *Sepioteuthis lessoniana* and five species of cuttle fishes, *Sepia aculeata*, *Sepia latimanus*, *Sepia pharaonis*, *Sepia prashadi* and *Sepiella inermis* have been identified in Sri Lankan waters (De Bruin *et al.* 1995). *Sepioteuthis lessoniana*, *Sepia australis* are relatively large neritic squids of commercial importance in Australia (Pecl 2001). The maximum lifespan of *Sepioteuthis lessoniana* in Australia, tropical and subtropical waters is six to seven months (Jackson and Choat 1992). Squid paralarvae were identified following Hanlon *et al.* (1992) and all individuals had their mantle length (ML) measured in millimeters using a stereoscopic binocular microscope at 40 × magnifications. Oceanographic conditions during the surveys were assessed with a modern technology and the water masses present at the sampling dates were classified according to the recorded temperature and salinity following Matsuura (1986) and Carvalho *et al.* (1998). Loliginidae paralarvae have been reported to be associated with upwelling areas (Rocha *et al.* 1999; González *et al.* 2005), where highest numbers are often caught during the upwelling events.

Squids comprises rapid body pattern changes that results from alteration in chromatic, postural or locomotor components of behavior (Mather and Mather 1994; Hanlon and Messenger 1996). Types of mating behavior observed in *Sepia australis* from Australian waters by Jantzen and Havenhand in 2003, include paired head to head mating, paired male parallel mating and sneaker and general mating behavior. Some squid species display two distinct phases of growth. Initially juveniles grow exponentially, followed by a logarithmic adult growth phase (Nigmatullin *et al.* 1995).

Furthermore, some of their behavioral abilities, such as making detours (Wells 1964; Moriyama and Gunji 1997), reversal learning (Mackintosh and Mackintosh 1964) and observational learning (Fiorito and Scotto 1992), are equal to those of lower vertebrates. The common cuttlefish *Sepia officinalis* Linnaeus, 1758 is widely distributed in eastern Atlantic shelf waters (Boletzky 1983), and the English Channel fishery is amongst the largest cephalopod fisheries in the eastern Atlantic. Annual landings of this fishery have more than tripled over the last decade, reaching approximately 15,000 t in 2002 (Anonymous 2002). However, there are few regulations controlling fishing activity on this stock, and only preliminary stock assessments to determine biomass trends and yields have been completed, using depletion methods or cohort analysis (Dunn 1999). *Sepioteuthis* inhabits inshore waters and is distributed over a broad geographical range that covers the whole Indo-west Pacific, from Japan in the north to New Zealand in the south and Hawaii in the east (Okutani 1973), Red Sea and the Indian Ocean (Rao 1954). Bianchi (1985) identified two species of loliginid squids exploited by artisanal fisheries

in the coastal waters of Tanzania. These are the Indian squid *Loligo duvauceli* and the veined squid *Loligo forbesi*.

The dynamics of a population are described from life-history parameters such as natural mortality, fishing mortality, maturity, life-span, recruitment and growth (Begg *et al.* 1999; Rodhouse 2001). Apart from obtaining size-at-age information from statoliths, there is also the potential to obtain ecological information on past growth histories of some squid species (Jackson 1994a). Linear relationships (of varying strengths) between statolith dimensions and body size and weight at hatching are evident for laboratory reared cephalopod *Sepioteuthis lessoniana* (Ikeda *et al.* 1999; Jackson and Moltschaniwskyj 2001.) Squid to be relatively long lived with asymptotic growth which can be described using the von Bertalanffy growth equation. This view essentially favours thinking of squid as fish and describes squid growth using finfish modelling techniques (Longhurst and Pauly 1987) *Alloteuthis lesueurii* adults attain a mantle length (ML) of 390 mm and are believed to migrate into deeper mesopelagic layers to spawn near the bottom (Nesis 1993).

The periodic growth increments in squid statoliths are bipartite structures consisting of a discontinuous zone and an incremental zone comprising aragonite (CaCO₃) crystals (Lipinski 1993). Specific morphological differences in the aragonite crystal structure have been illustrated between statolith regions within several squid species (Lipinski 1993). Crystals of the lateral dome region often display greater variation in shape, size, and orientation than the more homogenous wing crystals (Lipinski 1993). These

variations in crystal structure suggest that accretion is not uniform and that different regions of the statolith may grow at different rates. The present study provides an assessment of the growth and shape of *Sepioteuthis lessoniana* statoliths based on the linear measurement of statolith dimensions. Plasticity in loliginid squid growth is evident in both the variability in individual growth rates (Jackson *et al.* 1997) and the variability in size and age at maturity (Jackson and Yeatman 1996). These plastic growth responses may be influenced by such factors as temperature (Jackson *et al.* 1997) prey availability (O'Dor *et al.* 1980), population density (Dawe 1988), sexual maturation (Brodziak and Macy 1996) and sex-specific growth rates (Rodhouse and Hatfield 1990). Daily periodicity of growth increment deposition has been validated for hatchlings of *A. trigonura* (Bigelow 1994). The overall growth rates of squid exceed those of fish because growth continues during the adult phase (Moltschaniwskyj 1994).

However, only few data on age and growth are available for the English Channel, and have been derived from modal progression analysis using length frequency data (Medhioub 1986; Dunn 1999), which is considered inadequate for describing animals with fast grow multiple cohorts (Jackson 1997).

Periodic growth increments in squid statoliths are a reliable and accurate tool for determining the age structure of squid populations (Villanueva 1992; Arkhipkin 1993a; Bigelow 1994).

The Cephalopod *Sepia officinalis* exhibits a specific body patterns during agonistic behavior (Tinbergen 1939; Hanlon and Messenger 1988). Reproductive biology of the common cuttlefish *Sepia officinalis* have been studied in the eastern Atlantic and Mediterranean sea (Gauvrit *et al.* 1997). In contrast to *Sepia officinalis*, little is known about the biology of *S. pharaonis* (Silas *et al.* 1985). Several studies have been done on species identification and stock structure analysis including the use of ecological studies, tagging, distribution of parasites, physiological and behavioural aspects, morphometrics and meristics, calcified structures, cytogenetics, immunogenetics, blood pigments, allozyme electrophoresis and nucleic acid analysis for flying squids, *Illex* sp. (Carvalho and Hauser 1994; Ward *et al.* 1994). Life span and growth of cohorts of *Illex argentinus* have been studied by Hatanaka (1986) and Koronkiewicz (1986) from modal or mean length progression, and by Rodhouse and Hatfield (1990), Arkhipkin (1993b) by ageing individuals for counts of daily increments on ground sections of the statoliths. Hatfield *et al.* (1992) and Rodhouse and Hatfield (1992) have studied the absolute and relative growth of *I. argentinus* in relation to sexual maturation and examined the production of gonad and soma, as different stages of maturation. Maturation, fecundity and seasonality of reproduction of the commercially valuable cuttlefish, *Sepia pharaonis* and *Sepia dollfusi*, from the Suez canal have been studied by Gabr *et al.* (1998).

Patterns of growth at the whole animal level are reflected at any of a series of lower levels of biological organization such as relative growth of organs and tissues, growth dynamics of tissues, and the relative concentration of the biochemical constituents of tissues and organs (Weatherley 1990). The measurement of these various lower levels of

biological organization is used to assess the condition or health of an individual and can play an important role in understanding the observed plasticity of life-history traits (Ferron and Leggett 1994). Examination of mantle muscle tissue of cephalopods has allowed to understand the relative importance of fiber production and fiber growth to whole animal growth as cephalopods increase in size (Moltschaniwskyj 1994, Pecl and Moltschaniwskyj 1997, Preuss *et al.* 1997). It has also been used as a tool to understand differences in growth at different food levels and temperatures (Moltschaniwskyj and Martinez 1998) It is not yet examined how the relative rates of hyperplasia (new fiber generation) and hypertrophy (growth of existing fibers) differ among wild individuals growing at different rates. With both the mantle muscle and digestive gland tissue are proposed as energy storage substrates and sites in cephalopods, proximal analysis of the biochemical constituents of these tissues has been used to examine the dynamics of squid growth, reproduction and energy storage at population level (Clarke *et al.* 1994). However, there has been little attempt to examine condition at the individual level and relate this to their growth, as has been done with fish (Weatherley 1990). This may prove to be an approach which yields important information about the plastic growth of squids, by determining what changes at different levels of organization reflect a fast- or slow-growing individual.

Growth - rate calculations based on statolith age estimates indicate that tropical squid are short-lived and grow continuously throughout their lifespan (Jackson and Choat 1992). Growth rates of tropical squid can be strongly influenced by changes in their environment, including temperature fluctuations (Forsythe and Hanlon 1989), and

availability of food (Forsythe 1993). Consequently, growth rates, final size, and response to changing conditions of tropical squid may vary greatly within or between species (Jackson and Choat 1992).

The reproductive biology of the common cuttlefish of the eastern Atlantic and Mediterranean Sea, *Sepia officinalis*, is now known in considerable detail (Boletzky 1983; Le Goff and Daguzan 1991; Adamo and Hanlon 1996; Boal 1996; Gauvrit *et al.* 1997). Mangold-Wirz (1963, 1966) determined the maturity stages of *S. officinalis* in the Mediterranean based on size and appearance of the eggs, and the presence or absence of spermatophores in Needham's sac in males. Richard (1967) determined the stages west of sexual maturity of females from the English Channel based on the color of the accessory nidamental glands. Bakhayokho (1983) described five gonadal development stages for female *Sepia officinalis hierredda* in Senegal based on macroscopic and microscopic aspects of the gonads. In contrast to *Sepia officinalis*, little is known about the biology of *S. pharaonis* (Silas *et al.* 1985; Aoyama and Nguyen 1989).

In biology and demography, fecundity is the potential reproductive capacity of an organism or population, measured by the number of gametes (eggs), seed set or asexual propagates. Fecundity is important and well studied in the field of population ecology. Fecundity can increase or decrease in a population according to current conditions and certain regulating factors. For instance, in times of hardship for a population such as lack of food, juvenile and eventually adult fecundity has been shown to decrease. In squids

(Cephalopoda: Teuthoidea), many researcher have examined female fecundity through measures of potential reproductive output, such as the biomass or number of oocytes in the ovaries and ova in the proximal oviducts of dissected females (Voss 1983, Mangold 1987). For species within the family Loliginidae, especially for *Loligo spp*, a common finding is that ovarian oocytes range greatly in size and structure (Sauer and Lipinski 1990; Lum-Kong *et al.* 1992; Lum-Kong 1993; Boyle *et al.* 1995; Collins *et al.* 1995; Moltschaniwskyj 1995; Rocha and Guerra 1996). These observations challenge the traditional view, based in part on studies on *Loligo opalescens*, that female coleoid cephalopods lay all of their eggs in a brief period before death (reviewed in Mangold 1987, Mangold *et al.* 1993, Rocha and Guerra 1996) and seem more compatible with the notion that females of some species lay multiple clutches of eggs over a substantial portion of their life cycle. Female reproductive output in the longfin inshore squid *Loligo pealeii* was assessed by examining the ability of females to lay multiple clutches of eggs in captivity and initial data were reported by Maxwell *et al.* (1998).

Measures of the actual reproductive output of female loliginids are largely anecdotal (Roper 1965, Hixon 1980, Macy 1980), although Moltschaniwskyj's (1995) study of *Photololigo sp*, stands as a notable exception. *L. pealeii* females lay their eggs in gelatinous capsules one of which can contain up to several hundred ova. To distinguish the egg capsule from the unfertilized and fertilized ova that it contains, the term 'ova' is used to refer to the individual ova within the egg capsule. A female can lay a clutch of 50 or more egg capsules over the course of several hours (Drew 1911). The actual reproductive output of female is quantified in 2 ways: (1) the number of egg capsules that

she lays in captivity and (2) an estimation of the number of ova that are within these capsules. The terms 'actual reproductive output' and 'reproductive output' are used synonymously. Mantle length correlates positively with the combined number of oocytes and ova in the ovary and oviduct in several *Loligo spp.* (Coelho *et al.* 1994, Boyle *et al.* 1995, Collins *et al.* 1995). Earlier studies were motivated to introduce a more accurate combination of methods to assess fecundity in female squids.

The challenges of combining experiments on live squids with measurements and biometric correlations of anatomical features are formidable and expensive. Yet, fisheries managers and cephalopod biologists require live animals to understand the recruitment dynamics and life history strategies of some of the commercially valuable squid species (Rodhouse *et al.* 1998). The mature eggs of *Sepioteuthis species* are very large compared to those of other squids in the large range of 5 to 10 mm (Hanlon 1990).

The *Sepia officinalis* (cuttlefish) exhibits a specific behavioral pattern during agonistic the life history (Hanlon and Messenger 1988). Forward swimming, backward swimming, hovering, jetting (Moynihan and Rodaniche 1982; Hanlon *et al.* 1994, 1999), and turning are few examples for behavior pattern reported in *Sepia officinalis*. or consistency of analysis, parallel positioning was defined as paired squid aligned laterally and facing in the same direction, where any part of the bodies were closer than the paired male's body length (Jantzen and Havenhan 2003).

Mortality (fishing and natural mortality) rates are important for understanding the rate of population decay of the species (Beverton and Holt 1957; Ricker 1975). Direct estimates of mortality are often impossible to obtain (Stergiou and Papaconstatinou 1993) hence methods for measuring mortality are at best qualified estimates (Sparre and Venema 1998). Notwithstanding, Pauly's empirical formula has been used extensively in tropical and temperate fisheries to estimate mortality of the squid (Kraljevic' *et al.* 1996; Gabche and Hockey 1995; Sparre and Venema 1998). Stergiou and Papaconstatinou (1993) found that length-based methods produced low estimates for mortality; age-based methods produced higher estimates for mortality, while empirical regressions produced estimates closer to the mean.

3. Length – Weight relationship

3.1. Introduction

Length and weight data are useful standard results of fish sampling programs (Morato *et al.* 2001). In fish, size is generally more biologically relevant than age, mainly because several ecological and physiological factors are more size dependent than age-dependent. Consequently, variability in size has important implications for diverse aspects of fisheries science and population dynamics (Erzini 1994).

The knowledge of length – weight relationship plays a vital role in fisheries biology and population dynamics. It helps in estimating the standing stock or biomass and thereby establishing the yield by converting one variable into another which is often done during field studies (Petrakis and Stergiou 1995). Length – weight relationship parameters are useful to the fish farmers and farm managers in predicting the yield of the cultured fish from the equation. In the field it is easier to measure the length of fish than the weight and therefore the biomass or the stock could be computed only by measuring the length of the fishes (Sinovcic *et al.* 2004). Compared to other loliginid squid species, *Sepioteuthis lessoniana* appears to be the most adaptable species to the laboratory environment (Hanlon *et al.* 1991) and there exist a need for detail study on length weight relationship for this species. Various studies on length weight relationship of squids were studied by different authors in world waters (Flamigni and Giovanardi 1984; Gonzalez *et al.* 1992; Karnik and Chakraborty 2001; Krstulović Šifner 2000; Manfrin Piccinetti and Giovanardi 1984; Marano 1993).

No studies have been reported on mantle length – weight relationship of *Sepioteuthis lessoniana* in Sri Lanka, so far. Therefore the present study is an attempt to understand information on size distribution, mantle length - weight relationship parameters, a comparison between regression lines mantle length - weight relationships of male, female and indeterminates and growth pattern of *S. lessoniana* from the Jaffna lagoon.

3.2. Materials and methods

Squid samples for the present study were collected randomly from the commercial catches of Pasaioor, Gurunagar, Kakkaitivu and Ponnalai landing centres (Plate 2.) at weekly intervals from June 2007 to May 2009. In the Jaffna lagoon, fishermen use various techniques to capture squids. Mainly they capture squids by Sirahu valai. Being a small scale fishery, some fishermen use jiggers and pots to capture squids.

Mantle length (ML) was measured to the nearest 5 mm with the measuring board. The specimens were cleaned with tap water and plant parts or fish scales attached with suckers were removed. Then it was mopped with blotting sheet to remove the external moisture and weighed to the nearest 0.01 g on a top loading electrical balance (AND FY 300) and recorded. The values for mean weight by sex were simply compared by two – sample t – test.

According to Bagenal and Tesch (1978) and Ricker (1975), the relationship between total body weight (TW), and mantle length (ML) typically takes the form,

$$TW = a ML^b$$

or in the liner form

$$\text{Log TW} = \log a + b * \text{Log ML}$$

Where **a** and **b** are constants. The parameters 'a' (proportional constant or intercept) and 'b' (exponent) were estimated for male and female separately by using the logarithmic transformation. The regression line was computed by the method of simple least square regression analysis.

The 'b' values obtained for male and female *S. lessoniana* were tested by Students' *t* test to see whether the 'b' values differ significantly from 3 or not (Zar 1999). Students' *t* test was employed by dividing the difference between 'b' and '3' by standard error of 'b'. The regression lines of male and female *S. lessoniana* were then analyzed further for significant differences by General Linear Model Analysis of Covariance (GLMANCOVA) using MINITAB (Version 14) statistical software in the computer.

3.3. Results

A total of 2529 specimens (232 indeterminate, 1189 males and 1108 females) of *S. lessoniana* were analyzed.

3.3.1. Size range

The size (Mantle Length-ML) of *S. lessoniana* ranged from 2.4 to 30.2 cm (mean \pm SD = 15.03 \pm 4.26 cm). Males ranged from 3.8 to 29.7 cm ML (mean \pm SD = 14.53 \pm

4.38 cm), females ranged from 3.5 to 30.2 cm ML (mean \pm SD = 15.56 \pm 4.05 cm) while indeterminate ranged from 2.4 to 12.5 cm ML (mean \pm SD = 5.58 \pm 1.36 cm).

The results of two – sample t – test (Table 4) for weight data of male and female show that females were larger than males but there is no significant difference ($P > 0.05$) between males and females.

3.3.2. Length – weight relationship

The estimates of the regression parameters of mantle length-weight relationship for male, female and indeterminate obtained by regression analysis are shown in Table 5. The equations of mantle length - weight relationship and their logarithmic transformation are given in Table 6. The 'b' values 2.2205, 2.1137 and 2.396 obtained for male, female and indeterminate respectively indicate that the fish does not follow the cube law, its growth is proportionally three-dimensional ($n = 1188$, $r^2 = 0.878$, 95% CL a = 0.298 to 0.382, 95% CL b = 2.173 to 2.268 and coefficient of variation = 0.00329 for males; $n = 1107$, $r^2 = 0.8471$, 95% CL a = 0.191 to 0.274, 95% CL b = 2.060 to 2.166 and coefficient of variation = 0.00333 for females; $n = 232$, $r^2 = 0.7574$, 95% CL a = 0.1348 to 0.3311, 95% CL b = 2.137 to 2.654 and coefficient of variation = 0.01755 for Indeterminate). That is, with increasing age, rate of growth in terms of weight in this squid becomes slower than that of its length. Correlation coefficients (r) 0.937 for male, 0.920 for female and 0.8703 for indeterminate were found to be significant ($p < 0.01$) in all instances indicating good correlation between mantle length and weight.

Table 4. Two – sample t – test for weight data of male and female *S. lessoniana*

	Weight of body male	Weight of body female
Mean	150.15	152.36
Variance	13760.50	9120.85
Observations	1189	1108
Hypothesized mean difference	0	
Df	2255	
t stat	-0.4980	
P (T<=t) one tail	0.3092	
t critical one tail	1.6455	
P (T<=t) two tail	0.6185	
t critical two tail	1.9610	

Table 5. Mantle Length-weight relationship parameters of *S. lessoniana*

Sex	N	Df	b	a	Errors of estimation		r
					df (residual)	SS (residual)	
M	1189	1187	2.2205	0.3370	1186	15.3358	0.9372
F	1108	1106	2.1137	0.4137	1105	13.5349	0.9204
I	232	230	2.3960	0.2098	229	16.3603	0.8703
T	2529	1132	-	-	2291	-	-

(N=Number of observation, df=Degrees of freedom, b=Regression exponent, a=Constant, SS=Sum of squares, r=Correlation coefficient, M=Male, F=Female, I = Indeterminate and T=Total).

Table 6. Relationship between mantle length and weight of male and female of *S. lessoniana*

Sex	Mantle Length-weight relationship	Logarithmic transformation
M	$W = 0.3370 * TL^{2.2205}$	$\text{Log } W = -0.4723 + 2.2205 * \text{Log } ML$
F	$W = 0.4137 * TL^{2.1137}$	$\text{Log } W = -0.3833 + 2.1137 * \text{Log } ML$
I	$W = 0.2098 * TL^{2.3960}$	$\text{Log } W = -0.6780 + 2.3960 * \text{Log } ML$

(M=Male, F=Female, I = Indeterminate, W=Weight and ML= Mantle length)

The significance of variation in the estimates of 'b' for *S. lessoniana* from the expected value for the ideal fish (3.0) was tested by Students' t test (Snedecor and Cochran 1967; Jayaprakash 2001).

Students' t test was employed by dividing the difference between 'b' and '3' by standard error of 'b' (Zar 1999). The results are as follows:

Male: $(2.2205 \sim 3.0)/0.0239 = 32.615$ Significant

(computed $t_{\alpha(2),0.05,1187} > 1.960$)

Female: $(2.1137 \sim 3.0)/0.02701 = 32.814$ Significant

(computed $t_{\alpha(2),0.05,1106} > 1.960$)

Pooled: $(2.3960 \sim 3.0)/0.1310 = 4.610$ Significant

(computed $t_{\alpha(2),0.05,231} > 1.970$)

The above result shows that the 'b' values of male, female and indeterminate *S. lessoniana* significantly differ ($P < 0.05$) from the ideal value 3 and exhibit significant negative allometric growth in all instances.

The GLMANCOVA results for the comparison of regression coefficients (b) of the length-weight relationship of male, female and indeterminate is presented in Table 7. In GLMANCOVA a full rank design matrix was formed from the factors and covariates and each response variable was regressed on the columns of the design matrix.

The GLMANCOVA showed the slopes (b) of male, female and indeterminate exhibit significant interaction (computed $F_{2, 2528} < 3.69$ $P < 0.05$). Further, comparison of regression co-efficient of male and female using GLMANCOVA for the regression of log weight on log mantle length of male and female showed the 'b' values show significant differences ($P < 0.05$). The confidence intervals of 'a' for male and female do not overlap with each other and therefore there is significant difference between the intercepts, too. Interestingly, comparison of regression co-efficient of indeterminate with that of male and female using GLMANCOVA showed the 'b' values not to show significant differences ($P > 0.05$).

