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Prediction and modelling of marine fishery yields from the Arabian Sea off Karnataka using Ecosim

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Ecosim simulation exercise was carried out for predicting over 10 years the changes in fishery yields in the multi-species and multi-gear marine fisheries of the Arabian Sea off Karnataka. The present study elucidates that in all the gears (multiday and single day trawl; purse seine, drift gillnet, hook and line and artisanal) the key resources such as mackerel, sardines, seerfishes, tunas, sharks and skates and rays showed rapid decline in yields within 5 years due to a consistent increase in fishing effort (@ 17% per annum). The shrimp yields showed an increasing trend in trawls as they seem able to sustain the high fishing pressure as long as their predators are also harvested. In all gears excepting hook and line, there is no ecological and economic advantage in increasing the fishing effort. Also increasing the effort can result in rapid declines of many important marine resources. This will have a serious effect on the ecosystem functioning. Attempt has been made to model changes in the marine ecosystem due to fishing as part of the effort to move towards ecosystem based fisheries management. This is the pioneer effort for the same.

[**Keywords**: Species, Shrimp, Predator, Ecosim, Biomass]

Introduction

It has been established that removing biomass from a complex of species feeding on one another is bound to affect the food web[1]. It is in this context that the attention of fisheries scientists has been turned towards ecosystem function and the holistic concept of ecosystem based fisheries management (EBFM), as opposed to single species management. Models of trophic flows that quantify the interactions between components of an ecosystem are useful in assessing the direct and indirect effects of a fishery on the long-term viability of other fisheries. Ecopath[2] is one such ecosystem modelling tool which has gained widespread acceptance and has been extended into Ecosim[3] to address the dynamic aspects of fishing.

By virtue of the prediction capacities of Ecosim, it has been used for policy exploration in fisheries. Christensen[4] showed that intensive trawl fishing drove the Gulf of Thailand ecosystem into its present state dominated by low-value and low trophic level fishes. Shannon *et al.*[5] and Stevens *et al.*[6] have applied Ecosim from a wider perspective on the Benguela upwelling ecosystem and on Chondrichthyans respectively. An Ecopath model of West Florida Shelf was used by Okey *et al.*[7] to simulate effects of changing nutrient loading and fishing effort on the fishes of Tampa Bay. Similar studies have not been carried out for Indian marine ecosystems. Here, we attempt to study the changes in yield that would take place in 10 years to different resource groups (ecological groups) in the Arabian Sea off Karnataka State on account of continuous increase in fishing effort using Ecosim.

Karnataka State along the southwest coast of India has a 300 km coastline and is one of the frontline States of India in marine fisheries development[8]. It has 28 fish landing centers. Mechanized trawl fishing in the region is carried out principally by two fleets[9]. The largest fleet in all harbours is the small coastal trawlers (single day fleet (SDF) - 30-32 footers) operating on a daily basis in the near shore areas up to 25 m depth. From 1989, there had been a steep decline, in marine fish production following which production peaked again in 2002, The production has stabilized to 192,816 t in 2004[10]. The rise in overall production often masks the phenomenon of fishing down the food web in a fishery, wherein, higher trophic level species groups show a rapid declining trend and the lower trophic level species an increase in abundance[11]. It has also been shown that the

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application of single species management policies would in general cause severe deterioration in ecosystem structure, in particular the loss of top predator species[12].

Materials and Methods

The simulation exercise was carried out with an Ecopath model of the Arabian Sea ecosystem off Karnataka constructed by Mohamed *et al.*[13]. This Ecopath model had a pedigree index of 0.521 (scale from 0 for data that is not rooted in local data up to a value of 1 for data that are fully rooted in local data). The Karnataka model encompassed an area of 27,000 km^2 (from the shore to the edge of the continental shelf) and had 24 functional ecological groups (species assemblages) of which 23 were living groups and one dead group (detritus). Ecological groups ranged from apex predators like marine mammals, sharks and tunas to micro zooplankton and phytoplankton (Table 1). For construction of the Ecopath model the input parameters used were estimates of biomasses, production over biomass ratios (P/B or total mortality rates), consumption over biomass ratios (Q/B) (Table 2), diet compositions (Table 3) and ecotrophic efficiencies (EE) of all ecological groups. Besides, fleet wise estimates of fishery yields (= catch, Table 4) and the value of the catch for the period 1999-2001 were also used as inputs. The total system throughput which represents the size of the entire system in terms of flow was estimated as 11,522 tonnes/km^2/year, which is comparatively high, but is consistent with tropical marine ecosystems with high turnover.

