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An Economic Analysis of the Sustainability of Marine Fish Production in Karnataka

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AN ECONOMIC ANALYSIS OF SUSTAINABILITY OF MARINE FISH PRODUCTION IN KARNATAKA

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This report documents the research work done under the World Bank Aided India: Environmental Capacity Building Technical Assistance Project entitled “An Economic Analysis of Sustainability of Marine Fish Production in Karnataka”. This research results are based on the premise that the continued economic productivity of the fisheries depends upon the current biological and economic conditions and sustainability implications of continuing current exploitation rate and methods. The 1990s have seen global crisis in marine fisheries and maritime state of Karnataka is no exception. The modernization of fishing fleets and uncontrolled expansion of fishing effort are main reasons, for declining growth rates of total marine fish production.

First, the optimum level of harvesting individual fish species was estimated using single species model by computing the parameters such as stock, standardized effort, catchability coefficient, etc. The results indicated that most of the species are harvested very close to MSY level (biologically optimum) and beyond MEY (economically optimum) level.

In order to incorporate the multispecies multigear dynamics of the fishery and to incorporate multiple objectives of the fishery management authorities

Title of the project: AN ECONOMIC ANALYSIS OF SUSTAINABILITY OF MARINE FISH PRODUCTION IN KARNATAKA

Period of the study: April 1999 - August 2001

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1. Introduction

The marine fisheries are one of the major industries in coastal Karnataka. In the state's exclusive economic zone of 87000 sq. km., fishery resource is estimated to yield 425,000 tonnes per year (Government of Karnataka, 2000). Importance of the fisheries sector to the state and national economy is widely acknowledged. Its significance lies in three main areas: (1) as a source of animal protein for human consumption (2) as a source of employment and (3) as a source of foreign exchange earnings.

The extraction of fishery resources has undergone major changes in the last few decades. In the 1950s, the state fisheries were characterized by small-scale with fixed fishing gears such as shore seines. The total catch was low and the fish caught were destined for local markets. However, in the early 60s there was a shift in the preference towards more mobile fishing gears, which allowed the fishermen to actively pursue fish. In 1966, a scheme for the construction and distribution of trawlers was introduced through the Dakshina Kannada District Cooperative Fish Marketing Federation of Karnataka. In the following decades, as in other parts of the country, Karnataka adopted ambitious programs for modernization of fisheries.

The emphasis of the program was to increase fish production for domestic consumption and export. This had been sought through various devices such as motorization, port development and providing new boats and fishing gears. As a result, during the period from 1970s to early 1990s, fish catch increased at a record rate and became highly diversified in terms of species landed. As of now, more than 80 species are commercially harvested throughout the state's coast. Fishing technology also was highly diversified. As per the latest estimates, there are more than 2098 shrimp trawlers, 378 purse-seiners, 1180 gill-netters, 1179 other mechanized boats, and 11958 non-mechanized boats (Government of Karnataka, 1997).

The fishery modernization in the state has had mixed results. On the one hand, despite the growing size of the fishing fleet, the industry has by no means attained its full potential. For instance, the Karnataka's average annual fish landing has remained around 142,000 tonnes in over the last 10-15 years, much below its estimated total annual potential of 425,000 tonnes. On the other hand, there are growing signs of biological and socio-economic un-sustainability that threaten the coastal fisheries. The introduction of trawlers has adversely affected other shore seines' and its own catches. The Karnataka State Department of Fisheries reported symptoms of over fishing in shrimp and other high valued fishes (Government of Karnataka, 1997). Also, trawlers are alleged to have interfered with the fishing rights of traditional, small-scale fishers in the near shore areas, leading to rising social rifts between the two groups. The traditional rampani nets, which once accounted for 50-60 percent of the annual catch, have almost disappeared. There were episodes of clashes over resource users, which sometimes resulted in the loss of assets (Bhatta, 1996).

In the meanwhile, realizing the possibility of overexploitation, particularly along the inshore, the state government enacted the Karnataka Marine Fisheries (Regulation) Act (KMFRA) as early as 1986. The Act empowers the State Fisheries Department to regulate fishery through licensing. The overall package seems to prescribe limited entry, a standard policy instrument. The Act also has banned mechanized fishing during the Monsoon, which is the breeding season for most of the pelagic species. In addition to compulsory registration of vessels, this legislation imposed restrictions on fishing in specified areas, and on the number of vessels in specified areas and seasons. The compulsory registration of all the vessels both mechanized and non-mechanized also served as an authentic record on the number of various types of fishing vessels operating from the coast.

However, most part the Act was not vigorously enforced by the state government because of socio-political reasons, including widespread unemployment outside the fishery sector and lack of occupational and geographical mobility among fishing communities. Further, the costs of looking for alternative employment were high because of low education, cultural taboos and high indebtedness among fishers. One of the major difficulties faced by the fishery managers was the lack of quantitative information on the likely impact of fishery regulations on the output, income and employment levels in various fisheries and non-fisheries sectors.

After 15 years of KMFRA implementation, a number of issues still confront fishery managers in Karnataka, including the lack of better understanding of the fishery-wide impacts of regulations, conflicts between small and commercial fishers, and declining stocks of certain fishes. The fishery regulation has never been based on a scientific understanding of how certain policy instrument might affect the biological sustainability and economic viability of target species. Species vary widely in their economic and biological productivity. Also, the technical efficiencies of different gear types are not the same. In a fishery that produces multiple species obtained through different types of gears, there could be technical interactions among species and gear types. The limited-entry policies of KMFRA do not seem to recognize these technical interdependencies among species and gears, or the productivity differences across gear types. Such policies only have the illusion of keeping control over the total fishing effort. They could still fail to stem the depletion of certain primary or secondary target species. No effort has been made as yet to analyse the biological and economic effects of alternative management policies on different species.

Objectives

This research is an attempt to address certain management-related questions concerning the process of fishery modernisation and the concurrent regulations in Karnataka. The key research questions we ask include:

- What are the current biological and economic conditions of commercially important species in Karnataka?
- What are the future sustainability implications of the current level of fishing effort?
- If the current levels of fishing are not bio-economically sustainable, what policy options are there for the fishery management?

Answering these questions entails some important analytical tasks. In order to address these questions, we need to develop appropriate analytical tools to first estimate stocks and stock-effort-catch relationships, and then to characterise the optimal mix of fishing fleets under alternative management scenarios. Such an exercise is hoped to better inform the management process in its effort to move toward more sustainable fishing.

The Regulations for Fisheries Management

The ultimate objectives of regulations aim at increasing the productivity of the stock and the net economic yield, which is the maximum difference between total cost and total revenue of the yield. The sole fishery manager would be interested in expanding fishing effort up to the point of maximum rent, which lies before the maximum sustainable yield point. The maximum economic yield (MEY) is preferable to the maximum sustainable yield (MSY) both from the economic and ecological point of view. The regulatory mechanisms usually adopted are:

- Regulations such as gear selectivity and seasonal and area closures.
- Regulations that control the fishing effort and catching.

The first fishery regulation was enacted in 1897 to control destructive fishing activities in both marine and inland waters. It explicitly banned the use of explosives and poisons in harvesting fish. However, until 1970s the state governments did not find the need for controlling fishing effort, as the fishing was mostly artisanal in character and mechanized fishing was negligible. With the rising foreign and domestic demand for shrimp and other fish products private firms from outside the exploitation of traditional fishing communities saw a good opportunity for financial profits in the exploitation of marine resources. Modern mechanized trawlers were rapidly introduced in Karnataka with state and central subsidy programmes through cooperatives and commercial banks. During the early years most of these fishing units operated by domestic firms from within and outside the local communities. Thus the influx of large number of big trawlers in the early eighties the fishing pressure on the marine fishery resources increased tremendously leading to eventual stagnation of catch and decline of average profitability.

Modelling Sustainability of Fish Production: Insight from the Previous Studies

Fishery resource management is perhaps a widely discussed topic in natural resource studies. Scott (1979) and Panayotou (1982) discussed the basic bio-economic and social rationality of various fishery management regulations. Based on the conventional economic wisdom, “common property” and the associated economic inefficiency (Ciriacy-Wantrup and Bishop, 1975), a societal argument for fishery regulation is widely made. To quote Charles' (1988) conclusion from his review of various studies "... Left to their own devices, fishermen will destroy any social benefits that a fishery could produce. This conclusion, based on the assumption that fishermen are individualistic and myopic profit maximises, has led to the wide spread advocacy of measures to reduce the number of fishermen and " rationalise" the fishery".

Panayotou (1982) identifies broadly two parameters, which the fishery administrators have tried to manipulate: (a) the age or size of fish at first capture, and (b) the total amount of fishing effort. The ultimate objective of both the approach is to increase the productivity of the stock and net economic yield. The respective regulatory instruments usually adopted are: (a) regulations such as gear selectivity and seasonal and area closures which aim at affecting the size and age of fish caught, and (b) regulations such as catching capacity controls and catch quotas which aim at affecting the amount of total effort or the quantity of catch.

The productivity and sustainability of measuring the marine fish production cannot be done in the same way as the productivity of the land or forests. The fishery catch depends on the stock of fish in the fishery grounds as well as on inputs in terms of fishing efforts and quantity of fishing gear used. In order to measure the changes in the productivity over the years we need the historical data on catch, effort and gear (Parekh and Parekh, 1997).

As evident from the above overview, an understanding of the losses of fish productivity over the years is required for the development of fishery management plan so that the gears which cause un-sustainability could be identified and a plan to reduce them would involve a temporary reduction in the income and employment of the fishermen and other post harvest enterprises. This requires a careful examination of alternative policy regimes, including various forms of limited entry under multi-objective framework. Each of these plans must be evaluated in terms of three broad objectives: long-term resource survivability, efficiency and equity. Such analysis needs to evaluate the impacts that alternative management plans would have on various interest groups, including large fishermen, indigenous artisanal fishermen, fishery labourers, processors, retailers, fishery regulators and consumers.

In order to accomplish an objective evaluation of complex, multi-objective fishery management, a suitable analytical framework is essential.

Onal *et al.* (1991) give a quick review on fishery management modelling studies. In the early history of scientific fishery management, the biological concept of maximum sustainable yield (MSY) was used as an accepted criterion. However, this criterion does not include economic consideration. Moreover, under conditions of natural variability and multi-species fishery, fishing effort guided by MSY principle becomes “too risky”. Economists developed approaches that maximise economic benefits subject to biological properties. Griffin *et al.* (1976) used an analytical model of Gulf shrimp industry to maximise overall rent given constant prices, cost functions and yield-effort relations. This approach failed to recognise inter-temporal and spatial aspects of fishery population.

Recognising the dynamic nature of fishery population, economist found optimal control theory and dynamic programming highly suitable tools (Clark, 1976; Clark and Munro, 1975; Sadeh *et al*., 1989). Clark (1982) illustrated the use of optimal control model under a variety of regulatory policies, such as no regulation, total catch, restricted access (i.e., vessel licenses), allotted vessel quotas and taxes. However, most of the studies that used above approaches suffered from restrictive assumptions and failed to cover the complex mix of biological, economic and social aspects.

An alternative analytical tool adopted by fishery economist is linear programming (LP) (e.g. Rothschild and Balsiger, 1971). The validity of LP models to fishery is criticised in literature (Onal *et al*., 1991). The LP approach suffers from classical problem of linearity assumption while non-linearity is frequently observed in catch-effort-stock relationship. Further, prices, cost and stocks usually are considered constant and exogenous in these models. Exogenous stock assumptions assume away the fundamental aspect of overexploited fishery-dynamic change in stock owing to fishing effort (Onal *et al*., 1991). A non-discriminatory fishing effort applied to a given stock at a place and time influences stock abundance, productivity and size composition at other places and future. In a multi-species tropical environment, it is hardly possible to allocate the overall fishing effort between the constituent species of the total fish stock. Therefore, a proper model must consider endogenous catch-effort-multispecies stock relationship.

Griffin *et al.* (1983), Grant and Giffin (1979), Nance and Nichols (1987) developed bio-economic simulation models that explicitly considered nonlinearity in catch-per-unit effort. A practical advantage of such models is their ability to generate biological data that generally are not observed. Onal *et al*. (1991) adopted a nonlinear price-endogenous programming model, following Mc Carl and Spreen (1980). The model incorporated endogenously - derived market demand functions. Biological characteristics of the system and endogenous catch-effort-stock dynamics entered the model as constraints. Anderson (1984) developed a policy-endogenous fishery model, called bioregunomic model. In addition to economic and biological aspects this model endogenously determines the type and level of fishery regulatory measures.

Most of the above analysis focused on a single objective rent-maximisation. While the need for including other social aspects of fishery has long been recognised, formal effort to apply analytical economics to realistic multi-objective fishery problems is minimal. Hannesson(1981) refers to few multiple goal programming studies conducted on Norwegian fisheries. Bishop *et al.* (1981) proposed multi-attribute portfolio analysis as a valuable analytical tool. However, as Charles (1988) notes, the results of such multi-objective analysis are useful only if appropriate weightings are assigned to each of these objectives.

Developing effective measures of social indicators such as income distribution and employment is critical task that often concerns fishery analysts. Charles (1988) provides a good review of studies that developed various measures of income distribution. Several studies in Panayotou (1985) attempted to measure the socio-economic conditions in small -scale Asian fisheries. While these studies provide useful descriptive information about sociological conditions of a particular fishing community, this information needs to be further integrated into a multi objective analytical framework. Such modelling effort should enable policy analysts to objectively measure the interactions between income distribution, resource productivity and overall industry behaviour under alternative economic and policy scenarios.

The modelling framework developed in this study attempts to integrate mainly technological, economic and biological aspects of the Karnataka fisheries. The main purpose of the analysis is to investigate if the current harvesting mix is economically and ecologically sustainable, and if not, to further suggest suitable adjustments to existing technology regime in order to help fisheries make a transition toward sustainability. The model, however, can be easily modified to incorporate equity and other social aspects concerning the fishery production sector.

In this study we employ both single-species static models (see chapter 3) and multi-species dynamic (mathematical programming) model (see chapter 4). The purpose of the first set of models is two fold. First, these models would enable us to assess the sustainability of individual species at the state level. Second, these models provide various techno-economic and biological parameters and stock estimates required for the multi-species programming model. Multi-species model is designed for individual port-level. A state-level multi-species model would not be appropriate since there is a large variation across ports. Casting the entire state into a single model might yield huge aggregation error.

The rest of the report is organised as follows. The next chapter presents an overview of the Karnataka fisheries that includes a brief description of the study area, the current fishery trend and exogenous forces that influence the state fishery industry. Readers who are familiar with the state fisheries may skip this chapter. The third chapter presents the analysis of a single-species model at the state level. In the subsequent chapter is presented the conceptual and empirical framework for a multi-period, multi-species programming model for a specific fishery management unit. The final chapter draws policy conclusions from the empirical analyses.

2. Karnataka Fisheries: An Overview

Background of the study area

The coastal ecosystem of Karnataka is a mosaic of monsoon wetlands, beaches and mountains--some as high as 2000 meters--stretched along its 300 km long shoreline. The coastal eco-region of the state is separated by Western Ghats connected by a number of rivers that form vast estuaries. Coastal wetlands do serve as an important source of economic livelihood for the local communities. This coastal region provides fishery and plant products, water supply to urban and rural population, flood control, erosion buffering, wild life habitat, recreation and tourism. The vast natural resource base of sea and estuaries generates income in millions of rupees, which unlikely is sustainable due to the over exploitation of resources and ill-conceived projects. In the last 15 years, more than 17,000 hectares of area and 50,000 people were displaced in coastal region of Karnataka due to industrial projects such as harbour, refinery, naval base (sea bird) and hydro electricity projects (Central Water Commission, 1996).

The states fishery resources potential is estimated at 425,000 tons per year over an exclusive economic zone of 87,000 km^2 (Bhaktha, 1983). In addition to marine fisheries, coastal Karnataka also has a large potential for brackish water fisheries. Several major rivers originate in the Western Ghats and their tributaries flow through two coastal districts into the Arabian Sea, forming a mosaic of more than 8,000 ha of estuaries along the coast.

Traditional fishing was undertaken using indigenous techniques with non-motorized boats, and thus could be characterized as a subsistence economic activity. In the last 20 years, fishing technology has widely undergone mechanization with the help of government patronage and the introduction of multinational corporations in Indian waters (Kurien, 1995). However, modern technology and capital have been accessible to only a small group of fishers. A large class of traditional, small – scale fishers either continued to operate with indigenous techniques or worked for modern fishing farms, and thus have not reaped the benefits of fishery mechanization (Acharya and Acharya, 1995). Modern fishing vessels initially operated only in inshore waters and over – exploited the fishery resources. This depletion adversely affected fishing opportunities for small-scale, indigenous fishers and the traditional nets which once accounted for 50 –60 percent of the annual catch (Government of Karnataka, 1994*a;* Bhatta, 1996). These fishers have therefore been forced to depend more on inland or estuarine species, or to seek employment with large fishing firms.

Even though fisheries are an important economic activity in coastal Karnataka, this region is still predominantly agrarian because about 60 percent of all workers are dependent on agriculture and allied activities for their livelihood (Government of Karnataka,1994b). A major portion (71 percent) of croplands is cultivated for food-grain production. Rice is the leading crop followed by peanuts and horticultural crops.

Growth of transport, communication, electricity, education has resulted in rapid urbanization and in employment opportunities in secondary and tertiary sector. It is estimated that the district has about 1,50,000 transport vehicles, 243 km of national highways, 696 major factories and 10,250 small-scale industries. These industries directly employ 50,000 and 1,10,000 persons respectively (District Statistical Office, 1998). Many mega industries such as oil refineries, fertilizer plants, harbour, iron and steel plants were established during 1980's and 1990's which have attracted migration of skilled and unskilled workers from outside the state. Thus, there has been a tremendous growth in the industrial sector and is considered as one of the potential growth centres of the country. In 1996-97, at current prices the secondary sector generated a gross income of Rs.1,09,751 lakhs, which is nearly 30 percent of the total GDP of the district. The per capita GDP of the district is Rs.12,971 which is second highest in the state next to the state capital, Bangalore (Government of Karnataka, 2000). The net domestic income of the district (at 1980-81 prices) from the secondary sector was Rs.22,290 lakhs which is 7.5 percent of the state total income from the secondary sector.

Current status of marine fish production in Karnataka

Marine fisheries are increasingly becoming one of the highly globalized sectors of the world economy. The value of international fish exports, which was only US$ 17 billion in 1985 has almost trebled to US$ 47 billion in 1994 (FAO, 1998). The increase in fishing effort since 1950s has led to rapid increase in global landings, which grew by an average of over 6% per year until 1970s. In 1990s the slow increase in landings turned into stagnation, though masked by an increase in aquaculture production (Liao, 1997). Neo-classical economic theory states that induced scarcity of these fish should lead to an increase in their price more rapidly than those of their more abundant substitute (Gravelle and Rees, 1981). Such increase given the functioning of markets would then lead to rewards for conservative fishing practices, enabling continuous landings of the highly priced commodity. However, empirical evidences do not clearly support this theory.

The Indian marine fisheries is no exception to the global trend. The marine fisheries operations in the pre-independence days used to be carried out at a subsistence level, almost exclusively by the traditional fishermen. Today, this sector has attained the status of a capital-intensive industry, warranting close monitoring and management for sustainable development (Devaraj and Vivekanandan, 1995). In the course of the past five decades, the annual marine fish production of India increased from about 0.9 million tonnes in late 60s to the current level of 2.6 million tonnes (Table 2.1). Table 2.2 presents the group wise growth in annual fish production of Karnataka from 1969 to 1998. The table shows that the total fish production increased from 75,793 tonnes in 1969 to 2,51,012 tonnes in 1989 and started declining thereafter with a production of 1,39,676 tonnes. The contribution of annual pelagic fish production varied between 80 percent in 1975 to 50 percent in 1994. The percentage of demersal fishes varied between 9 percent in 1971 to 30 percent in 1983. Crustaceans, which accounted for a small proportion, during 1970s increased its share to 25 percent in 1987 and declined thereafter.

Table 2.3 presents the relative growth of the different species groups from 1969 to 1998. The table indicates that the relative growth was high for all the groups except for crustaceans during the period 1969 –74 to 1975-80. During 1981-86, the relative growth of molluscs production declined from the previous peaks. With higher concentration of effort on crustaceans due to increase in international market price led to an increase in production with a relative growth rate of 188 percent.

During 1987-92, the relative growth rate of demersal and crustaceans decreased and the miscellaneous group was further reduced. During the period of 1995-98 all the groups have shown negative growth except molluscs.

The species wise landings of pelagic for the period of 1970-98 are reported in Table 2.4. The average annual landings of oil sardine declined from 33,834 tonnes during 1970 to 8697 tonnes in 1998. Similarly anchovies, mackerel etc. are showing declining trend. Among pelagic species Tunnies, Ribbonfishes etc shows the increasing trend. But the total pelagic landings gradually decreased from 87,541 tonnes in 1970 to 78,161 tonnes during 1998.

