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Temporal patterns in cephalopod catches and application of non-equilibrium production model to the cephalopod fishery of Karnataka

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Non-equilibrium production models were fitted to cephalopod catch and effort statistics to arrive at limit reference points (LRP), Y_{MSY} and f_{MSY}. The parameter estimates, *K (carrying capacity), r (intrinsic rate of population growth)* and *q (catchability coefficient)* were 93,677 t, 0.403 per year, 8.614E-08 for Schaefer model. Estimated precautionary limit $Y_{MSY,}$ was 9,446 t and the corresponding f_{MSY} was 24,94,611 h. Despite the fact that the 2007 catches are currently around the Y_{MSY}, the current effort, f_{now} expended in the trawling ground is 29,32,214 h for a trawling period of 97.4 h per multi-day fleet (MDF) trip. Fishing effort is 28% in excess of the precautionary target, $f_{0.1}$ estimated at 21,07,060 h as well as 20% above the LRP for sustaining the fishery at MSY levels. It is recommended that trawling effort for the MDF be reduced so that the long-term catches of cephalopods correspond to the Y_{MSY} levels in the present fishing area.

[Keywords: Cephalopods, Karnataka, Limit reference points, Non-equilibrium production models.]

Introduction

Cephalopods were landed as by-catch in shrimp trawl in the eighties[1]. They emerged as valuable targeted resource, during the last decade, due to the tremendous export potential. While its production constitutes only 6.7% (2006) to the total marine landings in quantity, it contributed about one quarter (25.1% - INR 1,620 million) to the proceeds from marine fish production for the State. This fishery was centered around the neretic squids when the fishing efforts were focused on the post-monsoon congregations in inshore waters[2] and the ensuing recruits. Harvest rates for neretic squids are above the optimum levels within the inshore fishing area, implying that the fishery has impacted significantly on the stocks[2-5]. Considering the growing interest in the cephalopod fishery set against substantial increase in fishing capacity of the fishing fleets together with improvement in harvesting technology, it is necessary to advocate a precautionary approach in the exploitation of the resource for its long-term sustainability. The possible consequences of increasing exploitation of cephalopod are not carried out for specific region. Hence the study was undertaken to describe the cephalopod fishery of the region by analyzing the production trends; the changes in major groups and finally to arrive at the f_{MSY} using the non-equillibrium production models.

Non-equilibrium biomass dynamic models based on catch and relative abundance are applied to several cephalopod stocks in the world fisheries, for instance, in northern shortfin squid (*Illexillecebrosus*) and Japanese common squid stocks by Hendrickson[6] and Yatsu and Kinoshita[7] and more recently on neon flying squid (*Ommastrephes bartramii*) by Ichii[8]. In Karnataka, biomass dynamic models were applied to the multi-species trawl fishery for arriving at the precautionary target and limit reference points[9,10].

Though age-structured analytical models requiring several input variables are considered superior to the biomass dynamic models, it is fairly established that the non-equilibrium biomass dynamic models are practical and sometimes better for management purposes than those produced by age-structured models, at a fraction of the cost[11]. Therefore, non-equilibrium dynamic models have been widely applied as it provides a reasonable fit in situations where the data are compatible with the assumptions of the models[12]. In the present context, these statistical techniques are applied to the cephalopod group comprising squids, cuttlefishes and octopuses which support an important fishery along the Karnataka coast.

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Materials and Methods

Cephalopod catch trends: Monthly catch (t) and effort data of squids, cuttlefish and octopus fishery were collected from the landing centres of Karnataka following multistage stratified random sampling design[13]. The mechanized fishing season in the region which commences in August, continues up to June but remains suspended during the southwest monsoon for a period varying from 45 to 90 days. The single day fleet (SDF) comprising of smaller trawlers of <9 m overall length, undertake daily fishing in the inshore fishing grounds, within 20-30 m and the multi-day fleet (MDF) comprising of trawlers >9 m operate in deeper waters up to 500 m for different resources. The monthly catches of cephalopods from each gear were pooled to arrive at a time series of annual productions for the period 1961 to 2007 for Karnataka State. However, major emphasis was given for the cephalopod production from 1987-2007 in the study.

