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ESTIMATES OF GROWTH, MORTALITY AND STOCK OF THE INDIAN SQUID *LOLIGO DUVAUCELI* ORBIGNY, EXPLOITED OFF MANGALORE, SOUTHWEST COAST OF INDIA

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ABSTRACT

Both male and female *Loligo duvauceli* exploited off Mangalore exhibited allometric growth. The growth rate and asymptotic length (males = 41.5 cm; females = 24.5 cm) showed distinct differences between sexes. Females grew at a faster rate ($K = 1.15 \pm 0.086$ yr^{-1}; $P < 0.05$), while males grew slower ($K = 0.92 \pm 0.078$ yr^{-1}; $P < 0.05$) but reached a larger ultimate size and age. The life-span is estimated to be 3.2 years for males and 2.6 years for females. The total average annual stock was estimated as 1088 tons and the average exploitation ratio for the period was above 0.7 for both sexes, but showed a declining trend. The maximum sustainable yield (MSY) was estimated as 877.3 tons and this could be achieved by a 35% decrease in fishing effort. Studies revealed the need for regulation of the fishery by raising the age at first capture (from 0.3 to 0.8 yr for males and from 0.5 to 0.6 yr for females) by increasing the cod-end mesh size of the trawl net by 80%.

About 5–10% of the Mangalore trawler fleet catch is the loliginid squid *Loligo duvauceli*. Over the past decade, the otter trawl catch of squids increased from 244 t in 1982 to 994 t in 1991, contributing significantly to the marine products export earning from this area.

Unlike fishes, studies on management of squid stocks are not as developed. Although many models have been tried with varying degrees of success (Pauly, 1985), the inherent variability of squid growth has proven that the necessity for more intense study is required. In India, the scientific management of squid stocks has gained importance only recently due to its increased commercial value. The population dynamics of *L. duvauceli* in Saurashtra waters were studied by Kasim (1985). An assessment of squid stocks off Madras and Cochin was made by Silas et al. (1986) and the *L. duvauceli* population in the Gulf of Thailand has been studied by Supongpan (1988). Recently, Meiyappan and Srinath (1989) have reported the growth and mortality rates of the Indian squid from Cochin.

From Mangalore, the biology of *L. duvauceli* has been studied by Rao (1988) and recently, Mohamed (1993) has reported on the spawning congregations and non-semelparous reproduction in these squids. Presenting the status of the trawl fishery of the mid-shelf off Mangalore coast during 1979–1988, Rao et al. (1993) estimated the stock sizes of important exploited demersal species including the catchable potential yield of squids from the area.

The present study gives estimates of growth parameters, mortality rates and assesses the sustainable yield of *L. duvauceli* from off Mangalore using the yield per recruit model.

MATERIALS AND METHODS

Observations were made at Mangalore trawl landing center during 1987–1991. A multistage random sampling design developed by Central Marine Fisheries Research Institute (CMFRI), Cochin (Banerji and Chakraborty, 1972) was used for estimating the catch of squids and effort by trawlers. The observations were made for 12 h in a "center-day" comprising of two calender days. The catch of squids (at least 10% of the boats in a day) and effort (in trawling hours) by trawl boats were multiplied by the number of boats fishing on the day of observation to obtain the daily estimate. Then these data were pooled and multiplied by the number of fishing days in the month to obtain the monthly catch

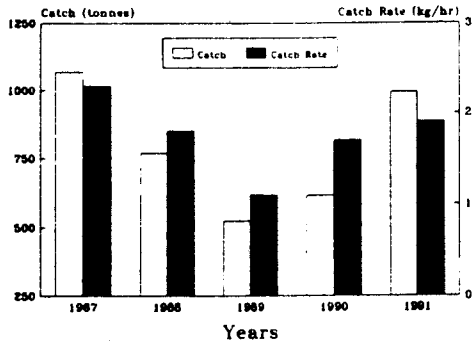

Figure 1. (left) Catch and catch rates of *L. duvauceli* landed at Mangalore during 1987–1991.