The landings of demersal species reported in Table 2.5 shows much serious impact of commercial fishing. The production of sharks, catfish, perches etc. are showing declining trend. The landings of molluscs (Table 2.6) shows that the overall production of these export oriented species have increased by 3 times from 2287 tonnes in 1990 to 7271 tonnes in 1998. The increase in the export demand reflected in higher price has boosted up the production.

The growth in the production of crustaceans (Table 2.6) shows two different scenarios. The production of traditionally export-oriented species such as paneiad prawns and Lobsters is declining in recent years. The production of shrimps doubled from 3098 tonnes in 1980 to 6688 tonnes in 1990 with the introduction of trawlers in inshore and offshore waters. However the signs of over harvesting is reflected indicated by the decline in the total landings itself apart from other signs. Some of the other species such as Crabs and Stomatopods gained export importance during early 1990s and with the concentration of more effort on these species the production though increased initially also have started declining in recent years.

Trend in marine fish production

The growth rate of annual fish production was estimated using the simple log linear growth function $Y = AB^t$, where Y = Annual fish production; A and B are estimated parameters and t is years. The estimated growth rate for the entire period of 1969-98 for individual group is presented in Table 2.7. The overall growth rate of pelagic, demersal, molluscs and crustaceans were 1.35%, 4.05%, 25.04% and 6.68% respectively. The overall growth rate of total production was 2.16 percent. This slow growth rate in pelagic species, an important commercial category, is at best an indication that the commercial fishery production is slowing down in the state.

The growth in the number of fishing vessels, which represents the intensity of fishing, is presented in Table 2.8 and 2.9. In contrast to the growth in fishery production, the total number of mechanised fishing boats doubled during the last two decades. During the corresponding period, the number of non-mechanized boats also increased. All most all these non-mechanised boats are motorised and fitted with outboard engines. The increase in the number of boats is also coupled with the enhancement of fishing capacity in terms of size (OAL), engine horsepower, electronic equipments etc. that is not properly reflected and quantified. Thus, one of the most important reasons for non-increasing landings could be over harvesting.

Environmental factors affecting fish production

The coastal environmental parameters are important for the growth of fisheries and are showing signs of degradation. Table 2.11 shows the quantity of effluent discharges from the mega industries into the coastal waters of Mangalore. The effluent discharged by these mega industries includes heavy metals, which are harmful to estuarine/coastal fisheries. However, the direct impact of these discharges on the population of aquatic animals has not been studied. On the other hand, it has been well documented that the composition of fish species has been changing over the years.

Some of the species such as fishing cat, otter, estuarine-crocodiles are now rarely found and are included in Schedule I (Endangered and highly protected species) of the Wild Life Protection Act (1972). Some of the grasses grown in tidal rivers of the district are recorded as extinct and included in IUCN Red Data Book of Rare and Endangered Plants (Hussain and Achar, 1999).

Conclusion

Karnataka is one of the most important coastal states contributing 5.23% of India's total fish production. Pelagic fisheries contribute around 60 percent of the total fish production in terms of the quantity followed by demersal (16%) crustaceans (13%) and molluscs (2%). The result of the time series data analysis indicates that the mechanization of the fishing technology has improved the catch during the 1970's to early 1980's. However symptoms of over fishing was observed during early the 1990s, as shown by decline in the growth rate of total fish production. The fishing effort in terms of the number of fishing units has doubled over the period of two decades. The commercial fishing is also seriously affecting species composition shifting from the high valued target species to low valued species. The data environmental parameters and pollution discharges from mega industries show that over the years the stress on coastal and estuarine fishes has increased.

Table 2.1. Contribution of Karnataka's marine fish landings in India (in tonnes)

Year	India	Karnataka	% share of Karnataka
1969	913630	75793	8.30
1970	1085607	116936	10.77
1971	1161389	103724	8.93
1972	980049	92676	9.46
1973	1220240	91484	7.50
1974	1217797	76263	6.26
1975	1422693	87494	6.15
1976	1352855	95283	7.04
1977	1259782	97152	7.71
1978	1403607	152860	10.89
1979	1388380	126384	9.10
1980	1249837	115322	9.23
1981	1278457	153349	11.99
1982	1415219	154836	10.94
1983	1583211	111598	7.05
1984	1614922	119622	7.41
1985	1522517	118654	7.79
1986	1679373	189231	11.27
1987	1649165	220575	13.37
1988	1785549	212411	11.90
1989	2208598	251012	11.37
1990	2142713	178334	8.32
1991	2222111	156654	7.05
1992	2277008	168810	7.41
1993	2245124	142369	6.34
1994	2358234	113522	4.81
1995	2258832	116579	5.16
1996	2414649	139544	5.78
1997	2680713	154453	5.76
1998	2668484	139678	5.23

Source: Marine Fisheries Information Service T& E Ser. No. 41, 52, 67, 136.
Annual Reports of Central Marine Fisheries Research Institute, Cochin

Table2.2 Marine fish landings in Karnataka during 1969-'98.

Year	Total Landings (in tonnes)	Percentage share of individual groups to the total landings				
		Pelagic	Demersal	Molluscs	Crustaceans	Miscellaneous
1969	75793	72.86	12.04	0.08	5.29	9.75
1970	116936	74.86	13.33	0.01	6.48	5.32
1971	103724	78.19	8.89	0.01	5.96	6.96
1972	92676	60.65	15.24	0.03	9.09	14.99
1973	91484	62.14	12.45	0.02	10.02	15.36
1974	76263	48.81	18.02	0.03	18.93	14.21
1975	87494	79.49	11.44	0.20	6.43	2.43
1976	95283	72.99	15.90	3.22	2.89	5.00
1977	97152	67.07	16.50	0.99	3.65	11.79
1978	152860	69.10	9.90	0.88	6.03	14.09
1979	126384	70.05	14.47	0.05	5.87	9.55
1980	115322	72.69	17.95	0.11	5.29	3.96
1981	153349	69.90	11.55	0.17	8.80	9.57
1982	154836	59.01	16.87	0.10	12.06	11.96
1983	111598	52.53	30.23	0.88	14.44	1.92
1984	119622	69.68	16.94	0.24	11.75	1.39
1985	118654	72.65	13.30	0.20	12.33	1.51
1986	189231	63.99	21.27	1.14	12.12	1.49
1987	220575	56.86	14.66	1.30	25.89	1.29
1988	212411	63.39	18.82	0.92	16.03	0.84
1989	251012	75.39	9.48	0.98	13.61	0.54
1990	178334	70.66	11.98	1.28	15.29	0.79
1991	156654	61.07	16.52	2.21	19.22	0.98
1992	168810	54.73	20.54	1.26	22.86	0.61
1993	142369	60.29	15.98	6.23	16.84	0.66
1994	113522	50.14	22.09	6.94	20.53	0.30
1995	116579	52.20	21.83	7.75	17.92	0.29
1996	139543	61.04	19.88	5.11	13.49	0.48
1997	154453	54.97	21.37	7.55	15.68	0.43
1998	139676	55.96	26.58	5.21	11.60	0.66
Annual average landings (1969-1998)	135753	64.32	16.49	1.89	13.09	4.21

Source: Marine Fisheries Information Service T& E Ser. No. 41, 52, 67, 136.
Annual Reports of Central Marine Fisheries Research Institute, Cochin

Table 2.3. Relative growth (percentage) of different species groups from 1969-1998

Group	1969-74		1975-80		1981-86		1987-92		1995-98	
	Average Total (Tonnes)	Relative Growth (Percent)	Average Total (Tonnes)	Relative Growth (Percent)	Average Total (Tonnes)	Relative Growth (Percent)	Average Total (Tonnes)	Relative Growth (Percent)	Average Total (Tonnes)	Relative Growth (Percent)
Pelagic	62,357	-	80,375	28.90	91,306	13.60	1,27,230	39.34	75,308	-40.81
Demersal	12,200	-	15,885	30.21	25,642	61.43	29,668	15.70	28,527	-3.85
Molluscs	23	-	957	4031.65	680	-28.96	2,524	271.13	8,641	242.39
Crustaceans	8,299	-	5,778	-30.38	16,651	188.20	36,885	121.51	21,236	-42.43
Misc.	9,935	-	9,421	-5.17	6,935	-26.39	1,660	-76.07	646	-61.08
Total	92,814	-	112,416	21.12	141,214	25.62	70737	-49.91	134,358	89.94

Table 2.4. Landings of pelagic in Karnataka during 1970 to 1998 (in tons)

Species	1970	1980	1990	Avg(1991-'97)	1998
CLUPEIDS	**38224**	**54625**	**54149**	**25671**	**26417**
Chirocentrus	124	171	342	392	177
Oil sardine	33834	42727	29718	6667	8697
Lesser sardines	2034	4135	6360	6146	7189
Hilsa ilisha	21	8	36	102	75
Other Hilsa	94	25	480	48	0
Anchovies	142	5621	89	24	0
Coilia	-	-	1	86	0
Setipinna	-	-	3	6	0
Stolephorus	-	-	10223	7433	5563
Thrissocles	1009	850	-	-	-
Other clupeids	966	1088	3482	2231	2619
Thrissina	-	-	-	-	-
Thryssa	-	-	3415	2536	2097
Bombay duck	**53**	**15**	**-**	**3**	**-**
Half beaks & Full Beaks	**182**	**180**	**163**	**157**	**134**
Flying fish	**-**	**55**	**-**	**-**	**-**
Ribbon fish	**280**	**1499**	**4071**	**4326**	**2585**
CARANGIDS	**871**	**4809**	**17210**	**18703**	**14955**
Horse mackerel	-	-	3805	2271	3208
Scads	-	-	6687	9046	3599
Leather-jackets	-	-	269	407	326
Other carangids	871	4809	6449	6979	7822
Indian Mackerel	**46337**	**19634**	**45136**	**27344**	**27257**
SEER FISHER	**1552**	**1941**	**1771**	**1300**	**1613**
S. commersoni	-	-	1339	1105	1505
S. guttatus	-	-	432	187	107
S. lineolatus	-	-	-	7	1
TUNNIES	**4**	**952**	**3180**	**2113**	**3047**
E. affinis	-	-	2214	1665	2362
Auxis spp	-	-	138	215	525
K. pelamis	-	-	-	-	14
T. tonggol	-	-	740	204	146
Other Tunnies	-	-	88	29	-
BILL FISHES	**-**	**-**	**11**	**32**	**87**
BARACUDAS (Sphyraena)	**-**	**84**	**299**	**705**	**1997**
MULLETS (Mugil)	**38**	**39**	**25**	**17**	**70**
Total	**87,541**	**83,833**	**1,26,015**	**80,249**	**78,162**

Table 2.5. Landings of demersal in Karnataka during 1970 to 1998 (in tons)

Name of Fish	1970	1980	1990	Avg (1991-'97)	1998
ELASMOBRANCHS	**1416**	**2910**	**2972**	**1354**	**1497**
Sharks	-	-	758	632	547
Skates	-	-	272	70	281
Rays	-	-	513	283	348
Eels	-	131	8	87	198
Catfish	9220	5354	1421	282	123
Lizard Fish	75	508	1144	2080	3883
Perches	**67**	**1069**	**2774**	**9600**	**19,897**
Goat fishes	**-**	**-**	**174**	**49**	**34**
Red mullets	**31**	**38**	**-**	**-**	**-**
Polynemids	**20**	**-**	**4**	**3**	**-**
Sciaenids	**1885**	**3500**	**4806**	**2779**	**2049**
Leiognathus	**1334**	**4671**	**3032**	**1432**	**2035**
Big-jawed jumper	**-**	**-**	**1161**	**797**	**1103**
Gazza	**-**	**42**	**-**	**-**	**-**
Lactarius	**562**	**998**	**-**	**-**	**-**
Pomfrets	**354**	**696**	**2355**	**2217**	**1111**
Flatfishes	**628**	**782**	**2936**	**7487**	**5511**
Soles	628	782	2918	7444	5457
Halibuts	-	-	18	43	54
Total	**15,592**	**20,699**	**21,358**	**27,798**	**38,617**

Table 2.6. Landings of molluscs and crustaceans in Karnataka during 1970 to 1998 (in tons)

Name of Fish	1970	1980	1990	Avg(1991-'97)	1998
Molluscs	**11**	**122**	**2,287**	**7,165**	**7, 271**
Bivalves	-	-	-	1	-
Gastropods	-	-	-	1	-
Cephalopods	11	122	2287	7165	7271
CRUSTACEANS	**7,573**	**6,101**	**27,259**	**25,704**	**16,199**
Penaied prawns	7538	3098	6688	7004	5271
Non-penaeid prawns	1	128	129	57	27
Lobsters	-	110	-	10	-
Crabs	34	2765	948	1293	666
Stomatopods	-	-	19494	17341	10235
Grand total	**7,584**	**6,223**	**29,546**	**32,869**	**23,470**

Table 2.7. Estimated growth rate and parameters for 1969-98 using the growth equation $Y = AB^t$

Parameters	Pelagic	Demersal	Molluscs	Crustaceans	Total Production
A	4.92	4.31	2.77	4.14	5.11
B	0.0058	0.0172	0.0971	0.0281	0.0093
R^2	0.13	0.65	0.76	0.56	0.37
Growth rate	1.35	4.05	25.04	6.68	2.16

Table 2.7a Growth rate of different species

Species	Growth rate	
	Compound	Exponential
Pelagic	1.16	1.01
Demersal	4.79	1.04
Molluscus	17.54	1.25
Crustaceans	4.77	1.07
Total production	2.06	1.02

Table 2.8. Growth of mechanized fishing units in Karnataka (number of vessels)

Year	Trawlers	Purse seiners	Gill-netters	Long liners	Others	Total mechanized
1984-85	2033	368	627	14	7	3049
1985-86	1984	396	722	22	7	3131
1986-87	1982	390	731	22	7	3132
1987-88	1962	391	815	30	2	3200
1988-89	1959	391	839	35	28	3252
1989-90	1964	395	884	56	431	3730
1990-91	1938	395	884	56	457	3730
1991-92	1938	369	884	56	599	3846
1992-93	2008	376	991	71	752	4198
1993-94	2065	374	1122	82	951	4594
1994-95	2098	378	1189	-	1179	4844
1995-96	2471	327	1639	-	983	5420
1996-97	2709	354	1935	-	1063	6061
1997-98	2636	357	3041	-	107	6141
1998-99	2506	360	3385	-	67	6318

Source: Department of Fisheries, Government of Karnataka, Bangalore

Table 2.9. Growth of non-mechanized fishing units in Karnataka (No. of vessels)

Year	Rampanies	Dugout canoes	Plank built boats	Pattabale units	Others	Total non mechanized
1984-85	83	5499	2010	1090	3165	11847
1985-86	74	5534	2202	1201	8143	17154
1986-87	69	5549	2203	951	3182	11954
1987-88	69	5551	2212	961	3186	11979
1988-89	69	4608	2250	904	4013	11844
1989-90	72	4526	2274	1160	3828	11860
1990-91	72	4526	2274	1160	3828	11860
1991-92	72	4526	2274	1160	3828	11860
1992-93	78	4378	1940	977	4381	11754
1993-94	116	4379	1940	985	4491	11911
1994-95	113	4400	1941	988	4510	11952
1995-96	148	4070	1874	838	4603	11533
1996-97	148	3581	1959	880	4032	10600
1997-98	273	1524	1504	6516	8946	18763
1998-99	283	1570	1553	6677	9209	19292

Source: Department of Fisheries, Government of Karnataka, Bangalore

Table 2.10 Cost of harvesting species in different gears (in Rs.)

Gear	Cost/kg	Cost/hour
Multi-day Trawl Net	15.26	458.67
Purse Seine	5.40	919.02
Trawl Net	14.00	409.97
Gill net	12.32	46.96
Out-board fishing units	11.95	48.99
Non-mechanized fishing units	44.48	135.42

Table 2.11. Mega industries and their particulars in Dakshina Kannada

Name of the Industry	Year of Establish-ment	Raw materials used	End products	Source and quantity of water (m^3/day)	Amount of effluent discharged (m^3/day)	Effluent contents
MCF	1976	Naptha, Ammonia, Phosphoric acid	Urea, Ammonimum bicarbonate, diammonium phosphate	Nethravathi river 15400	7200*	Ammonia, smaller quantities of chromium and venedium
KIOCL	1980	Iron ore	Iron ore concentrate, iron oxide pellets	Bhadra river 40000	15000*	Non recovered particulate metals with high pH.
MRPL	1996	-	-	Nethravathi river 20016	2880	Non-recovered hydrocarbons with heavy metals and oil and grease
BASF, India Ltd.	1996	-	Dyes and dispersions	Nethravathi river 273	NA	Increase BOD, suspended solids, heavy metals such as chromium and cadmium

MCF-Mangalore Chemicals and Fertilizers, KIOCL-Kuduremukh iron ore company limited, MRPL-Mangalore Refinery & Petrochemicals Limited. Source: Katti (1998).

*Lingdhal (1991).

3. Single-Species Model

The marine fish production comes from the interaction of two main systems: the biophysical and institutional environments. Various interactions within the biophysical environment and its fluctuating nature due to climatic changes make fishery production highly complex to understand. Human intervention into fisheries makes the system even more complicated. For instance, the stock externalities arise from the actions of fishers who fail to account for the costs they inflict on other fishers, operating the same and other types of gears as they harvest (Smith, 1968). That is, when a fisher harvests fish under an open-access regime, the level of fish stock decreases, and thus, increases the harvesting costs for other fishers. The harvesting cost increases because of the increase in the amount of search when there are too few fish. By not having to internalise these external costs to others, fishers expand their effort beyond the economically efficient harvesting level.

Another common problem with fisheries is technological externalities (Gardner *et al*., 1990). This externality arises when different types of gears entangle each other or they interfere in the flow of fish to other fishing gears. As a result, gear is either not fully utilized or destroyed in the operation. Finally, the problem can also arise in the form of lack of assignment (Gardner *et al*., 1990). The fish are unevenly distributed across different fishing grounds, and they concentrate in those areas where more food is available. If the number of fishers in each such spot exceeds the number that that spot can afford, the conflicts arises over the access to such spots among fishers.

The policy objective of most fishery management has traditionally been to maintain individual species stock at some sustained level. How and whether this policy goal can be actualised will depend on the institutional arrangements that exist for a given fishery. In most of the developing countries fisheries are open access resources with little or no regulation. Under this type of property rights, fishermen will apply effort until the point of zero rent. Since the fish stocks are jointly harvested, stock externality arises, and there is less incentive to conserve the resources for the future. Scott (1955) argues that the fishers harvesting from the open-access fishery heavily discount the future. Fishers maximise current returns instead of the future flow of fish.

Although Karnataka laws provide for regulating open access fishery, the enforcement has been inadequate. This makes one wonder if some of its commercial species have been already overexploited. It is equally likely that some species remain under-exploited as fishing effort might focus on a few commercial species. The primary objective in this chapter is to analyse the current status of major commercial species, specifically by estimating level of their current exploitation vis-a-vis sustained yield levels. The analysis is done for each species individually at the state level. A simple fishery bio-economic model is employed to estimate the indicators of sustained yields.

Bio-economic Model of Fishery

Resource managers have used two distinct measures of sustained yield for managing fisheries, depending on the underlying management goal. According to biologists, the optimal management goal would be to harvest fish at maximum sustainable yield (MSY). On the other hand, economists would advocate exploiting fisheries at maximum economic yield (MEY). While MSY results in the maximum quantity of catch of a given species each period, it normally is not economically efficient. The effort generating MEY results in the maximum annual net profit. By definition, both these yield levels have their corresponding effort levels that keep stocks sustained year after year, given everything else unchanged. In the context of tropical capture fishery, biological data such as fish growth, mortality, age class and stock recruitment required to set up the advanced model are not available. Therefore, simple model such as surplus production model is more useful to analyse fishery dynamics (Sparre, 1991). In the present study, the Fox model is used to estimate MSY and MEY and their respective effort levels. The Fox model is a modified version of Schaefer's model (Fox, 1970), in which a logarithmic relationship between catch per unit effort (CPUE) and fishing effort (E) is formulated as $\ln(CPUE) = f(effort)$. More formally,

$$\ln\left(\frac{Y}{E}\right) = a + bE \qquad (3.1)$$

where *Y* is total annual catch, *E* annual fishing effort, and *a* and *b* are constant parameters.