Production Model: The Schaefer non-equilibrium production model was fitted to the cephalopod catch and effort data series. The analysis was carried out using the Catch and Effort Data Analysis software, CEDA ver. 3.0[14] which provides estimates of current stock sizes, catchability and associated population dynamics parameters. These models assume that the growth in biomass through time is described by the logistic curve, and that a level of effort exists which reduces the biomass of the stock to a level where its growth rate/production is maximal (Maximum sustainable yield, Y_{MSY}). The cephalopod catch and effort data from the multi-day fishing for the period commencing from 1993 was subjected to the analysis since examination of CPUE values indicated a decline from 1993. In addition, this year marked the beginning of the targeted fishing for the resource in the region. Data input were (1) the annual cephalopod catch (t) and (2) the corresponding trawling hours of multi-day fishing (effort).

Preliminary exploratory analysis made use of Schaefer production model, including and excluding influential points. Sensitivity of the models to the initial proportions was also undertaken. The selection of Error model options: *least squares, log-transform* and *gamma* were attempted to determine the optimum error model and parameter mix. Several combinations of input parameters were explored to carry out a sensitivity analysis and resolve the error model. Prior exploitation of cephalopod stock before the start of the dataset or the initial proportion was assumed to be neither negligible nor completely wiped out, therefore fixed at an intermediate level. Based on the sensitivity analysis, the best fit was judged by the visual examination of residual plots of catch against expected catches and time; the coefficient of determination, R^2 and a comparison of the confidence interval (CI) of the estimates of maximum sustainable yield or Y_{MSY}. The intermediate parameters, the intrinsic rate of population growth, r; the catchability coefficient, q and the carrying capacity of the stock, K were used to estimate the precautionary target ($f_{0.1}$) and limit reference points (f_{MSY}) for the Schaefer production model. The f_{MSY}, fishing effort that maximizes the long term catch or Y_{MSY} and $f_{0.1}$, which is the fishing effort for which the derivative of the yield with respect to the fishing mortality is 10% of the carrying capacity, K were derived as f_{MSY} = r/2q; $f_{0.1} = 0.90 f_{MSY}$; *and* Y_{MSY} = rk/4 for Schaefer model.

The projections based on the present average rate in increase of annual fishing (trawling) effort of multi-day fleet (MDF) were made. The scenarios under the effort strategy at 2007 level or the f_{now}; at 10% annual rate of increase and at 10% annual rate of decrease in effort were projected for 2008-2014 period.

Results and Discussion

Cephalopod production trends and fishery

The analysis of the time-series of catch trends indicates three distinct development phases in the cephalopod fishery corresponding with changes in fishing patterns. Over the past five decades, the annual cephalopod production from the region by all gears increased progressively from a meager 1 t in 1961 to 16,197 t in 2006 (Fig. 1). Though export for squids and cuttlefishes from India commenced as early as 1974, the resource gained significance next to shrimps only recently. Cephalopods that formed incidental catches in shrimp trawlers, seines, hook and lines in early 1980s met the limited demand in the coastal areas as food and bait in the hook and line fishery besides contributing negligible quantity as exports[15].

In Karnataka, cephalopods were landed as by-catch in shrimp trawlers forming only less than 1% of the annual trawl landing in major mechanized fishing harbours of Mangalore-Malpe till early 1980s[1]. The production from the State was not substantial until 1985, given the growing demand in foreign trade for cephalopods as a valuable seafood item. This was