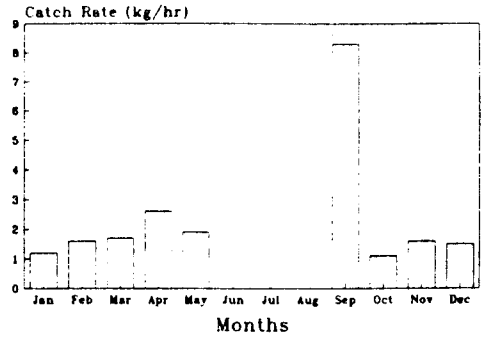

Figure 2. (right) Average seasonal abundance of *L. duvauceli* at Mangalore during 1987–1991 (Jun–Aug—closed season).

and effort estimates. The 95% confidence limits of these estimates did not exceed 12% (Kutty et al., 1973).

On every observation day, the dorsal mantle length (DML) of atleast 50 squids of each sex was measured and their weight recorded. The length (in cm) and weight (in g) of 136 males (length range 5.0–26.5 cm) and 136 females (length range 6.0–15.5 cm) were considered for estimating the length-weight relationship following LeCren (1951), and an analysis of covariance (Snedecor and Cochran, 1967) was carried out to find whether the observed difference between the constants is significant. Student's *t*-test was used to determine if regression coefficients differed from the isometric value 3.

The length data were grouped into 10-mm class-intervals and the time series of the modal lengths were plotted separately for males and females (Fig. 4A, B). Modes traceable for 3 consecutive months were used for estimation of von Bertalanffy growth functions (VBGF) following the integrated method (Pauly, 1983).

The annual mortality coefficient (Z) was estimated by using the length converted catch curve (Pauly, 1983) and the annual mean length (Beverton and Holt, 1956; Ssentengo and Larkin, 1973). The mean of the three values was taken as the estimate of annual Z. The natural mortality coefficient (M) was estimated using the methods of Cushing (1968), Sekharan (1974), Pauly (1980) and Srinath (1991). Of these, the method of Srinath (1991) using the empirical formula $M = 0.4603 + 1.4753K$ was found to give a more realistic (between 1.0 and 2.5) estimate of the M/K ratio and hence was used as an estimate of M. The fishing mortality coefficient (F) was derived from the relation $Z = F + M$. The exploitation ratio (U) was estimated from the equation $U = F/Z\ (1 - e^{-Z})$ and the total annual stock (Y/U) and average biomass (Y/F) were estimated by taking the annual catch (Y) of the species during 1987–1991.

The yield in weight per recruit (Yw/R) was estimated from the equation of Beverton and Holt (1957) for which the age at first capture (t_c) was derived from the length-converted catch curve as per Pauly (1984), and the age at recruitment (t_r) was taken as the age of the smallest animal represented in the fishery. The biomass per recruit (B/R) was estimated from the relation $B/R = (Yw/R)/F$ and the recruitment in numbers (R) from the formula $R = Y/Yw/R$). An approximation of the maximum sustainable yield (MSY) was derived from the yield per recruit graph at fMSY.

Results

Catch and Effort.—Squids are taken as by-catch by the trawl fleet operating from Mangalore. The trawlers confine themselves to an area about 60 km north and south of Mangalore and up to a depth of 70 m covering of 1540 nmi^2. Each fishing trip lasts upto 4–5 days. The fishing season usually commences by mid-November and ends by May. June to August is the monsoon season when rough seas prevent the trawlers from fishing. Trends in the catch and catch rate of *L. duvauceli* at Mangalore during 1987–1991 are shown in Figure 1. The average catch during the period was 794 ± 235 t and catch rate 1.75 kg·h^{-1}. Both catch and catch rate decreased until 1989 and then increased. Annual fishing effort fluctuated between 370,000 and 515,000 h (mean 454,579 ± 54,298 h). The