The level of effort that generates MSY can be obtained from equation (3.1) easily. Exponentiating both sides of (3.1) and solving for *Y*, we have

$$Y = Ee^{a+bE} \tag{3.1a}$$

Differentiating *Y* with respect to *E* in the above equation, setting the result equal to zero, and solving for effort (E_{MSY}) that maximises *Y* (i.e., that returns MSY), we obtain

$$E_{MSY} = -\frac{1}{b} \tag{3.2}$$

The corresponding MSY can be obtained by substituting equation (3.2) into equation (3.1a). That is,

$$MSY = -\frac{1}{b}[e^{(a-1)}] \tag{3.3}$$

The maximum sustainable yield (MSY) is what biologists try to shoot for while setting targets for fishing effort. With the increase in effort, the growth in the size of sustainable catches will be smaller until the effort reaches the point corresponding to the MSY. Beyond this point, each additional effort reduces sustainable yield.

Maximum Economic Yield

As mentioned earlier, managing fisheries at its biological maximum or MSY may not prove to be economically efficient. Integrating economic considerations such as fishery input and output prices with the biological and technical aspects discussed above becomes essential in order to maximise fishery net returns. A simple economic model introduced by Gordon (1954) is quite handy for this purpose. To begin with, in this model, fishery input and output values are expressed in terms of total cost and total revenue and as functions of fishing effort. The total cost consists of two parts i.e. fixed and variable costs of fishing effort. The fixed costs consist of costs required before any direct fishing effort is made. The variable costs consist of all the costs required directly to operate the fishing effort, such as fuel, food and labour. With this assumption costs per unit of fishing effort (c) is constant. Hence, the relationship between the total cost and fishing effort would be linear. This means average and marginal cost would be identical.

The total cost of fishing (*TC*), marginal cost (*MC*) and average cost (*AC*) can be written as:

$$TC = cE$$
$$AC = MC = c \quad (3.4)$$

where *c* is the cost of unit effort. Price in fishery can be considered either as fixed or variable depending on the type of product market. To keep the analysis simple and for the lack of better data, most studies in the past have assumed fixed output price. The assumption of fixed price is reasonable because it is determined by such uncontrolled factors as weather, environment and resource availability. This assumption implies that fishers in the study area are price takers and their supply will not affect the market price by any significant measure (Anderson, 1979). This also implies that the dynamics of the fishery can be described in terms of supply adjustment in response to price levels. This, in turn, indicates that any regulations on the fishery will only affect producers.

In the steady state condition of the Schaefer model, the sustainable catch curve is the long-run production function for the fishery from an economic point of view. This means that at any particular level of fishing effort the quantity of fish produced from such a resource is on a sustainable basis.

From an economic perspective, analysis of these relationships focuses on average and marginal sustainable catches. From this standpoint, the average and marginal sustainable catches are defined as the ratio between total sustainable catch and fishing effort and the change in sustainable catch due to a change in fishing effort, respectively. Assuming a fixed price *p* for the fish caught and using equation (3.1a), total revenue (*TR*) and marginal revenue (*MR*) functions can be expressed as:

$$TR = pY = pEe^{(a+bE)} \quad (3.5)$$

$$MR = p(bE+1)e^{(a+bE)} \quad (3.6)$$

The maximum economic yield (MEY) occurs at point of effort where the net profit from fishery is maximum. Using the simple marginality principle, MEY can be determined by equating equations (3.4) and (3.6), i.e., setting *MR* = *MC.* Thus,

$$p(bE+1)e^{(a+bE)} = c \tag{3.7}$$

By further simplification,

$$(bE+1)e^{bE} - \frac{c}{pe^{a}} = 0 \tag{3.8}$$

The above equation is in the form *f*(*x*) = 0, where *x* = *b E*. Using Newton's method of successive approximations, if $x_1, x_2, \ldots, x_n, x_{n+1}$ are the real root of the *f*(*x*) = 0, the successive roots are given by

$$x_{n+1} = x_n - \frac{f(x_n)}{f^{'}(x_n)} \text{ , } \quad \text{for n = 1,2,3,…} \tag{3.9}$$

Hence we suppose x_1 (for *n* = 1) to be near a root of the equation *f*(*x*) = 0, putting this value of x_1 in equation (3.9) we get x_2. Then putting this value of x_2 (for n=2) in (3.9) we get x_3 and so on. By successive operations we get a close approximation of the roots. This routine algebraic simplification solves equation (3.8) and yields an expression for the effort (E_{MEY}) that returns MEY.

$$E_{MEY} = \frac{1}{b}\left[-1 + \sqrt{\frac{c}{pe^{a}}}\right] \tag{3.10}$$

Knowing E_{MSY}, one can compute MEY using equation (3.1a) as follows:

$$MEY = E_{MEY}e^{(a+bE_{MEY})} \tag{3.11}$$

Note that the MEY effort is generally below the MSY effort. On the other hand, the sustained stock associated with MEY is greater than the stock corresponding to MSY. Thus, some economists believe both from economic and biological viewpoints, the management program that targets MEY is superior to that does MSY.

In order to estimate MSY and MEY, we first need to estimate the Fox model in equation (3.1). The Fox model at best applies to the case of single-species. However, in a multiple-gear, multi-species fishery like the one under study, the independent variable effort is not observed for each species individually. Therefore, one needs to first compute this variable by aggregating the pro rata effort of all different vessel types dedicated to a given species. The procedure employed for this aggregation is explained further in the chapter.

The value of landings used in equation (3.10) and (3.11) is ex-vessel prices. Ex-vessel prices are those received by fishermen for different species and sizes of fish, which generally fetch different prices. However, in this study the average ex-vessel prices for each species was considered. The cost of fish harvesting is assumed to increase proportionately with fishing effort. We have considered only operational cost of fishing and capital cost was not considered (Hannesson 1993). With those definitions, the relationships may be presented graphically as shown in figure 3.1

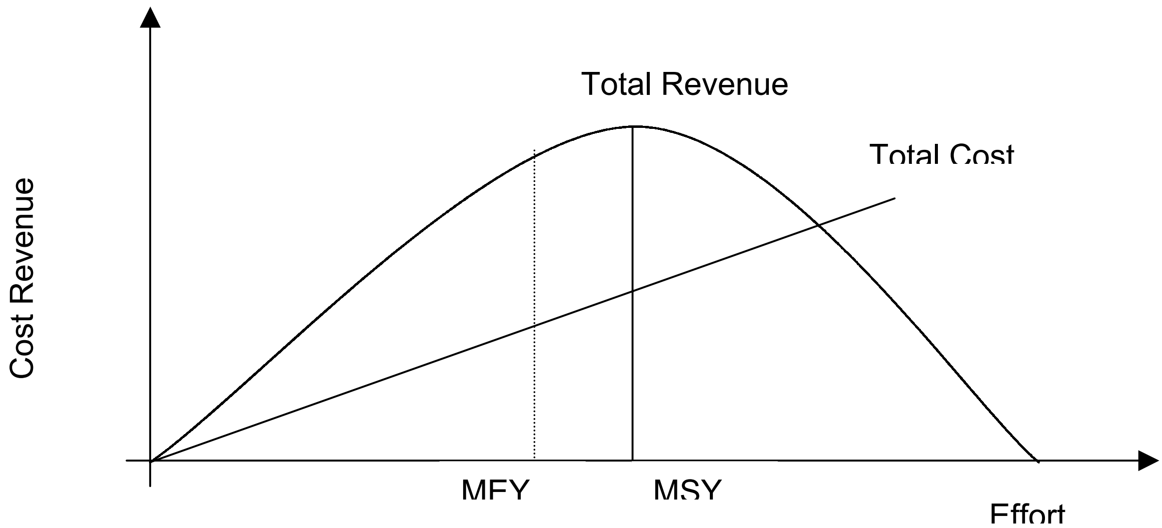

Figure (3.1) A fixed price model of fishery indicating MEY and MSY

Estimation of Stock

When we describe the dynamics of an exploited aquatic resource, a fundamental concept is stock, which means a group of fish species having the same growth and mortality parameters. The historical and current fish stock estimates are another set of measures that one could use for assessing the sustainability of each commercial species in Karnataka. The current stock estimates can also serve as benchmark for analysing the sustainability implications of current and future management policies. Therefore, an attempt is made here to estimate the level of stocks of study species in the Karnataka coast. However, the real problem is that the tropical fisheries are characterized by a large number of different species. Often only some species are of economic importance, and the data may not be available for all species. Therefore, our analysis focuses a select number of economically important species.

Following Conard and Clark (1995), the annual harvest (yield) of a fishery can expressed as a function of fishery effort and stock (*X*) in each period. That is,

$$Y = f(E, X) \tag{3.12}$$

Y and *X* are measured in the same unit. A stylized production function commonly used in the fishery literature is

$$Y = qEX \tag{3.13}$$

where *q* is the constant parameter, called catchability coefficient (Clark , 1985), representing the proportion of stock captured by a unit effort. The method for estimating the parameter *q* is explained below. The knowing the values of *q*, an initial period's annual catch *Y* and effort *E*, one can estimate the value of initial stock. Then for successive years, stock may be estimated using the dynamic equation of motion,

$$X_t = (1 + \alpha)X_{t-1} - Y_{t-1} \tag{3.14}$$

where α is the annual net biological growth parameter, and *t* is the time period.

Catchability Coefficient

The catchability coefficient describes the effectiveness of each unit of fishing effort. The constant catchability coefficient for each species implies there is no change in technology over a certain period of time. Even though the catchability coefficient may vary with time, its time variance is difficult to measure (Sparre and Venema, 1992).

Based on the regression results of the Fox model (i.e., coefficients *a* and *b*), the value of q_t for a given period *t* can be computed as follows:

$$q_t = \frac{\left|\left(z_t U_t^{1-m} + 1/_{-b}\right) / \left(z_t U_{t-1}^{1-m} + 1/_{-b}\right)\right|}{z_t m - z_t} \qquad (3.15)$$

where $z_t = -(a/_{-b}) - \hat{E}_t$

and $\hat{E}_t = (E_t - E_{t-1})/2$

From the individual years' catchability coefficients computed in (3.15), we can estimate the average catchability coefficient over n years:

$$\bar{q} = \exp\left[\sum_{t=1}^{n-1} \frac{\ln|q_t|}{(n-1)}\right] \qquad (3.16)$$

q_t : estimates catchability coefficient

U_t : catch per unit of standardised fishing effort in year t

E_t : standardised fishing effort in year t

n : number of observation in year, t = 1, 2, . . . , n

m : constant parameter with a value of 1.0001 for the Fox model

$\bar{q}$: average catchability coefficient

a and b : estimates coefficients in the Fox model

Source: Fox (1970,1975)

Data Collection and Analysis

Selection of species and data collection

Karnataka is known for very rich marine biodiversity. It is estimated that around 310 different marine fish species are available in the coastal waters of Karnataka apart from other migratory aquatic animals (Madhyastha, 1998). During the year 1998-99 the total fish production was 160,000 tonnes with a catchable potential of 270,000tonnes and with a continental shelf of 27,000 sq. km. From a list of species mentioned as commercially important by the Working Group of the Government of India, the following species were selected for our analysis. The selected species constituted 60 percent of the total landings in 1998.

The data for the descriptive and modelling part of Karnataka marine fisheries comes from mainly two sources. The landings and effort data for the period from 1994-98 was drawn from Central Marine Fisheries Research Institute (CMFRI). The CMFRI collects the statistics on marine fish production in major and minor landing centres of all the 11 coastal states. It uses the multi-stage stratified random sampling design for the estimation of marine fish production and fishing effort. Thus the basic material on landings and effort data was drawn from CMFRI data bank.

The second set of data on costs and earnings, harvested price, labour share and income, and other economic parameters were collected by conducing a sample survey of the fishery vessels in coastal Karnataka. The data were collected for the two coastal districts namely Dakshina Kannada and Udupi districts for the fishing season of 1999-2000. The costs of fishing trips, capital and fixed costs of crafts and gear were compiled from 15-20 fishing units in each vessel class to estimate the economic efficiency of each selected vessel. The table 3.1 shows the total number of different industries and the number of sampled industries in the study area. In most cases frequent visits to the fishing ports to observe the species landed, prices and cost of each fishing trips yielded much better data. Since fishing and fish harvesting takes place on a day-to-day basis unlike agriculture, such frequent observations were more useful in estimating accurate data. The market price data came from the published reports and documents.

Data development

Standardisation of fishing effort: Economists think of effort in terms of the boats, men, gear and so on. This is usually termed as nominal fishing effort and is expressed as fishing days or actual fishing hours. The fishing effort is proportional to fishing mortality. This creates problem when we have to compare the efforts from different gears. If two boats fish side by side during the same period of time and one of them catches twice as much, that boat is said to have double the fishing power. Obviously some boats or gears are more efficient in catching certain species than others. Hence, it was necessary to convert efforts of different vessel types to a standardised fishing effort before we could estimate various models and indicators discussed above. The vessel having the highest catch per unit of fishing effort (CPUE) is selected as the standard vessel. Then, the effort of other vessel of type, say Z, is given by the ratio of CPUE of vessel Y to CPUE of standard vessel, multiplied by fishing effort of Y.

The models and methods described in the standard literature have dealt mostly with a single stock exploited by one fleet. However, in the case of tropical fisheries this situation is an exception rather than a rule. In most cases a particular gear exploits several stocks, and several types of gears compete in exploiting the same resources. Thus we operate with three main types of interactions between the gears harvesting multiple species. The simplest way to deal with the multi-species and multi-fleet system is to apply the surplus production models to the total catch. However, we need to compute the aggregate fishing effort from all fleets on a particular species. This aggregate fishing effort on individual species is used for modelling and optimisation. The following four-step method was adopted to calculate the species-wise aggregate fishing effort.

Step 1: From the original CMFRI data on gear-wise, species-wise landings, calculate the proportion of species i's catch to the total catch of vessel j. That is, the ratio of catch i from vessel j (C_{ij}) to total catch of vessel j (C_j). Call it d_{ij}.

Step 2: Multiply the total annual effort (E_j) of vessel j by d_{ij} to compute the amount of effort dedicated to species i by vessel j. Call it E_{ij}

Step 3: Standardise E_{ij} of all vessels by multiplying each of them with their respective effort standardisation parameter, s_j. The s_j is determined by taking the ratio of the $CPUE_j$ of vessel *j* to the $CPUE_m$, where *m* is the vessel having the maximum CPUE. The CPUE for each vessel is computed by taking the ratio of C_j to E_j. Thus,

$$s_j = \frac{CPUE_j}{CPUE_m} = \frac{C_j / E_j}{C_m / E_m}$$

Step 4: Aggregate the standardised efforts of all vessel types dedicated to each species to arrive at the total effort (TE_i) for species *i*.

$$TE_i = \sum_{j=1}^{n} s_j E_{ij} \qquad \text{for species } i$$

Where *n* is the number of vessel types.

Step 3 above recognises that each gear has different efficiency levels in harvesting fish, and therefore, standardises efforts of participating vessels to a common denominator (Sparre and Venema, 1992).

Estimation of costs of production: The multi-sepcies, multi-gear fishery operation presents similar complication, as discussed above, for estimating the species-wise unit effort cost. The following procedure was adopted to compute the same.

Step1: Find the unit vessel effort cost ($UVEC_j$) of each vessel *j* from the collected vessel data.

Step 2: Compute the total effort cost (TC_i) of species *i* using the following formula:

$$TC_i = \sum_{j=1}^{n} UVEC_j E_{ij} \qquad \text{for species } i$$

Results

Fishing ports and their importance

Karnataka has 29 fish landing centres of which 13 are in Dakshina Kannada District (including Udupi) and rest are in Uttara Kannada district. These centres are spread along a coastline of 320 km. Out of the total landings of 160,627 tons of fish, 35 percent was landed in Mangalore port followed by Malpe (20 %) and Karwar (9 %) in 1998.

Table 3.2 shows that the proportion of landings in Malpe increased from 20 percent to 28 percent over the period from 1990-98 whereas there was a decline of 7 % in Mangalore port. However, in terms of effort 50-60 percent is concentrated in Mangalore port followed by Malpe (20-30 %), Gangolli and Tadri (Table 3.3). Table 3.4 presents the gear wise catch per unit of fishing effort (CPUE) from 1994-98. While the CPUE for trawlers, which mainly harvest high valued species, varies between 30-40 kilograms per hour, and for the purse seiners, it fluctuates over a very wide range as they harvest mainly pelagic resources. On the overall the CPUE varies in the range of 30-40 kilograms per hour of fishing.

Table 3.5 presents the catch per unit of fishing effort in different ports of Karnataka. Table shows that Mangalore, which has highest proportion of effort, has least CPUE followed by Malpe. Bhatkal and Gangolli had higher CPUE, which are relatively less dense in terms of effort.

Cost and Returns of Fishing Operations

It is well known that under the open access conditions of property rights, resource users tend to intensify capital accumulation in the production process in order to harvest the resources much faster. Further, increase in market prices could intensify harvesting even though the yield rate per boat might be decreasing. Tables 3.6 - 3.8 show the costs and returns of three major types of gears collected from previous research studies (Prabhakar S, 1991 and Aithal, 1993) as well as ones developed under the present study. It is evident that the costs have risen from 1988 to 1998. The capital investment cost has increased from Rs.6 lakhs to Rs.25 lakhs for purse seines, from Rs. 1.50 lakhs to Rs.14 lakhs for trawlers. The multi-day trawl fishing vessels introduced in early 1990s also shows a substantial increase within a period of 3 years. The investment cost of multi-day trawlers increased from Rs.14 lakhs in 1995 to Rs. 17.5 lakhs in 1998.

The operating costs, the major share of which is diesel and oil, also show a substantial increase in spite of diesel subsidy given by the state and central governments. The increase in the operating costs is to the extent of 153 percent and 54 percent between 1988 and 1998 for purse seines and trawlers respectively.

The rising cost of production over time is a partial indication of declining productivity and stocks for some species. Overcapitalisation and crowding of fishers would result in declining stock and productivity, and in turn, increasing costs of production.

Standardized Fishing Effort

The total standardized fishing effort on each of the selected commercially important species (both pelagic and demersal) is presented in Table 3.9(a) and Table 3.9(b). Over the period of eight years, the standardised fishing effort for shrimp increased by more than 10,000 hours (AFH) and that of threadfin breams increased by more than 25,000 hours. Among pelagic species maximum increase occurred in the case of tunnies, followed by seer fish and other species. These results point to the fact even in a short period of eight years, there has been an escalation in fishery capital in Karnataka.

Catch – Effort Relationship

The analysis of total catch, effort and CPUE for the pelagic species is presented in Table 3.10(a). The Indian mackerel constituted major part of the catch among pelagic species. However, total landings decreased by 36% from 42821 tons in 1996 to 27257 tons in 1998. During the corresponding period the standardised fishing effort and CPUE also decreased. The fishing units experienced a loss of more than 123 kilo grams per hour from 550 kilo grams per hour in 1996 to 417 kilo grams in 1998.

The oil sardine another important species has shown a marginal improvement since 1995. Though total catch is showing marginal increase the CPUE is stagnating and there has been a decline in 1998 to the extent of more than 100 kilograms per hour. The total landings of stolephorus also presents similar trend. Except in 1997, the CPUE has declined by nearly 50% form 622 kilograms to 353 kilograms. Other species such as tunnies, scads, hilsa shads, wolf herrings show fluctuating landings and CPUE. These species are harvested together with other species and their catch is relatively less.

The analysis of total catch, effort and CPUE for the demersal species is presented in Table 3.10(b). The catch, effort and CPUE for the threadfin breams shows that the increase in the effort was to the extent of 380% from 1994 to 1998 and the total catch has doubled from 5210 tons to the 13233 tons during the corresponding period. With the result, the CPUE declined by 58%. This trend was more permanent in catfish and sharks. The effort on sharks increased by two times and CPUE declined by nearly 3 times. Thus impact of increased effort on CPUE is clearly visible in the case of catfish and sharks.

The landings of pomfret on the other hand represent an example where the decline in the total catch has made the fishermen to reduce the effort leading to a marginal improvement in the CPUE. The total effort on shrimp, one of the most targeted species shows that total catch is stagnating and effort is declining. The CPUE is has been fluctuating around 150-250 kilograms per hour. Some of the field observations revealed that with average landings of Shrimp of 1500 kg's per trip of 6-8 hours during 1990's the current catch quantity has reduced to 1-5 kg per trip. Shrimp, which used to constitute 80-90% of the total catch quantity, today does not constitute even ten percent. Table 3.11 shows the cost of harvesting in Mangalore port by different gears. The table shows that the cost of harvesting per kilogram is lowest in purse seiners compared to other gears. But the cost per hour of fishing is low in gillnets and outboard fishing units.

Maximum Sustainable Yield and Maximum Economic Yield

The parameters of the Fox model used in the computation of MSY and MEY are reported in table 3.12(a) for demersal species. The R-square for most of the species were significant. The unit cost of harvesting and the market price for study species are also reported in the same table. It is evident that the difference between cost and price reflecting the surplus is highest for pomfret and shrimp followed by sharks and rays. Interestingly, the current harvest levels for these species have far exceeded the sustainable yield (Table 3.13(a)). Thus motivated by the higher economic surplus, the fishermen try to harvest more resulting in biological unsustainability of these resources. Table 3.12(b) presents the estimated parameter values for pelagic species. Since these species are short lined and highly fluctuating the estimation is not accurate. The stolephorus, mackrel and tunnies have highest revenue surplus, as presented in table 3.12(b).