By converting the linear equations of Ecopath models to differential equations, Ecosim provides a dynamic mass-balance approach, suitable for simulation[3]. The equations are derived from the Ecopath master equation, and take the form

$$dB_i / dt = g_i \sum_j C_{ji} - \sum_j C_{ij} + I_i - (M_i + F_i + e_i)B_i$$

where, dB_i/dt represents the growth rate during the time interval dt of group (i) in terms of its biomass,

Table 1—Components of functional ecological groups of the Karnataka Ecopath model (not an exhaustive list, only indicative; includes more than 120 species)

No.	Ecological groups	No.	Ecological groups
1	Marine mammals (Dolphins)	13	Clupeids (oil sardine, lesser sardines, rainbow sardines, *Thryssa* , white sardine, *Pellona)*
2	Sharks *(Rhizoprionodon, Carcharhinus, Scoliodon, Sphyrna* spp)	14	Anchovies and unicorn cod *(Stolephorus* spp, *Bregmaceros mcclellandi)*
3	Skates and Rays *(Rhynchobatus, Rhinoptera, Dasyatis* spp)	15	Crabs and lobsters *(portunus, Charybdis, Panulirus* spp)
4	Large Pelagics (seers, kingfish and barracudas)	16	Shrimps *(Metapenaeus, Parapenaeopsis, Trachypenaeus, Aristeus* spp)
5	Tunas *(Euthynnus, Thunnus, Auxis* spp)	17	Benthic Omnivores (soles, cornetfish, squilla)
6	Cephalopods (squids and cuttlefish)	18	Heterotrophic Benthos (epifauna-bivalves, gastropods, echinoderms, benthic crabs, amphipods and isopods)
7	Large Benthopelagics (ribbonfish, horse mackerel, catfish, wolf herring and queenfish)	19	Meiobenthos (benthic infauna-annelids, polychaetes, foraminiferans and hydrozoans)
8	Large Benthic Carnivores (rock cods, jobfish, lizardfishes, red snappers)	20	Micro-nekton (jellyfish, juveniles of fishes)
9	Medium Benthic Carnivores (sciaenids, flatheads, bull's eye, pomfrets, balistids, flounders)	21	Large Zooplankton (Alima larva, *Calanus* sp, Cladocerans, Mysids, Lucifer larva, Siphonophores)
10	Small Benthic Carnivores (threadfin breams, terapons, whitefish, silverbellies, goatfishes, cardinalfish, *Uranoscopus* sp and tetradon)	22	Micro-zooplankton (fish eggs, decapod eggs and larva, bivalve larva and tintinnids)
11	Small Benthopelagics (scads, carangids, moonfish and myctophids)	23	Phytoplankton *(Fragilaria, Coscinodiscus, Thalassiothrix, Nitzchia* spp etc)
12	Mackerel *(Rastrelliger kanagurta)*	24	Detritus

Table 2—Estimates of biomass, P/B, Q/B and EE obtained after mass-balance of the Karnataka Ecopath model (from Mohamed *et al* [13])