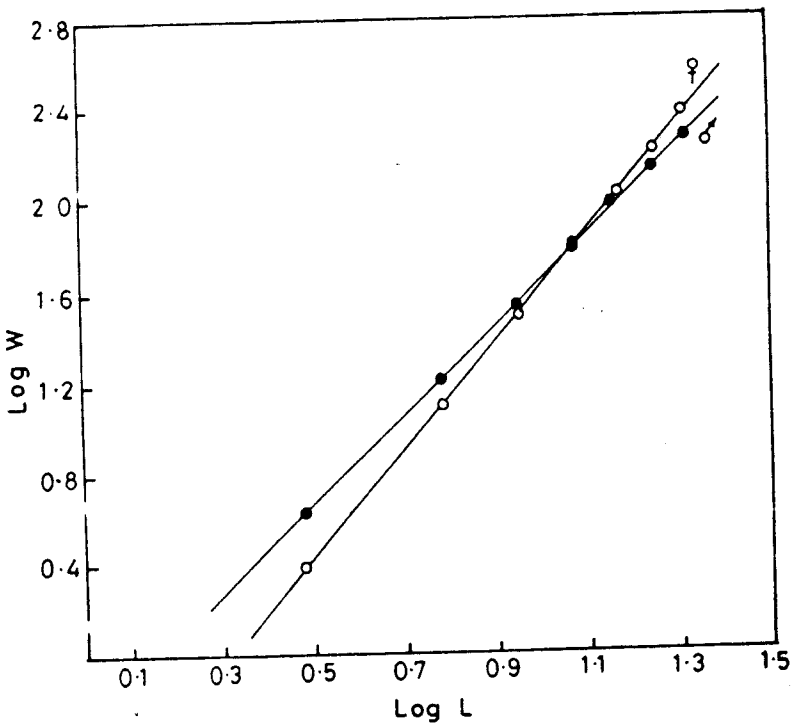

Figure 3. Length–weight relationship of male and female *L. duvauceli.*

maximum monthly catch rate was in September (Fig. 2) with secondary peaks in April and May.

Length–Weight Relationship.—The relationship was determined for males and females separately as:

$$\text{Males: } \log W = -0.31108 + 1.94514 \log L; \quad r = 0.97$$
$$\text{Females: } \log W = -0.72000 + 2.32678 \log L; \quad r = 0.92$$

This relationships show that for a given length (upto 12 cm DML) males are heavier than females. Above 12 cm DML females are heavier than males (Fig. 3). Analysis of covariance revealed that the slope of the curve of males and females are significantly different at the 5% level. Both b values were also significantly ($P < 0.01$) different from the isometric value 3 indicating allometric growth.

Estimation of Age and Growth.—The monthly modal sizes for males of the length range 4.3–33.5 cm and those for females of the length range 4.0–19.8 cm were plotted and the progression of modes in the following months were traced with a scatter diagram (males: Fig. 4A; females Fig. 4B). Multiple modes were seen in all the months and modes traceable for at least 3 consecutive months were used for estimation of the von Bertalanffy growth functions (VBGF) by regressing values of l_t against l_{t+1}. The L_∞ of males was 41.5 ± 12.8 cm ($P < 0.05$) and for females it was 24.5 ± 9.1 cm ($P < 0.05$). The growth coefficient K was estimated as 0.92 ± 0.078 ($P < 0.05$) for males and 1.15 ± 0.086 ($P < 0.05$) for females. The VBGF fitted for males and females separately is:

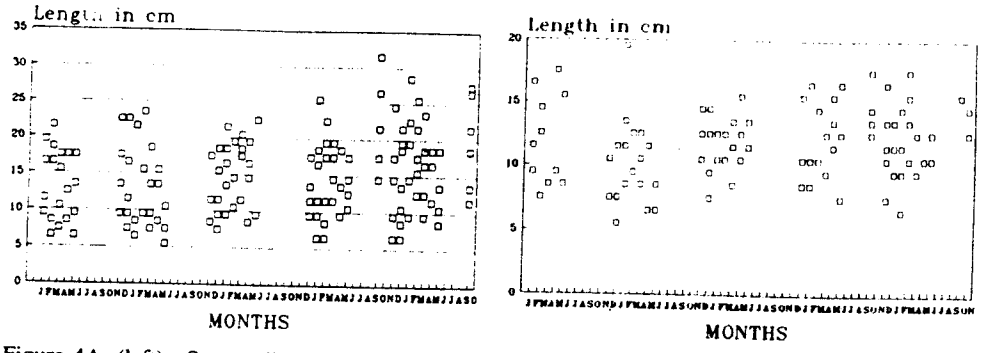

Figure 4A. (left) Scatter diagram of monthly modal lengths of male *L. duvauceli* used in the estimation of VBGF parameters.