Table 3.13 (a) presents the estimated values yield, effort and cost of MSY and MEY level for the selected demersal species against the harvest quantities of the base year 1998. The table shows that for most of the species the current harvest has executed both MEY and MSY, indicating some degree of over exploitation. For example by spending 19183 actual fishing hours (AFH), the fishery could have harvested 8400 tonnes of MEY and 8327 tonnes of MSY. However, by spending almost the same level of effort (19719 AFH) the current yield (1998) was only 2516 tonnes which represented the excess of fishing effort and hence societal loss. In the case of many other species, the current harvest quantity is more than the MSY and MEY.

The estimated values of MEY and MSY pelagic fishes presented in table 3.13(b) show that for some of the species such as mackerel, the symptoms of unsustainability is very clear. By spending 67582 AFH an MEY level of 30848 tonnes could have generated maximum revenue surplus. However, the comparison with the 1998 yield and effort shows that by spending almost same level of fishing effort (65288 AFH) the yield is only 27257 tonnes indicating a decline in profitability.

The sustainability of demersal species in value terms under three scenarios is presented in table 3.14(a). Scenario 1 and 2 represent the value of catch with the restriction of MSY and MEY. That means if the fishery managers were to impose the restriction, the actual catch value should have been only Rs.786.01 millions of MSY or RS.736.79 millions of MEY. However the actual (1998) harvest value for most of the species have exceeded both MSY and MEY levels representing excess harvest value over and above the sustainable level, with a total of Rs.1540.32 and Rs.1615.41 of MEY and MSY, respectively. Table 3.14(b) presents the results obtained for pelagic species. The table indicates that for tunnies, seer fish and stolephorus, there has been an excess harvest over and above the sustainable level. Though accurate estimation of sustainability for these species is difficult because of the highly fluctuating nature of these species, the results indicate that they are also under threat from the viewpoint of sustainability.

Conclusions

Over the years the infrastructure development in fishing harbours and ports have attracted more and more mechanised fishing vessels into such ports. Mangalore with developed port infrastructure and access to urban centres has highest concentration of fish landings and effort. However, the concentration effort was much higher than landings indicating lower CPUE compared to other ports.

The concentration of effort on each species during the period of 1990 - 98 indicate that for all the species the standardised efforts have increased. This expansion does not take into consideration, the improvement in the technology with more and more electronic and fish finding devices. There has been a substantial growth in the standardised effort over a period of 8 years. The concentration of effort on high valued species such as demersal group (Shrimp, Breams, Soles) has increased. However, in the case of pelagic species, which are mostly used for domestic consumption and are relatively low valued, the increase in the total effort was not as high as for demersal. Indian mackerel constituted major share of the total production among the pelagics. However, both CPUE and effort decreased during 1990s, indicating symptoms of un-sustainability.

For most species in Karnataka, we find that the current level of exploitation is either close to or over the MSY level. Therefore, some species are being currently harvested at their biological optimums, but clearly they are way above their MEY levels or economically efficient levels. This only indicates that the state fishers are losing substantial rents from the fishery due to excessive capitalisation and overexploitation of resources. Avoiding such rent loss may require several measures, including retiring some fishery fleet, readjustment of efforts across species, seasons and/or gear types, and other technological changes. In the next chapter, with the help of a more location-specific, decision-support harvesting model, we can show how one can articulate the above rent-loss reduction goal into specific management strategies.

Table 3.1 Fishery sectors and the sampled number of units

Sectors	Total No. of units	No.of units sampled
Boat building yard	18	6
Net making unit	3	2
Trawlers (deep)	1100	**
Trawler (steel)	8	**
Longliners	44	**
Purse seiners	222	**
Trawler (day)	802	**
Gillnetters	2200	**
Shore seines	63	**
Encircling gill net	167	**
Mini purse seine		**
Frozen	16	5
Meal and Oil	16	5
Canning	6	2
Dryfish	-	**
Fresh fish	-	**
Fish products		**
Ice	100	12

Note: ** Frequent visits to the sampled production and marketing firms.

Table 3.2: Concentration of fish landings (percentage) in major ports

Year	Catch (tonnes)	Mangalore	Malpe	Gangolli	Bhatkal	Tadri	Karwar
1994	113522	42.59	20.23	10.91	5.64	14.83	5.81
1995	116579	55.87	13.30	9.44	3.93	12.38	5.08
1996	139544	36.97	29.12	10.42	7.20	10.22	6.07
1997	154453	31.88	29.42	13.78	8.66	8.18	8.09
1998	139678	35.73	28.24	12.57	9.19	5.12	9.16

Table 3.3: Catch per unit Effort (kg / hr) in different Technologies

Year	Trawl net	Purse seine	Mechanized gill net	Outboard	Total
1994	34.25	167.86	-	43.18	47.77
1995	27.45	510.90	15.94	28.53	43.49
1996	29.23	215.78	11.36	38.37	48.83
1997	40.33	25.08	13.96	50.76	34.48
1998	36.85	285.72	14.79	30.05	56.60

Table 3.4. Concentration of fishing effort (percentage) in major ports

Year	Total Effort (hr)	Mangalore	Malpe	Gangolli	Bhatkal	Tadri	Karwar
1994	2376233	53.70	24.73	5.88	2.10	9.10	4.49
1995	2680671	60.80	22.01	5.56	1.95	7.78	1.91
1996	2857743	53.25	30.76	4.65	1.35	5.76	4.23
1997	4479937	73.30	15.62	4.02	1.76	3.37	1.92
1998	2468014	52.31	27.85	6.16	2.43	5.33	5.92

Table 3.5 Catch per unit Effort (kg/hr) for the major ports in Karnataka during 1994-1998

Year	Mangalore	Malpe	Gangolli	Bhatkal	Tadri	Karwar
1994	37.89	39.10	88.61	128.11	77.84	61.87
1995	39.97	26.30	73.87	87.92	69.25	115.36
1996	33.91	46.23	109.38	259.64	86.71	70.17
1997	39.55	64.95	118.05	169.59	83.60	145.14
1998	38.66	57.41	115.50	213.97	54.31	87.59

Table 3.6: Cost and Returns of Purse seiners over the years (in Rs)

	1988	1999	Percentage change
Investment cost	602215.6	2500000	315.13
Operating cost	344128.7	872400	153.51
Fixed cost	173947.2	937500	438.96
Total cost	518075.9	1809900	249.35
Total revenue	559889	2210200	294.76
Profit	41813.13	400300	857.35

Table 3.7. Cost and Returns of Trawlers over the years (in Rs)

	1988	1998	Percentage change
Investment cost	148555.7	1440000	869.33
Operating cost	155634.2	240700	54.66
Fixed cost	72000.54	430200	497.50
Total cost	227634.8	670900	194.73
Total revenue	228724	1044800	356.80
Profit	1089.24	373900	34226.69

Table 3.8. Cost and Returns of multi-day trawlers over the years (amount in Rs/Year per unit fishing)

	1995	1998	Percentage change
Investment cost	1400000	1765000	26.07
Operating cost	711096	694080	-2.39
Fixed cost	399590	533075	33.41
Total cost	1110686	1227155	10.49
Total revenue	1232000	1598715	29.77
Profit	121314	371560	206.28

Table 3.9(a). Standardized fishing effort for demersal species during 1990-98 (in actual fishing hours)

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998
Pomfret	3234.47	1482.08	7150.53	3596.05	19313.87	7149.43	8148.38	3112.15	3634.35
Shrimp	9185.61	4566.77	34682.14	7278.90	41223.17	16014.82	38730.32	12238.24	19719.70
Hallibut	462.18	671.29	631.52	2089.30	1537.23	363.21	523.26	415.65	1346.36
Threadfin breams	38566.55	2379.48	7214.63	5050.86	79401.83	182656.12	312733.76	109262.99	381152.30
Rockcods	5135.36	113.55	1182.67	27939.97	20399.01	47658.93	52742.00	13612.62	52462.13
Lizard fishes	29374.26	23786.52	26563.25	22097.01	33913.20	33965.00	115036.76	26124.42	108217.95
Catfishes	1951.67	527.89	942.29	78.77	940.77	4776.05	2482.53	2015.24	2510.96
Rays	704.58	137.95	1195.49	353.66	4303.60	8947.21	3608.05	2091.77	2260.30
Soles	4007.72	2267.95	58181.76	12556.43	77884.79	38508.41	36969.29	47660.41	22479.40
Shark	1041.07	520.92	766.01	2836.49	978.99	2594.83	5285.81	609.28	2516.31
Total Effort	**93663.47**	**36454.4**	**138510.30**	**83877.44**	**279896.50**	**342634.00**	**576260.20**	**217142.80**	**596299.80**

Table 3.9(b). Standardized fishing effort for pelagic species during 1990-98 (in Actual Fishing Hours)

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998
Tunnies	4367.56	815.74	23605.39	733.03	36152.89	1451.46	1323.99	8975.81	13065.14
Seer fish	2432.37	767.93	5862.09	2670.11	9127.86	1694.40	3362.60	4952.49	3914.41
Scads	9184.24	7783.93	56569.61	7759.55	11598.78	14945.13	15224.82	7755.75	15316.29
Horse mackerel	5225.97	3101.62	7096.04	2236.08	12337.20	3547.80	864.02	1571.41	9664.01
Wolf herring	469.72	123.01	852.55	763.58	5335.53	11471.17	5405.93	1946.40	1155.95
Stolephorus	14040.75	5669.37	17169.60	12148.11	12148.11	15801.35	8125.82	5789.23	15732.56
Indian Mackerel	61991.9	11021.5	48694.73	73171.61	87721.22	24528.23	77825.45	64022.93	65288.28
Oil sardine	40816.10	6655.43	26050.87	8003.90	5106.31	10890.37	11234.69	16060.50	21483.12
Hilsa shad	49.44	87.15	532.04	110.92	411.73	202.97	249.86	396.28	211.36
Total effort	**138578**	**36025.7**	**186433**	**107596.9**	**179939.6**	**84532.88**	**123617.2**	**111470.8**	**145831.1**

Table 3.10(a). Catch effort relationship of pelagic species in Karnataka

Species	Variables	1994	1995	1996	1997	1998
Oil sardine	Total catch in tonnes	1450	4112	6026	8608	8697
	Effort in A.F.H.	5106.31	10890.37	11234.69	16060.5	21483.12
	CPUE (kg per hour)	283.96	377.58	536.37	535.97	404.83
Indian Mackerel	Total catch in tonnes	19070	10623	42821	36050	27257
	Effort in A.F.H.	87721.22	24528.23	77825.45	64022.93	65288.28
	CPUE (kg per hour)	217.39	433.09	550.22	563.08	417.49
Tunnies	Total catch in tonnes	1734	772	473	642	3047
	Effort in A.F.H.	36152.89	1451.46	1323.99	8975.81	13065.14
	CPUE (kg per hour)	47.96	531.88	357.25	71.53	233.22
Scads	Total catch in tonnes	1686	9152	10130	4247	3599
	Effort in A.F.H.	11598.78	14945.13	15224.82	7755.75	15316.29
	CPUE (kg per hour)	145.36	612.37	665.36	547.59	234.98
Horse mackerel	Total catch in tonnes	1833	2292	497	1335	3208
	Effort in A.F.H.	12337.2	3547.8	864.02	1571.41	9664.01
	CPUE (kg per hour)	148.58	646.03	575.22	849.56	331.95
Hilas shad	Total catch in tonnes	110	146	35	15	75
	Effort in A.F.H.	411.73	202.97	249.86	396.28	211.36
	CPUE (kg per hour)	267.16	719.31	140.08	37.85	354.85
Seer fish	Total catch in tonnes	1230	977	1084	761	1613
	Effort in A.F.H.	9127.86	1694.4	3362.6	4952.49	3914.41
	CPUE (kg per hour)	134.75	576.6	322.37	153.66	412.07
Wolf herring	Total catch in tonnes	486	403	483	379	177
	Effort in A.F.H.	5335.53	11471.17	5405.93	1946.4	1155.95
	CPUE (kg per hour)	91.09	35.13	89.35	194.72	153.12
Stolephorus	Total catch in tonnes	7557	11312	4490	4752	5563
	Effort in A.F.H.	12148.11	15801.35	8125.82	5785.23	15732.56
	CPUE (kg per hour)	622.07	715.89	552.56	820.84	353.6

Table 3.10(b). Catch effort relationship of demersal species in Karnataka

Species	Variables	1994	1995	1996	1997	1998
Threadfin bream	Total catch in tonnes	5210	5556	8897	11270	13233
	Effort in A.F.H.	79401.83	182656.1	312733.8	1092623	381152.3
	CPUE (kg per hour)	65.62	30.42	28.45	103.15	34.72
Catfish	Total catch in tonnes	135	165	205	69	123
	Effort in A.F.H.	940.77	4776.05	2482.53	2015.24	2510.96
	CPUE (kg per hour)	143.5	34.55	82.58	34.24	48.99
Sharks	Total catch in tonnes	609	672	462	337	547
	Effort in A.F.H.	978.99	2594.83	5286.81	609.28	2516.31
	CPUE (kg per hour)	622.07	258.98	87.4	553.11	217.38
Soles	Total catch in tonnes	5605	4186	5085	6715	5457
	Effort in A.F.H.	77884.79	38508.41	36969.29	47660.41	22479.4
	CPUE (kg per hour)	71.97	108.7	137.55	140.89	242.76
Pomfret	Total catch in tonnes	2311	3358	1237	1171	1111
	Effort in A.F.H.	19313.87	7149.44	8148.38	3112.15	3634.35
	CPUE (kg per hour)	119.65	469.69	151.81	376.27	305.69
Halibut	Total catch in tonnes	40	12	15	92	54
	Effort in A.F.H.	1537.23	363.21	523.26	415.65	1346.36
	CPUE (kg per hour)	26.02	33.04	28.67	221.34	40.11
Shrimp	Total catch in tonnes	5931	5641	5640	7300	5271
	Effort in A.F.H.	41223.17	16014.82	38730.32	12238.24	19719.7
	CPUE (kg per hour)	143.88	352.24	145.62	596.49	267.3

Table 3.11. Cost of harvesting fish in different gears (in Rs)

Gear	Cost / kg	Cost / hour
Multi-day trawl net	15.26	458.67
Purse seine	5.40	919.02
Trawl net	14.00	409.97
Gill net	12.32	46.96
Out board fishing units	11.95	48.99
Non mechanized fishing units	44.48	135.42

Table 3.12(a). Estimated parameters of Fox model, average cost / kg / effort and price / kg of demersal species

Species	Intercept (a)	Slope (b)	(R-square)	Catch ability Coefficient	Cost / kg / effort (in Rs.)	Price per kg (in Rs.)
Catfish	6.55	-0.00075	0.52	0.000131	9.32	17.85
Haliibut	4.28	-0.0005	0.2	0.000221	12.57	9
Lizard fishes	4.24	-6.60E-06	0.28	7.56E-06	12.83	5
Pomfret	6.75	-0.00012	0.57	1.95E-05	7.91	53.53
Rays	6.39	-0.0004	0.68	0.000219	11.5	27.76
Rock cods	5.6	-4.70E-05	0.5	3.93E-05	14.3	6
Shark	6.89	-0.00048	0.71	0.000291	11.81	30.69
Shrimp	7.08	-5.20E-05	0.78	4.06E-05	10.8	53.49
Soles	6.78	-3.40E-05	0.67	1.36E-05	9.45	5.59
Thread fin breems	5.53	-7.10E-06	0.52	7.6E-06	12.85	5

Table 3.12(b). Estimated parameters of Fox model, average cost / kg / effort and price / kg of pelagic species

Species	Intercept (a)	Slope (b)	(R-square)	Catch ability Coefficient	Cost / k.g / effort (in Rs.)	Price per kg (in Rs.)
Hilsa shad	6.98	-0.00437	0.4	0.002266	6.74	4
Horse mackerel	7.04	-0.00015	0.61	7.2E-05	9.04	2
Indian mackerel	7.12	-1.50E-05	0.36	5.71E-06	5.95	17.83
Oil sardine	6.34	-3.90E-06	0.01	1.18E-06	5.69	10.43
Scads	6.48	-1.60E-05	0.1	9.73E-06	7.1	4
Seer-fish	6.46	-6.70E-05	0.52	5.4E-05	11.42	40
Stolephorus	7.52	-8.80E-05	0.52	0.000138	7.27	32.2
Tunnies	6.46	-6.70E-05	0.52	6.5E-05	4.78	14.07
Wolf herring	6.33	-0.00028	0.71	0.00017	12.31	6.9

Table 3.13(a): Yield and Effort at MSY and MEY Level, Cost at MSY, MEY of selected demersal species

Species	1998			Maximum Economic Level			Maximum sustainable level		
	Yield (tonnes)	Effort (A.F.H.)	Cost ('000 Rs.)	Yield (tonnes)	Effort (A.F.H.)	Cost ('000 Rs.)	Yield (tonnes)	Effort (A.F.H.)	Cost ('000 Rs.)
Catfish	123	2510.96	1,274.39	340.94	1329.97	3,532.49	338.02	1512.25	3,502.20
Halibut	2510.96	1346.36	723.28	53.43	2018.90	715.70	53.05	2272.01	710.52
Lizard fishes	9664.01	108218	53,132.21	3834.48	150788.98	52,468.31	3805.74	170048.61	52,075.09
Pomfret	21483.12	3634.35	9,697.49	2640.65	8425.90	23,049.21	2617.72	9588.12	22,849.11
Rays	3634.35	2260.3	4,297.80	544.99	2495.40	6,730.65	540.29	2838.64	6,672.53
Rock	2260.3	52462.13	24,825.36	2114.78	21286.16	29,880.53	2097.05	24169.16	29,630.00
Shark	3914.41	2516.31	7,072.70	758.65	2102.53	9,809.35	752.12	2391.32	9,724.87
Shrimp	2516.31	19719.7	60,747.54	8400.42	19183.22	96,813.71	8327.48	21829.52	95,973.03
Soles	19719.7	22479.4	54,379.59	9428.73	29104.95	93,958.32	9348.36	33081.16	93,157.41
Thread fin breams	15732.56	381152.3	181,512.05	13152.67	141468.14	180,410.27	13042.67	160603.91	178,901.35
Total	81558.72	596299.80	397662.41	41269.74	378204.20	497368.54	40922.50	428334.70	493196.11

Table 3.13(b): Yield and Effort at MSY and MEY Level, Cost at MSY, MEY of selected pelagic species

Species	1998			Maximum Economic Level			Maximum sustainable level		
	Yield (tonnes)	Effort (A.F.H.)	Cost ('000 Rs.)	Yield (tonnes)	Effort (A.F.H.)	Cost ('000 Rs.)	Yield (tonnes)	Effort (A.F.H.)	Cost ('000 Rs.)
Hilsa shad	1346.36	211.36	534.60	90.54	228.99	645.35	89.76	260.46	639.79
Horse mackerel	211.36	9664.01	32,212.15	2894.82	6869.55	29,067.44	2870.37	7803.48	28,821.96
Indian mackerel	27257	65288.28	178,433.16	30848.63	67582.11	201,945.15	30581.26	76895.81	200,194.84
Oil sardine	65288.28	21483.12	53,095.02	53205.98	253967.83	324,821.51	52748.14	288836.28	322,026.39
Rock cods	2260.3	52462.13	24,825.36	2114.78	21286.16	29,880.53	2097.05	24169.16	29,630.00
Scads	52462.13	15316.29	28,412.02	15260.14	63527.89	120,469.98	15129.39	72230.35	119,437.76
Seer-fish	15316.29	3914.41	15,687.45	1647.65	3552.68	16,024.41	3494.80	16985.42	33,989.17
Stolephorus	22479.4	15732.56	44,803.90	7688.92	11362.31	61,925.86	7622.35	12927.29	61,389.72
Tunnies	381152.3	13065.14	16,123.17	3525.37	14927.87	18,654.44	3494.90	16981.86	18,493.25
Wolf Herring	13065.14	1155.95	2,347.78	734.58	3551.11	9,743.71	728.41	4032.80	9,661.78
Total	580838.56	198293.25	396474.61	118011.41	446856.50	813178.38	118856.43	521122.91	824284.66

Table 3.14(a): Sustainability of some demeresal fish under alternative scenarios during 1998 (Value in Rs. in millions)

Species	Price (P) (Rs. / kg)	Scenario 1 (MSY * P) (in millions)	Scenario 2 (MEY * P) (in millions)	Scenario 3 (1998's total Catch * P) (in millions)	Surplus/Slack (+/-) under scenario1 (in millions)	Surplus/Slack (+/-) under scenario 2 (in millions)
Catfish	17.85	6.09	6.09	2.20	3.89	3.89
Halibut	9.00	0.48	0.48	22.60	-22.12	-22.12
Lizard	5.00	19.17	19.07	48.32	-29.15	-29.25
Pomfret	53.53	141.35	137.96	1149.95	-1008.60	-1011.98
Rays	27.76	15.13	15.13	100.90	-85.77	-85.77
Rock	6.00	12.69	12.69	13.56	-0.87	-0.88
Shark	30.69	23.28	23.28	120.14	-96.86	-96.86
Shrimp	53.49	449.34	403.61	134.60	314.74	269.01
Soles	5.59	52.72	52.72	110.26	-57.54	-57.54
Thread fin breams	5.00	65.76	65.76	78.66	-12.90	-12.90
Total	213.91	786.01	736.79	1781.19	-995.18	-1044.4

Scenario 1: Harvest level with the restriction of MSY
Scenario 2: Harvest level with the restriction of MEY
Scenario 3: Actual harvest without any restriction.