The scatter diagrams of weight versus length and log weight versus log length of male and female samples of *S. lessoniana* are illustrated in Fig. 4, 5, 6 and 7.

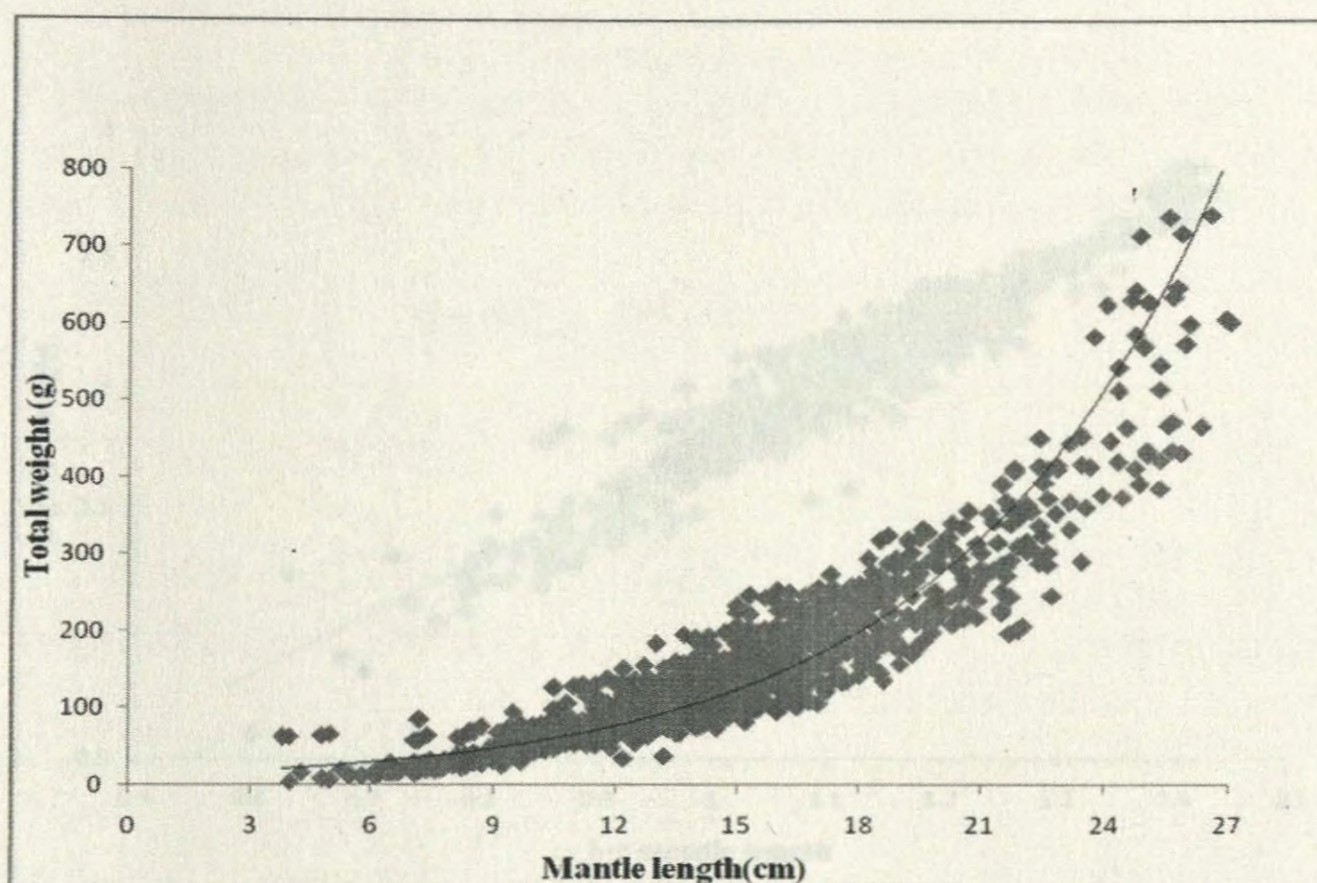


Fig. 4. Total weight versus Mantle length of male *S. lessoniana*

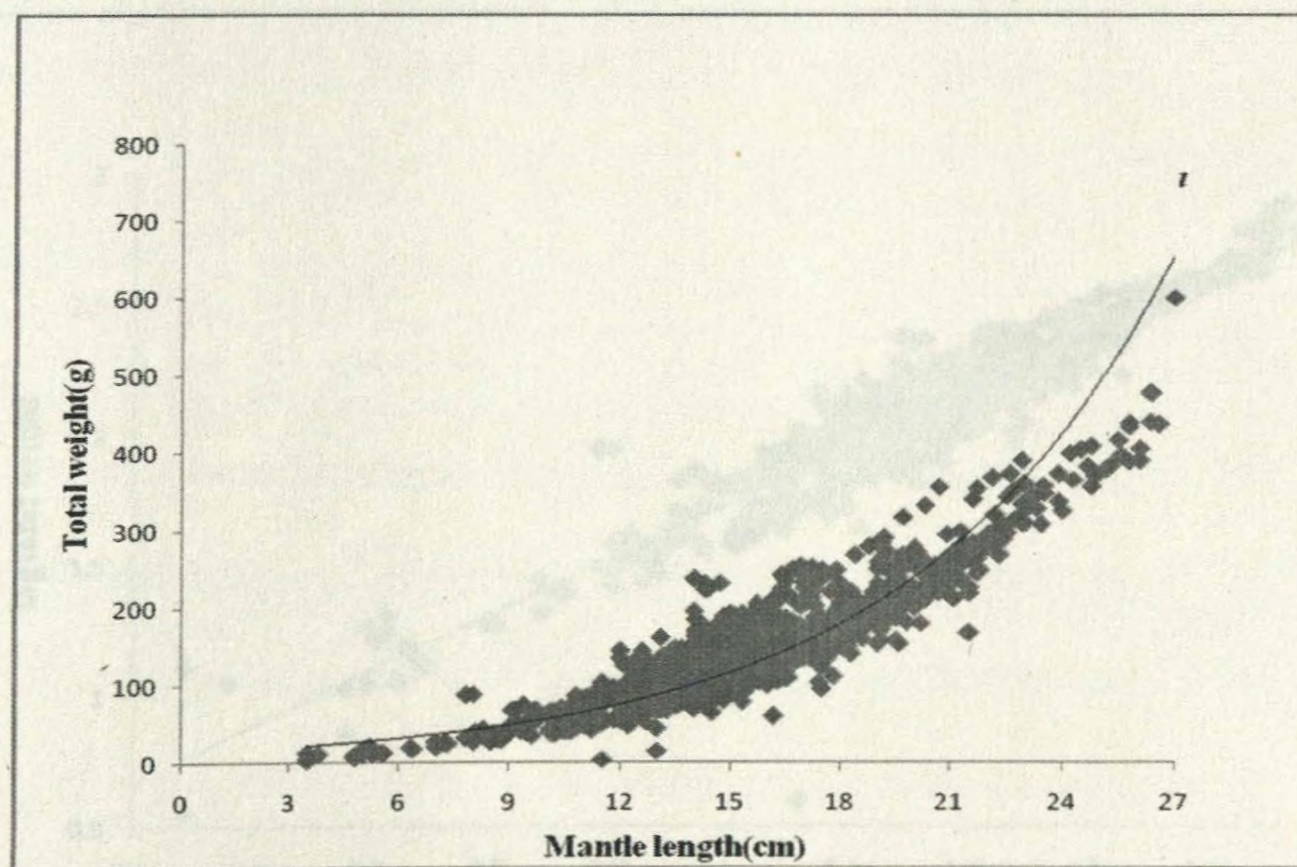


Fig. 5. Total weight versus mantle length of female *S. lessoniana*

Fig. 7. log total weight versus log mantle length of female *S. lessoniana*

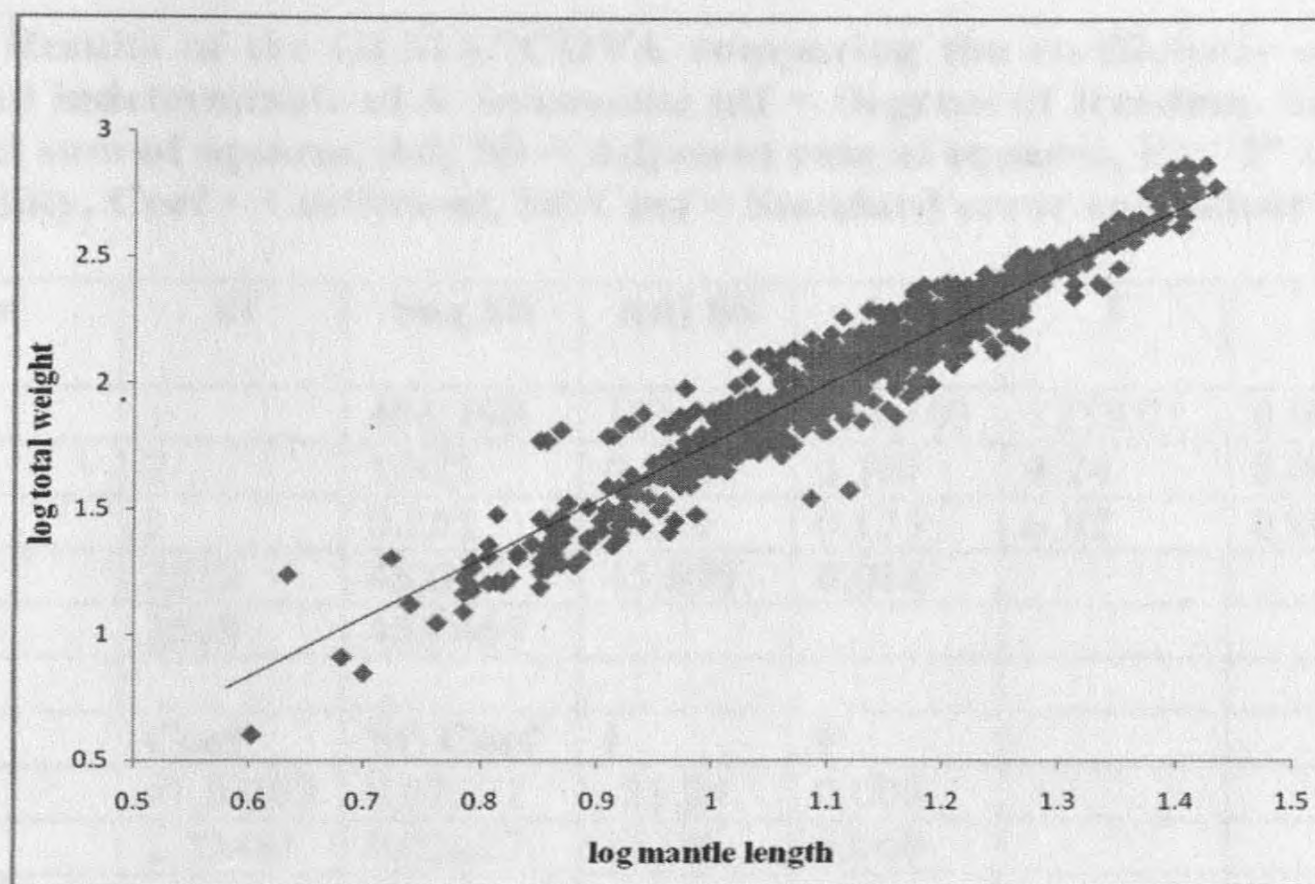


Fig. 6. log total weight versus log mantle length of male *S. lessoniana*

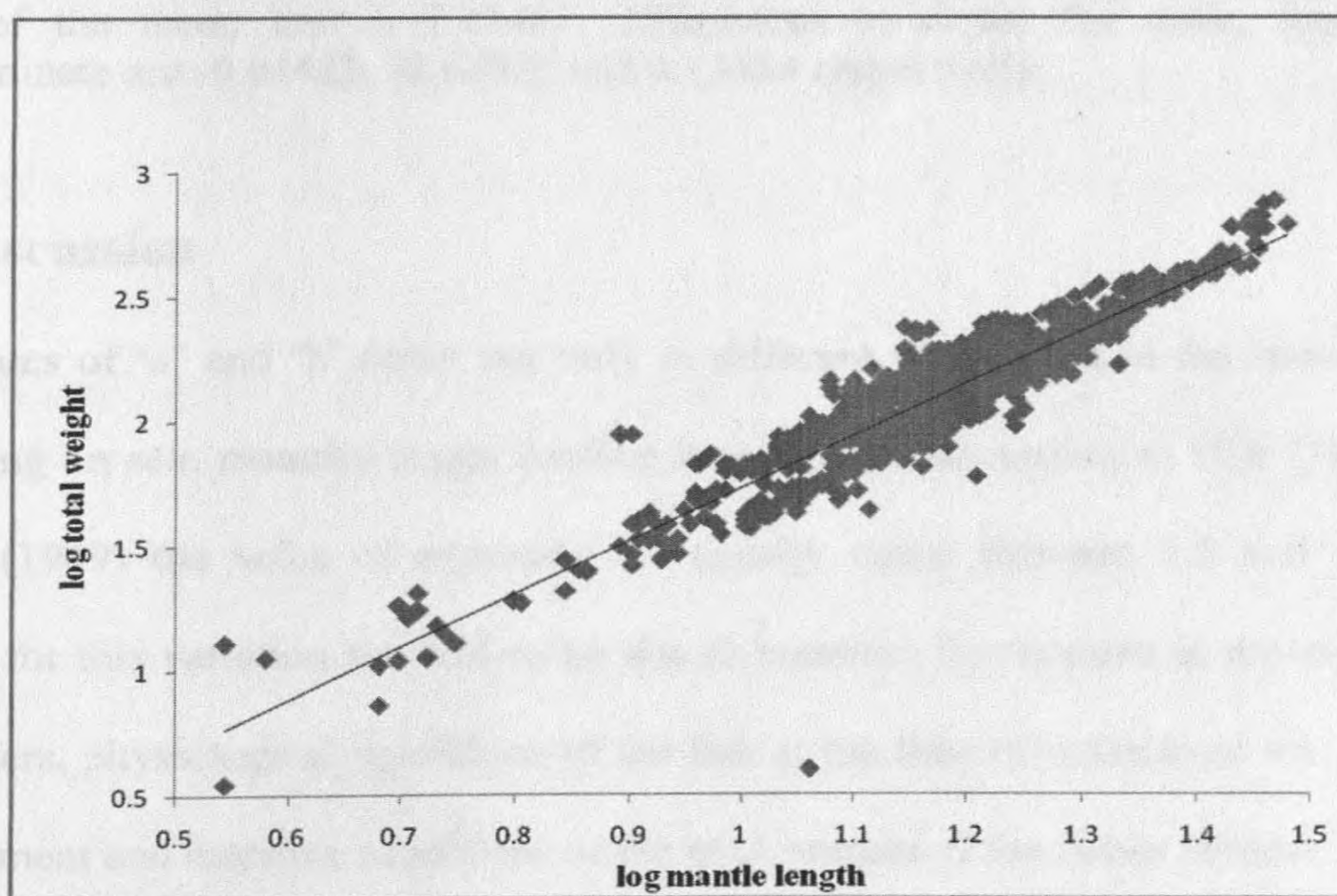


Fig. 7. log total weight versus log mantle length of female *S. lessoniana*

Table 7. Results of the GLMANCOVA comparing the coefficients of male, female and indeterminate of *S. lessoniana* (df = Degrees of freedom, Seq SS = Sequential sum of squares, Adj SS = Adjacent sum of squares, F = 'F' value, P = Probability, Coef = Coefficient, SE Coef = Standard error coefficient and t = 't' value).

Source	df	Seq SS	Adj SS	Adj MS	F	P
all	1	406.198	131.103	131.103	7238.01	0.000
sex	2	1.321	0.335	0.167	9.24	0.000
sex*all	2	0.251	0.251	0.125	6.92	0.001
Error	2523	45.699	45.699	0.018		
Total	2528	453.469				
Term	Coef	SE Coef	t	P		
Constant	-0.50393	0.02372	-21.24	0.000		
all	2.23481	0.02627	85.08	0.000		
all*sex						
Male	-0.01422	0.03096	-0.46	0.646		
Female	-0.12032	0.03239	-3.71	0.000		
Indeterminate	0.13454	0.04617	2.91	0.004		

Interpretation: F-value for “all” showed significant differences; F-value for “sex*all” (interaction) did not show significant difference in slopes (length-weight relationship); Slope of the mean line is 2.23481, differences in slopes for male, female and indeterminate are -0.01422, -0.12032 and 0.13454 respectively.

3.4. Discussion

The values of ‘a’ and ‘b’ differ not only in different species but in the same species depending on sex, maturity stage, feeding intensity etc. according to Hile (1936) and Martin (1949) the value of exponent ‘b’ usually range between 2.5 and 4.0. The reasons for this variation are said to be due to seasonal fluctuations in environmental parameters, physiological conditions of the fish at the time of collection, sex, gonadal development and nutritive conditions of the environment of the fishes (Froese 2006).

The length weight relationship parameters estimated for this species by previous studies expressed ‘a’ = 0.0005 and ‘b’ = 2.255 (Mhithu *et al.* 2001). The ‘b’ value

obtained for *S. lessoniana* in the present study is almost consistent with the recorded value for this species. The growth pattern also remains the same as that of previous studies.

Comparison of the relationship between mantle length - ML (mm) and total weight-TW (g) in different regions of the Mediterranean and eastern Atlantic, as well as comparison of different years indicated an allometric length-weight relationship which is positive in males ($b > 3$) and negative in females ($b < 3$) (Ragonese and Jereb 1992; Gonzalez *et al.* 1992).

Length – weight relationship and morphometric study for squids from Mumbai waters, west coast of India was studied by Karnik and Chakraborty (2001). Chojnacki (1972) described the length – weight relationship for squids *Illex illecebrosus* and *Loligo pealei* from Georges Bank. It was observed that the ‘b’ values obtained for these species exhibit negative allometry with high correlation coefficient value. This result is in consistent with the reported values for ‘b’ in the present study. In a study on *Illex coindetii* in Galician waters, Gonzalez *et al.* (1992) reported mature males had a greater body weight at the same length than the rest of the animals and the regression coefficient was significantly higher than ‘3’ and mature females showed a negative allometry. This result slightly differs from the present study in that negative allometry was observed in all cases, i.e. male, female and indeterminate. Some of the earlier results on length-weight relationship for squids in world waters are summarized in Table 8. Deviation in growth pattern i.e. allometric growth, in the present study could

be attributed to variations in ecology of the geographical locations, food availability and different environmental conditions.

The present study reveals important parameters which are useful in understanding the growth pattern of this species that would definitely lead to a successful management and information for successful culture of *S. lesoniana* in Sri Lankan waters.

Table 8. The parameters of length-weight relationship of squids from different regions of the world (ML – Mantle Length; TL – Total Length; Wt – Weight)

Species	Place	Type of relationship	Sex	a	b	Author
<i>Illex illecebrosus</i>	Georges bank	ML-Wt	M+F	0.2192	1.782	Chojnacki (1972)
<i>Loligo pealei</i>	Georges bank	ML-Wt	M+F	0.5144	2.056	Chojnacki (1972)
<i>Sepia officinalis</i> (Linnaeus, 1758)	Baltic Sea	ML-Wt	M+F	0.2204	2.773	Manfrin Piccinetti and Giovanardi (1984)
<i>Loligo vulgaris</i>	Gulf of Guinea	TL-Wt	M+F	0.4703	2.788	Flamigni and Giovanardi (1984)
			M+F	0.113	2.511	Marano (ed.) (1993)
			M	0.008	2.3501	Krstulović Šifner S (2000)
<i>Eledone cirrhosa</i> (Lamarck, 1798)	Adriatic Sea	ML-Wt	M+F	0.394	2.713	Marano (ed.) (1993)
<i>Eledone moschata</i> (Lamarck, 1798)	Atlantic	ML-Wt	M+F	0.858	2.389	Marano (ed.) (1993)
<i>Illex coindetii</i>	Galician waters	ML-Wt	M	1.496×10^{-5}	3.163	Gonzalez <i>et al.</i> (1992)
			F	3.901×10^{-5}	2.910	Gonzalez <i>et al.</i> (1992)
<i>Sepioteuthis lessoniana</i>	Jaffna lagoon	ML-Wt	M	0.20	2.477	Sivashanthini <i>et al.</i> 2009
			F	0.229	2.4347	Sivashanthini <i>et al.</i> 2009

4. Reproduction

4.1. Introduction

Knowledge on reproductive biology of squid is essential for evaluating the commercial potentialities of its stock, life history, culture practice and it is a central aspect of providing sound scientific advice for fisheries management and conservation of squid species (Bussarawit *et al.* 1990). Failure to recognize the spawning period and size at maturity, leads to misdirection in selective fishing and the depletion of brood stock and immature stocks. Age class distribution together with condition index and fecundity studies provides a rough estimation of sexual maturity.

Reproductive biology plays a large part in determining productivity and therefore a population resiliency to exploitation by fisheries or to perturbation caused by other human activities (Morgan 2008). The importance of quantifying productivity in terms of reproductive potential (RP) and recruitment, as well as the difficulty in doing so, have long been recognized (Ricker 1954; Hilborn and Walters 1992). Reproductive potential of a population is one of the basic exigencies to designate the individuals of that population in respect to their gonadal conditions.

The most suitable method of determining the reproductive cycle in male and female fishes is to observe seasonal developmental changes in the gonads (Karlou-Riga and Economidis 1997). Histological examination is considered for detecting details within

the maturation cycle as maturing fish, partially spawned fish, postovulatory follicles and atretic oocyte (Hunter and Macewicz 1985a; Schafer 1987). Information of gonadal development and the spawning season of a species make subsequent studies on spawning frequency of its population easier, which is important for its management. A thorough understanding of the early development of a species is also considered an important step for the fish culturists.