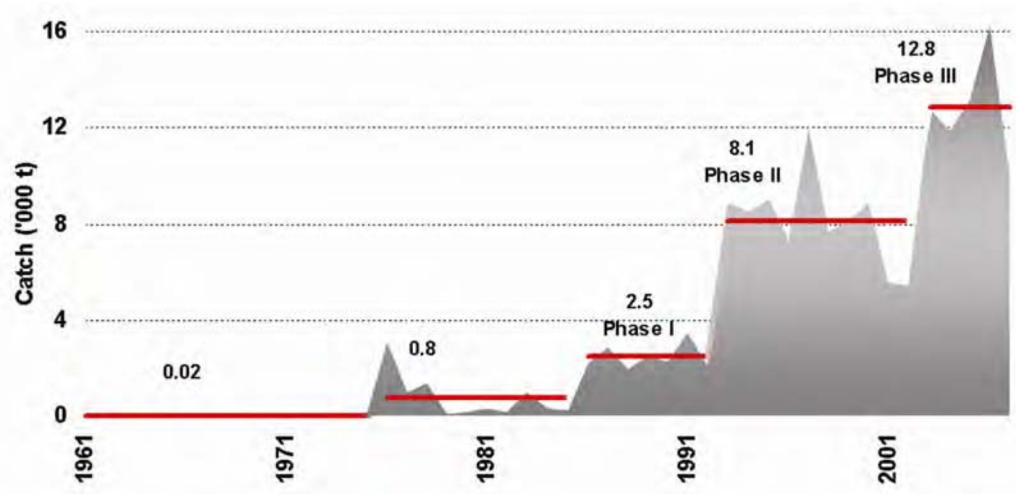

Fig. 1—Annual trends in cephalopod production in Karnataka

reflected in the catch trends that averaged about a meager figure of 755 t in 10 years (1976-85). Thereafter, the production increased substantially from 246 t in 1985 to 2,160 t in 1986 (Fig. 1) but subsequently fluctuated at an average figure of 2,472 t till 1992. It is seen that, during this period (phase I), in spite of an increase in effort (vessels) in mechanized trawling targeting high valued shrimps, the shrimp catches were only moderate. This phase also witnessed an increase in trawling hours, by way of adoption of stay-over fishing (1982-83). The dwindling shrimp catches and growing export demand for cephalopods served as an impetus for the increase in cephalopod production during phase I that was mainly brought about by retention as well as better handling of hitherto discarded cephalopod fraction of the shrimp by-catch. During phase I, maximum effort in shrimp trawling was expended in the trawling grounds in January (day-trawling) and March-April (night-trawling) months[1], whereas in the post-ban periods between September and November, the trawlers operate only for few days depending upon the availability of shrimps[2]. Therefore, the active fishing commenced only from December, which excluded the period of peak abundance of both squids and cuttlefish in the region[4].

This trend got reversed in the next phase (phase II) commencing from 1993 to 2002, that was characterized by targeted fishing for the cephalopod resource in the inshore waters, when the average production improved by four fold reaching 8,117 t (Fig. 1). This was mainly due to the progressive increase in the number of days or the duration in voyage of multi-day fishing in combination with expansion in fishing ground. This phase of expansion witnessed the use of high opening bottom trawl as well as the introduction of medium sized trawlers, resulting in expansion of the trawling grounds up to 150 m and strengthening of multi-day fishing[16].

The depth of operation of multi-day trawling increased over the years from 50 m in 1986[17] to 70 m in 1991[3]. The depth of trawling increased beyond 70 m when cephalopods were targeted reaching 100 m, in 1995[16] and continued to increase further, reaching depths of 150 m and beyond in certain seasons of 2001[18]. As a result, the cephalopod production increased from 8,873 t in 1993 to 11,977 t in 1997, but declined to 5,375 t during 2002.

Area of trawling has gradually extended far out in the sea over the years and at present trawling is done from 10 m to 500 m for various resources. Among the cephalopods, squids are caught from depths ranging from 18 to 55 m and cuttlefishes from 70 to 140 m and occasionally from deeper waters. The decline in the cephalopod production in 2001/2002 (Fig. 1) was attributed to the diversification of fishing effort for targeting deep sea shrimps in areas beyond 150 m[18,19]. The mechanized trawling operation in the area (during 1994-1995) within Cannanore in south to Karwar in north[16] gradually extended the limits further, reaching 10°50'N 75°15'E off Ponnani in south to 17°0'N 72°2'E off Ratnagiri in the north. The depth of fishing operation extended further offshore and presently the trawling operation for cuttlefish are mainly in *Bassas-de-Pedro Bank* (13°7'N and 72°5'E) and around the Netrani Islands, (14°8'N and 74°7'E) which are known for their abundance in cephalopods[20].