Table 3.14(b): Sustainability of some pelagic fish under alternative scenarios during 1998 (Value in Rs. in millions)

Species	Price (Rs. / kg)	Scenario 1 (MSY * P) (in millions)	Scenario 2 (MEY * P) (in millions)	Scenario 3 (1998's total Catch * P) (in millions)	Surplus/Slack (+/-) under scenario1 (in millions)	Surplus/Slack (+/-) under scenario 2 (in millions)
Hilsa shad	4.00	0.36	0.36	5.39	-5.02	-5.02
Horse mackerel	2.00	5.79	5.79	0.42	5.37	5.37
Indian mackerel	17.83	550.11	550.11	486.06	64.05	64.05
oil sardine	10.43	554.88	554.87	680.88	-126.00	-126.01
Scads	4.00	61.04	61.04	209.85	-148.81	-148.81
seer-fish	40.00	65.91	141.01	612.65	-546.75	-471.64
Stolephorus	32.20	247.56	247.56	723.78	-476.22	-476.22
Tunnies	14.07	49.60	49.60	5362.81	-5313.21	-5313.21
Wolf herring	6.90	5.07	5.07	90.15	-85.08	-85.08
Total	131.43	1540.32	1615.41	8171.99	-6631.67	-6556.57

Scenario 1: Harvest level with the restriction of MSY
Scenario 2: Harvest level with the restriction of MEY
Scenario 3: Actual harvest without any restriction.

4. Multi-species Model

As mentioned before, the most fishing ports of Karnataka have multi-species, multi-gear fishery. The single-species, static model presented in the previous sub-section is not adequate to incorporate the dynamic nature of fishery and multi-gear technical interactions into a management plan that is biologically and economically sustainable. A mathematical programming model is therefore used to represent the inter-temporal relationships between the stocks of various species and efforts exerted by fishing gears. The model will characterise optimal combinations of fleet effort levels and landings over time. Such optimal combinations of landings would result in the maximum net revenue from the given fishery subject to usual stock sustainability and other socio-economic conditions.

The model developed in the study could incorporate multiple objectives of a fishery management agency. Ideally, a public agency would like to optimise the combination of welfare accrued to fishery consumers (consumer surplus), producers (producer surplus) and labourers (wages). However, the main focus of this study is bioeconomic sustainability of fishery production. Also, productions from individual fishery management units, for instance, fishing grounds associated with ports, are not large enough to influence market supply and prices. Therefore, we do not consider the demand side of the market in the model. Thus included in the model is only the production side of a representative fishery.

The model explicitly considers alternative methods of fishing. The costs of operation and productivity vary between fishing methods. Fish stocks are assumed to be distributed uniformly across a given fishing area. Similarly, fishing effort by each gear type is assumed to be evenly applied across the fishing ground. Vessels of each harvesting technology target certain species, although there may be species overlap between two different harvesting technologies. For each period, the model keeps track of the effort applied by all vessel types toward each model species in terms of standardised fishing effort. Given this fishing effort, the total catch is determined using the catch-effort-stock relationship. For lack of better information and analytical simplicity, spatial (e.g., migration) and age structure aspects of fishery are ignored.

The model captures the dynamic nature of fishery through an inter-temporal stock growth equation. This equation balances the stock in each period to the previous period's stock plus net growth minus harvest. This gives the model the ability to track the impacts that the current fishing effort (technology and capital) has on future sustainability of fish stock. We can also impose a separate sustainability constraint that requires that each year's stock be more than or equal to the last year's stock. Through such constraint, one can analyse the trade-off between biological sustainability and social welfare impacts on fishing community.

Suppose that a public decision-maker attempts to maximise the following objective function:

$$\text{Max } Z = \sum_t \left(-\sum_v c_v E_{vt} + \sum_i p_i CT_{it} \right) \qquad (4.1)$$

where Z is the value of the objective function; E_{vt} is the level of effort spent by vessel type *v* (actual fishing hour) in year *t*, CT_{it} is the quantity of species *i* caught (tonnes) in year t, c_v is the average cost of fishing by vessel type *v* (Rs/actual fishing hour), p_i is the market price of species *i* (Rs/tonne). The objective function is the sum total of annual revenues generated from all fish species *minus* the annual costs of harvesting.

The objective function is maximised subject to the following constraints (4.2) to (4.9) (Onal *et al.*, 1991). The total annual harvesting effort for each vessel type *v* and year *t* is constrained by available fleet capacity, $efmx_{vt}$. This capacity could vary over time.

$$E_{vt} \le efmx_{vt} \qquad \text{for all } v \text{ and } t \qquad (4.2)$$

No fishery management agency would perhaps want to eliminate the entire fleet of an existing vessel technology at once. Therefore, a set of constraints that requires that fishery industry employ a minimum level of effort ($efmn_{vt}$) for each vessel class is included.

$$E_{vt} \ge efmn_{vt} \qquad \text{for all } v \text{ and t} \qquad (4.3)$$

The total catch of each given species is a result of efforts expended by multiple vessel types. In order to find the total effort directed toward a given species, we follow a two-stage computational process. In the first stage, we compute the constant proportion (d_{vi}) of total annual effort of vessel type *v* directed toward a given species *i*. This constant proportion can be derived by computing the ratio of the individual species catch of a given vessel type *v* to its total catch. Here we assume that the species distribution of effort of a given vessel is proportional to the species distribution of catch. The product $(d_{vi}E_{vt})$ is the effort of each vessel type directed toward a given species. We must note that the efforts of different vessel types are technologically different. Therefore, in the second stage, before we aggregate them in order to estimate the *total* effort toward a given species (TE_{it}), we need to convert the species-specific, individual vessel efforts to standardised efforts. A standardisation parameter s_v is computed by taking the ratio of the catch-per-unit effort (CPUE) of each vessel to that of the vessel class that has the highest CPUE. Thus, s_v for the vessel with highest CPUE is one and, for the rest of the vessel type, is less than one. Based on the above computations, added is the following set of constraints that sums up efforts exercised by all vessel types directed toward a species.

$$\sum_{v} s_v d_{vi} E_{vt} - TE_{it} = 0 \qquad \text{for all } i \text{ and } t \qquad (4.4)$$

The next set of constraints represents the standard non-linear catch-effort-stock relationship associated with every species and time period.

$$CT_{it} = \mu_i \, TE_{it} \, ST_{it} \qquad \mu_i > 0 \text{ for all } i \text{ and } t \qquad (4.5)$$

where CT_{it} is the quantity of fish species *i* caught during month *t*, ST_{it} is the natural stock of fish species *i* during period *t*, and μ_i is the constant parameter of the function. Specifically, μ_i is referred to as catchability coefficient, which represents the proportion of stock caught through a unit fishing effort. The above formulation is based on the Schaefer's (1954) assumption that the catch per unit effort or CPUE is a constant proportion μ_i of the stock. Onal *et al*. (1991) used a production function with constant return to scale of the type, $CT_{it} = \mu_i \, TE_{it}^{\delta} \, ST_{it}^{1-\delta}$. As they point out there is no empirical justification for either functional form. Therefore, we use the more conventional formulation of the type (4.5) for this study.

The next constraint set balances the fish stock in the next period to the current period stock *plus* current period net recruitment *less* current period catch. Factors such as age structure, size, spatial location, and migration are ignored in this study for lack of better information and model simplicity.

$$ST_{it+1} = \left(1 + (\varphi_i - \eta_i ST_{it})\right) ST_{it} - CT_{it} \qquad (4.6)$$

for all species *i* and year *t* except the initial period. The expression $(\varphi_i - \eta_i ST_{it})$ represents the density-dependent, annual rate of net growth of stock. φ_i and η_i are constant parameters. The initial year stock is exogenously set at user-defined levels ($inst_i$) for all species as

$$ST_{it} = inst_i \qquad (4.7)$$

The primary fishery production sector must operate within the constraints of post-harvest processing and storage sector. This constraint can be added to the model via the following equation:

$$\sum_i CT_{it} \leq stor_t \qquad \text{for each year } t \qquad (4.8)$$

Finally, the model must comply with usual non-negativity constraints:

$$CT_{it}, E_{vt}, TE_{it}, ST_{it} \geq 0 \qquad (4.9)$$

Data Analysis

The multi-species optimisation model is simulated for the Mangalore port. The Mangalore port is the largest fishing port in Karnataka, constituting 35 percent of the state's total fish landing in 1998. Seventeen most important species, which contributed more than 1.5 percent of the total port landing during 1994 to 1998, are included in the model. Based on the 1998 reported catch, these 17 species constituted more than 85 percent of the total fish catch in Mangalore (Table 4.1). The top five species harvested in 1998, in the order of their weight, are breams, Indian mackerel, stolephorus, sardine and cephalopods. For the same period, more than 10 different types of fishing vessel technologies are reported to have been employed. For the purpose of this study, these vessel classes are regrouped into five homogenous vessel classes: mechanised trawlers nets (MTN), purse seiners (PS), trawler nets (TN), out-board fishing nets (OBU), and non-motorised boats (NMB).

The model requires three types of data: (a) economic data consisting of market prices, fishing costs, storage capacity, and labour requirement; (b) technological data including vessel-to-species effort conversion parameters, effort standardisation parameters, catchability co-efficient, and annual available fishing capacity; and (c) biological data that include initial period stock estimates and growth parameters.

Market price data for the selected species are collected from the field observations (Table 4.1). The costs per actual fishing hour (AFH) are computed using data from a primary survey of different fishing firms. The method employed for computing the AFH costs for each fishing technology is explained in Chapter 3. The costs included are fixed cost (interests, insurance, maintenance, and depreciation), operational costs (cost of fuel, ice, auction marketing, labour and port charges) and crew share. Based on this computation, the unit fishing of costs are estimated at in Rs/AFH 410, 919, 460, 70, and 100 for technology classes MTN, PS, TN, OBU and NMB respectively. However, these costs represent the efforts that landed all the reported species in the port. For certain individual vessel classes, particularly for OBU and NMB, the species included in the model represent a small portion of the vessel's total effort (Table 3.2). The unit costs are therefore prorated based on the proportion of the vessel's effort directed toward the model species. The prorated unit costs of fishing are in Rs/AFH 368.63, 824.42, 395.96, 37.50 and 60.02, respectively (Table 4.2).

Table 4.3 presents the parameters that convert a unit effort of each vessel type to effort directed toward model species (d_{vi}). These parameters are computed by taking the ratio of the five-year total of individual species catch (1994-98) to the total catch reported for the same period for that vessel class. Also reported in the table is the effort standardisation parameter (s_v) that converts effort by each vessel class to a standard unit of effort. These standardisation parameters are derived by computing the ratio of the CPUE of each technology class to that of purse seiner vessel, which has the highest CPUE.

The catchability coefficients for most model species of Mangalore port are assumed to be the same as the estimates developed for the Karnataka state in the previous chapter. For certain model species, state-level estimates are not available. The catchability coefficients of most closely related species are used for such species. See Table 4.4 presents the estimates of these coefficients. The annual capacities of fishing vessels in AFH are assumed at the 1998 levels, which are reported in Table 3.4

The initial year exogenous stock levels are computed using the Fox model (equation 3.1). For using the Fox model, the 1998 levels of standardised effort are first computed for each model species of Mangalore port. These standardised effort values along with the estimates of catchability co-efficient (Table 4.4) and the observed quantities of species catch (Table 4.1) are plugged into the Fox model equation to estimate the initial year stocks (see Table 4.4). However, when we run the baseline simulation model, to be discussed later, our goal is to make sure that the model-generated catch values come as close to matching the observed catch values for the year 1998. Of the four variables above, catchability co-efficients are estimated using the state-level data of 10 years, which we think are more reliable than the initial year stocks estimates for Mangalore. The 1998 observed catch and effort values are certainly more accurate than the unobserved stock estimates. Therefore, for the purpose of this analysis, we calibrate the initial exogenous stock values so that the baseline model generates species catch distribution as close to the 1998 observed catch distribution as possible.

The data on the intercept and slope parameters of the annual net growth function (φ_i and η_i) are not easily available. Therefore, for lack of better information, these parameters are based on our best educated guess. The values are reported in Table 4.4.

The mathematical programming model is solved using the Generalised Algebraic Modelling System (GAMS) software (Brooke *et al*., 1998). This software has a routine for solving non-linear programming models. The model is run for a period of

10 years with annual increment. The baseline model has a total of 663 equations (belonging to 11 separate blocks of equations), 563 variables, and 2362 non-zero elements. The model could be run easily on a Pentium PC computer. Various sensitivity analyses also are carried out to evaluate various management and policy scenarios. See Appendix I for the GAMS program code for the model simulations.

Results and Discussion

Baseline Model and Validation

Before a model can be used for any meaningful policy and management analyses, the model results must first to be validated with reference to some historical or observed outcomes that the model is trying to predict. In an optimisation model like the current one, validation cannot be done by simply comparing the model-estimated values with some historical values since the model optimises effort and catch (Onal *et al.*, 1991). The reason is that the observed values may not be optimal to begin with. Alternatively, we force the endogenous effort levels for all the model years to be equal to the observed effort level of 1998 (Table 4.1). Then we compare the 1998 model catch values and the observed catch values. We call this the baseline simulation. This effort restriction on the model also allows us to understand how harvesting at the current effort level would impact the sustainability of the fishery stock and catch.

Table 4.5 and 4.6 present the results of the baseline simulation. Comparison of the 1998 observed catch and the model-estimated catch is made in Table 4.5. For most species, the differences between the model and observed levels of 1998 catch are within 11 percent. For ribbonfish and stomatopods, the difference is around 18 percent of the observed level. For black pomfret, there is a wide relative gap between the two values. There was a wide year-to-year fluctuation in the pomfret catch during 1994 to 1998. Also, this is one of the least significant model species in recent years. There may be errors in the specification of the unobservable biological parameters, and errors in collecting the third party data on catch and effort. Given these factors, we consider the model's overall performance quite satisfactory.

In the baseline simulation, the stocks of 9 out of 17 model species decline over time. These are Indian mackerel, rock cods, bream, ribbonfish, other carangids, black pomfret, prawns, stomatopods, and cephalopods. Stocks of six species viz, sardine, stolephorus, thryssa, other perches, and soles--increase. Stocks of two other species viz, other sardines and scads remain stable. The most interesting results to watch is mackerel. This species would become most unsustainable in terms of both stock and catch in 10 years if the exploitation continues at the current effort intensity. Mackerel, which is only second to breams in catch with 5,246 tonnes in 1998, experiences more than 40 percent reduction in catch. Similarly, other species that suffer drastic decline in stock and catch are prawns, stomatopods, and cephalopods.

The baseline harvesting results in total market revenue over 10 year period of little over Rs.4,929 million, whereas the total cost of harvesting is as high as Rs.4,844 million. That leaves a net fishery rent of only Rs.84 million or 1.7 percent of the total market revenue. Relative to the total market revenue, the rent margin under current harvesting scenario is insignificant. The crew-members salary is estimated at Rs.1,391 million or 28.23 percent. Since the declining species are mostly caught by trawlers, both mechanised and multi-day, the trawler industry would more likely be affected by this decline. Concurrently, the employees of this industry would be adversely affected too.

Optimal Fishery Harvesting

Our next goal is to run the model to characterise the optimal combination of vessel efforts. We run the simulation again without forcing endogenous effort values on the model like in the baseline run. Only restriction we would put is the minimum and maximum constraint on the effort. Minimum effort constraint is included to reflect the political reality that no single vessel class could be completely eliminated from the fishery. The maximum constraint is necessary to avoid the model to become unbounded. Also, there are real-world capital constraints on the limits to which fishery capital can expand in a given time period. The maximum fishing efforts are assumed to be 25 percent above the 1998 observed level for all vessel classes except NMB. For the latter, the effort restriction is placed at twice the current level. The minimum efforts are assumed at 50 percent of the current level.

The results of the optimal harvesting simulation are presented in Table 4.7, 4.8 and 4.9. While there is still some degree of over fishing in some cases, the stocks of all but four species either increase or remain stable. Indian mackerel, black pomfret, stomatopods, and cephalopods still experience a decline in the stocks. However, the rates of this decline, particularly for stomatopods, and cephalopods, are much slower than that they experience under the baseline scenario. Interestingly enough, the rates of stock and catch decline for Indian mackerel remain the same as the rates under the baseline situation. This is because of the fact that under the optimal scenario, the number of fishing hours by PS, the effort of which are mostly dedicated mackerel, increases quite substantially. This increase in PS effort is offset by any reduction in the effort by other vessel classes, for instance, OBU.

Another interesting finding is that the optimal model results show that there is almost no change in the total value of harvest (Rs. 4,969 million) from that of the baseline simulation (Rs. 4,929 million). However, there is a substantial reduction in the cost of fishing from the baseline level of Rs. 4,844 million to the optimal level of Rs. 3,155 million, resulting in a profit of Rs. 1,814 million or 36.50 percent of the total market value (Table 4.10). This is due to both biological and economic reasons. Biologically, more number of species become either sustainable, stable or less unsustainable over the ten-year period under the optimal scenario. This certainly increases the total catch of certain species. Economically, the model allocates effort more toward high value species and high-productivity (or unit cost) vessel. This helps the fishing industry realise higher rent from fishery. Thus, the optimal effort distribution not only increases fishery rent but also increases the chance of several model species to become either sustainable or more sustainable.

Biological and Economic Changes in Fishery Stocks

It is insightful for fishery managers to carefully look at the long-term effects of certain harvesting regime—current (baseline) or optimal harvesting strategy—in terms of biological and economic value appreciation of fish stocks and their catches. Table 4.10 presents the changes in the stock and catches due to the continuation of the baseline effort (1998 level). Seven species, which are commercially most important, such as stomatopods, Cephalopods shrimp, mackerel, ribbonfish and carangids experience depreciation in stock and catch by the year 2007. Some of the important export oriented species such as stomatopods and Cephalopods undergo loss in stock to the extent of 100 percent, followed by shrimp (78 percent), ribbonfish (68 percent) and mackerel (42 percent). The estimated catch levels of these species also decrease by corresponding percentage in 2007.

The table 4.11 shows the improvements in the stock and catches with the adoption of the optimal harvesting strategy. Though, some of the species still undergo depreciation in stock and catch between the initial year and terminal year (i.e., year 2007), the rate of decrease is considerably less than that are experienced under the baseline model (table 4.10). The stock (catch) of commercially important species such as shrimps, which would depreciate to an extent of 78 (78) percent under the baseline model, decreases by only 5 (46) percent under the optimal model. The rate of decline of ribbonfish was only 5 percent in stock and 47 percent in catch under optimal model. Further, the stocks and catch levels of several other species have considerably improved showing a positive impact of the optimal harvest strategy.

The table 4.12 shows the year-to-year percentage change in the economic value of a few selected species under both baseline and optimal scenarios. The percentage addition in the economic value decreases in the course of the period up to 2007, indicating that under a long term scenario most of the species become less and less sustainable. However, a comparison between baseline and optimal model shows that the economic value addition for each species is much higher for many of the species under optimal model indicating better management compared to baseline situation. The threadfin breams, rock cods, lizardfishes, ribbon fish, soles, shrimps, stomatopods, cephalopod improve their sustainability considerably under optimal model. On the other hand mackerel and pomfrets undergo higher loss over the years under optimal model compared to baseline model. The shrimps, which would decrease at the rate of 11 percent under baseline model, changes its path and we can observe the improvement in its sustainability and percentage rate of change in its economic value become positive.