Figure 4B. (right) Scatter diagram of monthly modal lengths of female *L. duvauceli* used in the estimation of VBGF parameters.

$$\text{Males: } L_t = 41.5\,[1 - e^{-0.9205\,(t\,+\,0.03762)}]$$
$$\text{Females: } L_t = 24.5\,[1 - e^{-1.1506\,(t\,+\,0.04011)}]$$

Based on the above relationship the growth curves are depicted in Figure 5. The L_∞ of males was larger with lower K, while females had smaller L_∞ with higher K, and therefore, males and females differed widely in their maximum size and age. The maximum sizes recorded previously from the study area are 38.0 cm for males (Mohamed, 1993) and 22.8 cm for females (Rao, 1988). The asymptotic weight (W_∞) was estimated as 686 ± 349 g for males and 325 ± 110

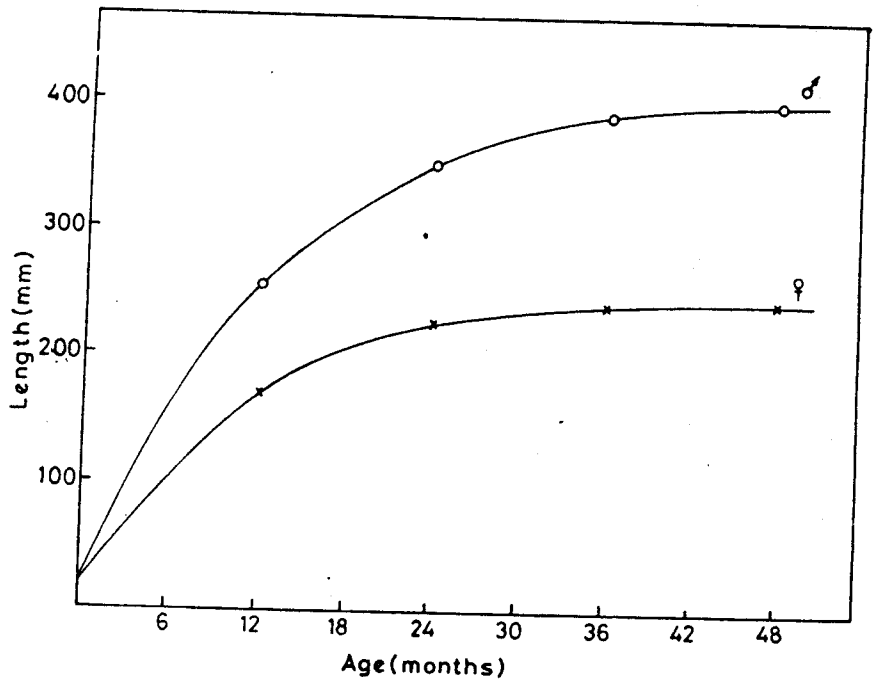

Figure 5. von Bertalanffy growth curves of male and female *L. duvauceli*.

Table 1. Lengths (cm) of *Loligo duvanceli* by season

Months:	6	12	24	36
Male	16.2	25.5	35.1	39.0
Female	11.3	17.1	22.2	—

g for females using the length-weight relationship. The lengths (in cm) at ages 6, 12, 24 and 36 months are given in Table 1.

The life-span (T_{max}) of the species is estimated to be 3.2 ± 0.4 years ($P < 0.05$) for males and 2.6 ± 0.2 years ($P < 0.05$) for females from the VBGF. The annual mean lengths (Fig. 6) showed an increasing trend for both males and females during the period. The majority of the squids exploited were less than a year old.

Estimation of Mortality Rates.—The length-converted catch curves for each year and the Z values are shown in Figure 7. The estimated Z values using the Beverton and Holt (1957) and Ssentengo and Larkin (1973) methods are given in Table 2 together with the annual average Z used in the study. The mean Z value for males during the period was 6.5 ± 1.64 and for females it was higher at 8.17 ± 0.72. The average Z values were higher for females in all the years except 1988.

The natural mortality coefficient (M) was estimated as 1.82 for males and 2.16 for females. The value was higher in females due to its shorter life-span and faster growth. The M/K ratio was therefore 1.98 in males and 1.88 in females. The values of annual fishing mortality coefficient (F) are given in Tables 3 and 4. The average value for males during the period was 4.68 ± 1.64 and for females it was 6.01 ± 0.72.