The big fin reef squid, *Sepioteuthis lessoniana*, is widely distributed throughout the Indo-Pacific (Okutani 1976) and is a valuable fishery resource. It is also becoming an important species for neurobiological and behavioral research (Ikeda *et al.* 2003). For these reasons, there has been growing interest in the development of culturing techniques for *S. lessoniana*. Many studies have been conducted on the population dynamics and reproduction of *S. lessoniana* (Segawa 1987; Ueta and Jo 1989; Ueta *et al.* 1999; Ueta 2000) and such studies have clear relevance for culturing efforts. For example, due to the broad geographic distribution of *S. lessoniana*, a temperature-related hypothesis explaining patterns of reproduction and life span in nature has been formulated: *S. lessoniana* in warmer equatorial waters have a relatively short life span and small adult body size (i.e., they have a 'hot' life-history strategy) compared to squids in cooler subtropical waters, which have longer life spans and larger adult body sizes (i.e. a 'cool' strategy) (Jackson & Moltschaniwskyj 2002). The implications of this hypothesis for culturing *S. lessoniana* are obvious, but despite substantial research on culture techniques (Lee *et al.* 1994; Nabhitabhata 1996; Walsh

et al. 2002b), numerous questions remain regarding maturation and spawning of this species in captivity.

A comparison of the reproductive patterns of captive and wild individuals has been made for *S. lessoniana* in Japan (Ikeda *et al.* 2009). In that study comparisons of rates of maturation, reproductive events and life span between cultured squid and wild-caught squid have been made.

Ovulation of squids may be distinguished as synchronous, group – synchronous and asynchronous ovulation according to oocyte formation and development (Rocha *et al.* 2001). Mode of reproduction in fishes can be expressed as two major types, iteroparous and semelparous. Iteroparous organisms have more than one reproductive event in their life - time whereas, semelparous organisms reproduce only once (Rocha *et al.* 2001).

Little is known about the spawning seasonality of tropical and subtropical squid and cuttlefish (Mangold 1987). In several loliginids mature females and eggs are found year-round. In the Gulf of Mexico *Loligo peali* spawns throughout the year. *Sepioteuthis sepioidea* in the western tropical Atlantic and *S. lessoniana* in the western Pacific also spawn year-around (Choe 1966). However the greater abundance of recruits during certain periods of the year suggests that some seasonality exists.

The present study was carried out to understand some reproductive characteristics such as spawning season, variation in maturation indices with months, fecundity, sperm count and relationships between various measurements and mantle length {for male squids, relationships of weight of testis (TEW) – mantle length (ML), spermatophoric complex weight (SCW) – mantle length (ML), and total sperm count – mantle length (ML) and for females relationships of the total weight of ovary (OW) – Mantle length (ML), weight of oviducal gland (OVW) – Mantle length (ML), Nidamental gland weight (NGW) – Mantle length (ML) and Fecundity (F) – Mantle length (ML)} of tropical *S. lessoniana* from the Jaffna lagoon of Sri Lanka. Such information provides detailed understanding about *S. lessoniana* and knowledge to formulate management measurements in the squid fishery in order to maintain sustainable squid fishery in Sri Lanka.

4.2. Materials and methods

4.2.1. Sampling

The same samples collected for length weight relationship analysis were analyzed for reproductive studies. After measuring the length and weight, squids were cut open ventrally and sexes were confirmed. For each specimen maturity stage was categorized by macroscopic observation of the gonads.

4.2.2. Histological analysis

A subsample of 5 - 10 squids (representing the available size range) was taken from each monthly sample for histological investigations. Gonads were carefully excised

from the body cavity, sex determined, staged macroscopically (Hunter and Macewicz 1985a & b; Schafer 1987 and West 1990) and weighed to the nearest 0.01g (GW). Nearly all immature and mature gonads were examined macroscopically. One gonad was randomly chosen for histological processing in which the medial portion of about 5-10 mm of gonad was removed (Forberg 1982) to avoid possible variation in the developmental stage of oocytes due to their position in the ovary. It was preserved in Formal Acetic Acid (FAA) solution immediately for histological sectioning. In females staged macroscopically as matured females, the remaining ovary was placed in modified Gilson fluid for fecundity counts.

Gonads selected for histological processing were placed in FAA for 2-4 days. Tissue samples were then rinsed overnight with flowing tap water and placed in 70% ethyl alcohol. Dehydrated tissues were embedded in paraffin, sectioned at 6 μ m and stained with Harris haematoxylin and eosin (H&E). Standard histological processing (Ratcliffe 1982) was performed for all samples. The slides prepared were examined by light microscopy with Olympus BX 51 microscope. Photomicroscopy was performed with a Nikon-coolpix 5200 mega pixel digital camera.

4.2.3. Monthly distribution of maturity stages of ovaries

The percentage occurrence of various maturity stages of ovaries in different months was computed by pooling the data for two years and represented graphically. Maturity stages recognized microscopically were categorized in to four stages.

4.2.4. Maturity indices

Various morphometric measurements were measured for males and females. For males, the weight of testis (TEW) and spermatophoric complex weight (SCW: Needham's Sac + spermatophoric complex + penis) were measured; then the spermatophoric complex was dissected to separate the spermatophores and the total numbers of macroscopic spermatophores were counted. For females, the total weight of ovary (OW), weight of oviducal gland (OVW), Nidamental gland weight (NGW) and colour of Accessory Nidamental gland were recorded. Length measurements were measured to the nearest 1 mm using vernier caliper and weight was measured to the nearest 0.001 g using a top loading electronic balance (AND FY 300).

Reproductive indices for females and males were calculated (Durward *et al.* 1979; Lipinski 1979; Juanico 1983; Gabr *et al.* 1998) as expressed in Tables 9 and 10 respectively. These indices were plotted against months for males and females.

Indices	Formula
Gonado Somatic Index GSI	$OW/BW \times 100$
Nidamental Gland Index NGI	$NGW/BW \times 100$
Maturity Co-efficient MCO	$(OW + OVW)/BW \times 100$

(BW is the body weight, OW is the ovary weight, NGW is the nidamental gland weight and OVW is the oviducal complex weight).

Table 10. Formulations of various reproductive indices for males.	
Indices	Formula
Gonado Somatic Index GSI	$TEW/BW \times 100$
Spermatophoric Complex Index SCI	$SCW/BW \times 100$
Maturity Co-efficient MCO	$(TEW + SCW)/BW \times 100$

(BW is the body weight, TEW is the testis weight and SCW is the spermatophoric complex weight. The spermatophoric complex includes the spermatophoric organ, vas deference, spermatophoric sac or Needam's sac, sperm duct and penis).

4.2.5. Fecundity

Fecundity was defined as the total number of maturing ova (with striation) and mature ova (large smooth ova) in the ovary, and the number of ova in the oviducal glands, proximal and distal glands (Gabr *et al.* 1998).

Collected eggs were preserved in Gilson's fluid for at least 48 hours in order to count the total number of eggs, the fecundity. Fecundity was counted in 464 females ranging from 7.0 to 26.0 cm mantle length. In the ovaries, there were different stages of ova; striation was used to group ova as small (without striation and milky in appearance), maturing (with striation) or mature (large and smooth – transparent) (Gabr *et al.* 1998).

4.2.6. Size at maturity

Length at maturity was analyzed for squids collected from August to February to reduce the possibility of classifying resting, mature squids as immature. Length at maturity was based on 689 females and 784 males (3.5 to 30.2 cm ML). The maturity data were grouped into 2.0 cm size groups and the percentage occurrence of the specimens in each size group was calculated. Size at first maturity was arrived by plotting the percentage occurrence of mature specimens against total length and by obtaining the length at 50% maturity (L_{50}).

4.2.7. Relationship between mantle length and other parameters

For male squids, relationships of weight of testis (TEW) – mantle length (ML), spermatophoric complex weight (SCW) – mantle length (ML), and total sperm count – mantle length (ML) were fitted by the logarithmic transformation of $\text{Log } Y = \log a + b \log X$ (Bagenal and Tesch 1978), where Y is the dependant variable and X is the independent variable.

Similarly for females, relationships of the total weight of ovary (OW) – Mantle length (ML), weight of oviducal gland (OVW) – Mantle length (ML), Nidamental gland weight (NGW) – Mantle length (ML) and Fecundity (F) – Mantle length (ML) were fitted by the least square regression analysis.

4.2.8. Sex ratio

Sex ratio was determined from the number of specimens of each sex sampled every month to test the significant deviations from an expected 1:1 sex ratio for all male and female fishes. The sex ratio values obtained every month were subjected to chi-square test (Sokal and Rohlf 1981) with Yate's correction (Zar, 1999) employing the formula,

$$X^2 = \sum [(o-e) - 0.5]^2 / e \quad (\text{Zar, 1999}).$$

where o = observed number and e = expected number.

4.3. Results

4.3.1. Sampling - Size range and sex determination

A total of 2297 specimens of *S. lessoniana* (1189 males and 1108 females) collected from commercial catches of squid fishery from the Jaffna lagoon of Sri Lanka were used for the study. The size (dorsal mantle length, ML) of male *S. lessoniana* ranged from 3.8 to 29.7 cm ML while that of females ranged from 3.5 to 30.2 cm ML. Two hundred and thirty two unsexed specimens which ranged from 2.4 to 12.5 cm ML were also collected.

Sexes can be differentiated externally in *S. lessoniana*. In female fresh specimens, whitish colour mass (Nidamental gland), and pale colored ovary were visible through the ventral side of the mantle and in fresh male specimens chromatophore arrangements create transverse bars in the dorsal side of the mantle and hectocotyle arms were also observed. External and internal features of male *S. lessoniana* is

shown in plate 7. Photograph and line drawing of hectocotylized arm is shown in plates 8 and 9 respectively. In comparison, matured males were narrow and longer (Mantle length and mantle width of male and female *S. lessoniana* was statistically significant, P value for two sample t-test > 0.05 in both instances) than matured females. Dissection through mid ventral axis clearly defined the sexes. External and internal features of female *S. lessoniana* are shown in plate 10.

Macroscopic observation of ovary showed presence of different stages of ova in the ovary (plate 11). In freshly dissected ovaries the matured eggs were observed in the peripheral region whereas immature and maturing eggs were observed as the central mass. Extrusion of matured eggs to the exterior through the oviduct and sperms through the penis was also observed in females and males and it is shown in plates 12 and 13 respectively. Interestingly some females had bunches of spermatophores at the buccal funnel region and a photograph of it is shown in plate 14.

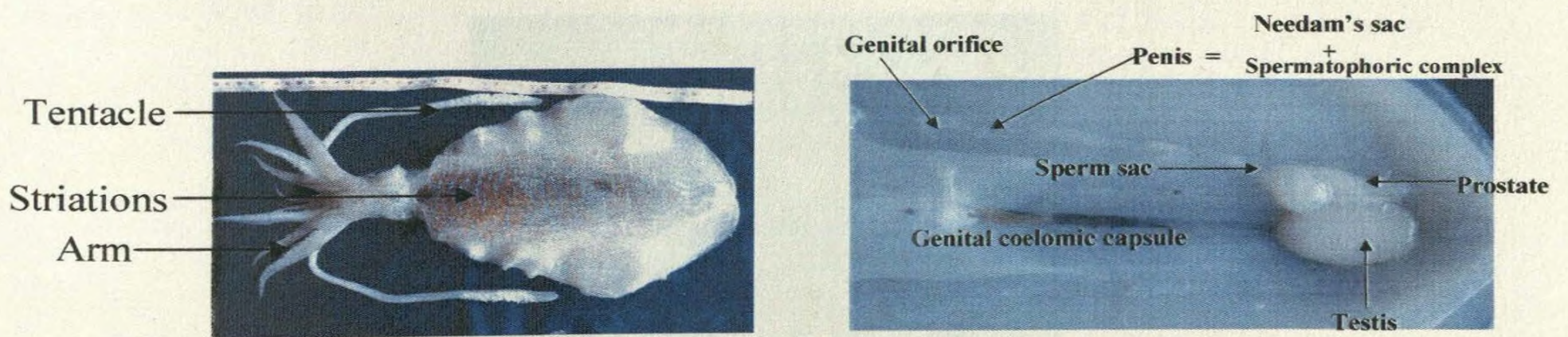


Plate 7. External and Internal features of male *S. lessoniana*

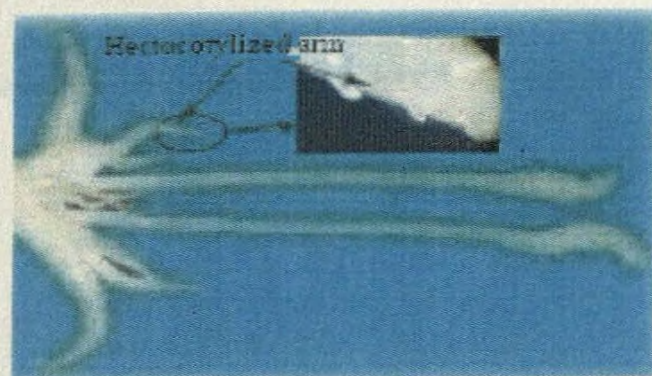


Plate 8. Detailed photograph of hectocotyli arm of male *S. lessoniana*

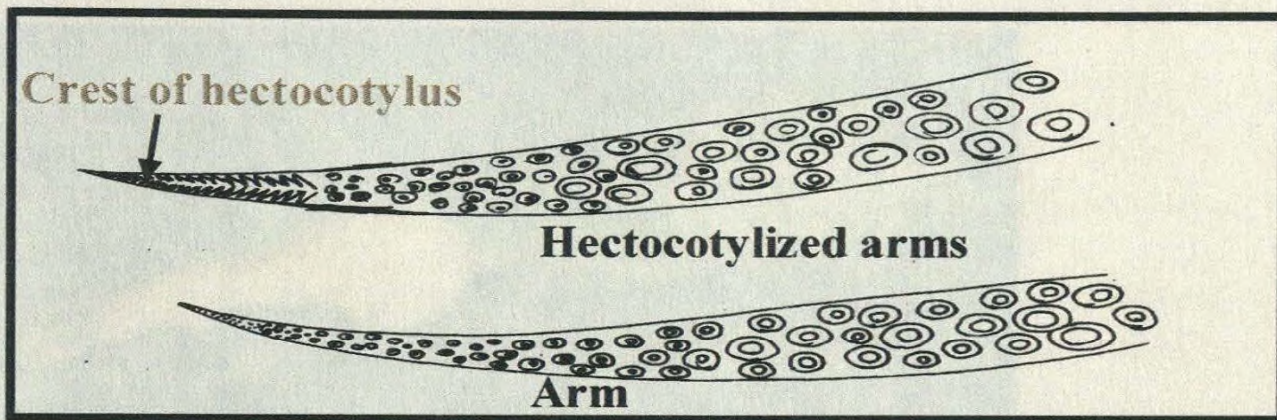


Plate 9. Detailed drawing of hectocotyli arm of male *S. lessoniana*

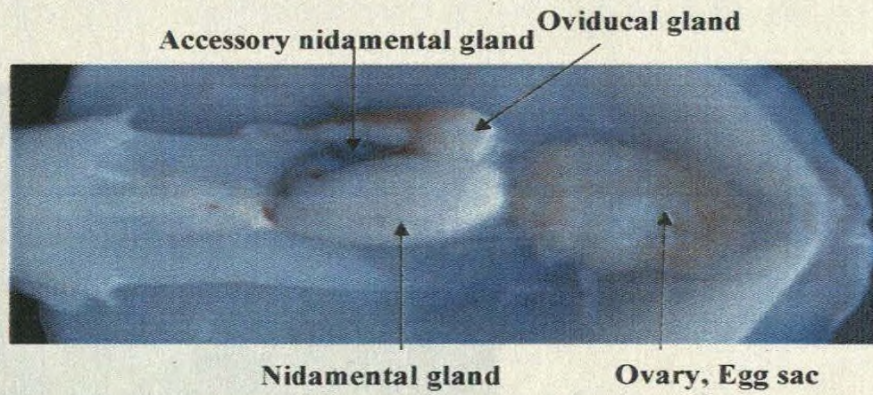
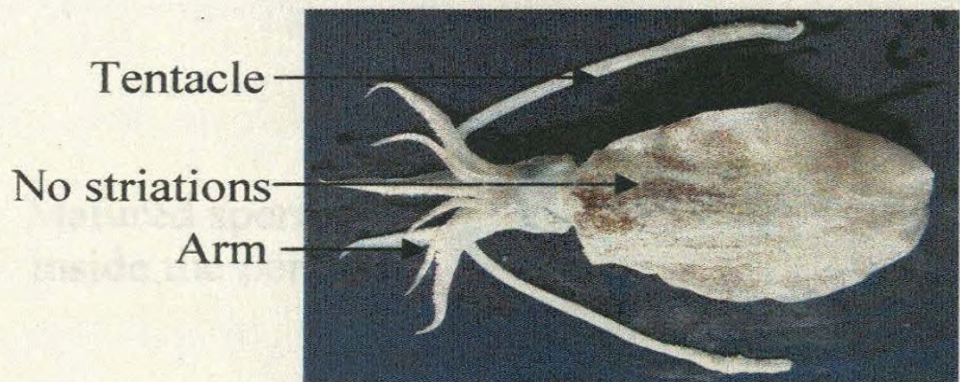


Plate 10. External and Internal features of female *S. lessoniana*

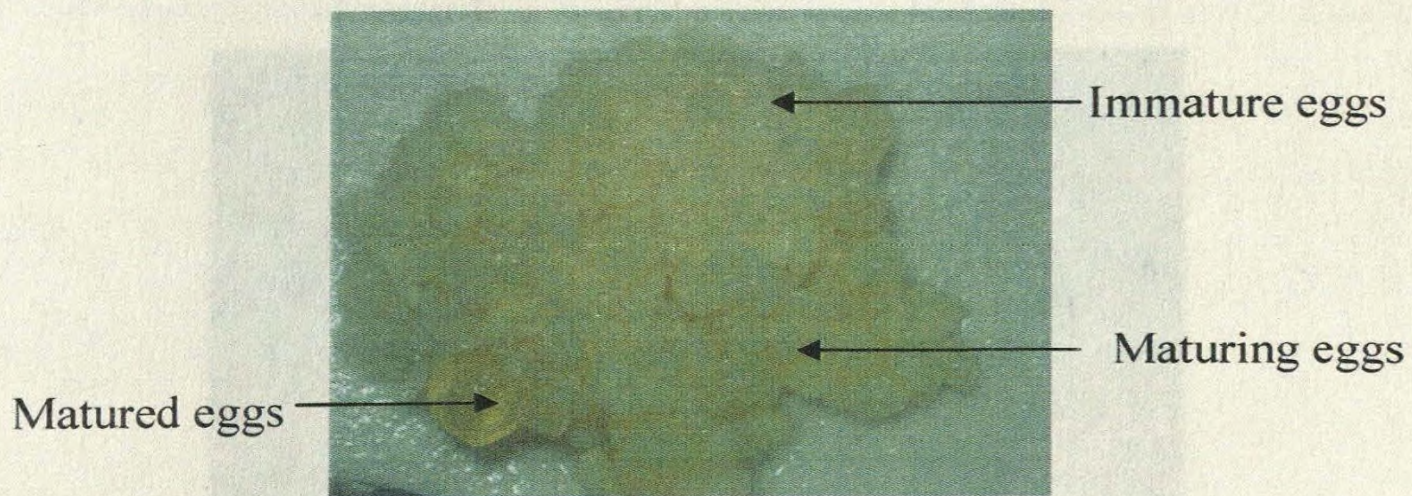


Plate 11. Different sizes of eggs *S. lessoniana*

4.3.2. Histology of gonads

All collected specimens were examined microscopically. According to the histological analysis of gonads females were categorized into immature, maturing, fully mature and spawning stages.

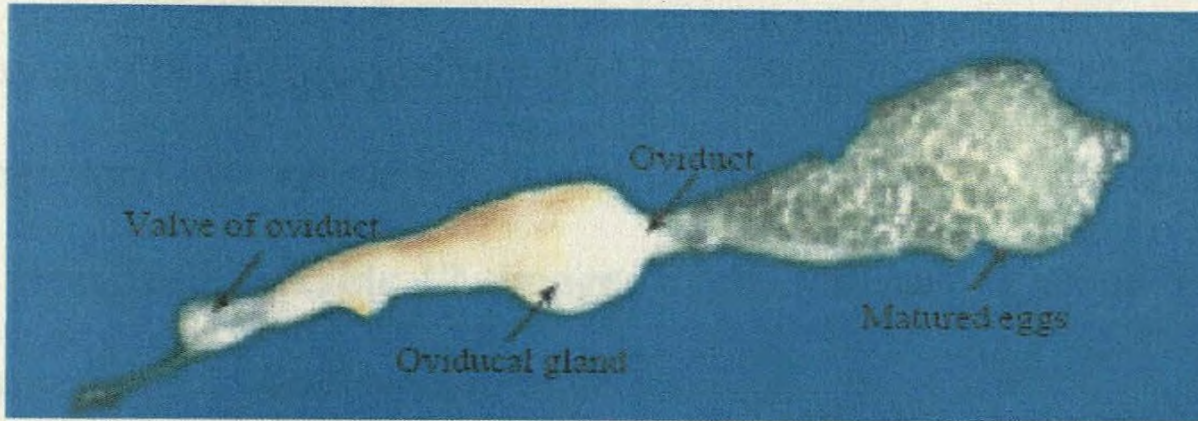


Plate 12. Matured eggs are expelling through the oviducal gland of *S. lessoniana*

Among the specimens analyzed 188 ovaries and 269 testes were subjected to histological study.