The introduction of steel trawlers as replacement to wooden trawlers improved maneuverability and fuel efficiency, resulting in increase in the number of days or the voyage of multi-day fishing from 4-7 days in 2000/2001 to 7-11 days in 2003, with some voyages lasting up to 15 days (2004-2007). This was reflected in cephalopod production, which increased sharply to 12,761 t in 2003, reaching 16,197 t in 2006 before plunging to 10,072 in 2007. During this phase (phase III-2003-2007), the production fluctuated around a relatively higher level, averaging about 12,810 t.

Cephalopod production trends by gear

The major mechanized landing centres in the State, the Mangalore and Malpe Fisheries Harbours accounts for 99.9% (2007) of cephalopod production from the region. Cephalopods constituted on an average about 13.7% (1987-2007) to the total fish landings by MDF, ranging from 4.4% in 1988 to 19% in 2005. With the intensification of trawling, the contribution of MDF to the cephalopod landings increased from 55% in 1987 to 99% in 2006. Over the years, though the number of fishing trips registered a declining trend, the annual MDF effort in actual fishing hours displayed a twelve-fold increase from 7.9 h in 1987 to 97.4 h in 2007, as a result of increase in the duration per trip (Fig. 2).

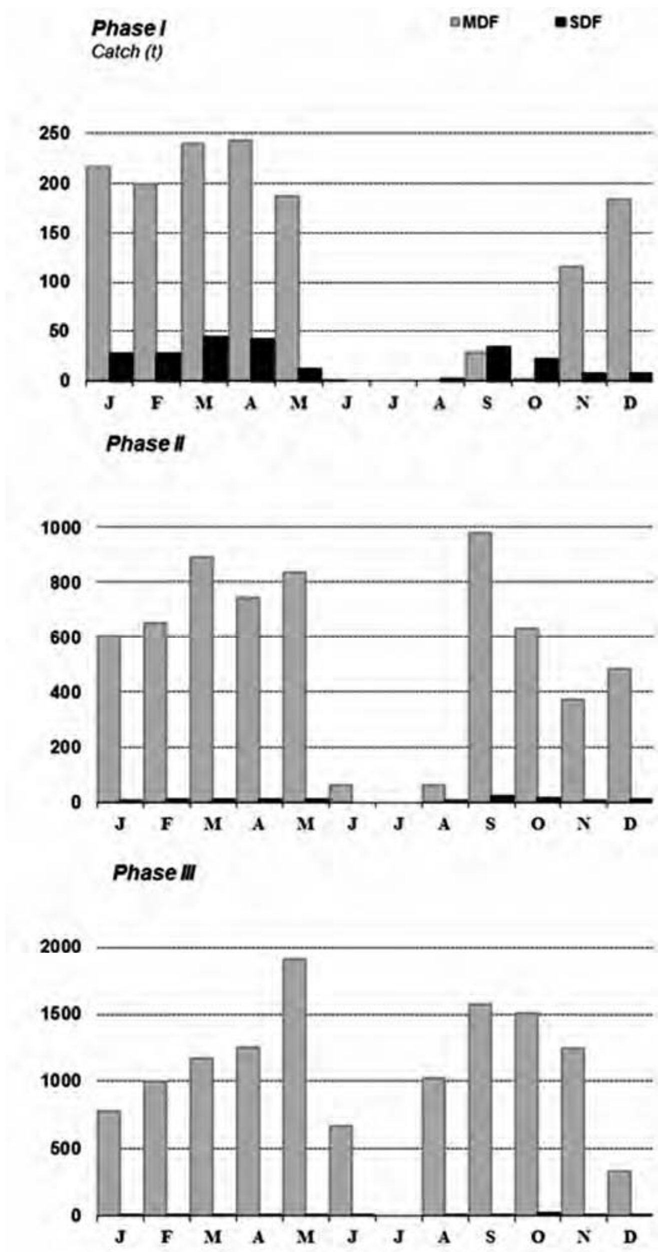

Fig. 2—Seasonal trends in cephalopod production by MDF and SDF in Karnataka.