Estimates of Stock.—The exploitation ratio, total annual stock and average biomass are given in Tables 3 and 4 for males and females respectively. The average exploitation ratio for the period was above 0.7 for both sexes, but showed a declining trend during 1991 for males (0.59). The total average annual stock

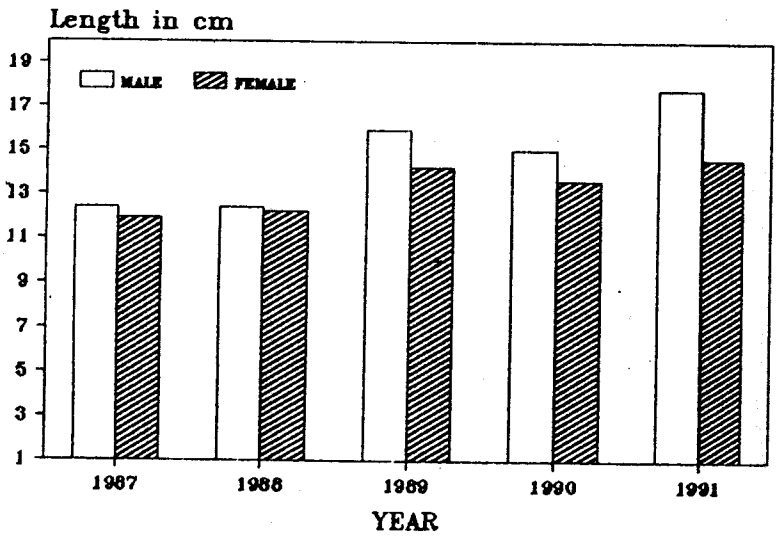

Figure 6. Annual mean lengths of male and female *L. duvauceli.*

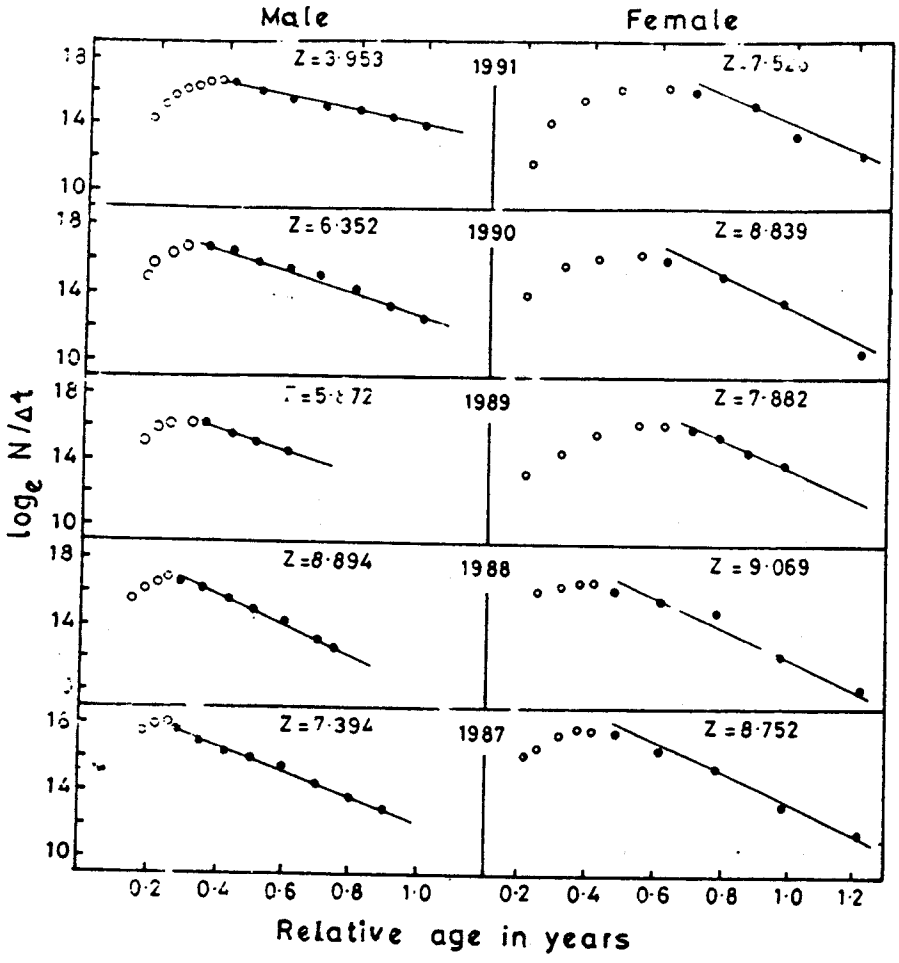

Figure 7. Length converted catch curves of male and female *L. duvauceli* during 1987–1991. Closed circles indicate points used for deriving Z.