Analysis of Alternative Management Policies

The fishery management policies in India are broadly governed by the Indian Fisheries Act of 1897 and the marine fisheries (regulation) acts of the respective states which were enacted in the eighties. The Karnataka Marine Fisheries (Regulation) Act of 1986 provides for the regulation of fishing through seasonal closure of fishing operation by specified vessels, restriction of fishing in specified areas and control of indiscriminate fishing of brood stock and juveniles through regulating mesh size. For example in Karnataka, fishing by mechanised fishing vessels are prohibited from fishing during monsoon season for two to three months. However, most part of the Act has not been implemented due to the lack of information on the impact of such policy measures on different stakeholders. In this section, we calibrate our model to simulate the impacts of various fishery regulation policies such that the results of the simulation will help to shed light on how the unsustainable harvesting as seen in the baseline or optimal fishery simulations can be corrected. For the purpose of the analysis, we consider two policy scenarios:

Policy Scenario I: Under this scenario, we analyse the effects of placing restrictions on harvesting technology that reduces the harvesting capacity of purse seiners. Both under the baseline and optimal harvesting scenarios, this vessel type is found to promote an unsustainable harvesting of mackerel, one of the commercially important pelagic species. The technology restriction may be implemented by changing the mesh size of nets that are used on this vessel. This policy change represented in the model by reducing the effort standardisation parameter for purse seiners from the baseline level of 1.0 to 0.7.

Policy Scenario II: For this scenario, a seasonal restriction of two months on all mechanised vessels such as purse seiners, trawlers and outboard fishing nets is considered. This policy allows stocks to rejuvenate during the spawning season and directly impacts the total annual effort expended by fishers. Moratorium on harvesting is most common under the Karnataka laws. Therefore, maximum effort constraints are reduced by 2/12 of the baseline levels for the above vessel types.

Table 4.13 and 4.14 presents the estimated values of stocks of selected species, gross returns, total cost, net profits and wage payments under policy scenario I and II. The initial stock (actual stock in 1998) presented in the table allows comparison of the effectiveness of each of the policy options in enhancing stock levels and also economic costs and returns. It is clear that the two policy options have different impacts on individual species. For most of the species both scenarios will result in much higher stock levels through the year 2007 than the optimal harvesting scenario discussed earlier, except in the case of species such as stomatopods and cephalopods. It is interesting to note that under the optimal harvesting plan, there is a decrease in the mackerel stock to all most half of the initial stock. However, each of the policy scenario discussed here shows an improvement of the stock. The stock of the oil sardines and stolephrous also improves under both the scenarios.

It could be observed from the table that some of the species which, are unsustainable under optimal harvesting scenario (Table 4.12) such as prawns, pomfrets and scads becomes sustainable under each of the policy scenarios discussed. The sustainability of prawns, which is one of the most highly targeted species by the trawlers, improves under Scenario II and I. The stock level of scads, which was reduced under optimal harvesting strategy to 10613 tons from the initial stock of 13000 tonnes increases to 14799 tonnes under Scenario I and to 12843 under Scenario II respectively.

As expected, the economic returns accruing to fishermen and payment to labour are slightly lowered under the subject scenarios. The gross returns diminished from Rs. 4.97 billion under the optimal harvest level to 4.21 billion and 4.56 billion under Scenario I and Scenario II, respectively. Similar trend can be observed with respect to labour payment. The total cost of harvesting also slightly decreases from Rs. 3.16 billion under optimal harvest levels to 2.93 billion in Scenario II due in most part to reduced fishing effort for two months.

All though two-month moratorium on fishing effort (scenario II) improved long-term stock levels of most species considerably, the major species of the Mangalore port such as Indian mackerel experiences a setback in stocks by the end of the simulation period by as much as 25 percent. High value species like cephalopods and stomatopods also lose their stock level significantly. It is clear that the current policy of seasonal restriction of two months is not fully potent in stemming the unsustainability of problem of at least some major species.

Conclusion

The results of the single species model estimated the sustainable yield and maximum economic yield without considering interactions between stocks, species, gears, labour, processing and marketing factors. On the other hand, multi-species model presented in this section incorporated the dynamic nature of the fishery and multi-gear technology interaction into a management plan in order to assess biological and economic sustainability. We conducted several simulations of the model. In the baseline model the endogenous effort level was forced on all the future ten years based on the observed effort level of 1998. This effort restriction enables us to understand the future sustainability of catch and stock given the current effort level. The result of the baseline model shows that stocks of most of the model species are declining over the period. The mackerel, which is one of the most important pelagic species, clearly suffers unsustainability in the future catch and stock if the current effort level is continued.

The optimal simulation is developed without current level effort restrictions. The results of the optimal model reveals declining stock levels of selected model species such as mackerel, cephalopod, stomatopod. The estimated total revenue from both the models are almost same. But cost of harvesting from the baseline level to optimal level decreases by 54 percent and hence profitability increases by 21 percent. Thus by promoting the effort combination, the biological and economic sustainability can be improved.

The above results clearly support the view that the fishing industry in Mangalore spends a way too much effort and cost to realise their market income. Through optimal re-distribution of its effort, the same market value of fishery output can be obtained at almost 35 percent less cost (Table 4.10). For the optimal scenario, the amount of labour payment is estimated at Rs. 1,425 million, only a slight increase from the baseline estimate (Rs. 1,391 million). Since the wage payment is a fixed portion of the market value of catch, and the total revenue does not change much, this small increase in the wage is reasonable.

Table 4.1. Quantity of catch (tonnes) by Model species and fishing units for Mangalore port, 1998

Species	Mechanized trawl net	Purse seine	Trawl net	Out board fishing units	Non mechanized fishing units	Total catch	% of species to port total	Market price (Rs/kg)
Oil-sardine	6	1735	116	22		1879	3.77	10.43
Other-sardines	1	4125	21	4		4151	8.32	7.00
Stolephorus	66	3459	1011	1		4537	9.09	32.20
Thryssa	71	400	294	77		842	1.69	20.00
Lizard-fishes	31		1728			1759	3.52	5.00
Rock-cods	67		1168			1235	2.47	6.00
Breams	117		7328			7445	14.92	5.00
Other-perches	84	1	2299	5	2	2391	4.79	5.00
Ribbon fish	37	1	529	10		577	1.16	15.00
Scads	31	1706	372	2		2111	4.23	4.00
Other-carangids	148	1494	1259	30		2931	5.87	3.00
Black pomfret	6	41	114	4		165	0.33	53.53
Indian mackerel	84	4239	488	143		4954	9.93	17.83
Soles	689	56	133	6	1	885	1.77	5.59
Prawns	597	33	714	233		1577	3.16	53.49
Stomatopods	1339		207			1546	3.10	2.06
Cephalopods	108		3763			3871	7.76	32.20
Port Total	3923	19377	25129	1467	5	49901	**85.88**	10.43
Effort (Actual Fishing Hours)	133932	113866	836371	204990	1908	1291067		
CPUE (kg/AFH)	29	**170**	30	7	3			

Table 4.2 Labour requirement and cost of fishing by vessel class in Mangalore Port

Vessel type	Actual cost of fishing (Rs / AFH)	Percent of effort spent on model species (1994-98 total)	Prorated cost of fishing (Rs/AFH)	Labour requirement (No. of people / AFH)
Mechanized Trawl Net	409.97	89.92	368.63	0.6110
Purse Seine	919.02	91.88	844.42	2.2341
Trawl Net	460.02	86.07	395.96	0.0897
Out-board fishing units	69.53	53.93	37.50	0.2184
Non-mechanized fishing units	100.04	60.00	60.02	1.1368

Table 4.3. Vessel to species effort conversion and vessel effort standardization parameters

Species	Multi-day trawl net	Purse seine	Trawl net	Out board fishing units	Non mechanized fishing units
Oil-sardine	0.0022	0.0646	0.0011	0.0059	0.0000
Other-sardines	0.0008	0.1358	0.0030	0.0367	0.0000
Stolephorus	0.0084	0.2308	0.0536	0.0235	0.0000
Thryssa	0.0134	0.0224	0.0145	0.0122	0.0000
Lizard-fishes	0.0142	0.0005	0.0492	0.0000	0.0000
Rock-cods	0.0263	0.0001	0.0350	0.0000	0.0000
Breams	0.0931	0.0000	0.1438	0.0000	0.0000
Other-perches	0.0178	0.0006	0.0594	0.0014	0.4000
Ribbon fish	0.0359	0.0000	0.0467	0.0056	0.0000
Scads	0.0041	0.1112	0.0243	0.0402	0.0000
Other-carangids	0.0386	0.0464	0.0523	0.0324	0.0000
Black pomfret	0.0026	0.0419	0.0078	0.0126	0.0000
Indian mackerel	0.0121	0.2577	0.0255	0.3308	0.0000
Soles	0.2255	0.0015	0.0395	0.0010	0.2000
Prawns	0.1023	0.0048	0.0472	0.0370	0.0000
Stomatopods	0.2635	0.0005	0.1215	0.0000	0.0000
Cephalopods	0.0384	0.0002	0.1364	0.0000	0.0000
Standardization parameter	0.1721	**1**	0.1766	0.0421	0.0154

Table 4.4. Estimates of catchability coefficients

Species	Catchability coefficient	Initial year estimated stock (tonnes)	Growth function parameters	
			Intercept	Slope
Oil-sardine	0.000001176	185,603	0.1084	0.000000452
Other-sardines	0.000001176	195,000	0.1084	0.000000452
Stolephorus	0.000001383	102,000	0.2098	0.000000871
Thryssa	0.000001383	123,456	0.2000	0.000001045
Lizard-fishes	0.000007557	28,000	0.2128	0.000003472
Rock-cods	0.000039280	4,979	0.3026	0.000030203
Breams	0.000007598	40,000	0.2528	0.000003356
Other-perches	0.000007598	32,000	0.3050	0.000005909
Ribbon fish	0.000035071	2,500	0.1720	0.000012350
Scads	0.000009735	13,000	0.2038	0.000004412
Other-carangids	0.000009735	20,000	0.2038	0.000004410
Black pomfret	0.000019528	3,194	0.1212	0.000010820
Indian mackerel	0.000005709	25,356	0.2500	0.000005400
Soles	0.000013595	5,200	0.2678	0.000006998
Prawns	0.000040622	3,800	0.3007	0.000021959
Stomatopods	0.000025622	3,200	0.2405	0.000001757
Cephalopods	0.000035071	5,900	0.2389	0.000012106

Table 4.5 Baseline model solution of species stock (tonnes)

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Oil-sardine	185,603	188,553	191,300	193,850	196,212	198,394	200,405	202,256	203,955	205,512
Other-sardines	195,000	195,297	195,569	195,817	196,043	196,250	196,439	196,611	196,768	196,912
Stolephorus	102,000	109,952	117,763	125,329	132,556	139,367	145,701	151,521	156,805	161,553
Thryssa	123,456	131,424	138,818	145,560	151,609	156,955	161,618	165,635	169,060	171,953
Lizard-fishes	28,000	29,619	31,166	32,626	33,989	35,249	36,401	37,445	38,383	39,220
Rock-cods	4,979	4,605	4,312	4,075	3,881	3,718	3,581	3,463	3,362	3,274
Breams	40,000	37,630	35,699	34,100	32,755	31,611	30,629	29,778	29,036	28,385
Other-perches	32,000	33,453	34,685	35,710	36,548	37,226	37,766	38,194	38,531	38,793
Ribbonfish	2,500	2,171	1,895	1,660	1,459	1,286	1,136	1,006	892	793
Scads	13,000	12,792	12,599	12,419	12,252	12,096	11,951	11,815	11,687	11,568
Other - carangids	20,000	19,552	19,153	18,795	18,474	18,185	17,923	17,686	17,470	17,274
Pomfret	3,194	3,133	3,076	3,022	2,970	2,921	2,874	2,829	2,787	2,746
Indian - mackerel	25,356	22,978	21,118	19,620	18,387	17,355	16,477	15,721	15,065	14,489
Soles	5,200	5,610	6,037	6,478	6,931	7,394	7,864	8,338	8,813	9,286
Prawns	3,800	3,052	2,501	2,080	1,749	1,484	1,267	1,088	939	813
Stomatopods	3,200	2,129	1,421	950	636	426	285	191	128	86
Cephalopods	5,900	3,143	1,780	1,037	614	366	220	132	80	48

Table 4.6 Baseline model solution of species catch (tonnes)

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Oil-sardine	1,664	1,690	1,715	1,738	1,759	1,778	1,796	1,813	1,828	1,842
Other-sardines	3,726	3,731	3,736	3,741	3,746	3,749	3,753	3,756	3,759	3,762
Stolephorus	4,398	4,741	5,078	5,404	5,716	6,009	6,282	6,533	6,761	6,966
Thryssa	872	928	980	1,028	1,071	1,108	1,141	1,170	1,194	1,214
Lizard-fishes	1,619	1,712	1,802	1,886	1,965	2,038	2,104	2,165	2,219	2,267
Rock-cods	1,132	1,047	980	926	882	845	814	787	764	744
Breams	7,106	6,685	6,342	6,058	5,819	5,616	5,442	5,290	5,159	5,043
Other-perches	2,255	2,357	2,444	2,516	2,576	2,623	2,661	2,692	2,715	2,734
Ribbonfish	681	592	516	452	398	350	310	274	243	216
Scads	2,112	2,078	2,047	2,018	1,991	1,965	1,942	1,920	1,899	1,880
Other-carangids	2,760	2,698	2,643	2,594	2,549	2,509	2,473	2,441	2,411	2,384
Pomfret	337	331	325	319	314	308	304	299	294	290
Indian-mackerel	5,246	4,754	4,369	4,059	3,804	3,590	3,409	3,252	3,116	2,997
Soles	793	855	921	988	1,057	1,128	1,199	1,271	1,344	1,416
Prawns	1,574	1,264	1,036	861	724	614	525	451	389	337
Stomatopods	1,823	1,213	809	541	362	242	162	109	73	49
Cephalopods	3,745	1,995	1,129	658	389	232	139	84	51	30

Table 4.7 Optimal model solution of species Stock (tonnes)

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Oil-sardine	185,603	188,180	190,575	192,795	194,849	196,744	198,490	200,095	201,569	202,911
Other-sardines	195,000	194,500	194,044	193,630	193,253	192,909	192,595	192,309	192,049	191,758
Stolephorus	102,000	109,732	117,312	124,642	131,635	138,219	144,341	149,965	155,075	159,637
Thryssa	123,456	131,534	139,035	145,879	152,022	157,452	162,187	166,266	169,742	172,659
Lizard-fishes	28,000	30,420	32,793	35,081	37,251	39,274	41,132	42,812	44,311	45,632
Rock-cods	4,979	5,169	5,338	5,484	5,610	5,718	5,809	5,886	5,950	6,003
Breams	40,000	41,183	42,237	43,168	43,985	44,697	45,313	45,844	46,299	46,689
Other-perches	32,000	34,567	36,816	38,722	40,291	41,549	42,538	43,302	43,884	44,320
Ribbonfish	2,500	2,512	2,524	2,535	2,546	2,557	2,568	2,578	2,588	2,595
Scads	13,000	12,646	12,322	12,023	11,748	11,493	11,256	11,037	10,832	10,613
Other-carangids	20,000	20,161	20,308	20,444	20,568	20,681	20,785	20,880	20,967	21,003
Pomfret	3,194	3,111	3,033	2,959	2,890	2,824	2,762	2,703	2,647	2,589
Indian-mackerel	25,356	22,415	20,171	18,396	16,954	15,756	14,746	13,880	13,130	12,314
Soles	5,200	5,998	6,884	7,859	8,918	10,054	11,255	12,504	13,783	15,068
Prawns	3,800	3,776	3,753	3,733	3,714	3,697	3,682	3,668	3,655	3,607
Stomatopods	3,200	3,037	2,883	2,737	2,600	2,470	2,347	2,231	2,121	2,017
Cephalopods	5,900	5,012	4,312	3,746	3,280	2,890	2,561	2,279	2,036	1,825

Table 4.8 Optimal model solution of species catch (tonnes)

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Oil-sardine	2,036	2,065	2,091	2,115	2,138	2,159	2,178	2,195	2,221	2,235
Other-sardines	4,523	4,512	4,501	4,491	4,483	4,475	4,467	4,461	4,508	4,502
Stolephorus	4,618	4,968	5,312	5,643	5,960	6,258	6,535	6,790	7,054	7,261
Thryssa	763	812	859	901	939	973	1,002	1,027	1,067	1,085
Lizard-fishes	818	889	958	1,025	1,089	1,148	1,202	1,251	1,295	1,334
Rock-cods	567	589	608	625	639	652	662	671	678	684
Breams	3,553	3,658	3,752	3,835	3,907	3,970	4,025	4,072	4,113	4,147
Other-perches	1,141	1,232	1,312	1,380	1,436	1,481	1,516	1,544	1,567	1,583
Ribbonfish	341	342	344	346	347	349	350	351	356	357
Scads	2,258	2,196	2,140	2,088	2,040	1,996	1,955	1,917	1,909	1,870
Other-carangids	2,151	2,169	2,185	2,199	2,213	2,225	2,236	2,246	2,298	2,302
Pomfret	360	351	342	333	326	318	311	305	302	296
Indian-mackerel	5,808	5,135	4,621	4,214	3,884	3,609	3,378	3,180	3,168	2,971
Soles	406	468	537	613	696	784	878	975	1,076	1,177
Prawns	850	845	840	835	831	827	824	820	853	842
Stomatopods	915	868	824	783	743	706	671	638	606	577
Cephalopods	1,876	1,594	1,371	1,191	1,043	919	814	725	647	580

Table 4.9 Comparison of Model performances between Actual, Baseline and Optimal Scenarios

Species	Actual 1998 catch (tonnes)	Baseline Model		Optimal Model	
		Catch (tonnes)	10 Year trend in stock	Catch (tonnes)	10 Year trend in stock
Oil-sardine	1879	1,664	Increasing	2,036	Increasing
Other-sardines	4151	3,726	Stable	4,523	Increasing
Stolephorus	4537	4,398	Increasing	4,618	Increasing
Thryssa	842	872	Increasing	763	Increasing
Lizard-fishes	1759	1,619	Increasing	818	Increasing
Rock-cods	1235	1,132	Decreasing	567	Increasing
Breams	7445	7,106	Decreasing	3,553	Increasing
Other-perches	2391	2,255	Increasing	1,141	Increasing
Ribbon fish	577	681	Decreasing	341	Stable
Scads	2111	2,112	Almost stable	2,258	Almost stable
Other-carangids	2931	2,760	Decreasing	2,151	Stable
Black pomfret	165	337	Decreasing	360	Decreasing
Indian mackerel	4954	5,246	Decreasing	5,808	Decreasing
Soles	885	793	Increasing	406	Increasing
Prawns	1577	1,574	Decreasing	850	Stable
Stomatopods	1546	1,823	Decreasing	915	Decreasing
Cephalopods	3871	3,745	Decreasing	1,876	Decreasing

Table 4.10 Comparison of cost and return in Baseline and Optimal Model

	Baseline Model		Optimal Model	
	In Rs.	Percentage share of gross revenue	In Rs.	Percentage share of gross revenue
Gross revenue	4,929,262,000		4,969,090,000	
Total harvesting cost	4,844,932,000	98.29	3,155,413,000	63.50
Net profit	84,329,890	1.71	1,813,676,000	36.49
Crewmen salary	1,391,638,000	28.23	1,425,652,000	28.69

Table 4.11 Changes in the stock and catches due to the continuation of the baseline effort

Species	Mangalore port							
	Stock (tones)		%change from 1998 to 2007	Rank	Catch (tones)		%change from 1998 to 2007	Rank
	1998	2007			1998	2007		
Oil-sardine	185,603	205,512	10.73	6	1,664	1842	10.73	6
Other-sardines	195,000	196,912	0.98	7	3,726	3762	0.98	7
Stolephorus	102,000	161,553	58.39	2	4,398	6966	58.39	2
Thryssa	123,456	171,953	39.28	4	872	1214	39.28	4
Lizard-fishes	28,000	39,220	40.07	3	1,619	2267	40.07	3
Rock-cods	4,979	3,274	-34.25	12	1,132	744	-34.25	12
Thread fin Breams	40,000	28,385	-29.04	11	7,106	5043	-29.04	11
Other-perches	32,000	38,793	21.23	5	2,255	2734	21.23	5
Ribbon fish	2,500	793	-68.29	14	681	216	-68.29	14
Scads	13,000	11,568	-11.02	8	2,112	1880	-11.02	8
Other-crngids	20,000	17,274	-13.63	9	2,760	2384	-13.63	9
Black pomfret	3,194	2,746	-14.01	10	337	290	-14.01	10
Indian -Mackerel	25,356	14,489	-42.86	13	5,246	2997	-42.86	13
Soles	5,200	9,286	79	1	793	1416	78.57	1
Shrimp	3,800	813	-78.6	15	1,574	337	-78.6	15
Stomatopods	3,200	86	-97.31	16	1,823	49	-97.31	16
Cephalopods	5,900	48	-99.19	17	3,745	30	-99.19	17

Table 4.12 Year-to-year Variation in the Economic Value of Catches for Selected Species (In Percent)

