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Stock assessment of Indian squid, *Uroteuthis (Photololigo) duvaucelii* (d'Orbigny [in Férussac & d'Orbigny], 1835) from south-western Bay of Bengal

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Stock assessment of the Indian squid *Uroteuthis (Photololigo) duvaucelii* off north Tamil Nadu coast from commercial trawl landings was studied during the period 2012-2016. The species is mainly caught by trawl net and the annual average landing of the species was 563.3 t contributing to 2 % to the total trawl landing along north Tamil Nadu coast. $L\infty$, K and t_0 were estimated as 260 mm, 0.84 yr^{-1} and -0.105 yr, respectively. Total mortality rate (Z), Natural mortality rate (M), and Fishing mortality rate (F) were 4.43 yr^{-1}, 1.67 yr^{-1} and 2.78 yr^{-1}, respectively. t_{max} was estimated to be 3.47 yr. The length at first capture (Lc_{50} = 62 mm) estimated by Length converted catch curve method was found to be lower than Length at first maturity (Lm_{50} = 80 mm). Furthermore, E_{curr} (current exploitation rate) was found be on higher side than the E_{max} (0.48) and $E_{0.1}$ (0.40) which indicates that the fishery is in overexploited stage. Thompson and Bell prediction model showed that a marginal decrease (20 %) in current level of exploitation would help in regeneration of stock for long term sustainability of the resources as well as in achieving maximized economic return.

[**Keywords**: Exploitation rate, Spawning stock biomass, *Uroteuthis (Photololigo) duvaucelii*]

Introduction

Overfished stocks of marine fisheries present great concern globally and about 33.1 % of stocks are currently being overfished[1]. There has been a steady increase in percentage of stock fished without giving concern to the sustainability. Although, fisheries resources are renewable resources, such huge irremediable depletion of fish stocks as a result of overexploitation has led to decline in fishery resources all over the world. This is where, stock assessment played an important role by giving information regarding status of the fishery *i.e.* whether it is being over exploited or underexploited. It also tells us the possible outcomes of different management actions to the fisheries managers.

Cephalopods belongs to the phylum mollusca and are represented by 800 species comprising of three main categories *i.e.* squid, cuttlefish and octopus. The commercial exploitation of cephalopods has been steadily increasing due to ever increasing demand in internal and external market. With the increasing demand for frozen cephalopods in the export basket to several countries, the fishery has transitioned from a by-catch resource to a targeting resource. Off late cephalopods product has become a major item exported from India. The resources are intensively exploited by single day and multiday trawlers. Among the cephalopods, cuttlefish formed the major fishery followed by squids and octopus along Chennai coast. *U.(P.) duvaucelii*, the Indian squid, is extensively distributed in neritic waters from Mozambique to the South China Sea and from the Philippines Sea up to Taiwan; occurring up to a depth of 120 m or even more[2]. In Tamil Nadu it is locally known as "Usikaddama" mainly exploited by single day and multiday trawlers. Several authors[3-7] have studied the fishery and population dynamics of Indian squid in Indian waters. However, the information on stock status of *U.(P.) duvaucelii* along the east coast is scarce. Studies on the stock status of commercially important species are essential for the long term sustainability of fishery resources and fishing industry. Furthermore, the paucity of information on population parameters and stock status of the Indian squid especially within east coast of India may cripple any management intervention towards the sustainable exploitation of the resources in India. It is against this back drop, current study has been conducted to estimate the stock parameters of *U.(P.) duvaucelii* to enhance the existing management intervention.

Materials and Methods

Weekly sampling was carried out from the commercial trawl landing at Madras fisheries Harbour (MFH) in Kasimedu, Chennai for a period of 5 years during January, 2012 to December, 2016 to collect the data on catch, effort and size composition of Indian squid (Fig. 1). Dorsal mantle length and the individual body weight was measured from fresh specimens of *U.(P.) duvaucelii* to the nearest mm and mg, respectively. An eye estimated catch of the species was recorded on the day of observation. Daily length frequency data collected for the species were raised by the raising factor (the total landing weight / sample weight of the species on the day of observation). Afterwards, the raised daily length frequency data were again raised to monthly landing, following the method adopted by Fisheries Resources Assessment Division (FRAD) of CMFRI[8]. The von Bertalanffy growth parameters ($L\infty$ and K) were estimated using monthly raised length frequency data in the ELEFAN 1 module of FiSAT II[9]. The age at length zero (t_o) was estimated by using Pauly's empirical equation: $Log_{10}(-t_0) = -0.3922-0.2752 \log_{10} L_\infty - 1.038 \log_{10} K$(ref. 10). Growth performance index (φ) was estimated from the formula: $\varphi = \log_{10} K + 2\log_{10} L_\infty$(ref. 11). Longevity ($t_{max}$) was calculated from the formula $t_{max} = 3/K + t_0$(ref. 12). The length-weight relationship of *U. duvacelli* was established using the formula, $W = aL^b$(ref. 13).