With changing trawling patterns, fluctuations in catch rates were also evident during the different phases. The catch rates varied between 1.9 and 3.8 kg/h during 1987-1992, improved with targeted exploitation in the subsequent phases, reaching 6.13 kg/hr in 1997, thereafter reducing to 2.81 kg/h in 2002 (Fig. 3). Upgradation in fishing vessels coupled with the focused interest in cuttlefish fishery lead to improvement in MDF catch rates from 2003 (5.83 kg/h) peaking at 7.24 kg/h in 2005. However, from then on the catch rates decreased by half, reaching 3.34 kg/h in 2007.

The contribution by SDF to the cephalopod landings reduced from 44% in 1987 to less than 1% in recent years as there was gradual replacement of small trawlers with medium sized trawlers during the change over from daily fishing to multi-day fishing (Fig. 4). Moreover, the catch rate of cephalopods in SDF also reduced from 5.3 kg/h to 0.14 kg/h during 1987-2007 because of shift in target in day-boats towards shallow water species of shrimps and soles (Fig. 3).

The contribution by other gears (purse-seine and indigenous gears) to the cephalopod production was negligible (Fig. 5) except during 1990-1991 periods, when purse-seine contributed 10-15% during the post-monsoon months, while targeting spawning congregations of neretic squid in inshore waters[2]. Due to the targeted trawling for squids, the share of purse seiners decreased to an insignificant fraction of the landings during later years.

Shift in major cephalopod groups

The cephalopod faction comprising of squids, cuttlefish and octopus also displayed three distinct phases in the production. Squids (60.2%) and cuttlefishes (37.9%) contributed to the cephalopod landings from the region. Octopus group was a later entrant in the fishery forming only 1.9% of the cephalopod production from 1997 onwards.

The squid landings ranged between 1,624 t in 1988 to 8,361 t in 1993 (Fig. 6) with an average of 4,600 t during 1987-2007. The annual cuttlefish landings ranged from 65 t in 1990 to 7,753 t in 2006 with an average production of 2,891 t during 1987-2007.

Initially (Phase I), when the trawling grounds were within the inshore waters, 90.3% of cephalopod landing from all gears was comprised of squids (Fig. 6). During the phase II, beginning from 1993, when cephalopods were targeted, the interest was focused on squids, where they constituted 64.5% of

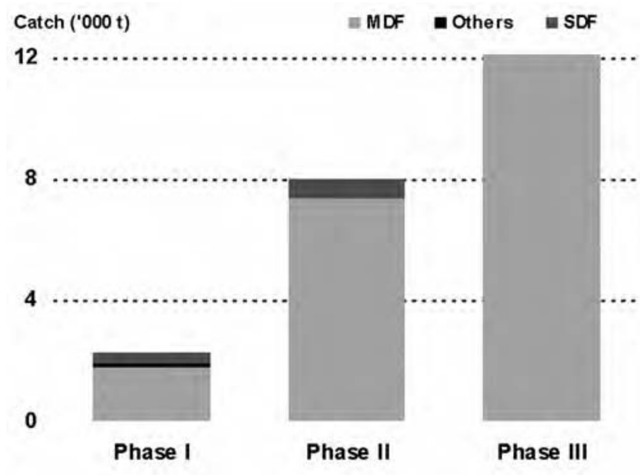

Fig. 3—Trends in contribution by different gears to the cephalopod production in Karnataka

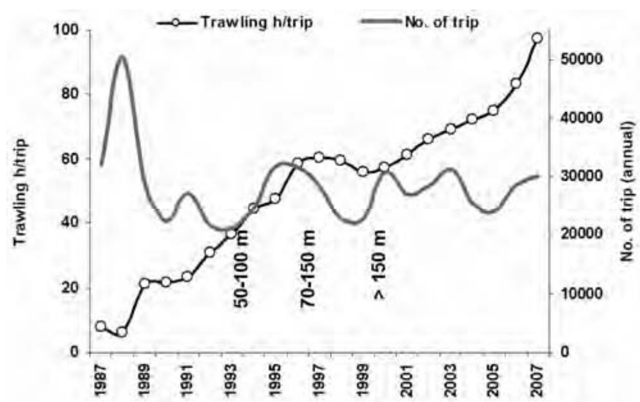

Fig. 4—Annual variations in the trawling hours per cruise and number of cruises carried out by MDF along Karnataka.