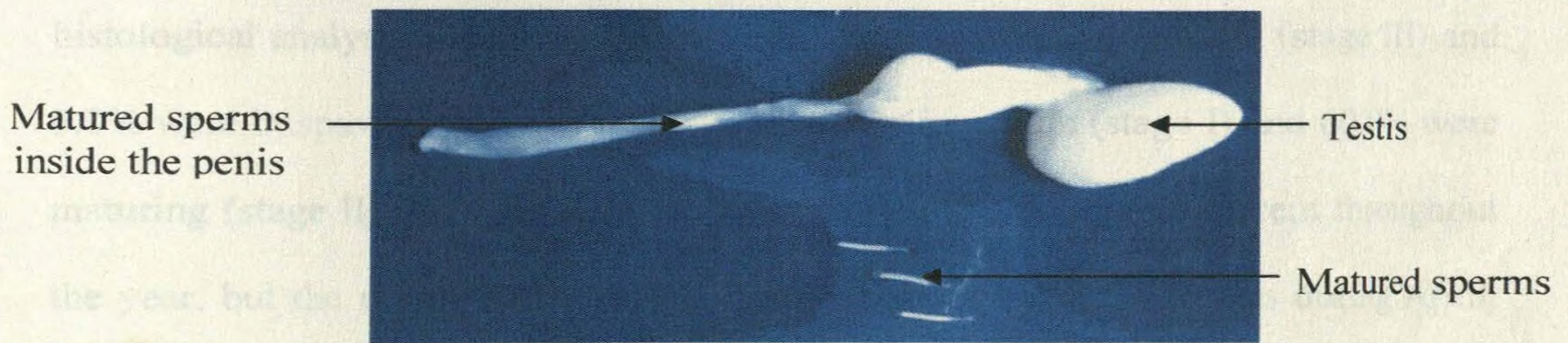


Plate 13. Matured sperms expelling through the penis of *S. lessoniana*

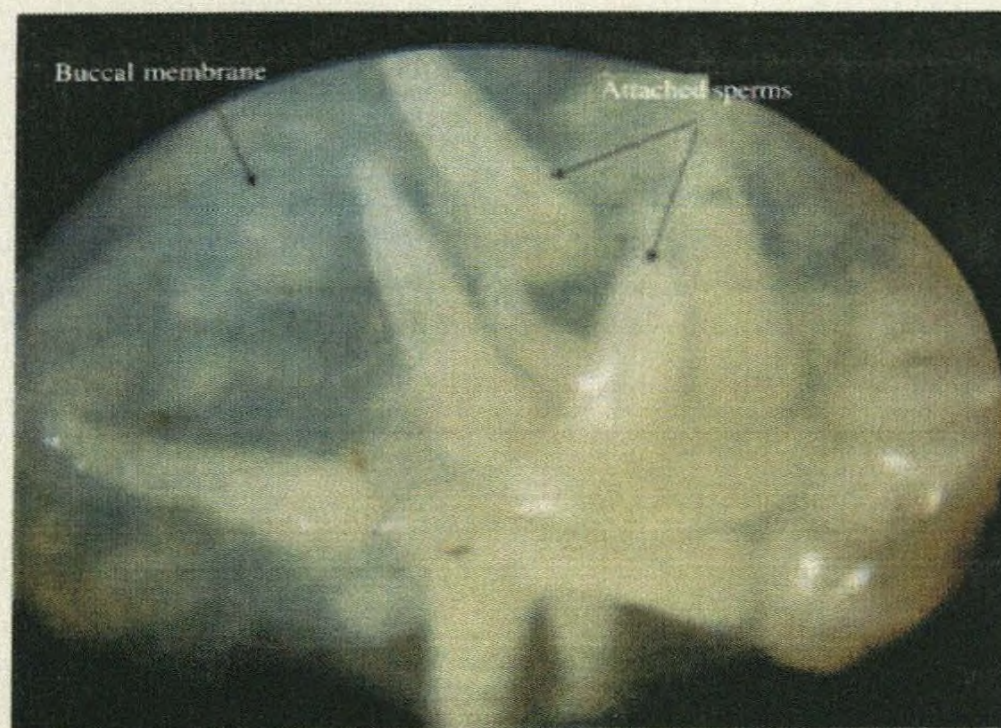


Plate 14. Sperms attached to the females buccal membrane

4.3.2. Histology of gonads

All collected specimens were examined macroscopically. According to the histological analysis of gonads females were categorized into immature, maturing, fully maturing / pre spawn and matured / spawn as described in Table 11 while males were categorized into immature, maturing, fully maturing / pre spawn and matured / spawn as described in Table 12. Images of the various stages of *S. lessoniana* ovary are shown in Plate 15 and testis in plate 16.

Among the specimens analyzed 305 ovaries and 269 testes were subjected to histological analysis. Of these, 11.0% were in pre spawning condition (stage III) and 5.0% were in spawn (stage IV) while 24.0% were immature (stage I) and 60.0% were maturing (stage II). Females with maturing ova (stages II) were apparent throughout the year, but the main occurrence of spawning and spent females was during April, August, October and November. Some spawning and spent females were evident throughout the year. Similar occurrence was also observed for males.

Table 11. Female maturity stages of *S. lessoniana*

Identified maturity stage	Size of oocyte	Morphological observations of the reproductive combine organs	Histological observation
Stage I Immature	All oocytes below 1 mm	Very small ovary. Transparent NG. No OG	Cluster of developing oocytes surrounded by the follicular cells
Stage II Maturing	All oocytes below 1 mm and uniform	Clearly visible NG. Transparent OG. Visibly granular like uniformly sized oocytes.	More oocytes surrounded by the follicular cells. Follicles initiate to penetrate the developing oocytes
Stage III Fully maturing/ pre spawn	All stages below 1mm, 1-2 mm and 2-6mm	White NG. OG begins from yellow to brown. Large number of 1-2 mm striated oocytes. Chromatophores create transverse bars in the dorsal side of the mantle.	More follicular epithelium initiates to enter the oocytes and forms the folds.
Stage IV Matured/ Spawn	All stages Less Number below 1mm, 1-2 mm and 2-6mm in more Number	Large ovary smooth oocytes surrounded the periphery of the maturing oocytes. Swallowed white NG. Full of smooth transparent oocyte in proximal end of the brownish OG	Degeneration of follicular epithelium.

Table 12. Male maturity stages of <i>S. lessoniana</i>			
Identified maturity stage	Size of Sperm	Morphological observations of the reproductive combine organs	Histological observation
Stage I Immature	No sperm	Small transparent testis, thin developing spermatophoric organ	Considerable numbers of spermatogonia mass along insides the wall of semniferous tubule
Stage II Maturing	No sperm	Enlarged thickened testis, poor developing lees number of sperm within the Needham's sac, chromatophores create transverse bars in the dorsal side of the mantle. Left ventral arm begins to hectocotyli by a modification of the distal 4 th of the arm.	Spermatogonia with large numbers of spermatocytes present
Stage III Fully maturing/ pre spawn	Below 6 mm	Transparent thread like bundle of poorly developed full of sperms within the Needham's sac. Left ventral arm is hectocotyli by a modification of the distal 4 th of the arm.	Spermatozoa in abundance
Stage IV Matured/ Spawn	6-7 mm	White needle like bundle of developed full of sperms within the Needham's sac.	

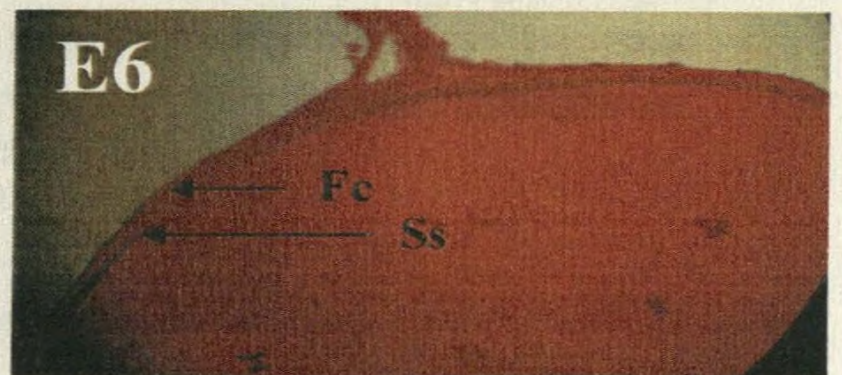
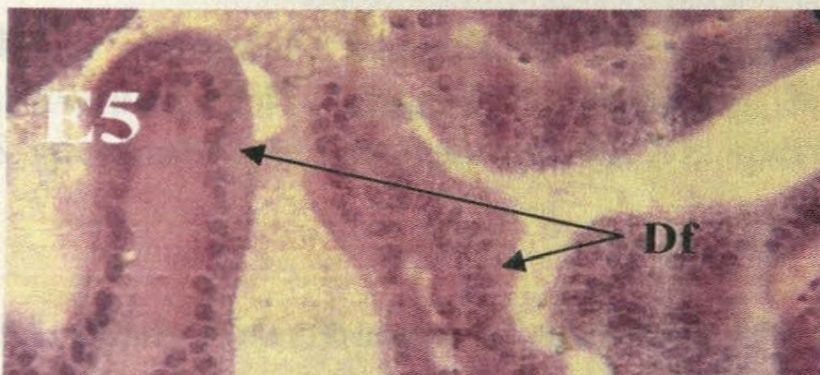
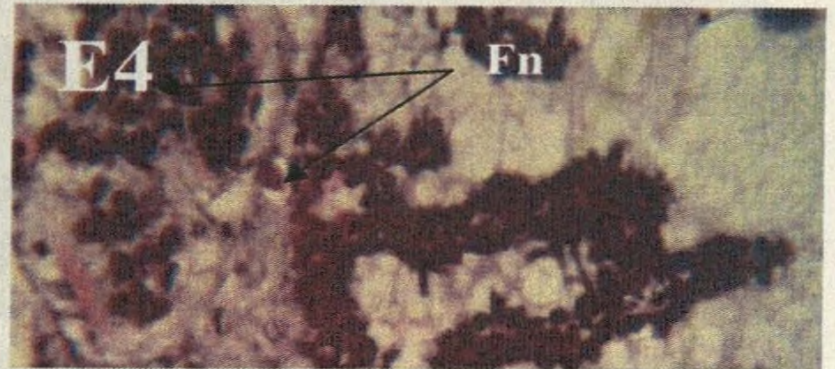
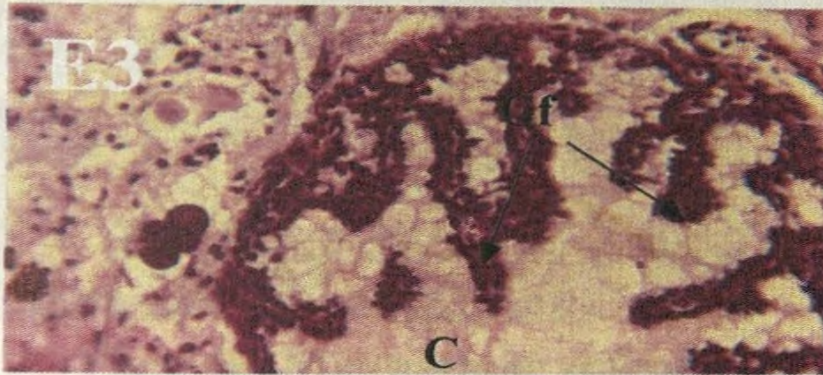
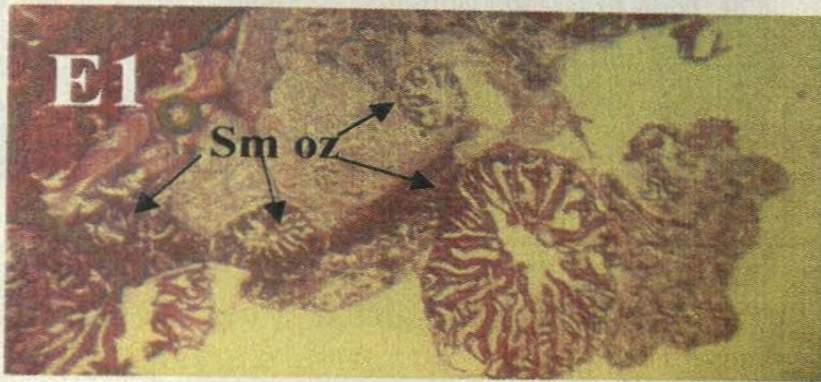


Plate 15. Microscopic stages of oocyte development of *S. lessoniana*

E1 - Stage I: Immature; **E2** - Stage II: Maturing; **E3**- Stage III: Pre spawning; **E4** - Pre spawning (enlarged); **E5** - degenerating stage; **E6** - Stage IV: Spawning; C: cytoplasm; Fc: follicle cell; Fn: follicle nucleus; Df: degenerating fold; Gf: generating fold; Sm oz: small oocyte; Ss: smooth surface; Str: striated oocyte.

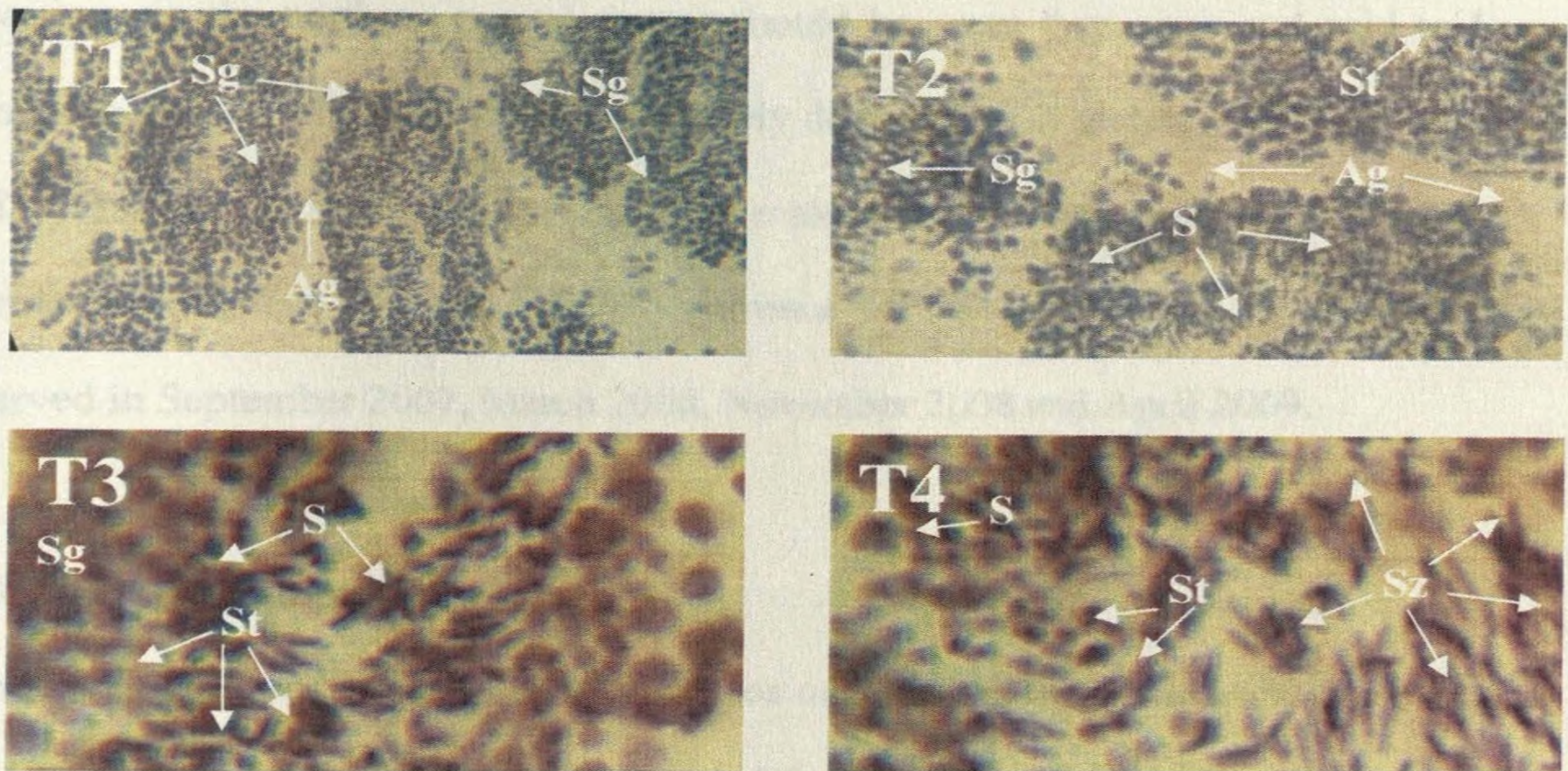


Plate 16. Microscopic stages of spermatid development of *S. lessoniana*

T1 - Stage I: Immature; **T2** - Stage II: Maturing; **T3** - Stage III: Pre spawning; **T4** - Stage IV: Spawning. Ag: artifactual gap Sg: spermatogonia; S: spermatocyte; St: spermatids; Sz: spermatozoa.

4.3.3. Monthly distribution of maturity stages of ovaries

Monthly distribution of maturity stages of ovaries of *S. lessoniana* is illustrated in Fig. 8. In female *S. lessoniana*, spawning stage was recorded throughout the year. High percentages i.e. 64%, 62% and 60% of immature squids recorded in September 2007, November 2008 and December 2007 & March 2009 respectively. No immature squids were recorded in August 2007. Maturing squids were recorded throughout the year; very low percentage in August 2007. High occurrence of spawning stage in squids was observed in August 2007, November 2007, April 2008 and October 2008. This suggests that the peak spawning period of *S. lessoniana* is in April, August,

October and November even though it spawns throughout the year. Presence of all stages of macroscopic eggs in the same ovaries confirms that the spawning of *S. lessoniana* in the northern coastal waters should be more than once and said to be asynchronous or group synchronous. Monthly distribution of maturity stages of testis of *S. lessoniana* is illustrated in Fig. 9. In male *S. lessoniana*, spawning stage was recorded throughout the year. High occurrence of spawning stage for males was observed in September 2007, March 2008, November 2008 and April 2009.

4.3.4. Maturity indices

Monthly variation of various maturity indices of male and female are shown in Fig. 10 and 11. For males, the MCO values varied from 0.956 to 4.022 with an average of 1.67 ± 0.605 ; GSI values varied from 0.648 to 1.5 with an average of 1.004 ± 0.256 ; SCI values varied from 0.443 to 3.357 with an average of 0.832 ± 0.565 . For females, the MCO values varied from 8.235 to 12.879 with an average of 10.568 ± 1.311 ; GSI values varied from 3.440 to 8.670 with an average of 6.393 ± 1.216 ; NGI values varied from 2.092 to 5.849 with an average of 4.241 ± 0.911 .