Table 2. Estimated annual mortality coefficients (Z) using different methods and annual average Z of male (M) and female (F) *L. duvauceli*

	Methods							
	Catch curve		Beverton and Holt		Ssentengo and Larkin		Average	
Year	M	F	M	F	M	F	M	F
1987	7.39	8.75	7.85	7.54	8.30	8.10	7.85	8.13
1988	8.89	9.07	7.93	6.54	8.38	7.10	8.40	7.57
1989	5.87	7.88	4.84	9.57	5.29	10.13	5.33	9.19
1990	6.35	8.84	6.17	8.08	6.62	8.65	6.38	8.52
1991	3.95	7.53	4.58	7.13	5.02	7.69	4.52	7.45

Table 3. Estimates of mortality coefficients, exploitation ratio, annual stock and average biomass of male *L. duvauceli*

Year	Z	M	F	Exploitation ration (U)	Catch (Y) t	Total stock (Y/U) t	Ave. biomass (Y/F) t
1987	7.85	1.82	6.03	0.77	459.3	596.5	76.2
1988	8.40		6.58	0.78	369.1	473.1	56.1
1989	5.33		3.51	0.66	256.2	388.1	72.9
1990	6.38		4.56	0.71	356.5	502.1	78.2
1991	4.52		2.70	0.59	586.4	993.9	217.4
Ave.	6.50	1.82	4.68	0.72	405.5	563.2	86.7

amounted to 1088 ± 363 t and the average catch during the period was 794 ± 235 t. The total average biomass was estimated as 151 t. The annual stock, average biomass and catch were marginally higher for males than females.

Estimates of Yield and Biomass per Recruit.—The average age at first capture (t_c) for males during the period was estimated as 0.286 year (L_c = 9.6 cm; 95% CI = 0.071 yr) and for females the average t_c was estimated as 0.493 year (L_c = 10.6 cm; 95% CI = 0.117 yr). The age at recruitment (t_r) for males was 0.116 year (4.3 cm) and for females the t_r was 0.155 year (4.0 cm). Using these and other paramaters (K, M, t_o, W_∞, Z), the Yw/R for males at M 1.82 was 22.1 g (Fig. 8) with an F_{max} of 2.0. However, the present average F(F_P) was 4.7. The MSY for males was estimated as 487 t. The Yw/R for females at M 2.16 was 17.4 g at F_{max} 5. The F_P was 6.1. The MSY for females was estimated at 390.3 t. The combined MSY for both sexes was 877.3 t. The biomass per recruit curve for both sexes is also given in Figure 8.

The Yw/R as a function of t_c (yield-mesh curve) with different average values of Z for both sexes is given in Figure 9. The maximum Yw/R for males can be obtained at t_c 0.8 year, while the present t_c is 0.29 year. For females the maximum Yw/R can be obtained at t_c 0.6 while the present t_c is 0.5 year.

Discussion

Loligo duvauceli is a commercially important component of the trawl catch from Mangalore. The squid catch and catch rate decreased up to 1989 showing signs of stock depletion and recruitment failure, but improved after 1989 mainly due to spawning congregations which occurred in 1990 and 1991 along the Mangalore-Malpe coast. According to Mohamed (1993) such an event occurs annually with varying intensities along the southwest coast of India during the post-monsoon period.

Table 4. Estimates of mortality coefficients, exploitation ratio, annual stock and average biomass of female *L. duvauceli*

Year	Z	M	F.	Exploitation ration (U)	Catch (Y) t	Total stock (Y/U) t	Ave. biomass (Y/F) t
1987	8.13	2.16	5.97	0.73	608.8	834.0	102.0
1988	7.57		5.41	0.71	399.8	563.1	73.9
1989	9.19		7.03	0.77	266.6	346.2	37.9
1990	8.52		6.36	0.75	258.1	344.2	40.6
1991	7.45		5.29	0.71	407.5	574.0	77.0
Ave.	8.17	2.16	6.01	0.74	388.2	524.6	64.6