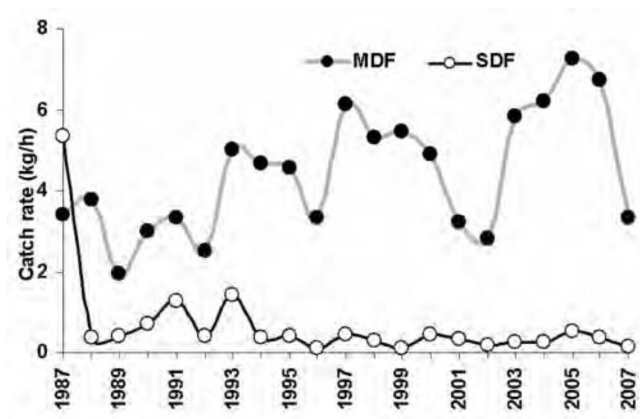

Fig. 5—Variations in catch rates of cephalopods in MDF and SDF

the cephalopod production (1993-2002) even though cuttlefishes also constituted sizable proportion of the landing. In late 1990s, consequent to the extension in the depth of operation to 70-100 m and beyond, by the multi-day trawlers, the contribution of cuttlefish by MDF increased from less than 10% during phase I to 33.8% during phase II, reducing the share of neretic squids in the cephalopod landings. During this period octopus landing was observed in multi-day trawl units, which fluctuated between 93 t in 1997 and 665 t in 1999. Currently, the cuttlefishes dominate the cephalopod catches forming 49.6% of the total production and contribute more than the squids (47.7%). This is facilitated mainly on account of the targeted trawling operation aimed at cuttlefishes during the post-monsoon months.

Estimated Sustainable Yield

The Schaefer production model was fitted to cephalopod catch and effort data. The scatter plots of the residual catches against expected catches and time identified two outliers (input data of 2001 and 2002) in the error models. These years were excluded in the analysis after considering the fact that the reduction in cephalopod catch rate was owing to the focus on the deep-sea shrimps for a period commencing from late 2000 and not corresponding to the reduction in abundance of the cephalopod resource in the fishing ground. The analysis excluding the outliers gave good fits with narrow confidence intervals for the Y_{MSY} in the log transform error model for the Schaefer models. The parameter estimates for *K*, *r* and *q* were 93,677 t, 0.403 per year, 8.614E-08 for Schaefer model. The model predicted Y_{MSY} of 9,446 t for cephalopods annually. The corresponding f_{MSY} value estimated was 24,94,611 h and the precautionary target, $f_{0.1}$ estimated was 21,07,060 h (Table 1). The cephalopod catches have exceeded Y_{MSY} during the period 2003-2007, when the average cephalopod catch in MDF trawlers was 12,555 t, peaking at 16,080 t in 2006 and declining to 9,783 t in 2007. Despite the fact that the 2007 catches are currently around the Y_{MSY}, current effort, f_{now} expended in the trawling ground is 29,32,214 h for a trawling period of 97.4 h per MDF trip. This indicates that f_{now} is 20% above the optimum levels for sustaining the fishery at MSY levels. Fishery management strategies which set fishing effort less than the target reference point $f_{0.1}$ aim to ensure a relatively stable and efficient harvest, necessitating reduction of f_{now} by 28% for attaining $f_{0.1}$.

Table 1—Parameter estimates for cephalopod catch in multi-day fleet.