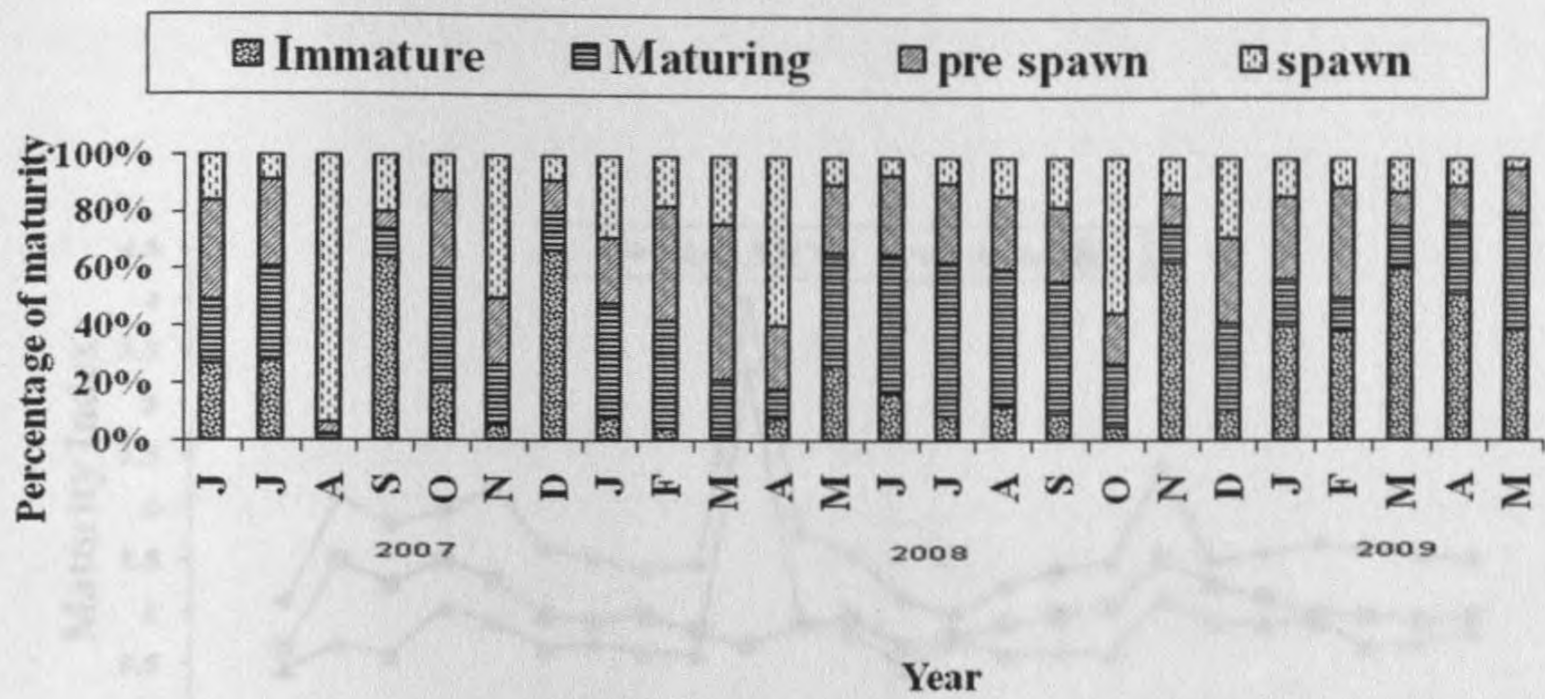


Fig. 8. Monthly distribution of maturity stages of female *S. lessoniana*

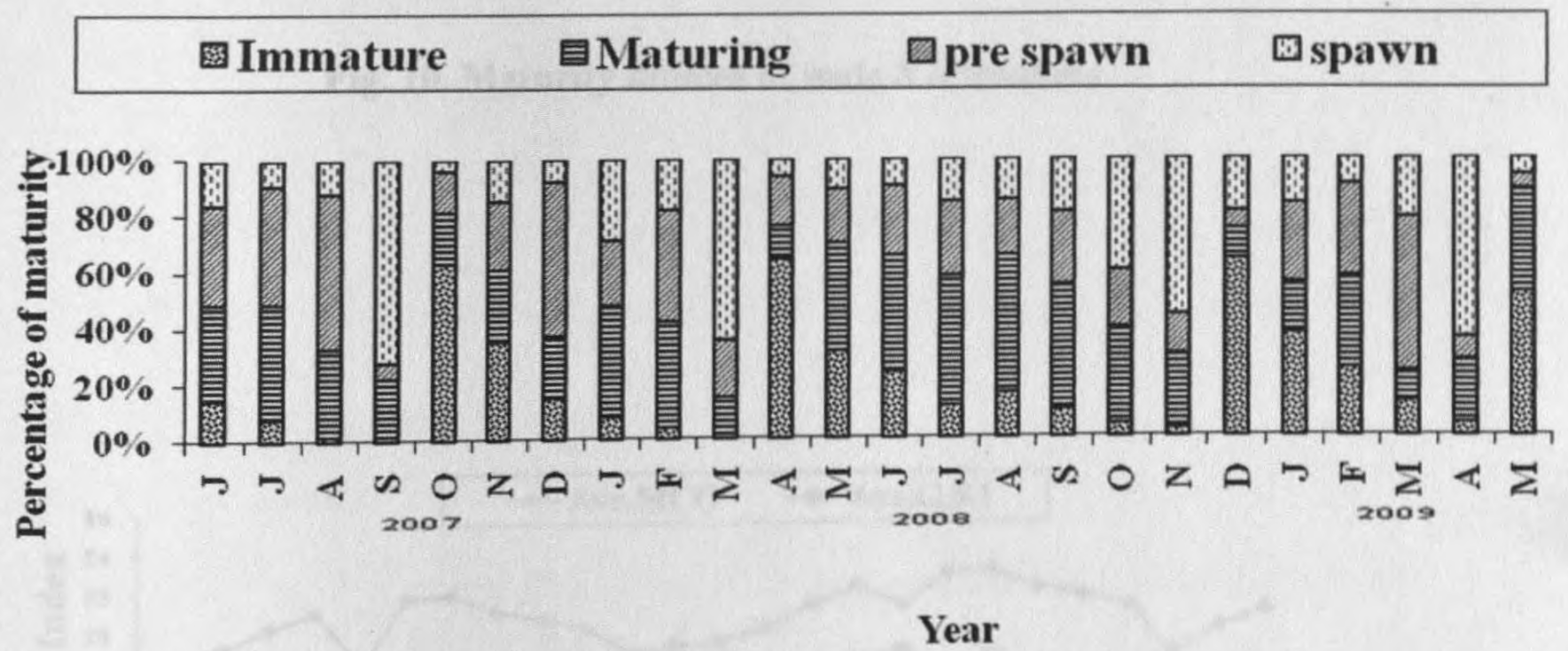


Fig. 9. Monthly distribution of maturity stages of male *S. lessoniana*

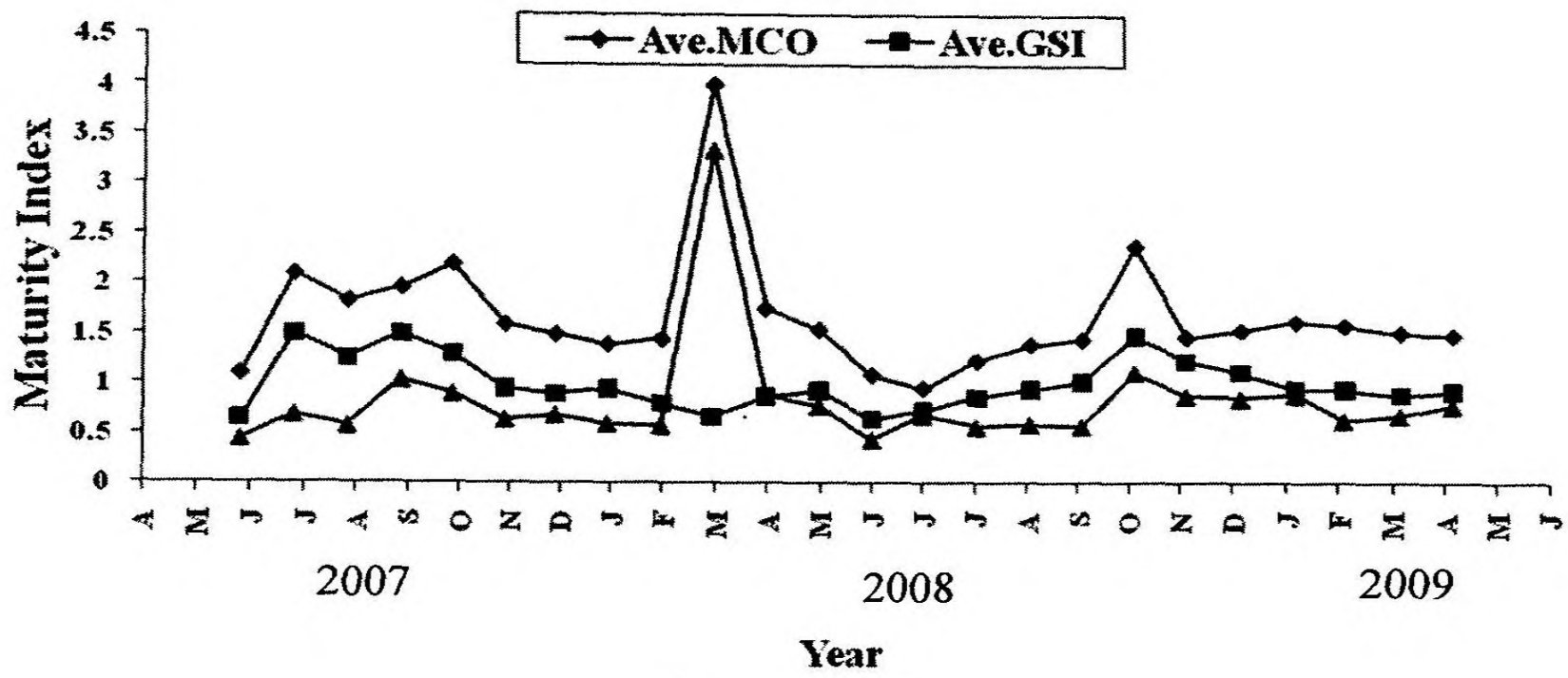


Fig. 10. Maturity indices of male *S. lessoniana*

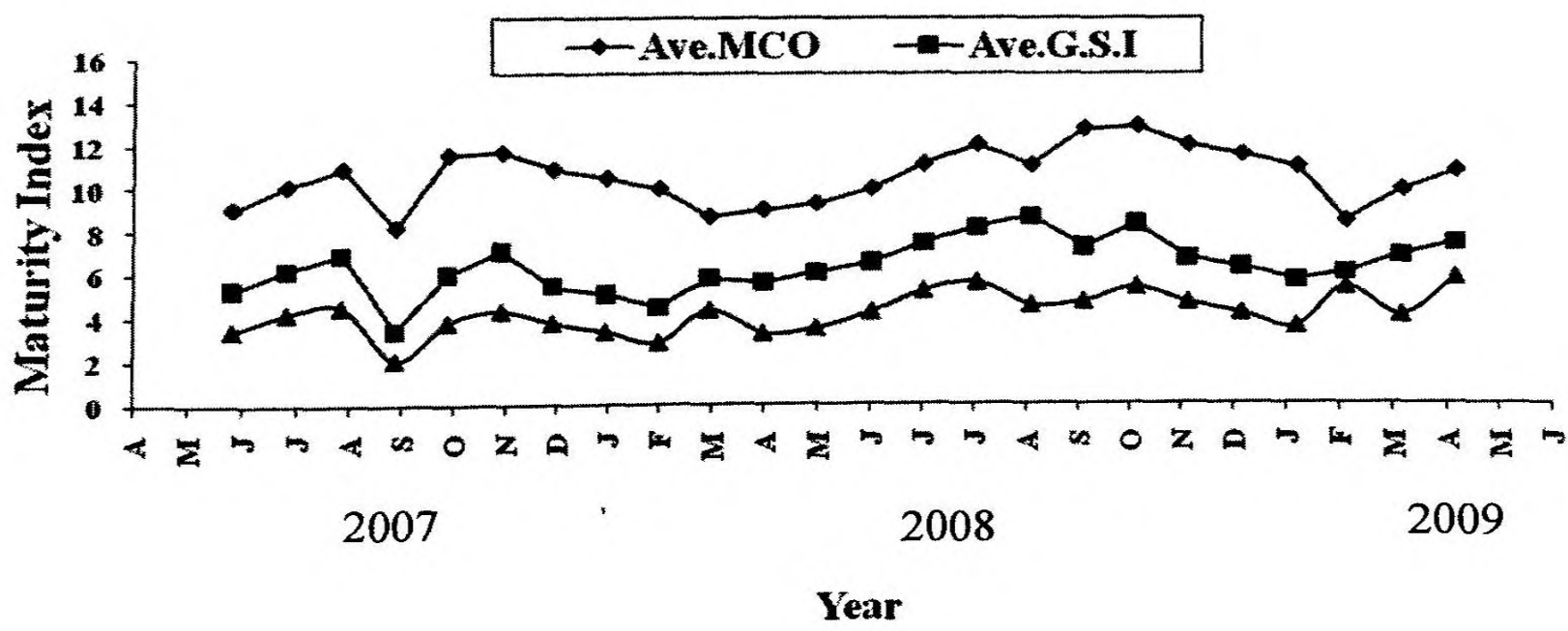


Fig. 11. Maturity indices of female *S. lessoniana*

4.3.5. Fecundity

Fecundity increased exponentially with mantle length (ML) from 20 (7 cm) to 852 (30.2 cm ML) but a significant correlation was obtained with mantle length ($r = 0.535$, $P < 0.01$), (Fig. 12). Regression equation for log fecundity versus log mantle length is given in Table 13. In males number of sperm varies from 5 to 568 for individuals of 9.8 to 29.7 cm dorsal mantle length.

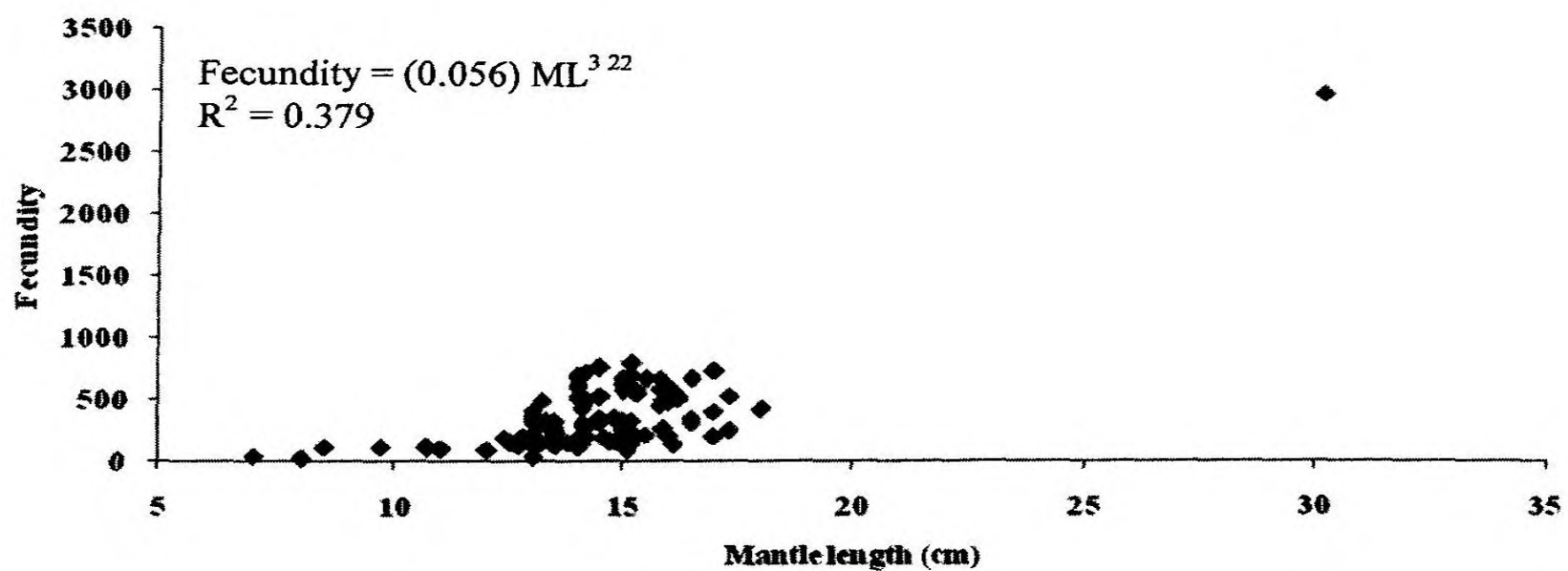


Fig. 12. Relationship between fecundity and mantle length of female *S. lessoniana*

4.3.6. Size at maturity

Plots obtained for percentage occurrence of mature squids (Fig. 13 and 14) against mantle length class interval indicates that *S. lessoniana* male reached maturity at 16.0 cm mantle length while female reached maturity at 17.0 cm mantle length. All males and females were matured at 22.0 cm mantle length.

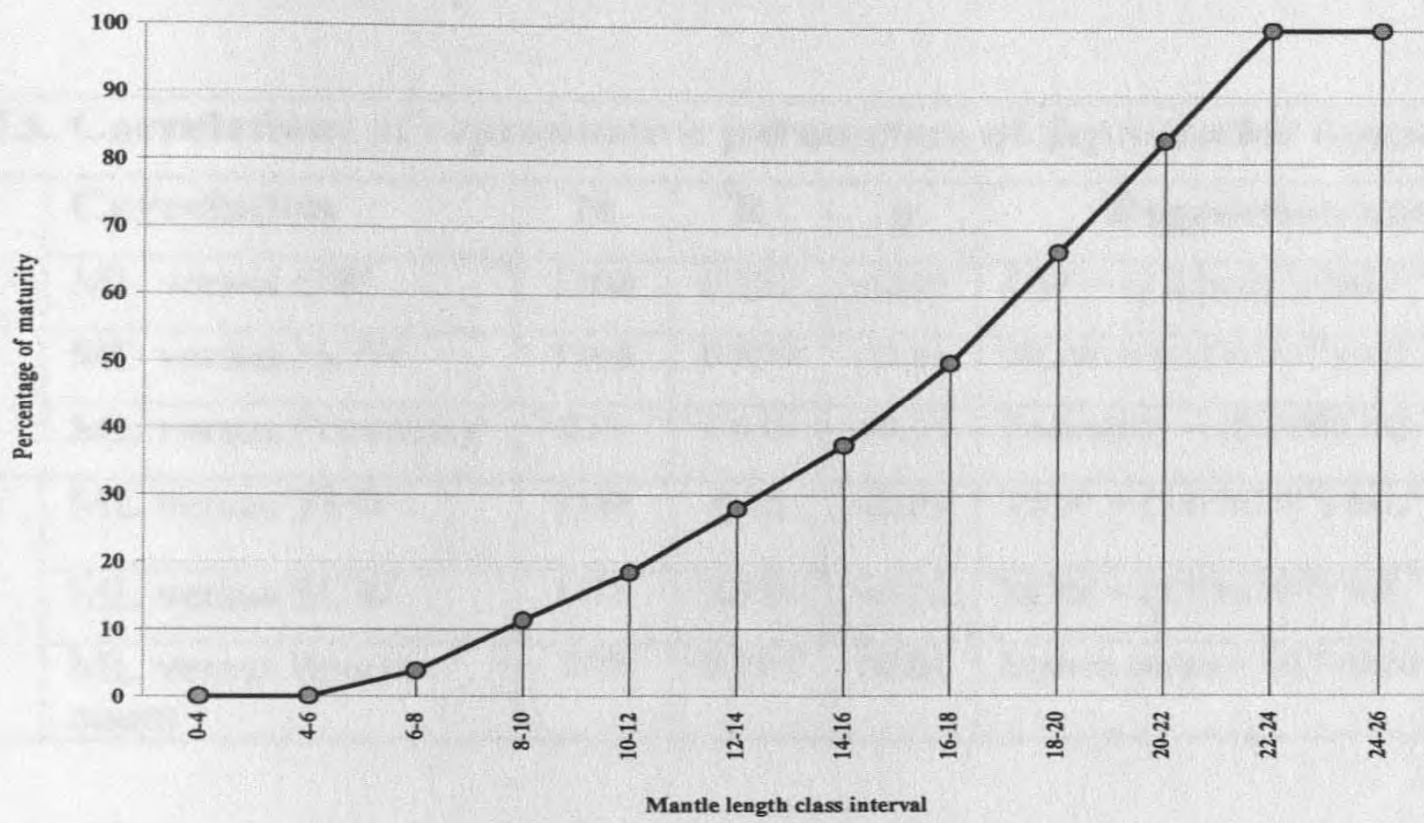


Fig. 13. Percentage maturity of female *S. lessoniana*

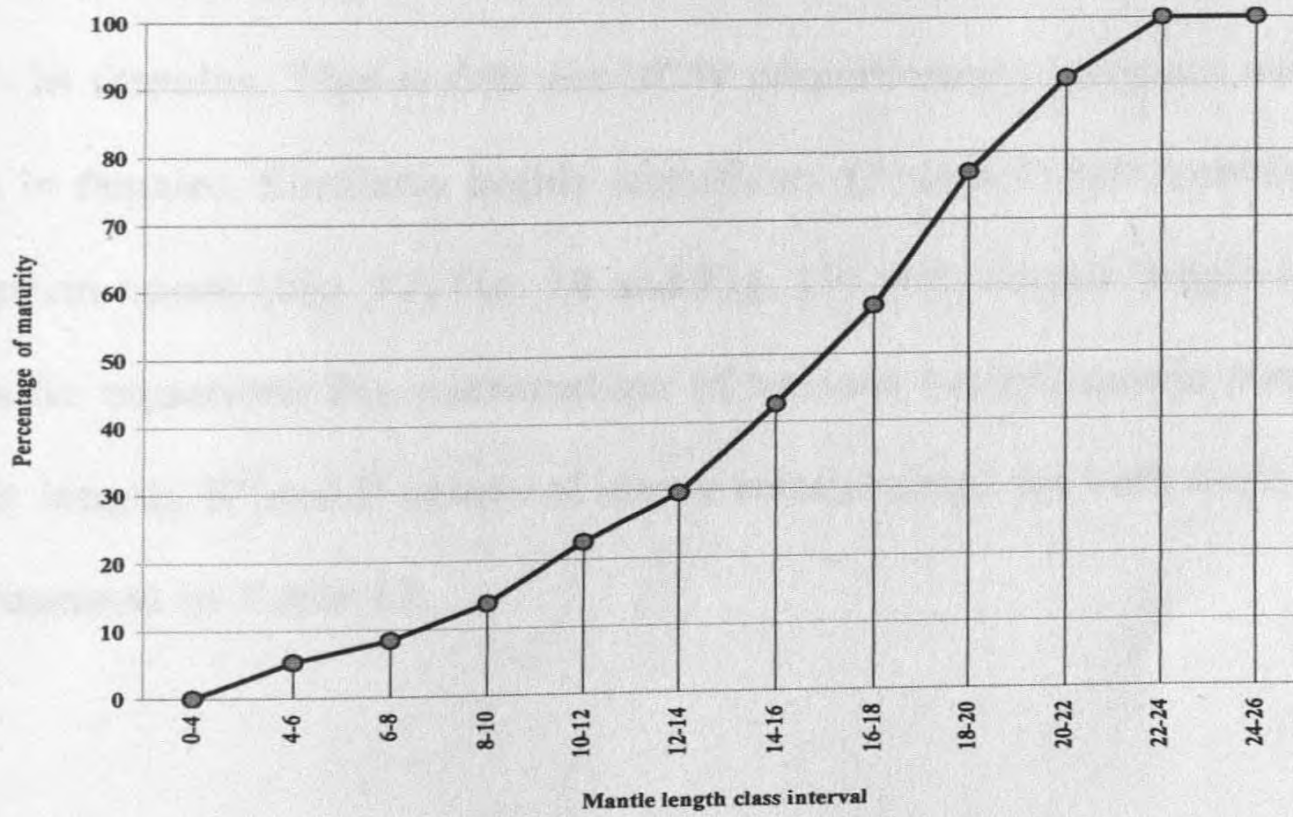


Fig. 14. Percentage maturity of male *S. lessoniana*

	Correlation	N	R	p	Regression equation
Female	ML versus OW	1108	0.767	<0.01	$OW = (2.24 \times 10^{-7}) ML^{6.46}$
	ML versus NGW	1108	0.879	<0.01	$NGW = (4.57 \times 10^{-7}) ML^{6.12}$
	ML versus Fecundity	233	0.616	<0.01	$Fecundity = (0.056) ML^{3.22}$
Male	ML versus TEW	1189	0.78	<0.01	$TEW = (5.62 \times 10^{-4}) ML^{2.95}$
	ML versus SCW	1189	0.854	<0.01	$SCW = (5.89 \times 10^{-5}) ML^{3.65}$
	ML versus Sperm count	217	0.767	<0.01	$Sperm\ count = (6.76 \times 10^{-3}) ML^{3.44}$

4.3.7. Relationship between mantle length and other parameters

The least square linear regression analysis expressed that there are highly significant ($P < 0.001$) relationships for OW and NGW (Fig. 15 and Fig. 16) with the mantle length in females. That is OW and NGW proportionately increased with increasing mantle length in females. Similarly highly significant ($P < 0.001$) relationships for TEW, SCW and sperm count (Fig. 17, Fig. 18 and Fig. 19) with mantle length obtained for males. Parabolic equations for relationships of various morphometric measurements versus mantle length, R^2 and P values of above relationships for both male and female squids are presented in Table 13.