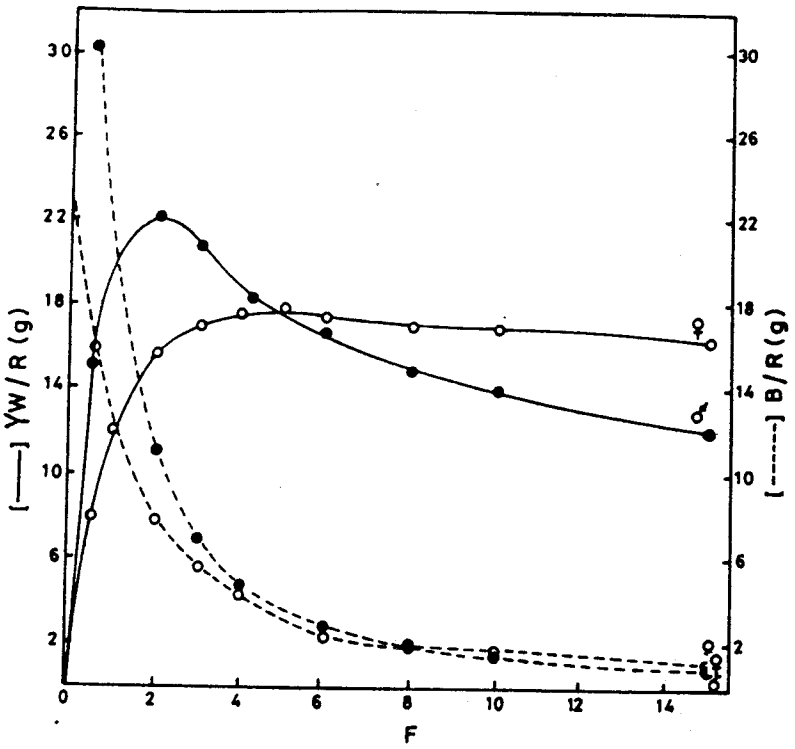

Figure 8. Yield per recruit and biomass per recruit in grams of male and female *L. duvauceli.*

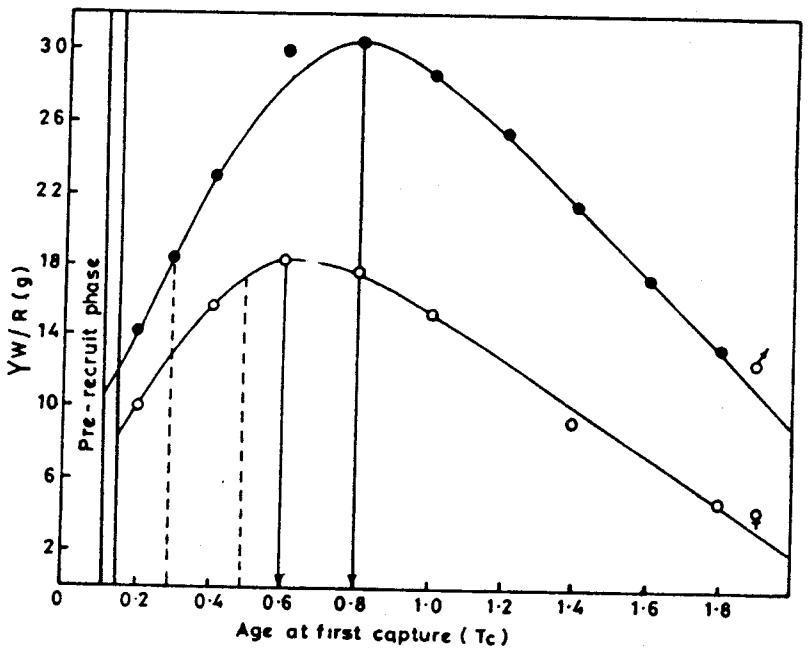

Figure 9. Yield mesh curves of male and female *L. duvauceli.* Dotted lines indicate present t_c. Arrows indicate maximum Yw/R values.

Table 5. Comparison of growth parameters, growth performance index ($\phi' = \log 10K + 2\log 10 L_\infty$) and ratio of natural mortality and growth coefficients (M/K) of *L. duvauceli* from different localities

Area	Sex	L_∞ (cm)	L_{max} (cm)	W. (g)	K (yr $^{-1}$)	M/K	ϕ'	Source
1, Saurashtra (Veraval)	Combined	33.4	—	692	0.50	3.00	2.75	Kasim (1985)
2, Cochin	Male	32.7	25.5	444	0.61	1.50	2.81	Silas et al. (1986)
	Female	20.5	19.0	165	1.19	1.50	2.70	
3, Madras	Male	20.0	17.0	201	0.95	1.50	2.58	Silas et al. (1986)
	Female	20.0	19.0	237	0.95	1.50	2.58	
4, Gulf of Thailand	Combined	26.6	26.0	265	0.84	1.07	2.77	Supongpan (1988)
5, Cochin	Male	37.2	33.0	590	1.10	2.00	3.18	Meiyappan and
	Female	23.8	18.6	276	1.70	1.29	2.98	Srinath (1989)
6, Mangalore	Male	41.5	38.0	686	0.92	1.98	3.10	Present Study
	Female	24.5	22.8	325	1.15	1.88	2.84	