Model	Schaefer
Fit	Log transformed
r^2	0.818
K (t)	93,677
q	8.614675E-08
r (per year)	0.4033697
f_{MSY} (h)	23,41,178
$f_{0.1}$ (h)	21,07,060
f_{now} (h)	29,32,214
f_{2003} (h)	21,54,767
f_{2002} (h)	18,32,615
Y_{MSY}	9,446 t
80% Confidence Interval	7,437-15,403 t
Average cephalopod catch 1993-2007 (range)	9,103 t (5,258 - 16,080 t)
Y_{2007}	9,783 t
Recommended % reduction in f_{now}	28.1 % reduction for $f_{0.1}$/retain at f_{2002} 20 % reduction for f_{MSY}

Projection

The average annual increase in effort in the analysis period for MDF was at a rate of 10%, hence the results of the projection under three effort strategies: (1) f_{now} (2) at 10% annual rate of increase in effort and (3) 10% annual rate of decrease in effort are shown in (Fig. 7). Further increase in effort or abiding at f_{now} levels would result in a decrease in the

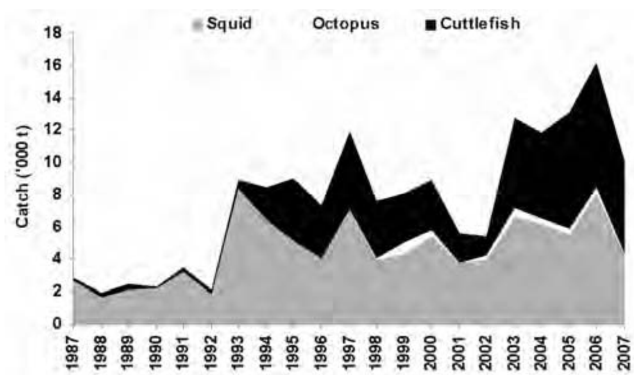

Fig. 6—Temporal variations in squid, cuttlefish and octopus production in Karnataka

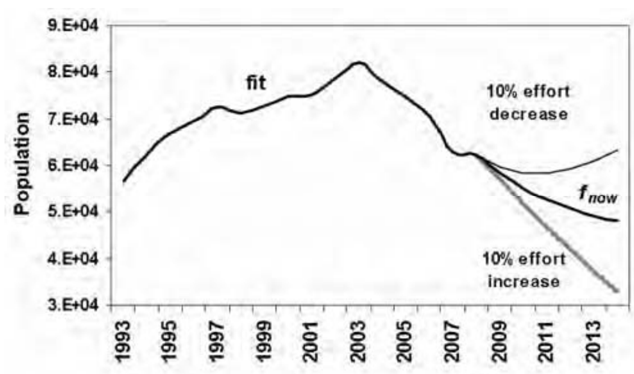

Fig. 7—Projection scenario for cephalopod population (biomass) for different effort based on Schaefer model

population, whereas a 10% annual rate of decrease from f_{now} indicated revival in population biomass by the year 2014, when the population is projected to reach that at 2007 level (Fig. 7). Therefore, the trawling effort for the MDF has to be reduced to that of the long-term average catches of cephalopods correspond to the Y_{MSY} levels in the present fishing area.

Earlier estimates of MSY using Thompson–Bell predictive model for neretic squids (1990-95) set the limit reference point at 6,069 t, when they formed 88% of the total cephalopod production. This analysis suggested 44% reduction in the trawl fishing effort by multi-day trawlers for attaining the LRP for squids when the fishing ground was within 100 m[5]. In a separate analysis using non-equilibrium production models, Mohamed and Zacharia[9], arrived at 15% annual reduction in fishing effort for the multi-day trawlers operating from the two major fishing ports of Karnataka when cephalopods constituted 13% of the catches. However, the expansion in fishing grounds invariably renders the use of the limit reference points impractical unless re-validated with the shifting/ expanding fishing ground. In a recent analysis, the f_{MSY} estimated for the MDF catch of Karnataka (2002-2006) indicated that the exploitation level of MDF fishing effort is 13% above the requirement for MSY[10]. The cephalopods being the second largest revenue earner in the marine fisheries sector, the results of the present study are important in the region and hence, substantial reduction in the fishing effort will be required for the multi-day fishery for achieving the resource management objectives.

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