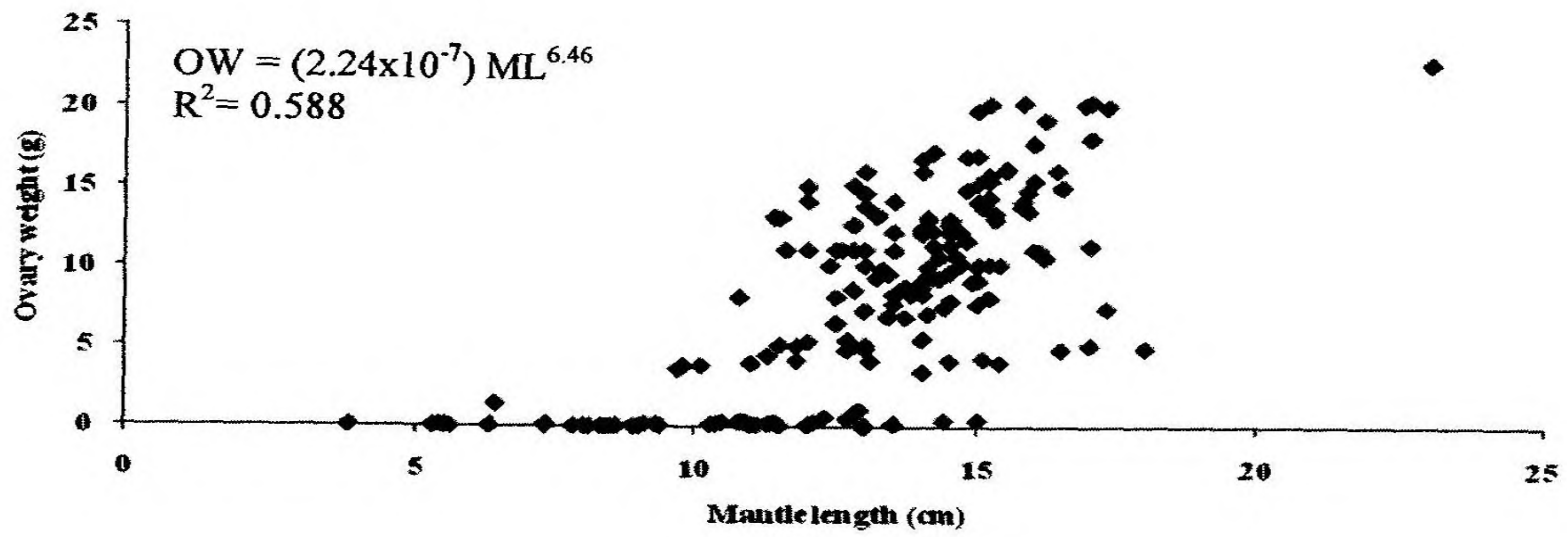


Fig. 15. Relationship between ovary weight and mantle length of female

S. lessoniana

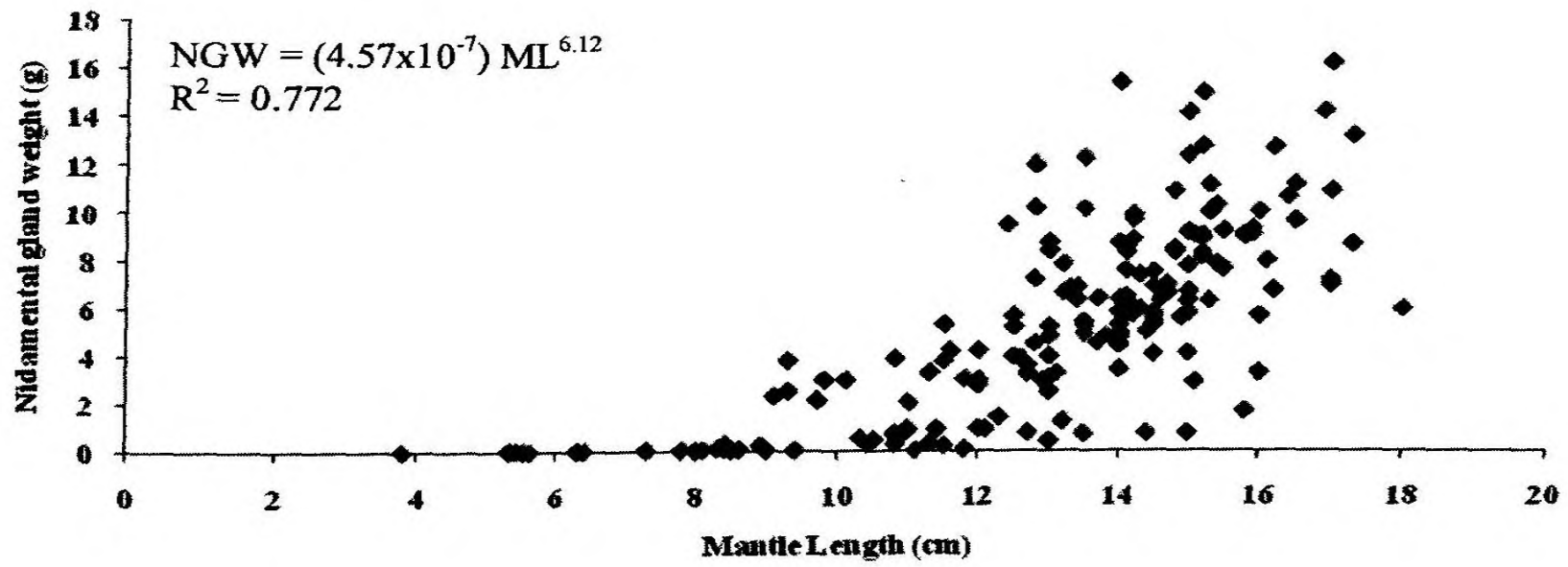


Fig. 16. Relationship between nidamental gland weight and mantle length of

female S. lessoniana

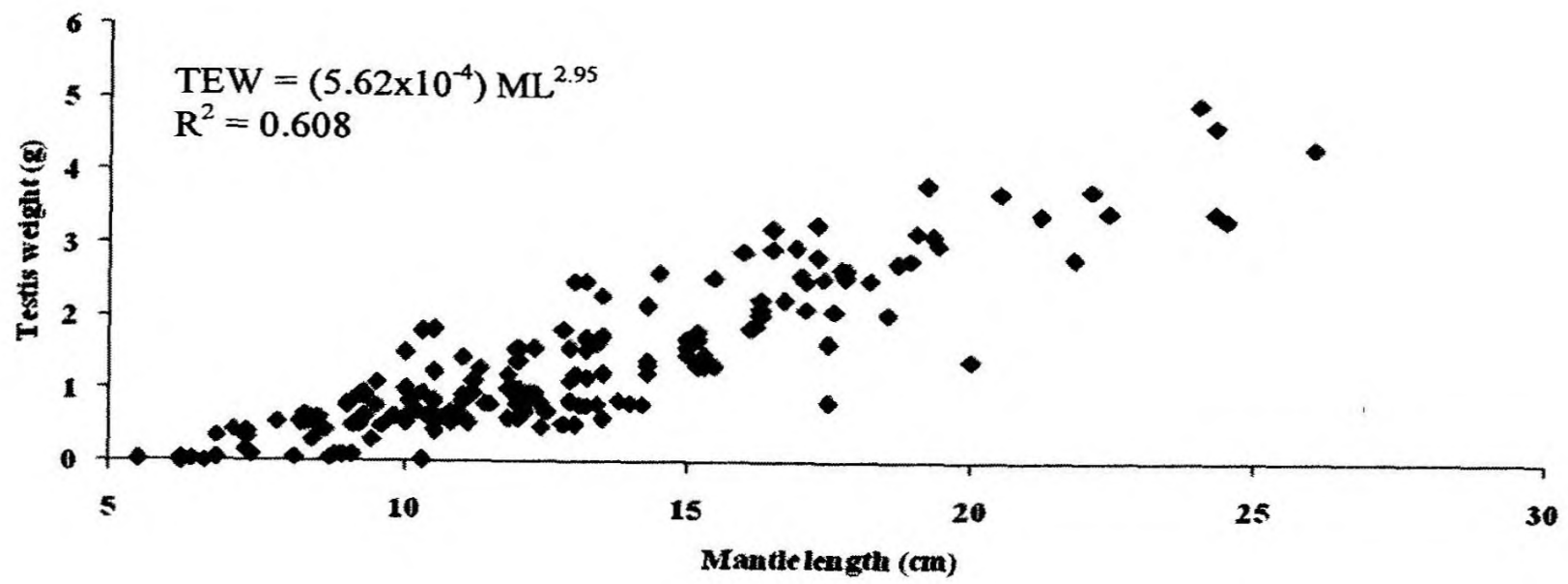


Fig. 17. Relationship between testis weight and mantle length of male *S.*

lessoniana

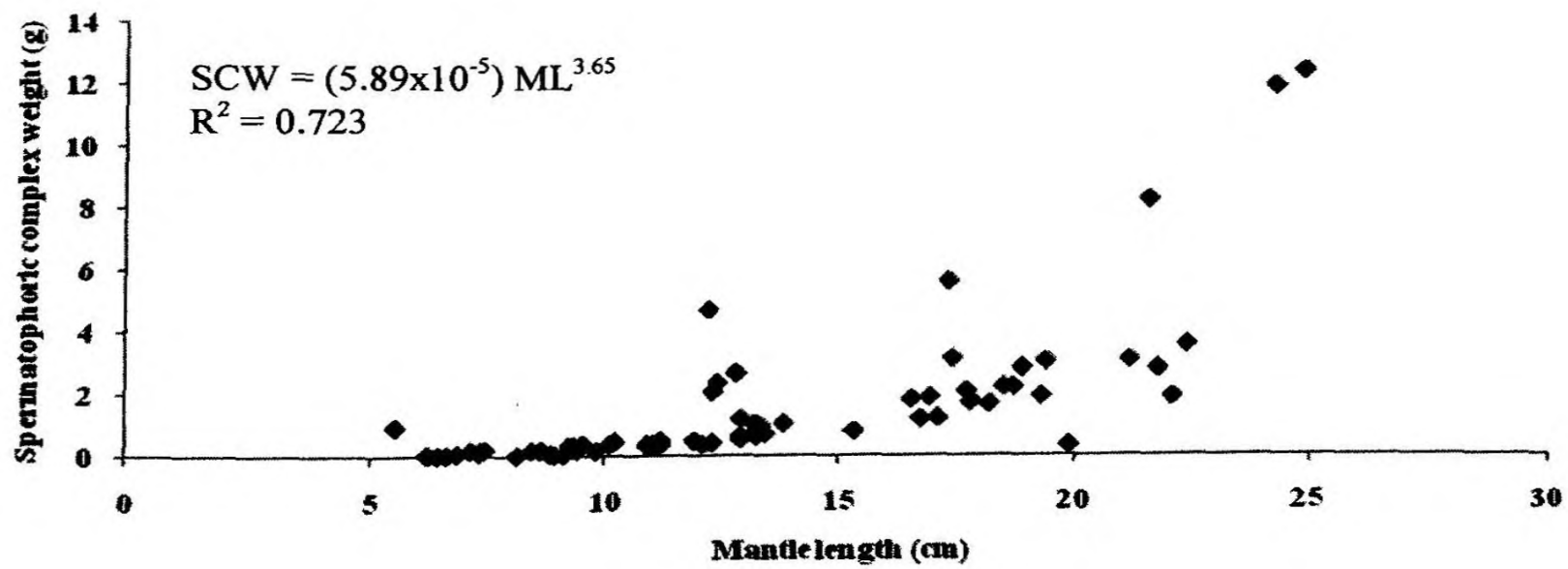


Fig. 18. Relationship between spermatophoric complex weight and mantle length of

male *S. lessoniana*

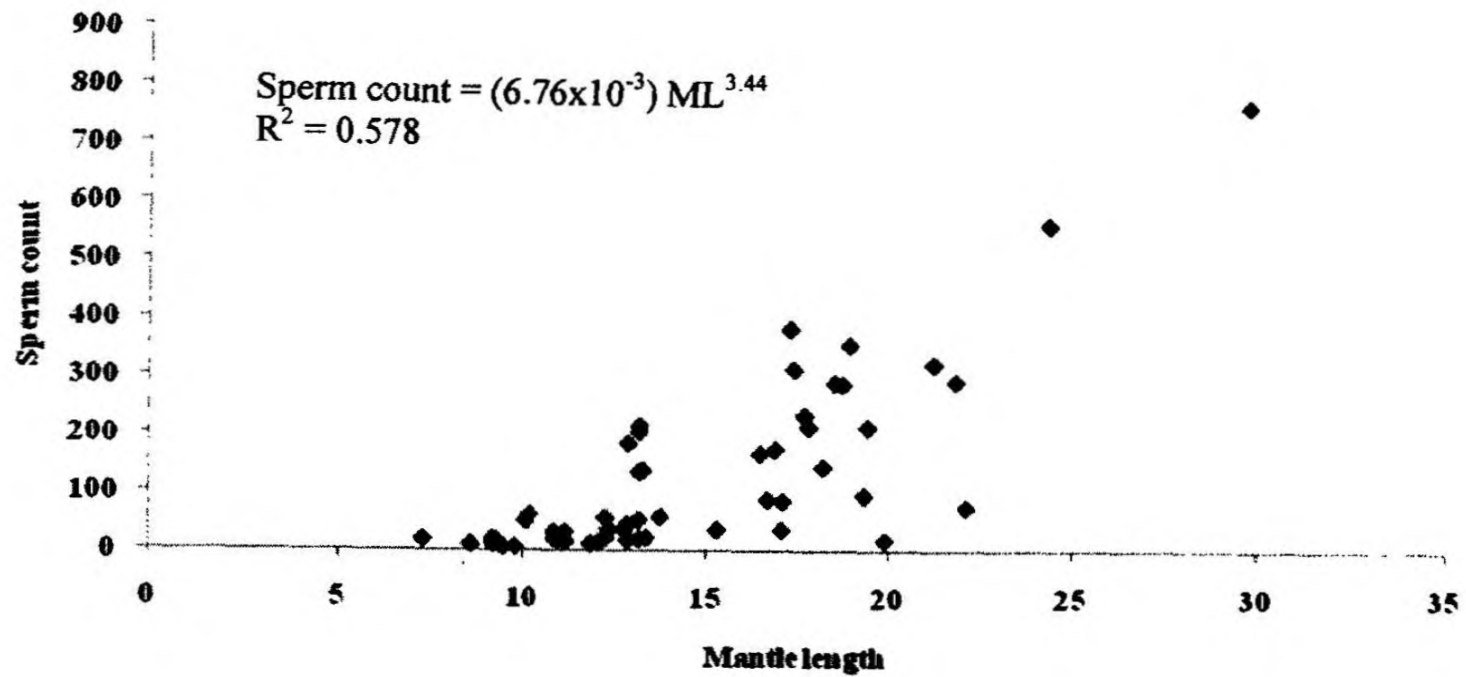


Fig. 19. Relationship between sperm count and mantle length of male *S. lessoniana*

4.3.8. Sex ratio

Of the 2297 *S. lessoniana* sexed, 1108 were females and 1189 were males. Chi-square values calculated month wise showed that the sex ratio conformed to the expected 1:1 in all the months ($P > 0.05$). Overall, sex ratio did not vary significantly from an expected 1:1 ratio, with slightly more number of males than females (0.932:1, $X^2 = 0.134$, $P > 0.05$). The percentage of females in the monthly samples of *S. lessoniana* ranged between 42.35 and 57.14 % while males ranged between 42.85 and 57.65 % (Fig. 20).

Length Class	No. of female	No. of male	Total	% of female	% of male	sex ratio	Chi value	P value
2.5-4.5	36	40	76	47.368	52.632	0.900	0.287	> 0.05
4.6-6.5	110	127	237	46.414	53.586	0.866	0.525	> 0.05
6.6-8.5	126	134	260	48.462	51.538	0.940	0.105	> 0.05
8.6-10.5	160	176	336	47.619	52.381	0.909	0.237	> 0.05
10.6-12.5	163	196	359	45.404	54.596	0.832	0.8455	> 0.05
12.6-14.5	186	191	377	49.337	50.663	0.974	0.028	> 0.05
14.6-16.5	160	149	309	51.780	48.220	1.074	0.137	> 0.05
16.6-18.5	121	129	250	48.400	51.600	0.938	0.112	> 0.05
18.6-20.5	22	25	47	46.809	53.191	0.880	0.417	> 0.05
20.6-22.5	8	8	16	50.000	50.000	1.000	0.01	> 0.05
22.6-24.5	8	9	17	47.059	52.941	0.889	0.356	> 0.05
24.6-26.5	3	3	6	50.000	50.000	1.000	0.01	> 0.05
26.6-28.5	3	1	4	75.000	25.000	3.000	25.01	< 0.05
28.6-30.5	2	1	3	66.667	33.333	2.000	11.12	< 0.05
Total	1108	1189	2297	48.237	51.763	0.932	0.134	> 0.05

Table 15. Month wise sex ratio of *S. lessoniana*

Month	No. of female	No.of male	Total	% of female	% of male	sex ratio	Chi value	P value
Jun-07	29	30	59	49.152	50.848	0.967	0.059	> 0.05
Jul-07	40	48	88	45.455	54.546	0.833	0.836	> 0.05
Aug-07	55	62	117	47.009	52.992	0.887	0.368	> 0.05
Sep-07	48	57	105	45.714	54.286	0.842	0.745	> 0.05
Oct-07	50	56	106	47.169	52.830	0.893	0.330	> 0.05
Nov-07	38	37	75	50.667	49.333	0.027	0.028	> 0.05
Dec-07	36	40	76	47.368	52.632	0.9	0.287	> 0.05
Jan-08	52	53	105	49.524	50.476	0.981	0.019	> 0.05
Feb-08	62	48	110	56.364	43.636	1.292	1.629	> 0.05
Mar-08	69	64	133	51.879	48.120	1.078	0.151	> 0.05
Apr-08	56	50	106	52.830	47.169	1.12	0.330	> 0.05
May-08	61	56	117	52.137	47.863	1.089	0.192	> 0.05
Jun-08	24	20	44	54.546	45.455	1.2	0.836	> 0.05
Jul-08	48	40	88	54.546	45.455	1.2	0.836	> 0.05
Aug-08	55	70	125	44.000	56.000	0.786	1.45	> 0.05
Sep-08	43	55	98	43.878	56.122	0.782	1.509	> 0.05
Oct-08	22	24	46	47.826	52.174	0.917	0.199	> 0.05
Nov-08	72	98	170	42.353	57.647	0.735	2.349	> 0.05
Dec-08	48	56	104	46.154	53.846	0.857	0.502	> 0.05
Jan-09	34	40	74	45.946	54.054	0.85	0.667	> 0.05
Feb-09	74	88	162	45.679	54.321	0.841	0.757	> 0.05
Mar-09	28	33	61	45.902	54.098	0.848	0.682	> 0.05
Apr-09	32	40	72	44.444	55.556	0.8	1.244	> 0.05
May-09	32	24	56	57.143	42.857	1.333	2.050	> 0.05
Total	1108	1189	2297	48.237	51.763	0.932	0.134	> 0.05

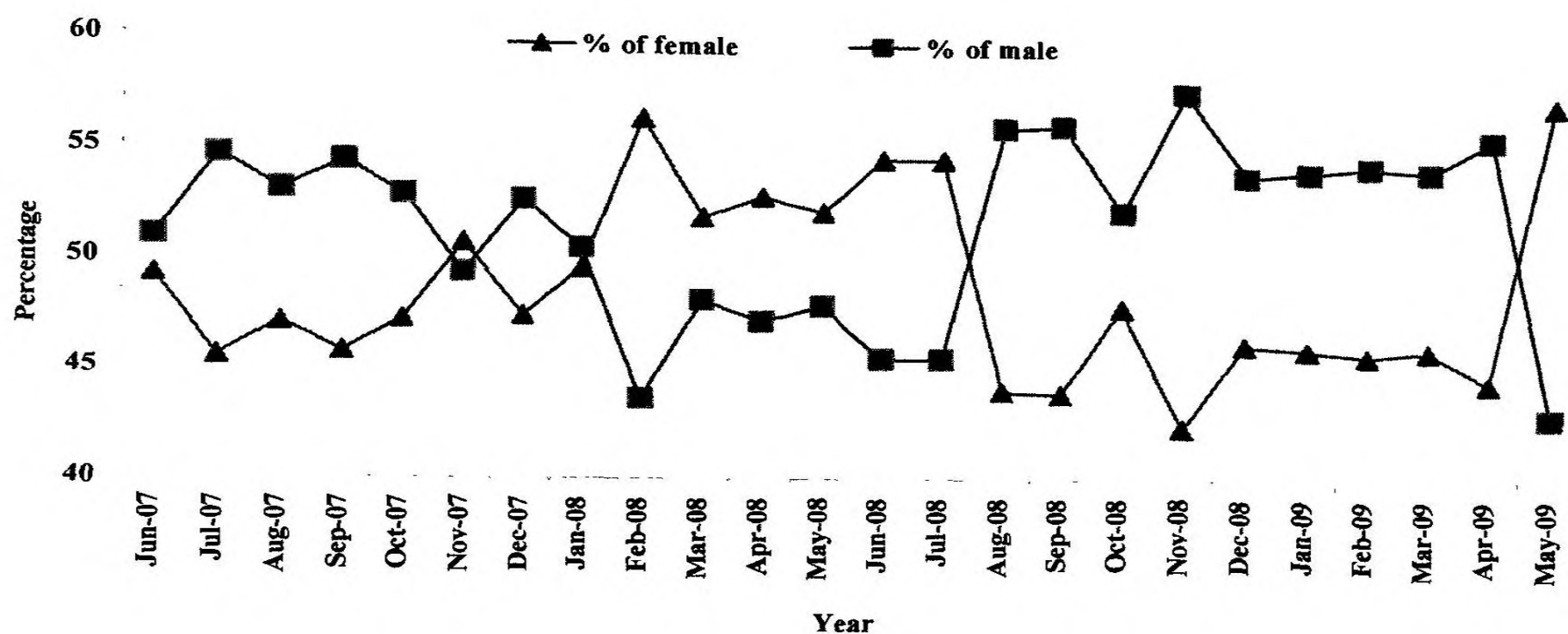


Fig. 20. Month wise sex ratio of *S. lessoniana*

The number of squids obtained in each length group and the ratio of males and females calculated from the pooled data are shown in Table 14. Chi-square values calculated for different length groups (Fig. 21) showed that the sex ratio conformed to the expected 1:1 in all length groups ($P > 0.05$) except 28 and 30 cm ML. Overall, sex ratio did not vary significantly from an expected 1:1 ratio (0.932:1, $X^2 = 0.134$, $P > 0.05$).