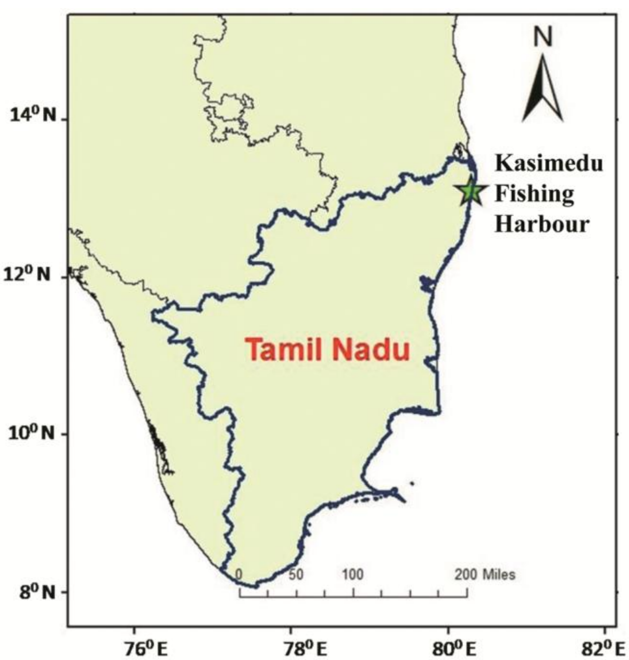

Fig. 1 — Map showing Kasimedu fishing harbour (13º 07´32´´ N & 80º 17´ 49´´ E) south western Bay of Bengal

The raised annual length frequencies of the Indian squid were pooled for all the years (2012-2016) and the pooled length frequency values were considered for further study. Instantaneous total mortality rate (Z) and Instantaneous natural mortality rate (M) were estimated by length converted catch curve method[14] and Pauly's empirical equation[15], respectively. The fishing mortality (F) was calculated as F = Z-M. Following the method described by Beverton & Holt[16], the exploitation rate ($U = F/Z (1-e^{-Z})$) and exploitation ratio (E = F/Z) were estimated. Using FiSAT, recruitment pattern of Indian squid was determined by backward projection on length axis of length frequency data. The restructured data was used to reduce the temporal spread and recruitment pattern was determined by maximum likelihood method using NORMSEP[17]. The length at recruitment (Lr) was considered to be the midpoint of the smallest length group in the catch during the five-year period. Length at first capture (Lc_{50}) was estimated from length converted catch curve method[13]. The probability of capture was estimated by backward extrapolation of regression line of descending limb of length converted catch curve and by using logit curve, the probability of capture of sequential length classes were regressed to obtain Lc_{50}. Size at first maturity (Lm_{50}), defined as the length at which 50 % of the female stock attain sexual maturity, was determined by graphical method[18]. The cumulative percentage frequency of II to IV stages were plotted against various length groups and the length at 50 % cumulative percentage frequency was considered to be length at first maturity. Maturity stages of female were assessed by visualising its internal organ and classified into the four point maturity scale following the method described by Silas for squid[19].

Based on the estimated growth parameters and fishery parameters of the species, the relative yield per recruit (Y'/R) and relative Biomass per recruit (B'/R) were estimated at different fishing levels using Beverton & Holt's relative yield per recruit analysis method[20]. By using Thompson & Bell bio-economic model[21], Yield (Y), Biomass (B) and spawning stock biomass (SSB) were predicted at different exploitation levels.