Group No	Group name	Trophic level	Habitat area	Biomass in habitat area (t/km^2)	P/B (/year)	Q/B (/year)	EE
1	Marine Mammals	4.06	1	0.019	0.200	12.750	0.051
2	Sharks	4.45	1	0.013	3.275	8.500	0.709
3	Skates & Rays	3.59	1	0.022	0.750	5.960	0.599
4	Large Pelagics	4.18	1	0.061	4.268	10.450	0.980
5	Tunas	4.14	1	0.032	5.028	16.290	0.703
6	Cephalopods	4.18	1	0.234	4.637	36.500	0.975
7	Large Benthopelagics	4.15	1	0.106	4.633	14.320	0.980
8	Large Benthic Carnivores	4.14	1	0.628	3.055	8.900	0.980
9	Med Benthic Carnivores	3.19	1	0.108	4.877	16.420	0.981
10	Small Benthic Carnivores	2.68	1	0.530	5.268	28.520	0.979
11	Small Benthopelagics	3.88	1	0.281	2.383	17.490	0.978
12	Mackerel	2.00	1	0.249	6.240	62.360	0.980
13	Clupeids	2.95	1	0.289	7.465	39.360	0.979
14	Anchovies	3.49	1	1.110	4.620	42.660	0.977
15	Crabs & Lobster	2.89	1	0.140	6.415	14.500	0.976
16	Shrimps	3.02	1	0.826	6.680	19.200	0.980
17	Benthic Omnivores	2.55	1	0.556	6.505	28.060	0.980
18	Heterotrophic Benthos	2.32	1	38.000	3.000	12.500	0.124
19	Meiobenthos	2.02	1	20.000	12.500	40.000	0.373
20	Micro Nekton	3.24	1	0.800	20.000	125.000	0.778
21	Large zooplankton	2.58	1	4.000	35.000	225.000	0.980
22	Micro Zooplankton	2.00	1	10.000	60.000	300.000	0.980
23	Phytoplankton	1.00	1	58.500	70.000	-	0.842
24	Detritus	1.00	1	9.300	-	-	0.552

B_i, g_i is the net growth efficiency (production/consumption ratio), M_i the non-predation (other) natural mortality rate, F_i is fishing mortality rate, e_i is emigration rate and I_i is immigration rate. The two summations estimate consumption rates, the first expressing the total consumption by group (i), and the second the predation by all predators on the same group (i). The consumption rates, C_{ji}, are calculated based on the foraging arena concept, where B_i's are divided into vulnerable and invulnerable components[3], and it is the transfer rate between these two components that determines if control is top-down (i.e., Lotka-Volterra), bottom-up (i.e., donor-driven), or of an intermediate type. The set of differential equations is solved in Ecosim using an Adams-Basforth integration routine. Ecosim calculates corresponding changes in biomass of each component when the fishing mortality of any particular group is altered. Using equilibrium simulations, where equilibrium biomass is plotted over a range of fishing effort values; Ecosim provides the facility to predict the potential equilibrium yield for the fished group.

Simulation settings: The duration of the simulated run was 10 years. Integration step which is the step size for the integration of biomass in the `fast' groups was set at 100 steps per year. Relaxation parameter (biomass change for each integration step) was set at 0.5. All other settings (relative feeding time; density dependant catchability; third party mediation; forcing function) in Ecosim assumed default values. The flow control was set as mixed (neither bottom-up or top-down) as is the custom when complete knowledge on feeding behaviour is lacking[4]. The scenario modeled was a graded increase in effort from the present to 4-times for all the six fishing fleets (MDF, SDF, PS, GN, H&L and AS) exploiting the Arabian Sea ecosystem of Karnataka. The average rate of increase modeled was 17% per annum. To input the mean value of future catches, a 5% discount rate was assumed.

Results and Discussion

Simulation results for MDF trawlers indicate that with fishing effort increase the yield of shrimps and large benthic carnivores (rock cods, serranids,

Table 3—Diet matrix used as input for Ecopath run (from Mohamed *et al* [13])