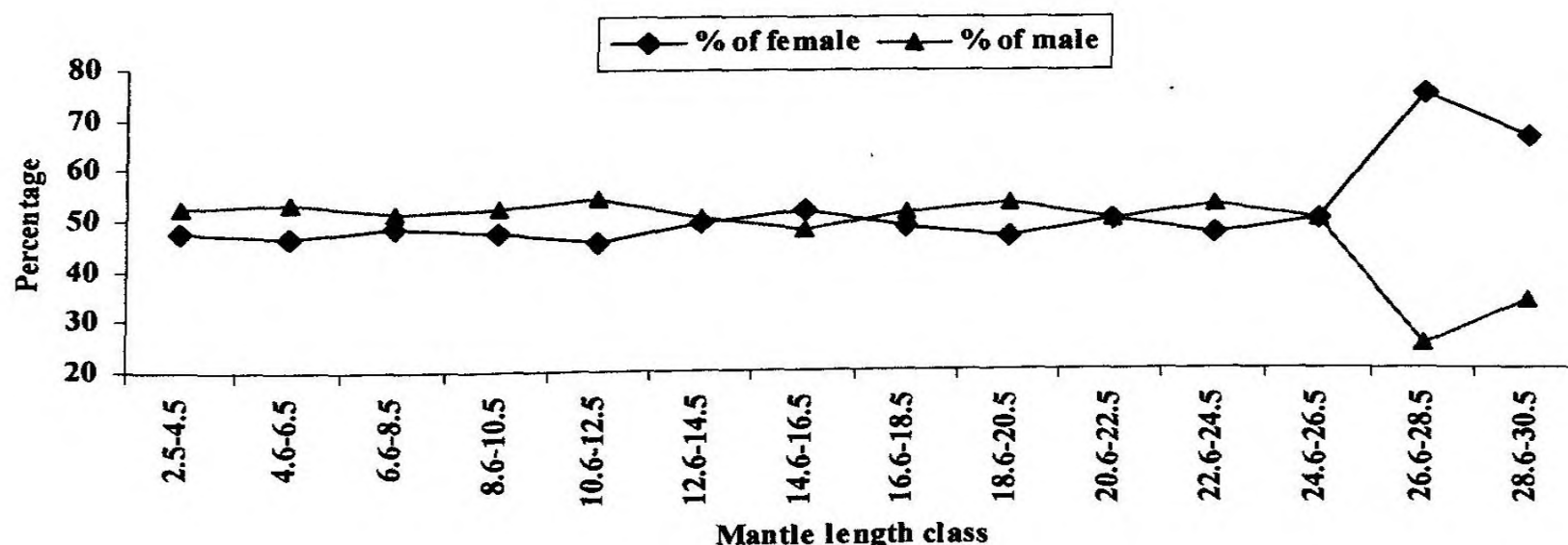


Fig. 21. Length wise sex ratio of *S. lessoniana*

4.4. Discussion

Some females had bunches of spermatophores on both sides of the mantle wall at the base of the gill near the opening of the oviduct. Sometimes more than two bunches of spermatophores were observed indicating the possibility of females mating more than once. Egg clusters of *S. lessoniana* were frequently found attached to hard substrate from August to January near the coasts further confirms the spawning period. Gabr *et al.* (1998) reported mating was evident in the form of stored sperm in the seminal receptacle or from spermatophores fixed to the buccal membrane of females on *Sepia pharaonis*.

Fecundity of *S. lessoniana* found to be lesser than that of *S. pharaonis* and *S. dollfusi* for example, numbers of ova in 14 cm ML *S. dollfusi* and *S. lessoniana* were 730 (Gabr *et al.* 1998) and 700, respectively. Fecundity of *S. pharaonis* ranged between 517 and 1525 ova for females of 11 – 24 cm ML (Gabr *et al.* 1998) whereas for *S. lessoniana* ranged between 20 and 793 for females of 7 – 26 cm ML. Fecundity for *S. lessoniana* in the Zanzibar coastal waters ranged from 180 to 1180 eggs for individuals of size range 14.0 – 24.9 cm ML (Mhitu *et al.* 2001) which is higher than the present value. The variation in fecundity for *S. lessoniana* may attributed to varying environmental factors, food availability in different habitats.

The correlation between fecundity and mantle length may have been resulted as some females of similar size have already been spawned different number of eggs.

Therefore all these individuals appeared to be in spawning condition, and it is an evidence of continuous egg production throughout the adult life confirming the multiple spawning. A similar result was also observed in *S. lessoniana* and *S. australis* of Australian waters by Pecl (2001). Multiple spawning strategy can also be explained by the fact that large eggs in the ovary causing the oviduct volume to be insufficient to accommodate all eggs. Therefore, number of egg masses must be spawned in several batches (Rocha *et al.* 2001).

Maturation in female *S. lessoniana* individuals was a size-related process, because weight of ovary, nidamental gland, and oviducal gland were all correlated highly with mantle length. Maturation in male *S. lessoniana* individuals was also a size-related process, because testis weight was correlated highly with mantle length. Similar results were obtained for *S. lessoniana* and *S. australis* from Australian waters Pecl (2001), for *Sepia pharaonis* and *S. dollfusi* from Suez canal (Gabr *et al.* 1998) and for *Loligo sanpaulensis* from southern Brazilian waters (Costa and Fernandes, 1993).

Finally, it can be concluded that squid *S. lessoniana* exhibits reproductive pattern of spawning more than once, group-synchronous ovulation and reproductive strategy of intermittent terminal spawning. This result is in consistent with the observation for other species for example *S. australis* by other researchers, too (Pecl, 2001). Wada and Kobayashi (1995) observed similar results for *S. lessoniana*. Peak or intense spawning of this squid in the Jaffna lagoon is in March, August and October to November. In a squid population an exploited stock can be renewed through

recruitment. If overexploitation occurs, matured squids could be reduced and subsequently reproductive capacity of the population diminished. Such situation can be managed by imposing restrictions on mesh sizes of the gears used to catch squids. Further, breeding females should be protected during the peak spawning period in order to maintain sustainability. Findings of the present study would definitely lead to formulate a management strategy and ensure a long term sustainability of *S. lessoniana* in the Jaffna lagoon.

5. Age and growth

5.1. Introduction

Issues of squid growth and population dynamics are increasing in prominence and importance. Increased fishing pressure is changing the trophic structure in many marine environments around the world (Pauly *et al.* 1998). As a result of this phenomenon, a greater emphasis is being placed on new fisheries and on cephalopod stocks in many parts of the world (Rodhouse 1997). The over-fishing of longer lived finfish has resulted in a shift to squid fishing (O'Dor *et al.* 1997).

Age and growth and stock assessment studies of fish are useful in the calculation of the exploitation rate and estimating the size of the exploited population (Ricker 1975). The same general aims and principles may be applied to squids. Although squids may not be functionally comparable with fish (Packard 1972), they have been described as ecologically similar (Longhurst and Pauly 1987).

Culture studies (Yang *et al.* 1986; Hanlon 1990; Jackson *et al.* 1993; Jackson 1994b; Lee *et al.* 1994; Nabhitabhata 1995, 1996) continue to reveal that squids have short lives, grow rapidly and non-asymptotically.

Different methods have been evolved for determining the age of the fish in an open system. These methods may be broadly classified into direct (counting of year rings on hard parts such as scales and otoliths) and indirect methods (conversion of length frequency data into age composition). Direct methods, however, require special expensive equipment and also it is impossible to read the seasonal rings in tropical fishes. Indirect methods involve conventional (integrated method, month mode curve,

probability plot method and Ford-Walford method) and unconventional or eccentric methods (Microcomputer program packages). There are several microcomputer program packages to determine the age and growth such as Length-based Fish Stock Assessment (LFSA) (Sparre 1987), COMPLEAT ELEFAN (Gayanilo *et al.* 1988), MULTIFAN (Fournier *et al.* 1990), LFDA (Holden and Bravington 1991) and FiSAT (Gayanilo *et al.* 1997).

Information available on the age and growth of squids which are quite essential for the judicious exploitation and management of the resource in Sri Lankan waters is meager. Therefore, the present study was undertaken to get information on the maximum size, age and growth parameters of *S. lessoniana* of Jaffna lagoon based on length frequency data.

5.2. Materials and methods

Squid samples for the present study were collected from the commercial catches of, Pasaioor, Gurunagar Kakkaitivu and Ponnalai landing centres at weekly intervals from June 2007 to May 2009.

Squid samples caught by sirahuvalai were identified into species and mantle length measurements were taken for all possible squids to the nearest 1 mm at the landing centres in order to arrange in to length frequency data.

The length frequency data were grouped sex wise into 2 cm class intervals, sequentially arranged for two years and used for estimation of growth. Length frequency analysis were done with FiSAT II (Gayanilo and Pauly 1997) software. As

the length frequency data obtained from different gear cannot be simply pooled, the length frequency data of *S. lessoniana* from the commercial sirahu valai catches were analyzed using ELEFAN I routine of FISAT II software (Gayanilo and Pauly 1997). The following stepwise procedures were adopted to estimate L_{∞} and K and for correction of length frequency data for mesh selection as per literature (Sparre and Venema 1992; Amarasinghe and De Silva 1992; Amarasinghe 2002).

- Preliminary estimation of asymptotic length (L_{∞}) and growth coefficient (K) using the initial estimates of L_{∞} estimated by Powell Wetherall method.
- Estimation of an initial value for asymptotic length (L_{∞}) and Z/K (Z = total mortality and K = growth coefficient) using the Powell – Wetherall method (Powell 1979; Wetherall 1986).
- Preliminary estimation of asymptotic length (L_{∞}) and growth coefficient (K) using the initial estimates of L_{∞} estimated by Powell Wetherall method.
- Estimation of probabilities of capture by detailed analysis of left ascending part of the catch curve using the preliminary estimation made on the asymptotic length (L_{∞}) growth coefficient (K) and computed t_0 .
- Correction of the original length frequencies using probabilities of capture (Pauly 1986 a, b and c) for incomplete selection for length classes smaller than the first fully selected length through appropriate routine.
- Estimation of best optimized estimates of L_{∞} and K through ELEFAN I routine (Gayanilo and Pauly 1997) from the corrected length frequency data.

L_{∞} and K values were obtained through the four options such as, curve fitting by eye, response surface analysis, scan of K values and automatic search routine. In this

method the growth parameters L_{∞} and K were estimated following the von Bertalanffy growth equation. The equation for growth in length is given by,

$$L_t = L_{\infty} (1 - \exp^{-K(t-t_0)}) \dots\dots\dots(1)$$

Where L_t is the length at age t , L_{∞} the asymptotic length, K the growth coefficient and t_0 theoretical age at which fish would have had zero length if they had grown according to the above equation. The most optimized L_{∞} and K values were obtained by ELEFAN I – automatic search routine and the restructured length frequency histograms were also obtained.

The growth performance index (\emptyset) was computed using the following equation (Pauly and Munro 1984):

$$\emptyset = \log_{10} K + 2 \log_{10} L_{\infty} \dots\dots\dots(2)$$

As ELEFAN cannot estimate the t_0 value from the length frequency data, a very approximate value of ‘ t_0 ’ was estimated by substituting the L_{∞} (in cm) and K (year⁻¹) in the following equation (Pauly 1983):

$$\log (-t_0) \approx -0.3922 - 0.2752 \log L_{\infty} - 1.038 \log K \dots\dots\dots(3)$$

where -0.3922, -0.2752 and -1.038 are constants derived from 153 triplets of t_0 , L_{∞} and K selected from the compilation of length growth parameters such as to cover a wide diversity of taxa and size.

Longevity was obtained from the following equation (Pauly 1983):

$$t_{\max} = t_0 + 3/K \dots\dots\dots(4)$$

Where t_{\max} is the approximate maximum age the fish of a given population would reach.

5.3. Results

A total of 4216 specimens of *S. lessoniana* ranging from 3.8 to 27.8 cm were analyzed for the age and growth studies.

The analysis of length frequency data by the Powell - Wetherall method (Fig. 22) gave an initial estimate of L_{∞} value of 33.0 cm [$r = -0.996$; regression equation, $Y = 81.61 + (-0.302)*X$] and Z/K value of 4.09. The optimized values for K and L_{∞} obtained by the ELEFAN I was 0.83 year^{-1} and 31.10 cm. The goodness of fit index (R_n) for the obtained K and L_{∞} value was 0.177.

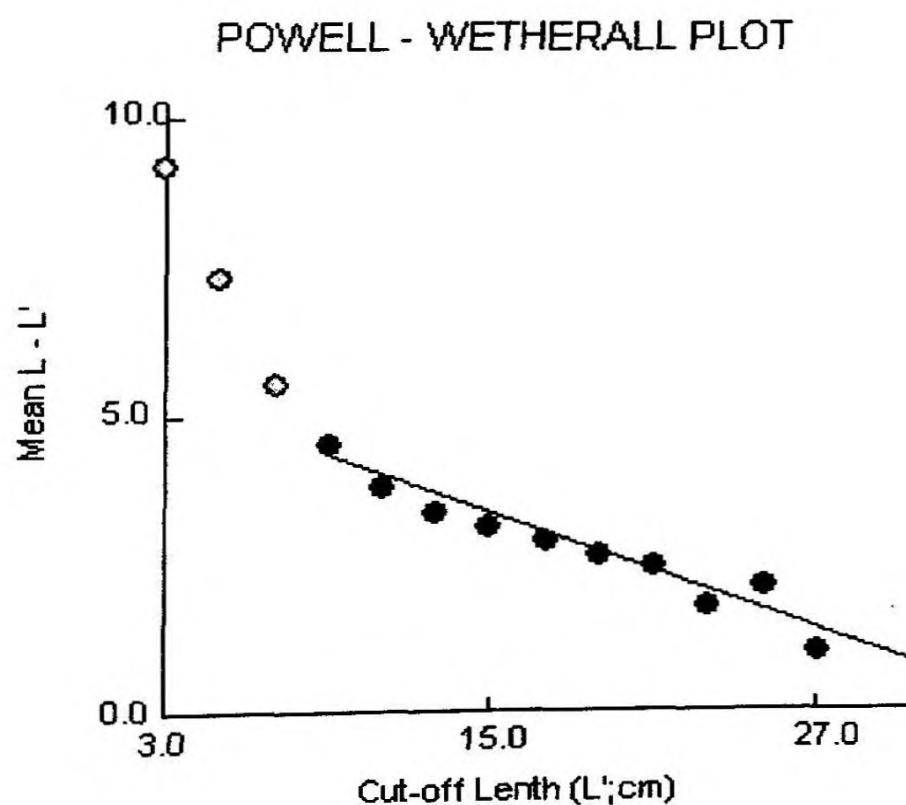


Fig. 22. Powell Wetherall plot of *Sepioteuthis lessoniana*

Usually, the R_n value ranges between 0 and 1 in the ELEFAN - FiSAT package. The oscillation parameter (C) and winter point were assumed to be 0 as it is a tropical

species. The non seasonalized restructured length frequency histogram with growth curve is shown in Fig. 23.

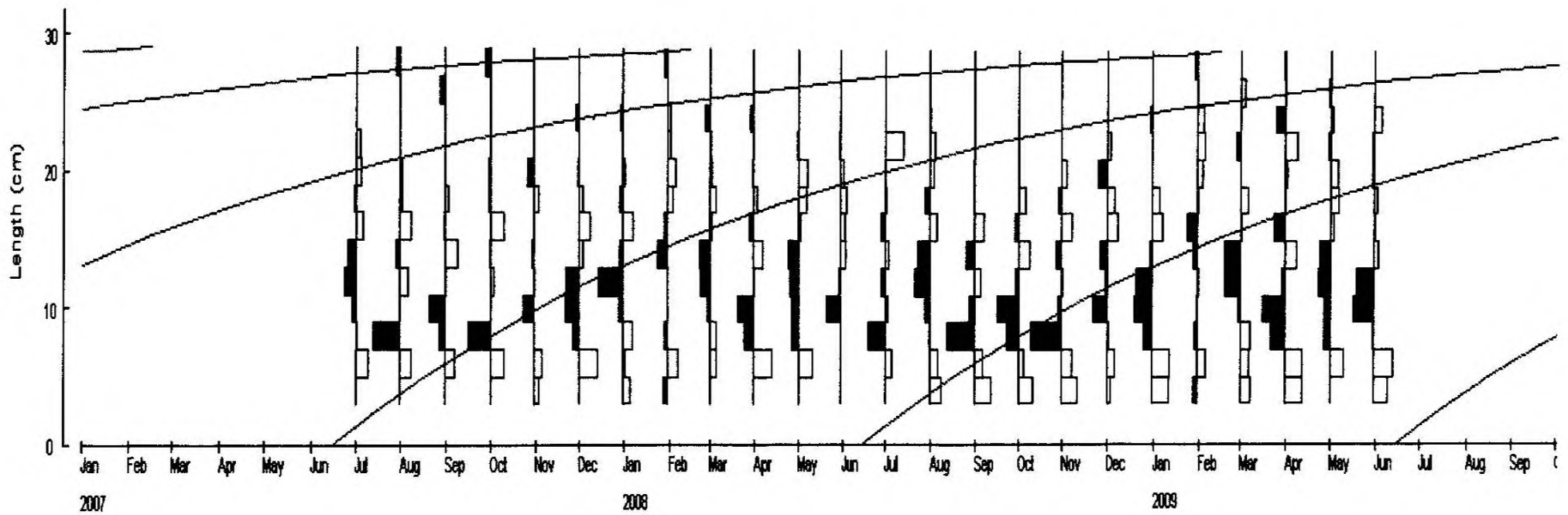


Fig. 23. Growth curve of *Sepioteuthis lessoniana* drawn using ELEFAN I programme

The estimated growth performance index (Φ) was 2.904. The estimated t_0 value was -0.191.

The von Bertalanffy's growth equation for *S. lessoniana* can be expressed as:

$$\text{Male: } L_t = 31.10 [1 - \exp \{-0.83(t-0.191)\}] \dots\dots\dots(8)$$

Estimated longevity for *S. lessoniana* calculated from Pauly's equation is 3.423.

5.4. Discussion

Age and growth parameters of the squid *S. lessoniana* were not reported in Sri Lanka and this is the first study to estimate those parameters. One related preliminary study was performed for *S. lessoniana* and it is the study by Balgos and Pauly (1998) in Philippine waters. However growth and mortality parameters were not clearly defined in that study. Few other studies were performed on *Loligo duvauceli* in Indian waters (Chakraborty *et al.* 1997; Karnik *et al.* 2003; Meiyappan and Srinath 1989; Mohammed and Rao 1997; Neethiselvan and Venkataramani 2002 and Silas *et al.* 1986).

The L_{∞} and K values estimated for congeners of *S. lessoniana* are given in Table 16. The estimated values of L_{∞} for *L. duvauceli* differ at all instances from those of *S. lessoniana*. It clearly expresses the variation of maximum length for different species of squids as well as in different geographical location. The K value obtained is also extremely differing with that of *L. duvauceli* (Chakraborty *et al.* 1997) and consistent at only one instance that is with the *L. duvauceli* found in Mumbai coast (Karnik *et al.* 2003).

The estimated growth performance (\emptyset) index for *S. lessoniana* shows the growth performance index is 2.904. Higher estimated growth performance index for this species is due to high growth rate constants and it clearly shows how fast these squids approach their asymptotic length. This clearly shows the reliability of the estimates of K and L_{∞} in the present study. Such estimation for growth performance index was not computed for *S. lessoniana* and therefore a comparison cannot be made at this juncture. The growth performance index of 2.9 calculated for *Doryteuthis sibogae* by

Neethiselvan and Venkataramani (2002) from Tuticurin waters is same as that of the result obtained for growth performance index in the present study. High annual growth rate of a fish can lead to high turnover rates or production per biomass (P:B) ratios (Gunderson, 1997).

Table 16: The growth parameters estimated for squids from different regions of the world

Species	Sex	L_{∞} (mm)	K (annual)	Region	Source
<i>Loligo duvauceli</i>	Male	327	0.61	Cochin	Silas <i>et al.</i> 1986
	Female	205	1.19		
<i>Loligo duvauceli</i>	Male	372	1.1	Cochin (Kerala coast)	Meiyappan and Srinath, 1989
	Female	238	1.7		
<i>Loligo duvauceli</i>	Combined	343	0.49	Mumbai coast	Charaborty <i>et al.</i> 1997
<i>Loligo duvauceli</i>	Combined	371	1.4	Karnataka coast	Mohammad and Rao, 1997
<i>Doryteuthis sibogae</i>	Combined	395	0.4	Thoothukudi coast	Neethiselvan and Venkataramani, 2002
<i>Loligo duvauceli</i>	Combined	385	0.85	Mumbai coast	Karnik <i>et al.</i> 2003
<i>Sepioteuthis lessoniana</i>	Combined	311	0.83	Jaffna lagoon, Sri Lanka	Present study

Fast growth rate and small asymptotic length indicate that the fish species in these waters mature early in life and has a short life span (Sparre and Venema 1992). Hendrickson (2004) found the lifespan of winter cohort of *Illex illecebrosus* in United State waters ranges from 115 to 215 days. However it is not consistent with the present study of *S. lessoniana*. Moreover, the allometric relationships for the *Illex illecebrosus* was studied by Staudinger *et al.* 2009 in North Carolina.

6. Stock Assessment

6.1. Introduction

A "stock" is a population of a species living in a defined geographical area with similar biological parameters such as productivity, growth, size at maturity, fecundity, recruitment and mortality, made up of fishing and natural mortality rate (Lassen 2001). Stock size is the number of fish by age group or length group at a particular point in time (Lassen 2001). The purpose of fish stock assessment is to provide estimates of the current status of the stock, to project the yield, total and spawning stock biomass and recruitment for specified scenarios of fishing mortalities and to project the relationship between the stock status and a number of biological reference points. These estimates can be used to formulate biological advice on fishery management, and evaluate whether the stock is within safe biological limits, i.e. productivity (growth, recruitment) is not adversely affected by fishing (Lassen 2001). A thorough understanding of fisheries biology is needed to define these biological parameters.

Stock assessment involves mathematical and statistical models to examine the retrospective development of the stock and to make quantitative predictions to address the past, current and future status of stock under alternative management choices. Number of fish is being increased by the reproduction of adult fish, which eventually results in small fish being added, or recruited, into the stock (King 1995). In addition, the weight, or biomass, of the fish stock is increased by the growth of individuals. Concurrently with these increases, the stock is reduced in numbers by natural

mortality and, in exploited species, by fishing mortality as well. Fishing mortality refers to fish caught by fishers, and natural mortality refers to fish which die by other means, most commonly by predation (King 1995).