Both males and females of *L. duvauceli* exhibited allometric growth. Similar findings have been reported earlier by Rao (1988), Supongpan (1988) and Meiyappan and Srinath (1989) in *L. duvauceli*. The b values of males and females also differed significantly from each other with males being heavier than females up to 12 cm after which females were heavier. The size at first maturity of female *L. duvauceli* at Mangalore is 11 cm (Mohamed, 1993) and this could explain the sudden increase in weight at lengths above 12 cm.

Due to the variability in squid length data, growth in squids is percieved to be either linear, exponential, asymptotic or oscillating (Pauly, 1985). In spite of these differing growth patterns, most workers have used the asymptotic growth model (VBGF) with and without modifications. The growth rate of the Mangalore population of *L. duvauceli* using the VBGF was distinctly different between sexes. Females had a faster growth rate than males, but had a shorter life-span. A comparison of the growth parameters and growth performance index (ϕ') of *L. duvauceli* stocks from other areas is given in Table 5. The ϕ' did not show much variation and ranged between 2.58–3.2, indicating within-species constancy of the parameter. The estimates of M/K for Cochin and Mangalore poulations lay within 1.5–2.0. However, such estimates for Saurashtra and Gulf of Thailand seem to be over- and under-estimated respectively. The M/K ratio generally lies in the range 1.5–2.5 (Beverton and Holt 1959).

Kasim (1985) estimated the the longevity of *L. duvauceli* at Veraval to be 6 years. Other estimates of longevity are far below this figure. In the Gulf of Thailand Supongpan (1988) estimated the T_{max} to be more than 3.5 year, while at Cochin, Meiyappan and Srinath (1989) estimated the T_{max} to be 2.7 year for males and 1.8 year for females. The T_{max} observed in the present study lies between these two estimates. One-year-old and younger squids dominated the fishery during the period. Older age groups were seen in few numbers only and mainly during the spawning congregation of September–October of 1990 and 1991.

The annual Z estimates provided by all the three methods are close. The annual Z estimate 6.5 for males and 8.2 for females seem relatively high but is justified considering the intensive trawling taking place during the relatively short season. The precise separation of F and M from Z is one of the major hurdles in the study of population dynamics. The estimate of M used in the present study seems appropriate due to the cannibalistic nature of the species (Oomen, 1977) and its high percentage in the diet component of major demersal fishes like lizard fishes and threadfin breams at Mangalore (Zacharia, Pers. Comm.).

The observed exploitation rates were above the E_{opt} of 0.66. The average catch during the period was 73% of the total stock and 14% of the stock was the

standing crop or average biomass. The present stock estimate of 1088 t is in close agreement to the catchable potential yield of 1050 t estimated by Rao et al. (1993) and the total standing stock of 1030 t estimated by the swept area method by Rao et al. (1993). Estimates of stock of *L. duvauceli* at Cochin and Madras (Silas et al., 1986) are far below these. At both Cochin and Madras, the female stocks were greater whereas at Mangalore, the male stock was marginally higher.

The yield curve for male *L. duvauceli* was dome shaped with a sharp peak, while the same curve for females was less dome shaped and more or less flat topped. The biological significance between the two is that much weight is put on during the exploitable life-span when the peak is sharp and in the latter case the animals do not grow much during the exploitable life-span (Cushing, 1968). A similar difference between sexes in the yield curves was also noticed in the Cochin and Madras populations of *L. duvauceli* (Silas et al., 1986).

The results of the Yw/R analyses indicate that fishing pressure is excessive and, if it is reduced, catch could be increased. Combining the data on sexual differences, a 35% decrease in F from the present level would result in a 10.5% increase in catch to obtain the MSY. Similarly, the yield mesh curve also indicates scope for increasing the cod-end mesh size and hence the t_c. The average cod-end mesh size of the trawl nets at Mangalore is 32.5 mm (Rao et al., 1993). Taking the average values of t_c for both sexes, the mesh size has to be increased by 80% (from 32.5 to 58.5 mm) to maximize the yield and this would result in the t_c being increased to 0.7 yr.

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