Year	Oil-Sardine		Stolephorus		Indian - Mackerel		Thryssa	
	Baseline	Optimal	Baseline	Optimal	Baseline	Optimal	Baseline	Optimal
1998[1]	173.51	212.37	1416.09	1486.97	935.41	1035.76	70.53	61.69
1999	1.59	1.39	7.80	7.58	-9.38	-11.60	6.45	6.54
2000	1.46	1.27	7.10	6.91	-8.10	-10.01	5.63	5.70
2001	1.33	1.16	6.42	6.25	-7.09	-8.80	4.86	4.92
2002	1.22	1.07	5.77	5.61	-6.28	-7.84	4.16	4.21
2003	1.11	0.97	5.14	5.00	-5.62	-7.06	3.53	3.57
2004	1.01	0.89	4.55	4.43	-5.06	-6.42	2.97	3.01
2005	0.92	0.81	3.99	3.90	-4.58	-5.87	2.49	2.51
2006	0.84	1.15	3.49	3.89	-4.18	-0.36	2.07	3.89
2007	0.76	0.67	3.03	2.94	-3.82	-6.22	1.71	1.72

contd…

Year	Ribbonfish		Scads		Soles	
	Baseline	Optimal	Baseline	Optimal	Baseline	Optimal
1998[1]	63.56	31.78	84.49	90.32	44.34	22.68
1999	-13.14	0.48	-1.60	-2.72	7.89	15.34
2000	-12.74	0.47	-1.51	-2.57	7.60	14.78
2001	-12.40	0.45	-1.42	-2.42	7.31	14.16
2002	-12.11	0.44	-1.35	-2.29	7.00	13.48
2003	-11.86	0.43	-1.27	-2.17	6.68	12.74
2004	-11.65	0.41	-1.20	-2.06	6.36	11.94
2005	-11.46	0.40	-1.14	-1.95	6.03	11.10
2006	-11.30	1.32	-1.08	-0.43	5.69	10.35
2007	-11.16	0.25	-1.02	-2.02	5.36	9.32

[1] Cell values are in Rs. Lakhs

contd…

Year	Lizard fish		Rock cods		Threadfin breams	
	Baseline	Optimal	Baseline	Optimal	Baseline	Optimal
1998[1]	80.93	40.92	67.90	34.05	355.32	177.66
1999	5.78	8.64	-7.50	3.83	-5.93	2.96
2000	5.22	7.80	-6.38	3.25	-5.13	2.56
2001	4.68	6.98	-5.49	2.74	-4.48	2.21
2002	4.18	6.18	-4.77	2.30	-3.94	1.89
2003	3.71	5.43	-4.19	1.92	-3.49	1.62
2004	3.27	4.73	-3.70	1.59	-3.11	1.38
2005	2.87	4.08	-3.28	1.32	-2.78	1.17
2006	2.51	3.50	-2.93	1.09	-2.49	0.99
2007	2.18	2.98	-2.62	0.89	-2.24	0.84

contd…

Year	Shrimp		Stomatopods		Cephalopods		Pomfret	
	Baseline	Optimal	Baseline	Optimal	Baseline	Optimal	Baseline	Optimal
1998[1]	841.68	454.69	37.61	18.88	1205.67	603.97	180.56	192.64
1999	-19.68	-0.64	-33.47	-5.10	-46.72	-15.05	-1.90	-2.60
2000	-18.04	-0.59	-33.28	-5.07	-43.38	-13.97	-1.83	-2.51
2001	-16.83	-0.54	-33.15	-5.04	-41.73	-13.13	-1.77	-2.43
2002	-15.91	-0.50	-33.07	-5.02	-40.83	-12.44	-1.71	-2.35
2003	-15.18	-0.46	-33.02	-4.99	-40.32	-11.88	-1.65	-2.27
2004	-14.60	-0.42	-32.98	-4.97	-40.02	-11.40	-1.60	-2.20
2005	-14.12	-0.39	-32.95	-4.95	-39.84	-11.00	-1.55	-2.14
2006	-13.73	3.97	-32.94	-4.93	-39.74	-10.66	-1.50	-0.69
2007	-13.40	-1.30	-32.93	-4.91	-39.67	-10.37	-1.46	-2.17

[1] Cell values are in Rs. Lakhs

Table 4.13 Impact of alternative policy scenarios on stocks

Species	Initial Year (1998) Actual Stock (In tonnes)	Fish Stocks in the Final year, 2007		
		Optimal Harvesting Simulation	Policy Scenario I	Policy Scenario II
Oil-sardine	185603	202911	207103	205256
Other-sardines	195000	191758	200263	196517
Stolephorus	102000	159637	170118	165474
Thryssa	123456	172659	173728	173266
Lizard-fishes	28000	45632	45670	45653
Rock-cods	4979	6003	6008	6006
Threadfin breams	40000	46689	46689	46689
Other-perches	32000	44323	44353	44341
Ribbonfish	2500	2595	2591	2595
Scads	13000	10613	14799	12843
Other-carangids	20000	21003	23617	22465
Black pomfret	3194	2589	3283	2964
Indian -mackerel	25356	12314	18287	15566
Soles	5200	15070	15149	15115
Prawns	3800	3607	3776	3720
Stomatopods	3200	2017	2027	2023
Cephalopods	5900	1825	1830	1828

Table 4.14 Impact of alternative policy scenarios on economic returns

	Optimal Harvesting	Policy Scenario I	Policy Scenario II
Gross Return	4,969,042,000	4,211,925,000	4,557,032,000
Total Cost	3,155,127,000	3,168,920,000	2,953,211,000
Net Return	1,813,915,000	1,051,032,000	1,603,822,000
Wage Payment	1,425,610,000	1,244,500,000	1,302,095,000

5. Conclusions and Recommendations

The marine fisheries of Karnataka are one of the major sectors contributing significantly to the income and employment of the regional economy. Over a period of 30 years the industry has undergone technological change and has moved from the subsistence to commercial status. This modernization has resulted in the growing signs of unsustainability. The negative growth rate in marine fish production during 1990s showed the symptoms of over harvesting. The state government though passed marine fisheries regulations to impose limited entry into fishery, it could not implement the provisions of the act due to possible socio-economic impact of such a measure. The present study is an attempt to study the biological and economic sustainability of the Karnataka marine fishery under alternative scenarios. Some of the important conclusions of the study are presented.

1. The increase in fishing effort during 1970s and 1980s has led at first to rapid increase of commercial landings, which grew at the rate of 2.6 % and 5.95% until early 1990s. During 1990s there was a negative growth of total production. Legal framework to control the fishing efforts was not enforced for socio-economic reasons.
2. In order to study the biological and economic sustainability of the Karnataka fishery, to help fishery management authority to limit the effort level single species model was constructed. The results of single species model, shows that most of the species are harvested at very close to maximum sustainable yield levels and above the maximum economic yield.
3. Multi-species mathematical programming model implemented for representative Mangalore port estimates the response of stock and catch levels under various scenarios. The objective function was to maximize the net benefits from a fishery given a set of constraints. The results of baseline simulation model with forcing of 1998 effort level on the next 10 years shows that the most of the model species are biologically and economically unsustainable. The policy simulation of effort restriction and seasonal moratorium indicate that these policies do help sustain some species, but fail

to protect most popular species like Indian mackerel and high value species like cephalopods and stomatopods.

Recommendations

As shown by the results, we cannot expect to get increased catches by simply increasing fishing effort. On the other hand, we can improve the sustainability by changing exploitation pattern. At present the fisheries exploitation is based on fishing through trawlers of different types. However, by encouraging some the fishing techniques such as purse seining and administering the proper mesh size the efficiency of harvesting can be achieved. It is possible to achieve important economic and biological benefits by proper re-allocation of fishing effort and keeping fishing cost at their minimal level.

Further, rebuilding of stocks through increased mesh size, closing areas and seasons for fishing at least for destructive fishing the sustainability can be improved.

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Annexure I

Description of species-by-species

Table 1 Classification of the selected species

Demersal species	**Pelagic species**
Halibuts	Tunnies
Threadfin breams	Seer Fish
Rock cods	Scads
Cat fish	Horse Mackerel
Rays	Wolf herring
Pomfret	Stolephorus
Soles	Indian mackerel
Shrimp (paneied prawns)	Oil sardine
Shark	Hilsa Shad
Lizard fish	

Indian Oil –sardine

Oil sardine is the most important resource in the neritic pelagic zone off the west coast of India. The coastal areas between Kerala and the Karnataka are rich in traditional fishing grounds for the Oil-sardine, although in certain years its commercial abundance extends to other sections of the west and east coast. The annual average catch of Oil-sardine for 1994 was 1,01,677 tonnes forming 3.76% of the total marine fish catch of India and 2,03,909 tonnes forming 7.6% of the total marine fish catch of India (26,69,480 tonnes) in 1998. During the year 1999 the oil sardine received a higher landing. The landings increased from 2,03,909 tonnes in 1998 to 2,40,978 tonnes in 1999, an increase of 18.18 percent. The oil-sardine ranks as one of the best-known commercially important fish of India and is commonly used as food in the fresh and cured conditions.

Oil sardines are mainly caught with two types of nets - the boat seine and gillnet. In Karnataka, rampani was the major gear of exploitation before the introduction of purse seiners. During the mid seventies, purse seiners replaced the traditional gears like rampan, which helped in increasing the oil- sardine landings.

Indian Mackerel

The mackerel is a pelagic fish in neritic waters and its oceanic phase is little known except that it is caught in deeper waters by fishing trawlers occasionally. It is a shoaling fish, not moving singly or in small schools of a few members but in appreciably large numbers spreading over a wide area and moving steadily in one direction.

Indigenous crafts and gears employing traditional methods mostly exploit the mackerel, but the introduction of the mechanized boats has greatly affected the catch rates of traditional small-scale gears. The basic types of gears viz., boat seine, drag nets or beach seine, gill nets of several types including drift nets and the cast nets and types of craft viz, dugout canoes, canoe boats, plank-built boats and catamarans are employed for the capture of mackerel in different states along the west and east coasts. Among the mechanized boats the purse seines followed by trawel nets harvest more than 80% of the mackerel.

The annual average catch of mackerel for 1993 was 2,49,186 tonnes forming 11.10% of the total marine fish catch (2,245,124 tonnes) of India and in 1998 it was found to be 1,77,172 tonnes forming 6.64% of the total marine fish landings (26,69,480), as reported by CMFRI. The landings increased from 1,77,172 tonnes in 1998 to 2,09,741 tonnes in 1999, an increase of 18.38 percent.

Anchovies

Most Anchovies are marine, but some can tolerate low salinities or even fresh water. Although usually small, many are shoaling species of great importance to fisheries; some are used for food, others for bait. During 1990, the reported catch for anchovies in India totaled about 110 tonnes.

It's a valuable marine fish as a source of food and fish meal and is also suitable for salting and sun drying as well as canning. In the years when both the sardines and the mackerels are scarce, the anchovies are in plenty in our waters. In India, they occur all along the east and west coasts. The Purse seine, and trawl nets are used for harvesting anchovies.

Stolephorus

Stolephorus is a pelagic marine fishes always with a distinct silvery lateral band. Purse seines and trawlers are use to harvest this species. These fishes are the most important among the anchovies. In 1990, the reported catch for stolephorus in India totaled about 70,741 tonnes. The landings decreased from 72,637 tonnes in 1998 to 49,543 tonnes in 1999, a decrease of 31.8 percent

Thryssa

This is a small-sized anchovy and good catches of this fish are obtained on the Andhra coast during February and from June to September. It also constitutes a fishery along the coasts of Kerala and Tamil Nadu from June to September. These are caught using seines and stake nuts. The landings decreased from 42,231 tonnes in 1998 to 31,547 tonnes in 1999, a decrease of 25.24 percent

Lizard fishes

The lizard fish do not form an important independent fishery but are caught in small quantities, forming a supporting fishery to the other major fisheries. They are normally considered in the category of demersal fishes.

These fish are relished as food in fresh as well as in dry condition by poor people. Most of the lizardfishes are inshore shallow-water forms, usually living on sandy or muddy bottom adjacent to rocky or reef areas.

Edible, but of poor quality. In India, they occur all along the west Pacific coast. The annual catch was 20,378 tonnes during 1994. The landings decreased from 24,115 tonnes in 1998 to 17,707 tonnes in 1999, a decrease of 26.6 percent. The types of nets used in the lizard fishery are gill net boat seine and purse seine. Lizard fishes are also caught in trawls operated up to 30 fathom depth.

Threadfin breams

These are small to moderate sized, slightly compressed fishes and inhabit shallow coastal waters of the tropical Indo-pacific; most brightly colored and geographically distributed around south-east coast of India, through the East

Indies, to the Philippines and Australia. The fishery is of minor significance on the Tamil Nadu coast. Trawl is the principal gear of exploitation. The landings decreased from 81,340 tonnes in 1998 to 73,994 tonnes in 1999, a decrease of 9 percent.

Ribbonfish

Ribbon –fishes are poor quality food fish and constitute one of the important commercial fisheries in India. The annual catch was 1,13,883 tonnes during 1998 forming 4.23% of the total landings. The landings increased from 113883 tonnes in 1998 to 124548 tonnes in 1999, an increase of 9.37 percent.

These fishes are caught almost all along the Indian coast and form an exclusive fishery of considerable magnitude at several places, especially in the southern peninsula region; the states of Andhra Pradesh, Tamil Nadu and Kerala account for the the grater percentage of annual catches. The usual gear for these fishes is the boat-seines.

Carangidae

This family contains some very important food fishes and plays a significant part in the commercial fisheries of our region. These fishes constitute a fairly high proportion of the catches both on the east and west coasts of India. The carangidae form an important demersal fishery resource along the Karnataka coast, accounting for 5.17% of the total marine landings (Govt. of Karnataka, 1997). The landings decreased from 147474 tonnes in 1998 to 126297 tonnes in 1999, a decrease of 14.36 percent.

Horse mackerel, scads and leather-jackets belong to the family of carangidae, white leather jacket belong to the family Aluteridae.

Pomfrets:

Pomfrets are excellent table fish, much relished and highly priced. In India they support important fisheries both along the west coast and the east coast regions. They are found on the continental shelf at all depths, generally up to 100 fathoms. Like many other groups of coastal fishes, pomfrets often enter the estuaries and brackish water zones. They occur widely in the Indo-west pacific. In the 22-year period (1958-79) pomfrets formed an average of 2.4 percent and in 1993 1.86 percent (i.e. 41,767 tonnes out of 22,45,124 tonnes of total landings) of the all India annual landings of marine fish.

More over, the landings decreased from 49364 tonnes in 1998 to 34009 tonnes in 1999, decrease of 31 percent.

They are harvested using multiple types of gear right from shore seine to deep-sea trawlers.

The Flat fishes:

Flatfishes are characterized by their doroso-ventrally compressed body with eyes sinistral or dextral. This group of fish, specialized in bottom dwelling/burrowing habits includes *halibuts, flounders, and soles.*

The soles, though they occur along both the coasts of India, constitute a fishery of considerable importance along the Malabar Coast, next to the oil-sardine, mackerel and prawn fisheries. They contain less fat and hence are suitable for quick drying and preservation.

Soles:

These include mostly small fishes found in all but the coldest seas, from the shore to fairly deep-waters. Many are of importance, highly esteemed as food.

Seer fish:

Seer fish fishery in India is supported by three commercially important species, Scomberomorus commerson, S. guttatus and S. lineolatus. Seer fish have white flesh with high fat content. Being highly esteemed fish, they have great demand in inland as well as foreign market. Besides, they are important, being available along both the coasts of India.

Diverse crafts gear are employed in the seer fish fishery. Both mechanized and non-mechanized boats are deployed along the Gujarat Maharashtra and

Karnataka coasts. Gill nets and hooks and lines are the principal gear used for seer fish. Besides, they are also caught in appreciable quantities in other types of gear used for different fishes.

Tunnies:

The tunas comprise a highly valued group of fish, the meat of which either in fresh or processed state is much in demand all over the world. They are tropical and subtropical in their distribution in the world oceans and their occurrence is by far greater in the oceanic waters beyond the territorial limits of the fishing nations than in the coastal waters. They are very much under fished from Indian coasts. Tuna fisheries are of international importance as these resources occur in all the world oceans. The tuna catches of India are mostly obtained from the inshore waters. Much of the tuna catch is consumed in fresh condition. It is transported chilled in ice or cold stored before marketing. Part of the catch is brine cured and sun-dried.

Cephalopods:

The cephalopods belong to the family of Molluscs, occurring in abundance in the shallow coastal waters of the seas, estuaries and brackish water habitats. Annual fluctuations in cephalopod landing in India are very marked. In the nine year period (1971-79) the lowest catch of cephalopods was 1026 m.t. in 1972 forming 0.104 percent of the total marine fish catches estimated at 980,049 m.t. and the highest was 15,931 m.t. in 1978 forming 1.14 percent of the total marine fish of 1,403.607 m.t. Kerala, Maharashtra and Tamil Nadu rank high in the order of abundance. Karnataka and Andhra Pradesh rank next with moderate catches. An export trade in what is known as the “squid fingers” is being built up. As an item of food some of the members of the same species after cephalopods are utilized as food items. In 1994 these formed 3.54 percent of total marine fish landings of 27,07,439 tonnes.

Catfishes:

Catfishes are scaleless bony fishes inhabiting marine, estuarine and freshwater habitats. They generally prefer muddy grounds. The commonly important catfishes are marine forms. The catfishes are landed by different types of seine nets and hooks and lines by indigenous non-mechanized craft and in trawl nets operated by powered fishing vessels. In 1994 they formed 3.2 percent of total annual Indian marine fish landings of 27,07,439 tonnes.

Elasmobranches (Shark, Rays and Skates):

Elasmobranches form one of the important commercial fisheries of India, in 1994 forming 3.1 percent of total annual Indian marine fish landings estimated at 2707439 tonnes. They widely distributed in the tropical, subtropical and temperate water of the seas around the world. Although they are essentially marine,. a few species enters the estuaries. A very large number of species of sharks, skates and rays occur in the Indian water supporting fisheries. They form an appreciable proportion in total annual marine fish landings of the country (3.2 to 6.5 percent in the past two decades). Some species yield quantities of liver oil of medicinal value because of their high vitamin A content. The skin of sharks suitably tanned can be used as leather. Elasmobranches are caught in types of gears operated by the mechanized and the non-mechanized crafts in coastal waters in fair abundance usually upto about 30 mt. depths.

The Ministry of Environments and Forests of the Government of India, considering the over harvesting of some of the rare species such as whale sharks included it in the Schedule I of the Wildlife Protection Act. The whale shark is the first species to get protection under the Act. After including the whale shark in the negative list, it is expected that the official exports are likely to come down. However, underground exports are likely to flourish unless the whale fishermen are properly rehabilitated.

Wolf-herrings:

These compose a single Indo-Pacific genus, Chirocentrus with two species as representatives. Wolf-herrings are voracious carnivores. Their contribution of about 8000 tonnes to India's annual total marine fish catch forms about 1 percent (1984).

Shrimps

The shrimps are of the most targeted species due to its high value in the international market. A major portion of the landings is exported in frozen from to US, Japan and European markets. The shrimps are mainly targeted by trawl nets. The production of shrimp increased from 188755 tons in 1985 to 242425 tons in 1993. However, thereafter the total shrimp production in India stagnated around 320023 tons until 2000. The large-scale trawl fishing caused the shrimp biomass to diminish dramatically in these regions. Reduction in the shrimp biomass could also be to changes in the sea conditions.

Hilsa (shads)

It has considerable economic importance in India and Pakistan, Bangladesh and Burma. The esteem to which the 'hilsa' is held in Bengal is reflected in the many references to its quality and flavor in Sanskrit and Bengali literature. This is one of the best known of Indian clupeids and is a migratory fish ascending all the major river systems, where it was caught in considerable quantities.

Lobsters

In addition to the recent demand for lonbsters from big catering organizations, the lobster market has come into prominence mainly because of the exports. The market is still expanding but the supply of Indian lobsters is not commensurate with the demand, as India has to face stiff competiton because of increasing demand for live lobsters. On the south-western coast of India the three types of gear in use are lobster traps, anchor hooks and scoop nets.

Lobster fishing with all these three gears is carried out at night. In the north, west Maharashtra and Gujarat coast fixed nets, traps and drag nets are the common gears used.

Annexure II

GAMS Program

Sustainable Harvesting of Multi-species in Karnataka Marine Fishery

This is a multi-period problem of estimating of environmentally and economically sustainable levels of harvesting multiple species of marine fisheries using multiple fishery technologies.

The project was funded by the World Bank and administered by IGIDR.

The programming software support was given by the GAMS Development Corporation, Washington, DC.