Results and Discussion

Fishery

The data on annual landing and annual effort data for total squids as well as *U.(P.) duvaucelii* during

2012-2016 is shown in Table 1. The analysis indicated that annual squid landing at MFH fluctuated between 732 and 1671 t during 2012-2016, with maximum landing in 2015. Along north Tamil Nadu coast cephalopods were mainly targeted by multiday and single day trawl net and *Sepia pharaonis* forms the major fishery followed by *U.(P.) duvaucelii* among cephalopods in north Tamil Nadu coast. The average landing of *U.(P.) duvaucelii* was 1050.6 t during 2012-2016 with an average CPUE of 1.14 kg hr^{-1} (Table 1). Although maximum landing of the species was recorded in 2015, its percentage contribution to the total squid landing of north Tamil Nadu was lowest in that year, where it formed only about 38 %; while in the other years it formed 53-68 %. It was because of more quantity of other species of squid landed along the coast during 2015. Generally along North Tamil Nadu Indian squid forms the major fishery and it contributes more than 65 % of the landing while other species *viz*. *U.(P.) edulis*, *U.(P.) singhalensis* and *Loliolus (Nipponololigo) uyii* landed in insignificant quantities.

Length -weight relationship (LWR)

The relationship between dorsal mantle length (ML) and total body weight (W) was estimated for pooled individuals as well as for both individual sexes (male and female) separately. The length-weight relationship was estimated based on 153 males (in the ML range of 13.5 to 26.6 cm and weight in the range of 14 to 117 g) and 319 females (in the ML range of 12.8 to 31 mm and weight in the range of 12 to 214 g).

The LWR in Indian squid can be expressed as:

Male: $W = 0.35(ML)^{1.92}$ ($R = 0.87$)

Female: $W = 0.14(ML)^{2.54}$ ($R = 0.91$)

Pooled: $W = 0.19(ML)^{2.19}$ ($R = 0.89$)

The value of b found in present study for male, female and pooled sexes indicates negative allometric growth pattern in Indian squid. However male showed higher degree of negative allometric growth pattern compared to the female. The statistical comparisons indicated a significance difference ($p = 0.0009 < 0.01$) between LWR of male and female. The LWR of *Uroteuthis (Photololigo) duvaucelii* was studied by several authors[4,22-26] and they reported negative allometric growth pattern, as found in the present study.

Growth parameters

A total of 2093 Indian squids were randomly collected for the current study and the specimens which are used for the present study were in the size range of 25-239 mm. The restructured length frequency distribution and growth performance of *U.(P.) duvaucelii* is shown in Figure 2. The von Bertalanffy growth parameters ($L\infty$ and K) were estimated at 260 mm and at 0.84 y^{-1}, respectively. The t_0 was estimated as -0.105 yr while longevity (t_{max}) was estimated to be 3.47 yr. Thus, von Bertanlaffy equation for *U.(P.) duvaucelii* from south-western Bay of Bengal can be expressed as $L\infty = 260*(1-e^{(-0.84*(t-(-0.105))})$. The growth curve indicated that *U.(P.) duvaucelii* grows to a ML of 157.32 mm in 1^{st} year, 215.63 mm in 2^{nd} year and 240.85 mm at the end of 3 years of its life. Thomas & Kizhakudan[7] reported that the Indian squid grows upto 189, 260, 287 mm at the end of the first three years of its life along the Gujarat coast, with longevity of 3.06 years. However, Karnik *et al.*[27] reported the length at the end of I to III years for *U.(P.) duvaucelii* as 221, 315 and 355 mm along Mumbai coast, with longevity of 3.5 years.

The L_∞ estimated in the current study is comparatively smaller than the earlier reports[(2,3,6,7,22,27-33)] except Meiyappan *et al*.[4] from the east coast (Table 2). They reported L_∞ of 220 mm for male and 205 mm for female from east coast of India and higher values of 360 and 232 mm for male and female respectively from west coast of India. An earlier study by Mohamed[34] indicated that females grew faster than males, while males ultimately reach larger size. As

Table 1 — Catch and effort of *U.(P.) duvaucelii* along south western Bay of Bengal

Year	Effort (fishing hours)	Total trawl landing (t)	Squid landing (t)	*U.(P.) duvaucelii*		
				Landings (t)	CPUE (kg/hr)	% contribution to total squid landing
2012	422819	23124	732	435	1.03	59.41
2013	470457	26277	989	526	1.12	53.18
2014	432884	28985	940	637	1.47	67.82
2015	476284	29386	1671	639	1.34	38.24
2016	783387	35348	921	579	0.74	62.87
Average	517166.2	28624	1050.6	563.2	1.14	56.30