Prey\Predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1 Marine Mammals																						
2 Sharks																						
3 Skates & Rays																						
4 Large Pelagics		0.192		0.078																		
5 Tunas																						
6 Cephalopods	0.071	0.107		0.079	0.000	0.031	0.062	0.057		0.000		0.005										
7 Large Benthopel		0.134	0.002	0.105		0.031																
8 Large Benth Car	0.073		0.013	0.042		0.129	0.061	0.023	0.000		0.046											
9 Med Benth Carni		0.025		0.056			0.009	0.025	0.000													
10 Small Benth Car	0.201	0.010	0.352	0.126	0.002	0.122	0.064	0.065	0.000	0.000	0.048											
11 Small Benthopel	0.000	0.003	0.022	0.027	0.056		0.146	0.001		0.000												
12 Mackerel				0.092		0.059		0.007	0.000													
13 Clupeids	0.045	0.110	0.003	0.057	0.211	0.044	0.062	0.004	0.000		0.003											
14 Anchovies	0.036	0.143	0.171	0.087	0.229	0.231	0.005	0.266	0.000	0.000	0.211	0.000	0.000		0.037							
15 Crabs & Lobster			0.027	0.035		0.021	0.091	0.084	0.000	0.000	0.000											
16 Shrimps	0.428	0.034	0.006	0.015	0.480	0.325	0.112	0.169	0.000	0.000	0.171		0.000	0.000	0.003		0.000					
17 Benth Omnivores	0.142	0.224	0.075	0.164	0.016	0.038	0.128	0.189	0.057	0.041	0.045		0.000	0.000		0.000	0.000					
18 Hetero Benthos		0.003	0.198				0.000	0.002	0.013	0.010	0.002		0.002	0.013	0.140	0.012	0.197	0.020				
19 Meiobenthos		0.008			0.007				0.004	0.051	0.040			0.012	0.596	0.154	0.214	0.143	0.021			
20 Micro Nekton			0.004	0.015			0.168	0.114	0.258	0.099	0.189		0.125	0.121		0.015		0.013				
21 Large zoopl	0.003	0.000					0.001		0.312	0.127	0.134	0.000	0.322	0.631	0.504	0.045	0.069		0.588			
22 Micro Zoopl									0.007	0.131	0.012	0.000	0.157	0.188		0.010	0.001	0.041	0.002	0.281	0.584	
23 Phytoplankto									0.004	0.026	0.027	0.893	0.297	0.006	0.006	0.022	0.102	0.001	0.075	0.416	1.000	
24 Detritus		0.008	0.126	0.022		0.053		0.344	0.515	0.067	0.107	0.098	0.029	0.224	0.299	0.522	0.624	0.976	0.043			
Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

lutjanids and lizard fishes) are likely to increase by a factor of 4 (Fig. 1A). The yield of cephalopods is also likely to increase for the first 5 years and then decline. However, the yields of large benthopelagics (ribbon fish, horse mackerel, wolf herring and catfishes) are likely to suffer a rapid decline within 5 years. Other groups, which are also prone to decline, are large pelagics and small and medium benthic carnivores. The latter two groups contribute to bulk of the catch in MDF. Overall the total catch in MDF and its value show only a marginal increase in the 10 year period. In the Gulf of Thailand, Christensen[4] also found a steep increase in the biomass of shrimps when the fishing pressure was increased by 16 times. The major predators of shrimp in the ecosystem are tunas, cephalopods and marine mammals[13], and their decrease in biomass due to increased fishing pressure by PS, MDF and DGN respectively is likely to have helped to increase shrimp yields in MDF. Therefore shrimps seem able to sustain the high fishing pressure as long as their predators are also harvested.

The simulation results for SDF (Fig. 1B) indicate that while the yields of crabs and lobsters, and shrimps are likely to increase with increase in effort, the total catch and value of the SDF is unlikely to increase substantially. The yields and biomass of benthic omnivores (mainly flatfishes and *Squilla* sp.), small benthic carnivores (terapons and silverbellies) and medium benthic carnivores (mainly sciaenids) are liable to decline drastically. These groups are the mainstay of the SDF trawl fishery and the simulation suggests that within 6 years (at double the effort) neretic sciaenids such as *Johnieops sina* would be depleted.

All the resources exploited by the PS fleet except anchovies show a declining trend in yield and biomass (Fig. 1C). Yields of groups like clupeids (oil sardine and lesser sardines), mackerel, large pelagics and tunas show a very rapid (within 5 years) decline. The total catch and value, which show a dip during the first 5 years, are likely to return to the present level within 10 years. Anchovies are the main forage fish for higher trophic level groups such as tunas, cephalopods and large benthic carnivores in the Karnataka ecosystem[13]. A substantial decrease in the biomass of these groups has resulted in the positive impact on anchovy biomass. The price structure of anchovies is presently low and that coupled with the decline in mackerel and tuna yield is the reason why even after a 4-time increase in anchovy yield it did