THIS PROGRAM SIMULATES 'BASELINE' and 'OPTIMAL HARVESTING' SCENARIOS

```
Sets
    i   species  /oil-sardine,
                  other-sardines,
                  stolephorus,
                  thryssa,
                  lizard-fishes,
                  rock-cods,
                  breams,
                  other-perches,
                  ribfish,
                  scads,
                  other-crngids,
                  blkpomfret,
                  ind-mackerel,
                  soles,
                  prawns,
                  stomatopods,
                  cephalopods           /

    j   vessels  /mdtraw, pseins, trawlr, oboard, nonmec    /

    t   years   /1998*2007                          /

    par growth parameters /intercept, slope/  ;

Parameters
```

```
     s(j)  parameter that converts vessel j's effort into a standard unit of effort

      /    mdtraw      0.17212
           pseins       1.00000
           trawlr      0.17656
           oboard       0.04205
           nonmec       0.01540       /

     catchco(i) catchability coeff - proportion of stock harvested with a unit effort
      /    oil-sardine        0.0000011764
           other-sardines     0.0000011764
           stolephorus        0.0000013831
           thryssa            0.0000013831
           lizard-fishes      0.0000075566
           rock-cods          0.0000392797
           breams             0.0000075985
           other-perches      0.0000075985
           ribfish            0.0000350713
           scads              0.0000097347
           other-crngids      0.0000097347
           blkpomfret         0.0000195277
           ind-mackerel       0.0000057086
           soles              0.0000135946
           prawns             0.0000406219
           stomatopods        0.0000256219
           cephalopods        0.0000350713   /

     labco (j)  per unit-effort labor requirement (employees per fishing hr)
      /    mdtraw        0.610981692
           pseins        2.234082167
           trawlr        0.089708993
           oboard        0.218391141
           nonmec        1.136792453  / ;
Parameters

     price (i) market price of species i (rupees per kg)
       /   oil-sardine        10.43
           other-sardines      7.00
           stolephorus        32.20
           thryssa            20.00
           lizard-fishes       5.00
           rock-cods           6.00
           breams              5.00
           other-perches       5.00
           ribfish            15.00
           scads               4.00
```

```
          other-crngids      3.00
          blkpomfret        53.53
          ind-mackerel      17.83
          soles              5.59
          prawns            53.49
          stomatopods        2.06
          cephalopods       32.20     /


     effcost (j) average cost of fishing by vessel class (rupees per hour)

        / mdtraw          368.63
          pseins          844.42
          trawlr          395.96
          oboard           37.50
          nonmec           60.02      /

     crewsh (j) percent of crew members' share in total return

        / mdtraw            0.25
          pseins            0.30
          trawlr            0.25
          oboard            0.50
          nonmec            0.80      /;

* Converting price per kg to price tonnes

     price(i) = price(i)*1000;

  Table recpar(i, par) recruitment parameters
                          intercept        slope
          oil-sardine       0.10838      0.00000045
          other-sardines    0.10838      0.00000045
          stolephorus       0.20982      0.00000087
          thryssa           0.2000       0.00000104
          lizard-fishes     0.2128       0.00000347
          rock-cods         0.3026       0.00003020
          breams            0.2528       0.00000336
          other-perches     0.3050       0.00000591
          ribfish           0.1720       0.00001235
          scads             0.2038       0.00000441
          other-crngids     0.2038       0.00000441
          blkpomfret        0.1212       0.00001082
          ind-mackerel      0.2500       0.00000540
          soles             0.2678       0.00000700
          prawns            0.3007       0.00002196
```

stomatopods	0.2405	0.000001757
cephalopods	0.2389	0.00001211 ;

Table d(i,j) proption of effort of vessel j dedicated to species i

	mdtraw	pseins	trawlr	oboard	nonmec
oil-sardine	0.0022	0.0646	0.0011	0.0059	0.0000
other-sardines	0.0008	0.1358	0.0030	0.0367	0.0000
stolephorus	0.0084	0.2008	0.0536	0.0235	0.0000
thryssa	0.0134	0.0224	0.0145	0.0122	0.0000
lizard-fishes	0.0142	0.0005	0.0492	0.0000	0.0000
rock-cods	0.0263	0.0001	0.0350	0.0000	0.0000
breams	0.0931	0.0000	0.1438	0.0000	0.0000
other-perches	0.0178	0.0006	0.0594	0.0014	0.4000
ribfish	0.0359	0.0000	0.0467	0.0056	0.0000
scads	0.0041	0.1112	0.0243	0.0402	0.0000
other-crngids	0.0386	0.0464	0.0523	0.0324	0.0000
blkpomfret	0.0026	0.0359	0.0078	0.0126	0.0000
ind-mackerel	0.0121	0.2577	0.0255	0.3308	0.0000
soles	0.2255	0.0015	0.0395	0.0010	0.2000
prawns	0.1023	0.0048	0.0472	0.0370	0.0000
stomatopods	0.1835	0.0005	0.1215	0.0000	0.0000
cephalopods	0.0384	0.0002	0.1164	0.0000	0.0000 ;

Parameters

EFF98 (j) 1998 effort levels

/ mdtraw 133932
pseins 113866
trawlr 836371
oboard 204990
nonmec 1908 /

maxco(j) factor defining maximum effort level w.r.t. 1998 level
/ mdtraw 1.25
pseins 1.25
trawlr 1.25
oboard 1.25
nonmec 2.00 /

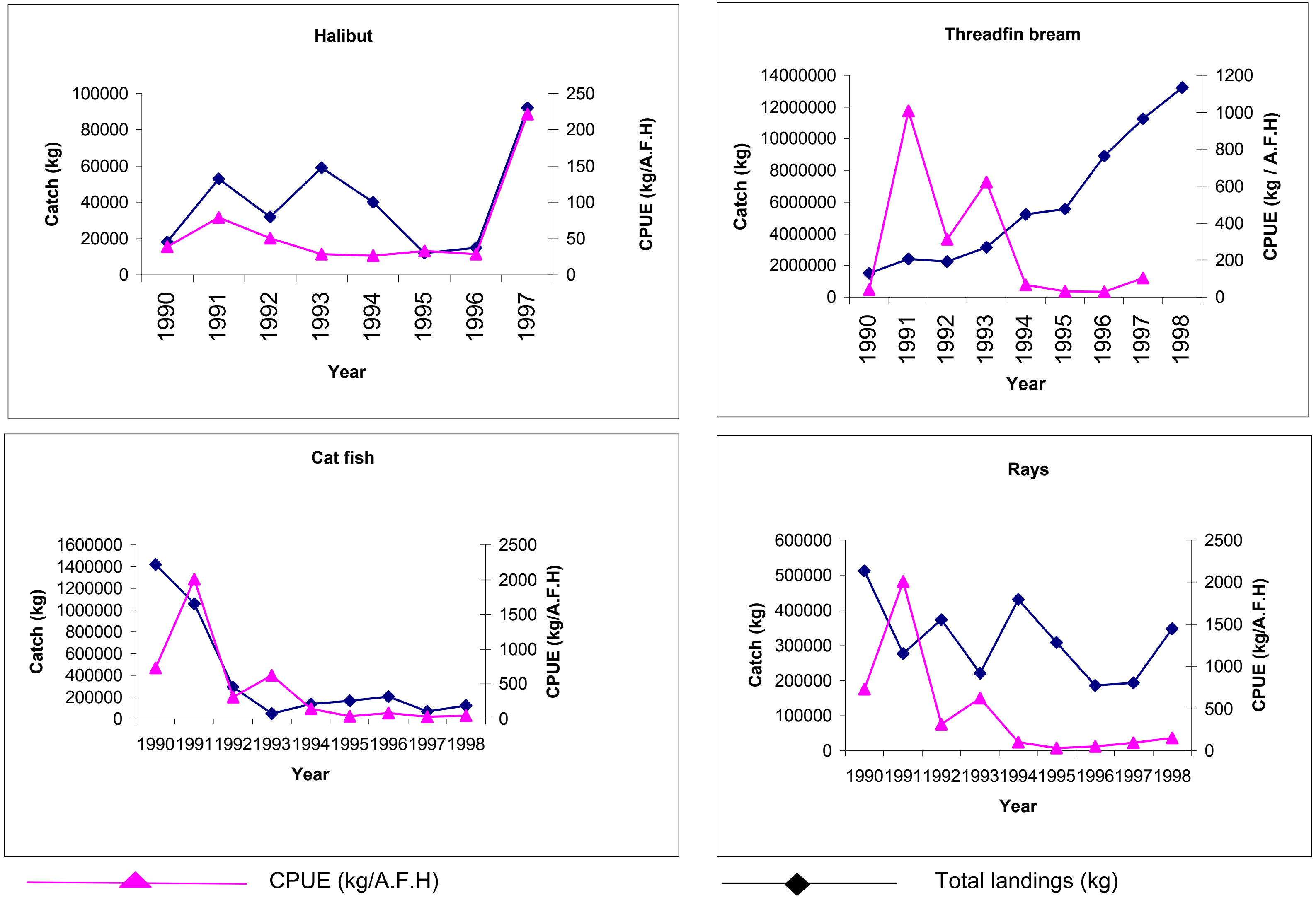
minco(j) factor defining minimum effort level w.r.t. 1998 level
/ mdtraw 0.5

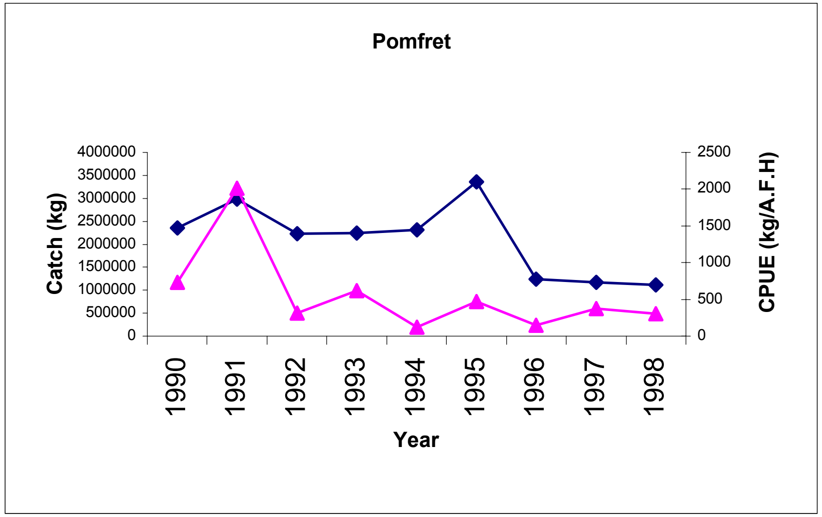
```
        pseins       0.5
        trawlr       0.5
        oboard       0.5
        nonmec      0.75       /

   INISTOCK (i)

     /  oil-sardine      185603
        other-sardines   195000
        stolephorus      102000
        thryssa          123456
        lizard-fishes     28000
        rock-cods          4979
        breams            40000
        other-perches     32000
        ribfish            2500
        scads             13000
        other-crngids     20000
        blkpomfret         3194
        ind-mackerel      25356
        soles              5200
        prawns             3800
        stomatopods        3200
        cephalopods        5900     / ;


 Variables
    stock(i,t)   stock of fish species i in year t (tonnes)
    effves(j,t)  effort of vessel class j in year t (hours)
    effspe(i,t)  effort dedicated to fish species i in year t (hours)
    catch(i,t)   quantity of fish catch of species i in year t (tonnes)
    NR           Net return from fishery (rupees)
    GR           Gross Return
    TC           Total cost
    wage         Total wage payment by all vessels
    grid(i,g,t)  Linearized grid variable   ;


Positive Variables stock, effves, effspe, catch;

Equations
    profit        define objective function
    grreturn      gross return
    totcost       total cost
    wagepay       total wage payment by vessel class j (rupees)
    speffort(i,t) distribute vessel to each effort
```

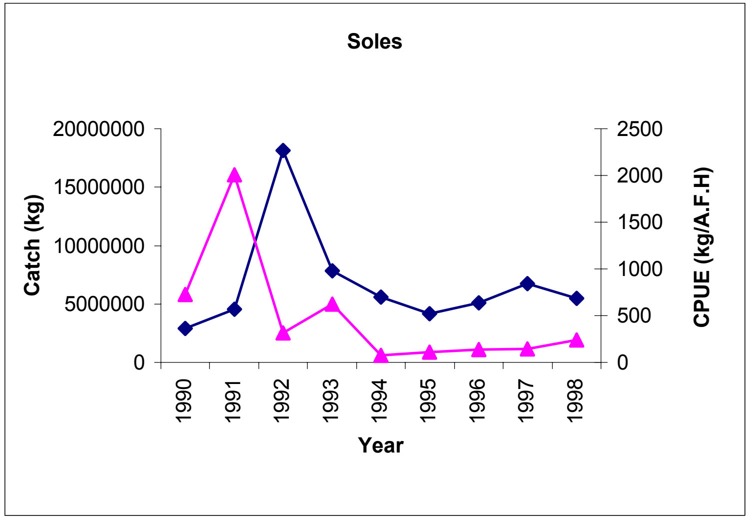
```
      effmax(j,t)    maximum annual effort by vessel class j
      effmin(j,t)    minimum annual effort by vessel class j
      fcatch(i,t)    production function for species i in year t
      sdynamics(i,t) catch-effort-stock relationship
      istock(i)      initial year stock
      aleffort(j,t)  all year effort
      incatch(i)     initial year catch  ;

*Construction of Objective function

  profit ..   NR =e=  - sum((j,t), effcost(j)*effves(j,t))

                   + sum((i,t), price(i)*catch(i,t) )  ;

  grreturn.. GR =e=  sum((i,t), price(i)*catch(i,t) )  ;
  totcost..  TC =e=  sum((j,t), effcost(j)*effves(j,t));

*Accounting row for the computation of total labor payment by all vessel classes

  wagepay ..  wage =e= sum  ((i,j,t), ( s(j)*d(i,j)*effves(j,t)/effspe(i,t))
                         *price(i)*catch(i,t)*crewsh(j) );

*Initializing first year stock and computing rest of the stocks using approximation

  istock(i).. stock(i, '1998') =e= INISTOCK(i)*1.00;

*Initializing first year vessel effort;

  aleffort(j,t).. effves(j,t) =e= EFF98(j);

*Minimum and maximum constraints on vessel efforts

  effmax(j,t).. effves(j,t) =l= maxco(j)*EFF98(j);

  effmin(j,t).. effves(j,t) =g= 0.50*EFF98(j);

*Summing up portions of efforts spent by all vessels toward each species i in year t

  speffort(i,t).. sum(j, s(j)*d(i,j)*effves(j,t)) - effspe(i,t) =e=0;

*Catch-effort-stock relationships (production functions) for each species

  incatch(i)..    catch(i, '1998') =e= (catchco(i))*effspe(i,'1998')*INISTOCK(I);

  fcatch(i,t+1).. catch(i,t+1) =e= (catchco(i))*effspe(i,t+1)*stock(i,t+1);
```

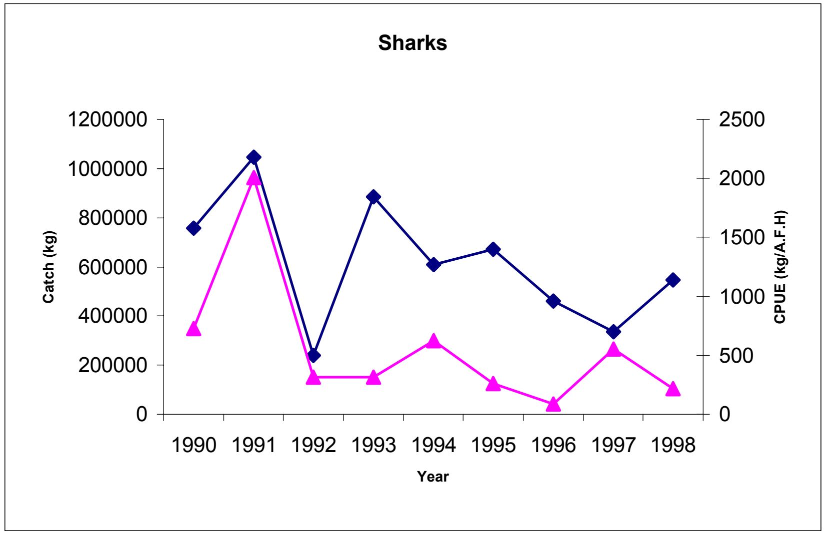
```
*Dynamic stock growth equation

  sdynamics(i,t+1).. stock(i,t+1) =e= stock(i,t)*(1+ recpar(i, 'intercept'))-
recpar(i,'slope')*stock(i,t)**2
                                        - catch(i,t);

*Sustainability conditions

  sustain(i,t+1)..  stock(i,t+1) =g= stock(i,t);

  Model mangalore /profit,
                grreturn, totcost,

*               aleffort,

* The baseline model for IGIDR study is run with "aleffort" constraint.
* The Optimal Fishery Harvesting model is run without "aleffort" constraint.
* The rest of the constraints are common to both models.

                istock,
                incatch,
                fcatch,
                speffort,
                sdynamics,
                effmax,
                effmin       /;

  option nlp=minos5;

  Solve mangalore using nlp maximizing NR ;

  Display stock.l, effves.l, catch.l, GR.l, TC.l, NR.l  ;

  parameter wwage total labor payment;

  wwage = sum  ((i,j,t), ( s(j)*d(i,j)*effves.l(j,t)/effspe.l(i,t))*price(i)*catch.l(i,t)*crewsh(j) );

  parameter vescatch(j,t) vessel catch;
  vescatch(j,t) =  sum ( i, (s(j)*d(i,j)*effves.l(j,t)/effspe.l(i,t))*catch.l(i,t));

  display wwage, vescatch;

*************End of the program*************
```

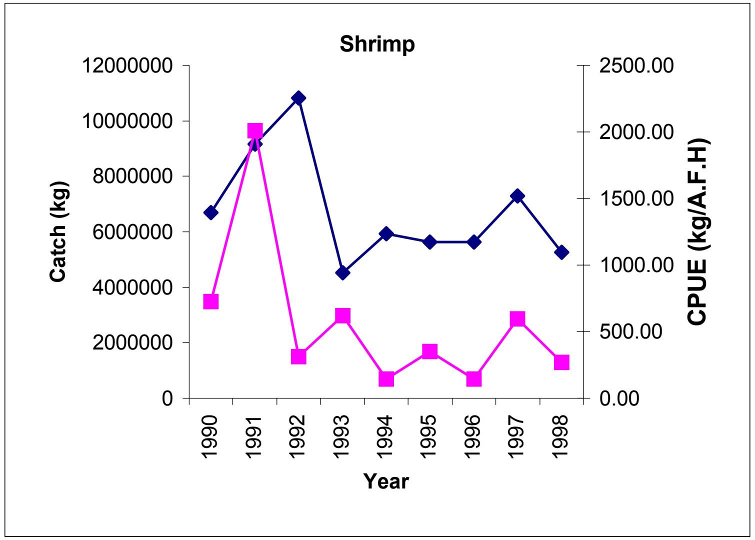
Catch and CPUE for the selected species of Karnataka





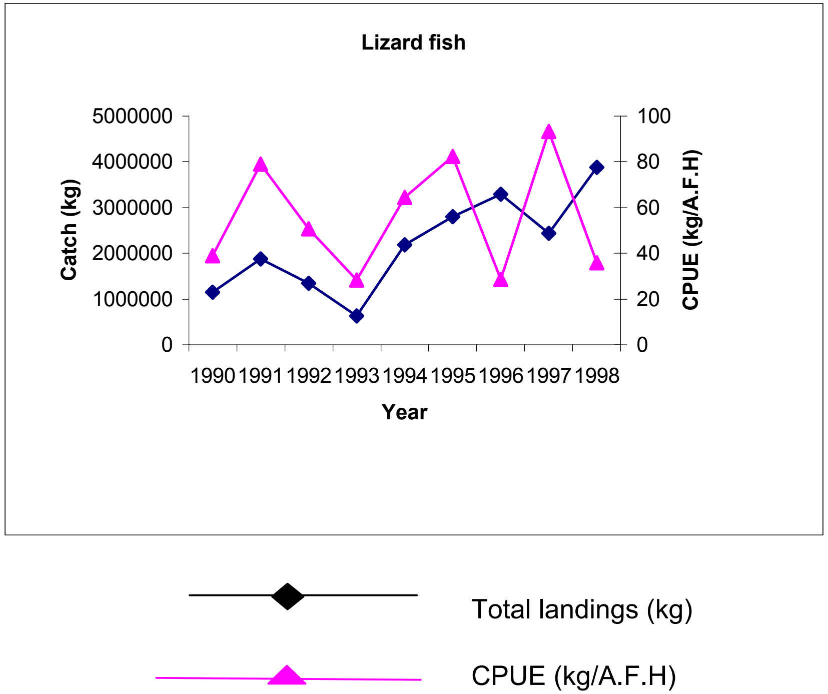






CPUE (kg/A.F.H).

Total landings (kg)


Lizard fish
Catch (kg)
5000000
4000000
3000000
2000000
1000000
0
100
80
60
40
20
0
CPUE (kg/A.F.H)
1990 1991 1992 1993 1994 1995 1996 1997 1998
Year
Total landings (kg)
CPUE (kg/A.F.H)