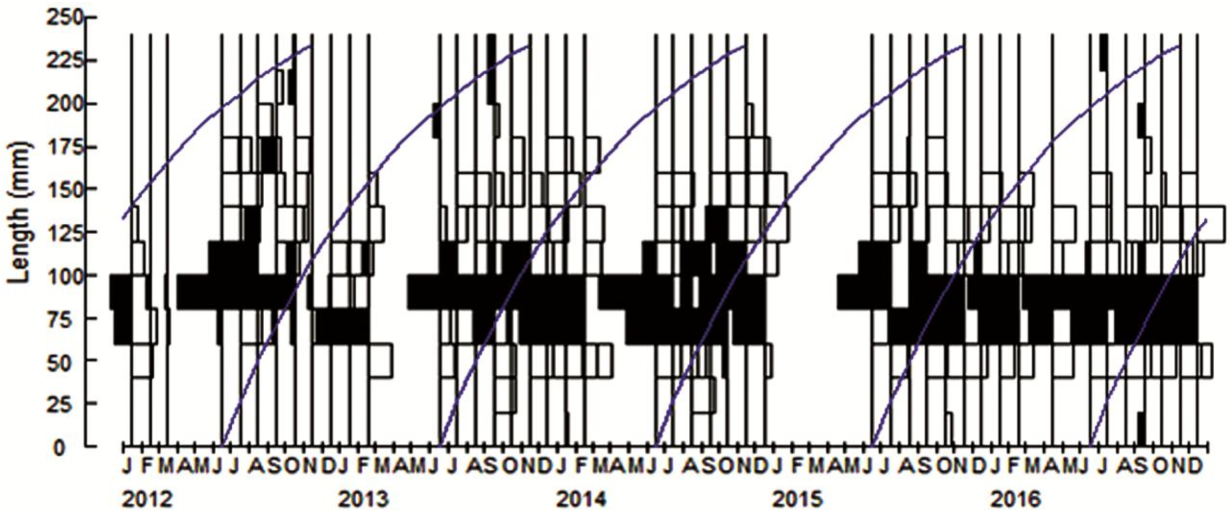

Fig. 2 — Restructured length frequency of *U.(P.) duvaucelli*

Table 2 — A summary of earlier reports on growth and mortality parameters

Authors	Region	Sex	L∞ (mm)	K (yr^{-1})	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	t_0 (yr^{-})	t_{max} (yr)
Silas *et al.*[22]	Cochin coast	M	327	0.61					
		F	205	1.19					
Kasim[3]	Veraval coast	Pooled	300	0.98	3.94	1.74	2.20	0.56	3.10
Supongpan[28]	Thailand coast	Pooled	266	0.86					3.49
Meiyappan & Srinath[2]	Cochin coast	M	379	1.10	9.0				
		F	238	1.17	10.6				
Vidyasagar & Deshmukh[29]	Mumbai coast	Pooled	323	0.45	1.83				
Meiyappan *et al.*[4]	East coast of India	M	220	0.90					
		F	205	1.30					
Chakraborty *et al.*[30]	Mumbai coast	Pooled	343	0.49	2.90	1.10	0.99		
Mohamed & Rao[6]	Karnataka coast	Pooled	343	1.43					2.50
Karnik *et al.*[27]	Mumbai coast	Pooled	385	0.85	4.29	1.82	2.47		3.53
Thomas & Kizhakudan[7]	Veraval coast	Pooled	303	0.98	3.94	1.74	2.20		3.06
John[31]	Cochin	Pooled		0.75	2.61	1.37	1.24		
Chakraborty *et al.*[32]	Mumbai	Pooled	380	0.90	4.43	1.41	3.02		3.33
Nitin *et al.*[33]	India	Pooled	376	0.95	4.50	1.82	2.68		3.10
Present study	North Tamil Nadu, South western Bay of Bengal	Pooled	260	0.84	4.43	1.67	2.76	-0.105	3.47

the estimation of L_∞ is greatly influenced by L_{max} in the sample, L_∞ may vary from location to location.