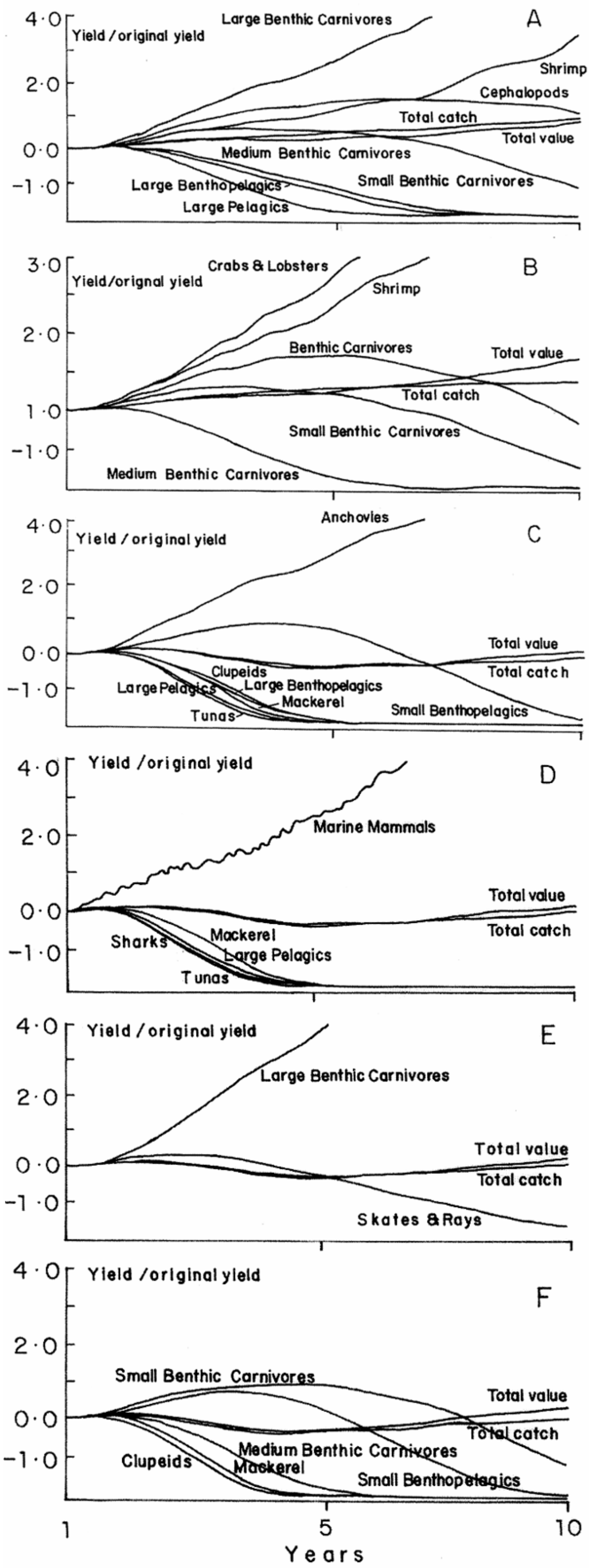

Fig. 1—Ecosim simulation of effects on fishery yields in (A) MDF; (B) SDF; (C) PS; (D) DGN; (E) H&L and (F) AS fleets. Only key ecological groups in fleets are shown. Yield is plotted relative to original yield.

not increase the total value of the catch in PS. In the Bering Sea ecosystem model[14], reducing pelagic fish biomass caused significant declines in piscivorous birds, sea lions and large flat fish that fed on them. A similar trophic cascade effect seems to work in the Arabian Sea ecosystem off Karnataka too.

The simulation results for DGN shows that while the marine mammal bycatch are likely to increase manifold; all commercially important groups are likely to suffer a decline in yield and biomass with increase in effort (Fig. 1D). The total catch and value of the fishery are also prone to decrease. Marine mammals are a protected species in Indian waters and fishers do not deliberately target these animals. The initial biomass estimated for marine mammals was a high 0.019 t/km^2, and this is one of the reasons for the increase in its catch with increased effort. Moreover the market demand for these animals is very low and they occupy, along with sharks, the topmost trophic level. Marine mammals also exert high degree of control over shrimp biomass in the ecosystem as shrimp forms more than 40% of marine mammal dietl[13]. Reducing baleen whales in the Bering Sea ecosystem increased zooplankton biomass and increased their major competitors (pollock and cephalopods) which were fed upon by other marine mammals[14]. Increasing DGN effort and increasing the take of marine mammals is therefore fraught with significant damage to the ecosystem and needs to be discouraged.