Stock assessment of tropical resources has been developed rapidly in the last two decades through the works of Pauly (1980b, c, 1984a, b, c), Pauly and David (1981), Munro (1983), and also because of the rapid development of microcomputer hard and softwares (Sparre and Venema 1998). Recently, several investigations have been carried out on the population dynamics of commercially important fishes occurring in the coastal waters of Sri Lanka for *Hyporhamphus limbatus* (Ajithkumara and Amarasinghe, 2008), *O. mossambicus*, *O. niloticus*, *L. dussumieri* and *O. mossambicus* (Athukorala and Amarasinghe, 2010), *Ehirava fluviatilis* (Amarasinghe and Sriya, 2002) and in coastal waters of India such as the mackerel (Noble *et al.* 1992), oil sardine (Annigeri *et al.* 1992), silverbellies (Murthy *et al.* 1992), sciaenids (Chakraborty 1997), threadfin breams (Zacharia 1998) and multispecies assessment of demersal fish stocks (Vivekanandan 2002).

However, no work has been done on the stock assessment of squids in the Sri Lankan waters and therefore, the present investigation was carried out to quantify the mortality, stock and exploitation rate of *S. lessoniana* from the Jaffna lagoon.

6.2. Materials and methods

The length frequency data grouped into 2 cm class intervals, sequentially arranged for two years and used for estimation of age and growth were used for the estimation of total and natural mortality using the FiSAT II package (Gayaniilo *et al.* 1997). The fishing mortality was computed by subtracting the natural mortality from total mortality. In the present study the stock was estimated mainly by two methods i.e. by relative Yield per Recruit and relative Biomass per Recruit model and Virtual Population Analysis available in the FiSAT II package using the length frequency data.

A multi-stage stratified sampling design (Bal and Rao 1984) developed by the Central Marine Fisheries Research Institute (CMFRI), Cochin was adopted to make a record of the catch at size data from the Jaffna lagoon. A month was split into three clusters of 10 days each. Observations were made for six consecutive days with a gap of 10 days between two sets of clusters. During the six days, data were gathered at four centers, for two consecutive days at each center. During the two days, observations were made for six hours i.e. from 12.00 h to 18.00 h in the first day and from 06.00 h to 12.00 h the next day; night landings if any, were recorded by enquiry from the fishers. Thus, enumerating a center for 24 hours which ultimately means three days' observation at three centers in a cluster of 10 days, or nine days of actual observation in a month. As it is difficult to enumerate the catch of all the boats at a center, 10% of the boats landed were enumerated if the number is more than 50, 20 % if they are between 21 and 50%, 50% if they are between 11 and 20 and all boats if they are 10

or less. The number of boats landed was noted separately. From the catch at size data, the monthly catch for that zone was estimated from the following formula:

$$Y = (N/n) \sum Y_i$$

Where Y is the estimated catch for a month in a zone, N is the total number of landing centre days, n is the actual number of center-days observed, and Y_i is the catch during an observed center-day. Due allowance was made for holidays and non-fishing days. The duration of the collection of data was from June 2007 to May 2009.

The total mortality coefficient (Z) was estimated using length converted catch curve analysis (Gayaniilo and Pauly 1997) in the FiSAT II program using the input parameters L_0 , K and t_0 . The histogram showing probability of capture for each size class was obtained by backward extrapolation of the straight portion of the right descending part of the catch curve. The length at first capture L_c was obtained from the plot of cumulative probability of capture against mid-length of class interval, through detailed analysis of ascending part of catch curve.

Natural mortality rate was obtained through Pauly's empirical model (Pauly 1980a),

$$\ln(M) = -0.0152 - 0.279 \ln(L_\alpha) + 0.6543 \ln(K) + 0.463 \ln(T) \dots \dots \dots (5)$$

Where M is the natural mortality, L_α is in cm, K is annual and T is the mean annual temperature (in $^{\circ}\text{C}$) which is taken as 30°C .

Fishing mortality was calculated using using the formula (Pauly 1983),

$$Z = M + F \dots \dots \dots (6)$$

Exploitation rate E was determined from the relationship (Pauly 1983),

$$E \text{ (exploitation rate)} = F/Z \dots\dots\dots(7)$$

The relative yield per recruit (Y/R) was predicted by considering Y/R as a function of U and E and M/K by employing Beverton and Holt Y/R analysis (selection ogive) in the FiSAT package. The relative yield per recruit equation which gives a quantity proportional to Y/ R was derived from the method of Beverton and Holt (1959) through a number of algebraic manipulations according to the following model:

$$Y'/R=EU^{M/K}[1- (3U/1+m) + (3U^2/1 + 2m) - U^3 / (1+ 3m)] \dots\dots\dots (8)$$

where

$$M = (1 - E) / (M/K) = K/Z .$$

$$U = 1 - (L_c / L_\alpha) \text{ and}$$

$$E \text{ (exploitation rate)} = F/Z$$

Relative Biomass-per-recruit (B'/R) was estimated from the following relationship:

$$B'/R = (Y'/R) / F$$

while E_{max}, E₁₀ and E₅₀ were estimated by using the first derivative of this function.

The predicted values were obtained by substituting the input parameters of L_c/ L_α (L_c is the minimum length captured; obtained from the extrapolation of length converted catch curve) and M/ K in the FiSAT II package (Gayaniilo and Pauly 1997). The assumptions considered in this model being fishing and natural mortalities are constant from the moment of entry to the exploited phase recruitment is constant and the length weight relationship has the exponent 3.

Virtual population analysis (VPA) is a modeling technique commonly used in fisheries science for reconstructing historical fish numbers at age using information on death of individuals each year. This death is usually partitioned into catch by fisheries and natural mortality. VPA is the most commonly used term to refer to cohort reconstruction techniques used in fisheries. It is virtual in the sense that the population size is not observed or measured directly but is inferred or back-calculated to have been a certain size in the past in order to support the observed fish catches and an assumed death rate owing to non-fishery related causes.

Length cohort analysis or length-structured virtual population analysis (Pauly 1984a) was used to estimate stock size and fishing mortality. Input parameters in this analysis were a (constant from length weight analysis), b (constant from length weight analysis), natural mortality M , terminal fishing mortality (F_t), L_α , K and the total landings of fish distributed over length groups in terms of numbers of fish. The totals are obtained by raising the length distributions of random samples of the landings by 10^4 , using information on the total landings obtained.

Input parameters a and b were obtained from the length-weight relationship of pooled data for males and females (Chapter 3). L_α and K obtained from ELEFAN I were considered. M values obtained from the Pauly's equation were taken here. F_t was assumed to be 1.5 at all instance.

Theoretical equation of this method is:

$$N_t = C_t \cdot (M + F_t) / F_t$$

where N_t is the terminal population, C_t is the terminal catch (i.e., the catch taken from the largest length class), M is the natural mortality and F_t is the terminal fishing mortality.

6.3. Results

The length-converted catch curve for *S. lessoniana* is shown in Fig. 24. The length-converted catch curve gave a Z value of 3.75 year^{-1} (confidence interval of $Z = 3.368 - 4.127$; standard deviation of the slope = 0.55 ; $r = 0.98$). The lengths at first capture L_c (length at 50% capture) estimated by backward extrapolation of the straight portion of the right descending part (Fig. 25) of the catch curve was 8.57 cm .

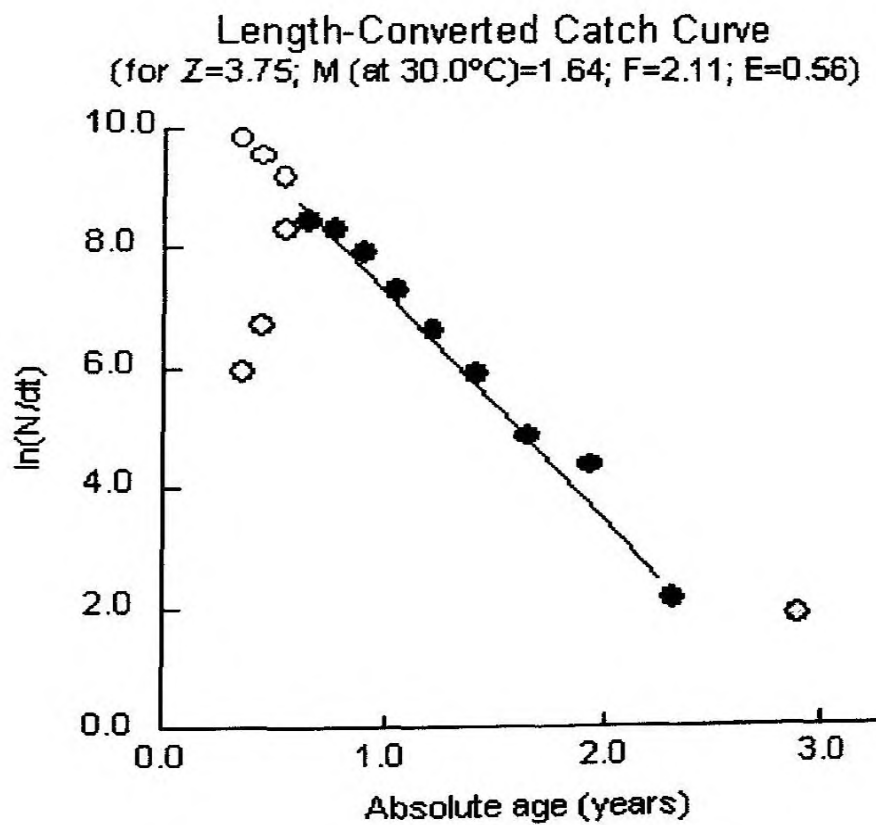


Fig. 24. Length converted catch curve of *Sepioteuthis lessoniana*

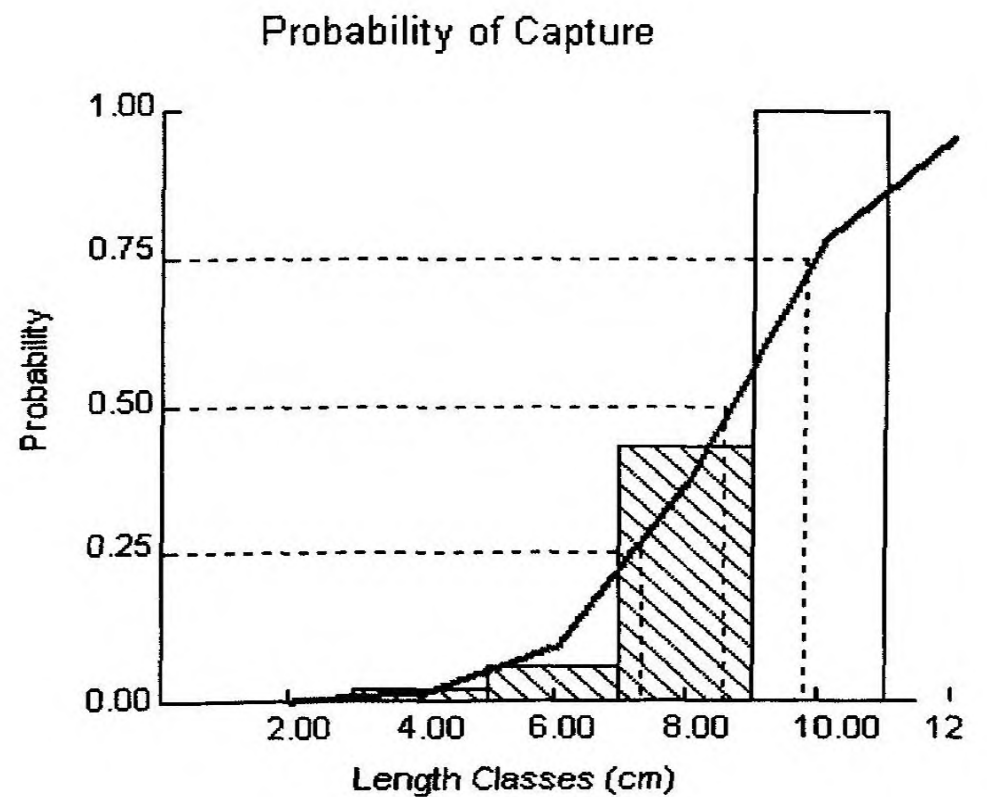


Fig. 25. Probability plot of *Sepioteuthis lessoniana*

The natural mortality coefficient (M) obtained through Pauly's empirical model at 30°C surface temperature was 1.64 year^{-1} . Therefore, the computed instantaneous fishing mortality coefficient (F) for *S. lessoniana* is 2.11 . The respective current

exploitation ratio (E) for *S. lessoniana* is 0.56. The selective ogive procedure (Fig. 26) for the analysis of relative yield-per-recruit gave predicted values of 0.501 for E_{max} for *S. lessoniana*. The computed current exploitation rates (E) of 0.56 for *S. lessoniana* is .059 above the predicted E_{max} (0.501) for *S. lessoniana*. The implication is that the stock is slightly overexploited. Thus, the fishing pressure on the stock has to be reduced. More capture should be prohibited by a reasonable decrease in the effort or by modifying the mesh size of the net for *S. lessoniana* species.

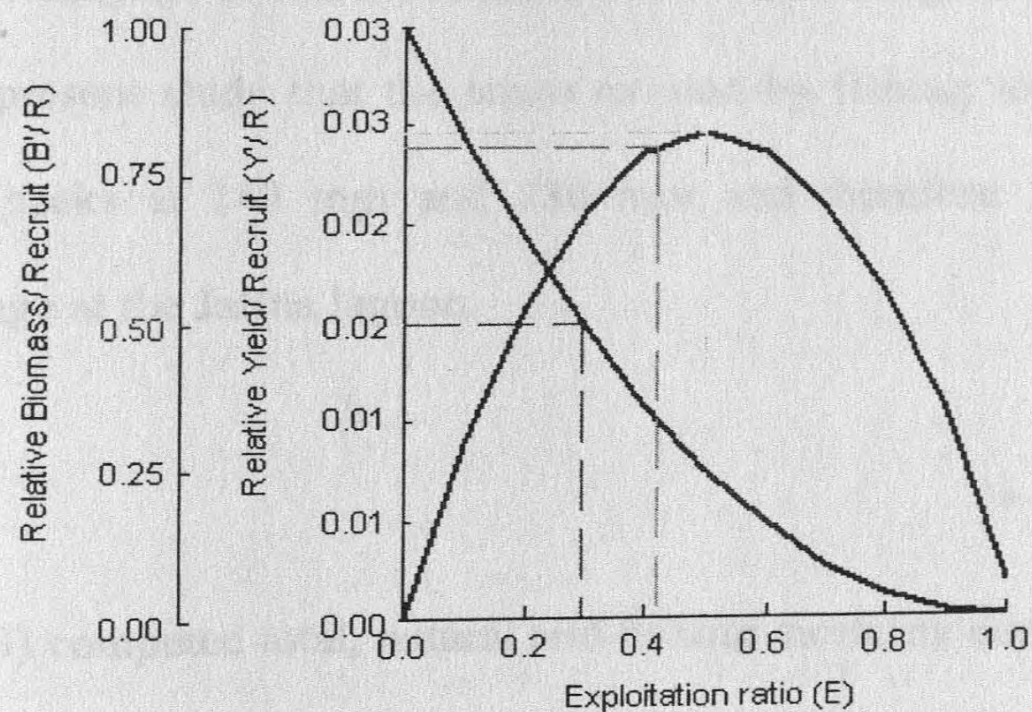


Fig. 26. Relative yield per recruit using selective ogive for *Sepioteuthis lessoniana*

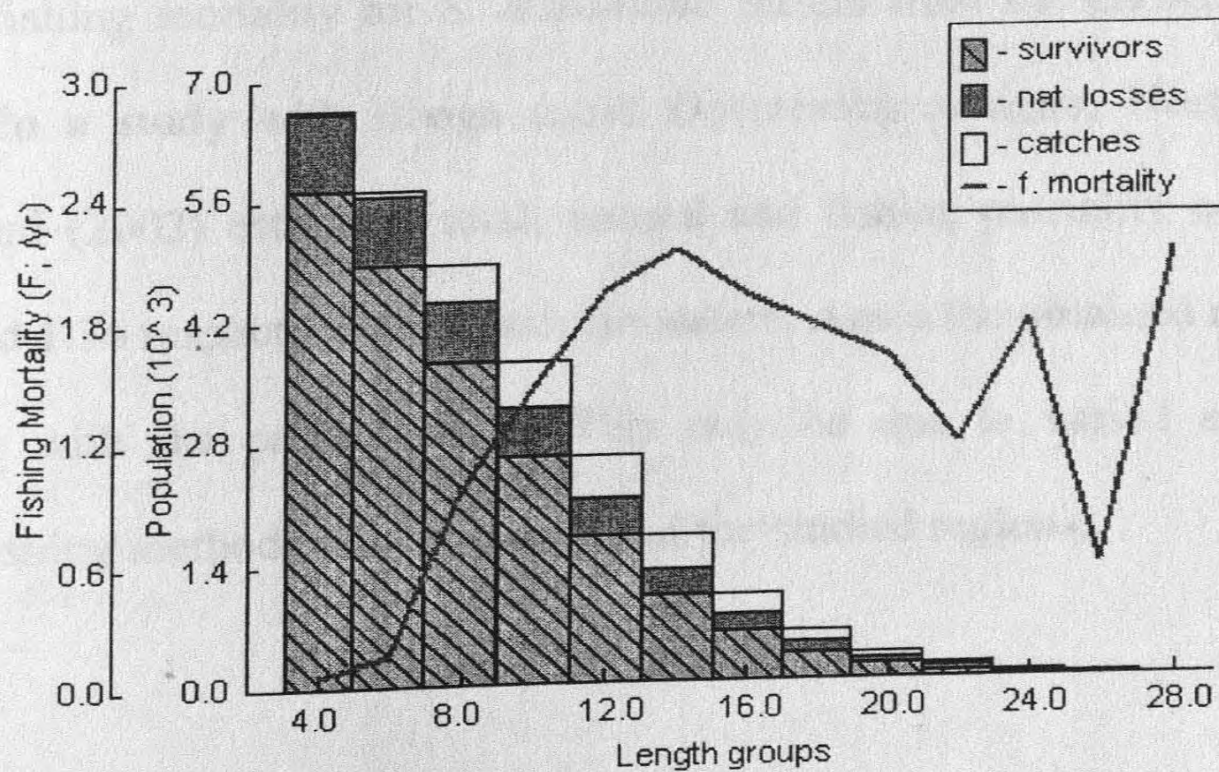


Fig 27. Virtual population analysis for *Sepioteuthis lessoniana*

The results of the virtual population analysis are shown in (Fig. 27). In *S. lessoniana*, specimens below 140 mm were found less vulnerable to exploitation. The fishing mortality increased up to 140 mm length group and attained a maximum F of 2.13. Again it decreased gradually fluctuated and reached maximum of 1.77 at 240 mm length groups. Then it decreased and increased to attain the F_t of 2.11 at 280 mm length group.

Higher fishing mortality for *S. lessoniana* may be due to its higher growth rate. It is evident from the present study that the stress exerted by fishing mortality to the *S. lessoniana* stock peaks at 140 mm and 280 mm and therefore this is the most vulnerable size range at the Jaffna lagoon.

6.4. Discussion

Karnik *et al.* (2003) computed total, natural and fishing mortality coefficients of 4.29, 1.82 and 2.47 respectively for *L. duvauceli* in Mumbai waters. The computed total, natural and fishing mortality for *S. lessoniana* differs from the earlier study for *L. duvauceli*. In a study with siboga squid *Doryteuthis sibogae*, Neethiselvan and Venkataramani (2002) estimated total, natural and fishing mortality coefficients of 2.27, 0.91 and 1.36 respectively in Tuticorin waters. Again the obtained results are not in consistent with the present study. This may be due to varied environmental conditions, fishing methods and topography of the studied regions.

Generally M/K is used as an index for checking the validity of M and K values estimated by different methods and it is known to range from 1 to 2.5 (Beverton and Holt 1959). The M/K ratios obtained in the present study (1.92) was well within this range. Instantaneous total mortality computed by length converted catch curve for *Loligo duvauceli* in a previous study was 4.29 (Karnik *et al.* 2003) and the values obtained in the present study is lower than that. Only one earlier report is available for *S. lessoniana* for growth parameter estimates (Balgos and Pauly 1998) which lacks information about mortality and virtual population analysis.

In the relative yield per recruit and biomass per recruit prediction models the descending curves showed decrease in biomass / recruits (B'/R) as exploitation ratio increased. The other curve showed increase in yield / recruit (Y'/R) with increase in exploitation ratio (E) up to E_{max} . The E_{max} is the value of E with the highest Y'/R value that is possible with a given value of L_c i.e. exploitation rate which produces maximum sustainable yield (E_{MSY}) which represents the mean maximum catch that can be taken from the fishery without affecting the biology of the stock or the balance of the system. E_{50} is the value of E associated with a 50% reduction of the biomass (per recruit) in the unexploited stock. When harvesting at the MSY level, fishing mortality (F) is roughly equal to the natural mortality (M) and harvesting above MSY denotes over fishing. The present computed yield per recruit analysis showed exploitation rate (E) of 0.56 which is 0.059 above the predicted maximum value of 0.501 for *S. lessoniana*.

Neethiselvan and Venkataramani (2002) found a slightly lower value of exploitation rate (0.53) for *Doryteuthis sibogae* from Tuticurin waters whereas Karnik *et al.* (2003) also estimated a very close value of 0.57 for *L. duvauceli* from Mumbai waters. In both instance a slightly higher exploitation was observed and a reduction of fishing effort was recommended. Further size selectivity of trammel net for oval squid *S. lessoniana* in Tateyama Bay, Chiba prefecture was studied by Akiyama *et al.* in 2004. Akiyama *et al.* (2004) further studied the capture characteristics of a trammel net for oval squid *S. lessoniana* in Tateyama Bay, Chiba prefecture.

Present study reveals a significant difference statistically between the exploitation rate and predicted maximum value reflecting overexploitation rate of squid stocks in the Jaffna lagoon. Thus, the fishing pressure on the stock has to be reduced. More capture should be prohibited by a reasonable decrease in the effort or by modifying the mesh size of the net for *S. lessoniana*. The suggested recommendation would also be either banning the catch of cephalopods during the peak spawning period or imposing restriction on the size of squids during certain months based on the findings in this study.

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