Similarly the value of growth coefficient 'K' obtained in this study is found to be on higher side compared to the value estimated by Vidyasagar & Deshmukh[29] and Chakraborty *et al*.[30] from Mumbai waters and by John[31] from Cochin waters. However, Mohamed & Rao[6] estimated significantly higher value of K from Karnataka coast. The estimated value of K in the current study is in agreement with Karnik *et al*.[27] and Supongpan[28]. Growth parameters may vary for different stocks belonging to different geographic locations. It has been reported that in some squids, particularly those belonging to family Loliginidae, the growth parameters are highly variable for different stocks[35].

Mortality parameters

By using length converted catch curve[14] method, the total mortality rate was estimated to be 4.43 (Fig. 3). The natural mortality (M) and fishing mortality (F) were estimated as 1.65 and 2.78, respectively. The present obtained values of natural mortality, fishing mortality and total mortality has been compared with earlier studies (Table 2). The total annual mortality of the Indian squid obtained in the current study is comparatively on higher side than the

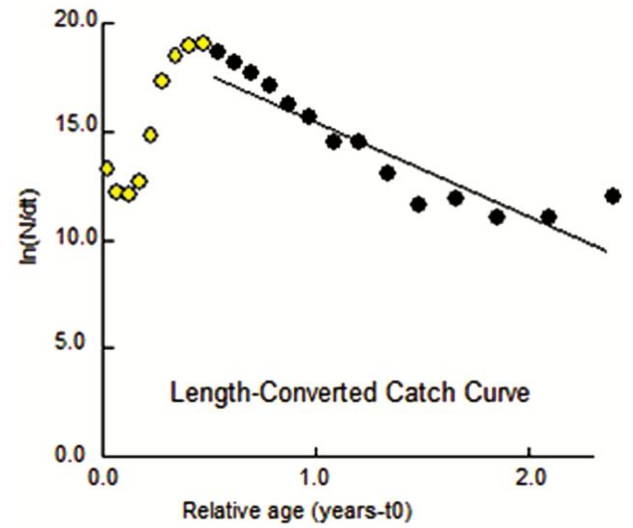

Fig. 3 — Estimation of Z from length converted catch curve (Z = 4.43)

earlier reports[(2,3,7,29-31)]. Nevertheless, the present estimated value of total mortality is slightly closer to the earlier reports by Chakraborty *et al*.[32] and Karnik *et al*.[27]. Natural mortality was compared with earlier studies and it seems to be different for various geographic locations. The variation in natural mortality observed in the present study may be because of environmental conditions as well as fishing methods which influence the abundance of predators and competitors[36]. *U.(P.) duvaucelii* is a preferred food of most fishes in the marine ecosystem, and the abundance of predators may affect the natural mortality. Nevertheless, M/K is used as an index of reliable estimation of M and K value and it ranges from 1 to 2.5[(ref. 36)]. The present estimated value of M/K (1.96) indicated a reasonable estimation of natural mortality.

The current fishing mortality rate (F = 2.78) is comparatively higher than natural mortality (M = 1.63) revealing overexploitation of Indian squid. However, a stock is considered to be in a healthy state and at optimum exploited phase, if the fishing mortality and natural mortality are equal in a natural ecosystem (*i.e.* E = 0.5)[37]. However, the present value of exploitation rate is comparatively higher than the optimum exploitation rate affirming the evidence of overfishing of squid along the north Tamil Nadu coast.

Length at first capture (Lc_{50}) and Length at first maturity (Lm_{50})

The length at first capture *i.e.* length at which 50 % of the squid in the stock become vulnerable to the gear was found to be 62 mm while maturity studies indicated that 50 % of the squid attain maturity at DML of 80 mm. The Lm_{50} was relatively higher than Lc_{50}, indicating that the squid are mostly exploited before they attain maturity, which is clear sign of growth overfishing. Moreover the value of $Lc/L\infty$ (0.24) was far below the recommended value of 0.5[(ref. 38)] indicating that majority of the catch consists of juveniles, a common feature of growth overfishing. The bulk landing of juvenile squid may be due to the use of trawl gear with small mesh size (< 30 mm) which is used to target shrimp, and also due to the use of non-selective gears for squids along the north Tamil Nadu coast. The optimum Lc_{50} which corresponds to the mantle length for obtaining maximum possible yield, was estimated to be 157.88 mm. Lm_{50}, estimated in the present study is observed to be close to earlier reports[39,40]. However, Rao[41] reported a higher value of Lm_{50} (108 mm) from Mangalore coast. Smaller size at maturity may be due to the effect of high fishing pressure.