In the H&L fleet the yields of large benthic carnivores (mainly the jobfish, *Pristipomoides filamentosus* and rock cods) can be markedly improved by increasing the effort (Fig. 1E). However at more than double the effort it would drastically affect the biomass and yields of skates and rays. The H&L effort can be doubled to reap higher yields of large benthic carnivores, and since the total value does not show much increase, a recommendation for a further increase in effort can be made only when there is a substantial increase in the price of *P. filamentosus* and rock cods. Skates and rays (chondrichthyans), by nature of their K-selected life history strategies and high position in trophic food webs, are more likely to be affected by intense fishing activity than most teleosts[6]. The group may in fact function as indicators of high fishing pressure as the shark yield in DGN is likely to decline to very low levels within 2 years.

Table 4—Estimated average gearwise catch (tonnes/km^2/year) during 1999-2001 used as input for ECOPATH run (from Mohamed *et al* [13])

Grp No Group Name	MDF	SDF	PS	GN	H&L	AS	TOTAL
1 Marine Mammals	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2 Sharks	0.013	0.001	0.000	0.012	0.000	0.004	0.030
3 Skates & Rays	0.005	0.001	0.000	0.001	0.001	0.001	0.009
4 Large Pelagics	0.056	0.003	0.038	0.080	0.000	0.008	0.185
5 Tunas	0.003	0.000	0.085	0.019	0.000	0.006	0.113
6 Cephalopods	0.258	0.015	0.002	0.000	0.000	0.003	0.278
7 Large Benthopelagics	0.217	0.030	0.083	0.010	0.000	0.011	0.351
8 Large Benthic Carnivores	0.242	0.007	0.000	0.002	0.027	0.003	0.281
9 Med Benthic Carnivores	0.172	0.068	0.027	0.005	0.000	0.058	0.330
10 Small Benthic Carnivores	0.709	0.051	0.008	0.003	0.000	0.045	0.816
11 Small Benthopelics	0.109	0.030	0.179	0.016	0.000	0.046	0.380
12 Mackerel	0.041	0.001	0.709	0.074	0.000	0.120	0.945
13 Clupeids	0.058	0.039	0.924	0.018	0.000	0.400	1.439
14 Anchovies	0.090	0.009	0.100	0.000	0.000	0.002	0.201
15 Crabs & Lobster	0.018	0.033	0.000	0.001	0.000	0.009	0.061
16 Shrimps	0.100	0.151	0.004	0.006	0.000	0.045	0.306
17 Benthic Omnivores	0.086	0.746	0.002	0.000	0.000	0.010	0.844
18 Heterotrophic Benthos	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19 Meiobenthos	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20 Micro Nekton	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21 Large zooplankton	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22 Micro zooplankton	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23 Phytoplankton	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24 Detritus	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	2.177	1.185	2.161	0.247	0.028	0.771	6.569

An increase in fishing effort of the AS fleet results only in marginal increase in yields of small benthopelagics and small benthic carnivores during the first 5 years and subsequently an overall decline in 10 years (Fig. 1F). The yields and biomass of clupeids and mackerel show a drastic decline within 5 years. The total catch and value does not show much change. The AS fleet (mainly *matabale* or mini-purse seines) operates primarily in the neretic shallow zone and the decline in 10 years of all the major groups exploited by the gear reveals the fragile nature of the near-shore marine ecosystem of Karnataka.