Recruitment pattern

The recruitment pattern of *U.(P.) duvaucelii* was continuous throughout the year with, one major peak during June to August and with one minor peak during February to March (Fig. 4). Highest recruitment was found to be in the month of April (14.65 %) and May (23.35 %). The presence of recruits in fishery throughout the year revealed that the Indian squid spawns throughout the year. Silas *et al*.[42] observed mature gonads in squids almost throughout the year all along the coast which is in agreement with the present study. The observed smallest mantle length at first recruitment (Lr) was 35 mm, providing the evidence of the use of small mesh trawl gears by fishermen along the north Tamil Nadu coast.

Stock assessment

By using input parameters of L_c/L_∞ (0.24) and M/K (1.96) the Beverton and Holt's relative yield per recruit and biomass per recruit analysis was carried out for the stock assessment of *U.(P.) duvaucelii*. It showed that maximum yield/recruit could be obtained at exploitation rate of 0.48; while the optimum yield *i.e.*, half of its virgin biomass, can be obtained at exploitation rate of 0.29 (Fig. 5). Nevertheless, as the aquatic ecosystem is highly uncertain, as precautionary approach $E_{0.1}$ = 0.40 can be taken as management reference point. The current exploitation rate (E = 0.63) is relatively higher than this reference point, indicating the overexploited status of the Indian squid in the south-west Bay of Bengal along the north Tamil Nadu coast.

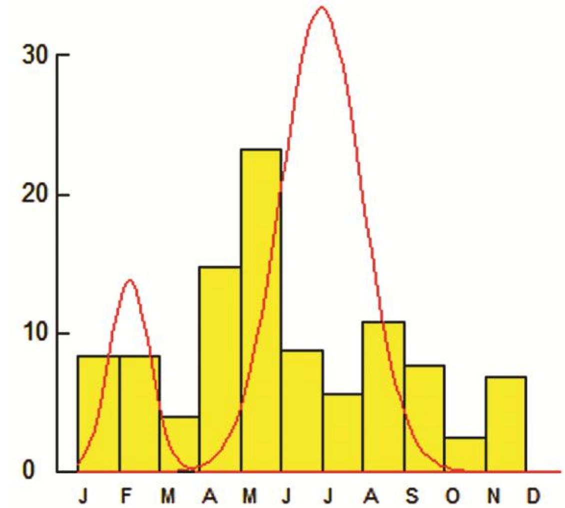

Fig.4 — Recruitment curve of *U.(P.) duvacelii* along south western Bay of Bengal coast

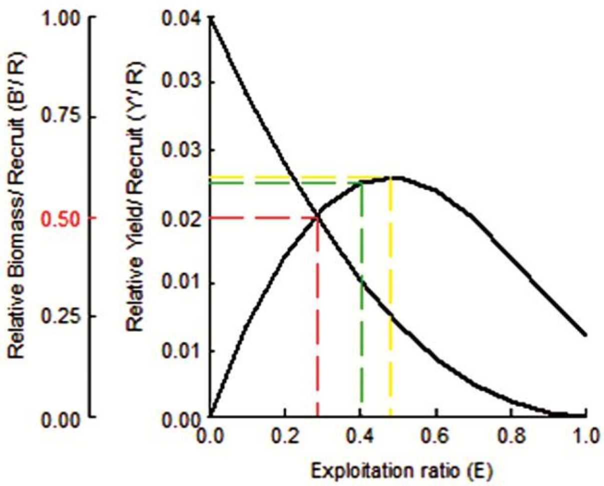

Fig. 5 — Yield per recruit and biomass per recruit showing the maximum yield per recruit at exploitation rate levels {E_{max} = 0.48, E_{10} = 0.40, E_{50} = 0.29} of *U.(P). duvaucelii* from the North Tamil Nadu, south west Bay of Bengal

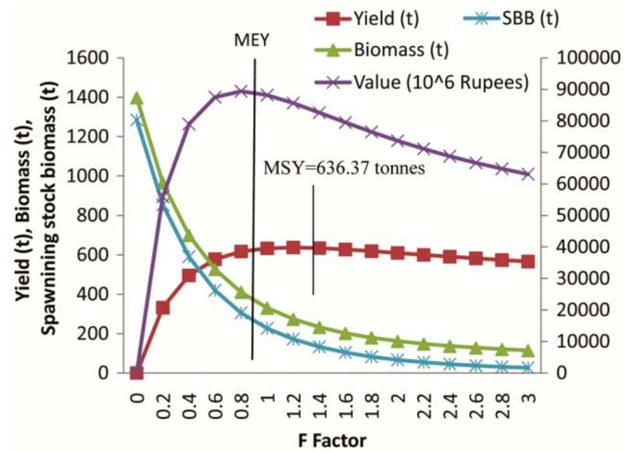

Fig. 6 — Length based Thompson and Bell analysis of *U.(P). Duvaucelii* along North Tamil Nadu, south western Bay of Bengal coast predicting the yield, spawning stock biomass and total stock biomass at different effort level

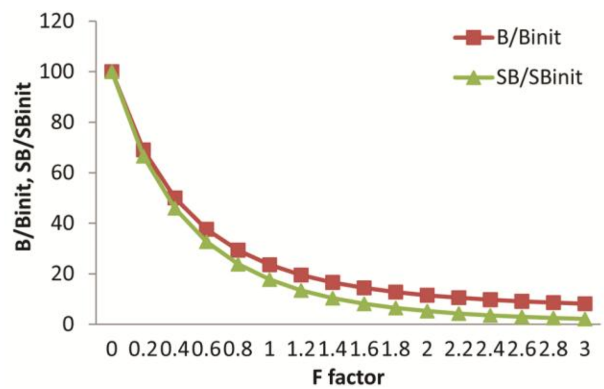

Fig. 7 — Percentage of initial biomass spawning stock biomass of *U.(P). duvaucelii* at different fishing effort level of F

Managing fisheries under uncertainty has become a top priority and a major challenge in recent times. The Beverton and Holt's relative Y/R and B/R analysis has some limitation while estimating management reference points as it tends to overestimate the E_{max} unrealistically for smaller species with high natural mortality in tropical ecosystem. Moreover, the above analysis does not consider spawning stock biomass[43-44]; whereas spawning stock biomass is an important indication of health status of the stock. There should be sufficient spawning stock biomass in the ecosystem for the regeneration of exploited stock and it is always advisable to maintain the virgin spawning stock biomass at 20-30 % in the ecosystem to minimize the risk of recruitment overfishing and to ensure the availability of adequate amount of spawners in the ecosystem[45].

Due to risk uncertainty in fisheries stock assessment, Thompson & Bell bio-economic model[21] was used to study the impact of different fishing levels on Yield (Y), Biomass (B) and spawning stock biomass (SSB) and the results (Fig. 6) indicated that the current fishing effort can be increased by 20 % to obtain Maximum Sustainable Yield. However, this may lead to a decline in the spawning stock biomass to 13.4 %, which may be detrimental to the prolong sustainability of Indian squid fishery along the coast. In order to achieve Maximum Economic Yield, the current fishing level needs to be decreased by 20 % and at that level spawning stock biomass could be maintained at 23.78 % (Fig. 7). The marginal decrease in effort by 20 % would help in regeneration of stock as well as in achieving maximized economic return. However, in a tropical country like India where multispecies multi-gear fisheries exist, stock status of other resources inhabiting the same ecosystem should be carefully studied before arriving at any management intervention, as the decrease or increase in effort level may affect the fishery of other species.

Conclusion

Sustainability is a major goal of fisheries management. The present study indicates that the continued use of trawl gear with small mesh size for fishing as well as higher fishing effort can lead to lower economic return, reduction in CPUE (Catch per unit effort) and can eventually lead to a collapse of fishery of Indian squid in the near future. Therefore it is advisable to reduce the effort level in order to minimise the risk of growth overfishing as well as recruitment overfishing, since large mesh fishing gear targeting large sized individuals will allow the juvenile fish to grow and spawn at least once, ensuring sustainability of the resource.

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Conflict of Interest

There is no conflict of interest.

Author Contributions

Data collection: EMC, NR and SS. EMC: Data analysis and wrote the paper. SJK and MS: reviewed the manuscript and coordinated the work.

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