A key resource group exploited in the Arabian Sea off Karnataka is the mackerel. The fish *(Rastrelliger kanagurta)* is exploited by PS (juveniles and adults); DGN (mature adults) and AS (pre-recruits, juveniles and adults). In all the gears, mackerel yields have shown a declining trend within 5 years of increased effort. Mackerel which forms a large fishery in the region have surprisingly very few predators in the ecosystem[13] and that is probably the reason they successfully occupy a wide variety of ecological niches in the ecosystem. However, the predicted rapid decline in yields and biomass of mackerel indicates poor resilience, as also indicated by recorded cyclic failures in the fishery[15]. The present fisheries policy exploration using Ecosim is a preliminary exercise, but it shows the immense potential of such predictions to arrive at sound fisheries management plans. Ecosim tracked trophic interactions over 10 years of simulation. It showed how altering the yields of one species can affect others, and how the system as a whole might respond. Ecosim has identified important indirect effects of fishing, particularly on shrimp and anchovies. It is therefore a useful tool for understanding what role commercial fisheries may play in restructuring the Arabian Sea ecosystem off Karnataka. The simulations revealed that in all gears excepting H&L, there is no ecological and economic advantage in increasing the fishing effort. On the other hand, increasing the effort can result in rapid declines of many of the state's important marine resources, which will have a serious effect on the ecosystem functioning. This is the first attempt in India to simulate changes in the marine ecosystem due to fishing and such exercises need to be replicated in other Indian marine ecosystems in our effort to move towards EBFM. Moreover, development of a complex Ecosim model of the Arabian Sea off Karnataka is an ongoing process which could be continuously improved with the addition of new data and information.

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References

1 Pauly D, Christensen, V & Walters C, Ecopath, Ecosim and Ecospace as tools for evaluating ecosystem impact of fisheries, *ICES J Mar Sci,* 57 (2000) 697-706.

2 Christensen, V & Pauly D, ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling,* 61 (1992) 169-185.

3 Walters C, Christensen V & Pauly D, Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments, *Rev Fish Biol Fisheries,* 7 (1997) 139-172.

4 Christensen V, Fishery-induced changes in a marine ecosystem: insight from models of the Gulf of Thailand, *J Fish Biol,* 53 (1998) 128-142.

5 Shannon L J, Cury P M & Jarre A, Modelling effects of fishing in the Southern Benguela ecosystem, *ICES J Mar Sci, 57* (2000) 720-722.

6 Stevens J D, Bonfil R, Dulvy N K & Walker P A, The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems, *ICES J Mar Sci,* 57 (2000) 476-494.

7 Okey T A, Vargo G A, Mackinson S, Vasconcellos M, Mahmoudi B & Meyer, C A, Simulating community effects of sea floor shading by plankton blooms over the West Florida shelf, *Ecological Modelling,* 172 (2004) 339-359.

8 Mohamed K S, Muthiah C, Zacharia P U, Sukumaran K K, Rohit P & Krishnakumar P K, Marine Fisheries of Karnataka State, India, *Naga ICLARM* Q, 21 (1998) 10-15.

9 Zacharia P U, Mohamed K S, Purandhara C, Mahadevaswamy H S, Gupta A C, Nagaraja D & Bhat U S, A bioeconomic evaluation of the dual-fleet trawl fishery of Mangalore and Malpe, *Mar Fish Infor Serv T & E Ser,* 144 (1996) 1-12.

10 Srinath M, Kuriakose S, Ammini P L, Prasad C J, Ramani K & Beena M R, Marine Fish landings in India 1985-2004, estimates and trends, *Cent Mar Fish Res Inst Spec Publ, 89* (2006) 166p.

11 Vivekanandan E, Srinath M & Kuriakose S, Fishing the marine food web along the Indian coast, *Fish Res,* 72 (2005) 241-252.

12 Walters C J, Christensen V, Martell S J & Kitchell J F, Possible ecosystem impacts of applying MSY policies from single-species assessment, *ICES J Mar Sci,* 62 (2005) 558-568.

13 Mohamed K S, Zacharia P U, Muthiah C, Abdurahiman K P & Naik T H, Trophic model of the Arabian Sea ecosystem off Karnataka and simulation of fishery yields, *CMFRI Bull*, 51 (2008) 141p.

14 Trites A W, Livingston P, Mackinson 5, Vasconcellos M, Springer A. & Pauly D, Ecosystem change and the decline of marine mammals in the eastern Bering Sea: testing the ecosystem shift and commercial whaling hypothesis, in *Fisheries Centre Research Reports, (*University of British Columbia, Vancouver), 7 (1999) 107p.

15 Yohannan, T.M. and Sivadas, M., The Indian Mackerel, in *Status of Exploited Marine Fishery Resources of India* ed. Modayil, M.J. and Jayaparakash, A.A., (Cent Mar Fish Res Inst, Kochi, India.) 2003, pp. 60-65.