Attachment 1

AN ECOPATH MODEL OF THE NORTHEASTERN ARABIAN SEA (MAHARASHTRA AND GUJARAT COASTS) WITH EMPHASIS ON SMALL PELAGIC HERBIVORES

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AN ECOPATH MODEL OF THE NORTHEASTERN ARABIAN SEA (MAHARASHTRA AND GUJARAT COASTS) WITH EMPHASIS ON SMALL PELAGIC HERBIVORES[1]

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Historical Background

The states of Maharashtra and Gujarat along the western coast of India (Northeastern Arabian Sea - NAS) are prominent contributors to India's marine fish production. They boast long coastlines, rich ecosystems, and a long tradition of fishing. Maharashtra has a coastline of around 720 km, harbouring a variety of commercially important fish species like Bombay duck, prawns, mackerel, cephalopods, sardines, pomfrets, tuna, and sharks. The state faces challenges like overfishing, habitat degradation, and pollution. The lack of infrastructure and modernization in some fishing communities also hinders optimal productivity. The Maharashtra government implements various schemes to promote sustainable fishing practices, improve infrastructure for fishermen, and encourage aquaculture. Gujarat's coastline stretches over 1600 km, and its marine fisheries are a major source of income for the coastal communities. Key commercial fish species include prawns, cephalopods, pomfrets, catfish, hilsa, tuna, and sharks. Similar to Maharashtra, Gujarat grapples with issues of overfishing, pollution and climate change impacting fish stocks. Ensuring sustainable fishing practices and adopting mariculture techniques are crucial areas of focus.

Both states share a rich fishing culture with traditional fishing practices employed alongside modern techniques. They face common challenges related to overexploitation of fish stocks, habitat destruction, and environmental degradation. Both Maharashtra and Gujarat have undertaken initiatives to promote sustainable fishing and aquaculture for long-term benefits. Overall, the marine fisheries sector in Maharashtra and Gujarat plays a significant role in the Indian economy and food security. By adopting sustainable practices and promoting responsible fishing, these states can ensure the continued viability of this vital resource.

The traditional approach to fisheries resource management in India has been based on single species assessments. However, the results emanating from such studies have little meaning in multi-species and multigear fisheries. To address the management of fish stocks holistically, it is necessary to move towards an ecosystem approach. There are many recent developments in building trophic models of aquatic ecosystems. Such modelling can now be performed more rapidly and rigorously than ever before, providing a basis for viable and practical simulation models that have real predictive power. The utilization of sound ecological models as a tool in the exploration and evaluation of ecosystem health and state has been encouraged and endorsed by the leading bodies in an ecosystem approach to fisheries.

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Few ECOPATH with ECOSIM (EwE) models have been developed for different aquatic ecosystems in India. A pilot study was conducted for the southwest coast ecosystem and a preliminary model was constructed by Vivekanadan et al. (2003). A more detailed trophic model for the Arabian Sea off the Karnataka coast was developed (Mohamed et al., 2008) and simulations were carried out to see the implications of different fisheries management scenarios (Mohamed and Zacharia, 2009). More recently, trophic models have been developed for a tropical estuarine ecosystem in Goa (Sreekanth et al., 2020) and the impacts of different fishery regulations have been simulated (Sreekanth et al., 2021). Very recently a trophic model of the Kerala Arabian Sea Ecosystem (KASE) was modelled to examine the impact of closed seasons on different ecological groups (Kuriakose et al 2024, MS).

In 2007, the ICAR-Central Marine Fisheries Research Institute (CMFRI) launched a project to model fisheries ecosystems of the Northwest Coast (NWC), Gulf of Mannar (GOM) and the Northeast Coast NEC) of India to move towards an ecosystem approach to fisheries management. The models were built using the ECOPATH software, however, they were not published and remained as reports. Currently, the use of small pelagics (particularly sardines) by M/s Omega Fishmeal Company, Ratnagiri has necessitated the development of an ECOPATH model for the region and the NWC model developed by CMFRI scientists in 2008 was used as a base for the creation of a new model with updated parameters. The newly developed model also helped to make a THEN and NOW comparison of the ecosystem.

Ecosystem modeling

Version 6.6 of Ecopath with Ecosim (EwE) software was utilised to create the mass balance model. Built by solving a straightforward set of linear equations, the mass-balance model Ecopath has two equations that quantify the quantity of material (measured in biomass, energy, or tracer elements) going into and out of each compartment in a simulated food web (Christensen et al., 2005).

The first master equation describes the energy balance for each group, so that:

consumption = production + respiration + unassimilated food ------ (1)

In the second master equation, the production is split into five components: the biomass removed by natural causes of mortality other than predation, by predation, by fishing, plus the net migration and biomass accumulation:

Production = fishery catches + predation mortality + biomass accumulation +

net migration + other mortality

$$P_i = Y_i + B_i.M2_i + E_i + BA_i + P_i(1 - EE_i) \text{ ------------------- (2)}$$

Where P_i is the total production rate of (i) Yi is the total fishery catch rate of (i), $M2_i$ is the total predation rate for the group (i), B_i the biomass of the group, E_i the net migration rate (emigration – immigration), BA_i is the biomass accumulation rate for (i), while $P_i(1 - EE_i)$ is the 'other mortality' rate for (i).
Predation mortality can be also represented as

$$M2_i = \sum_j^n Q_j \times DC_{ji} \text{ ---------------------------------- (3)}$$

Where, Q_j is the consumption rate for predator j and DC_{ji} is the proportion of prey (i) in the predator's (j) diet.

The mass-balanced model can be also given by:

$$\left(\frac{P}{B}\right)_i \times B_i \times EE_i = \sum_j^n B_j \times \left(\frac{Q}{B}\right)_j \times DC_{ji} + Y_i + E_i + BA_i \quad \text{---------------------} \ (4)$$

Where, i is prey and j is predator, $\left(\frac{P}{B}\right)_i$= Production/ Biomass, B_i = Prey biomass, EE_i= Ecotrophic efficiency, $\left(\frac{Q}{B}\right)_j$ = Consumption/Biomass, Y_i = Total catch, E_i = Net migration and BA_i = Biomass accumulation.

For each group, one of the four main parameters (biomass, production/biomass ratio, consumption/biomass ratio, and ecotrophic efficiency) is estimated and the other three must be entered, along with the remaining ones (diet compositions, catch rate, net migration rate, biomass accumulation rate) (Christensen and Walters 2004). The estimation of EE is the primary tool for data calibration in Ecopath: independent estimates of consumption and production of different species often lead to initial conclusions that species are being preyed upon more than they are produced (EE > 1.0), which is impossible under the mass-balance assumption.

The Northeastern Arabian Sea Ecosystem (NASE)

The northeastern Arabian Sea (between 15°30'-23°30'N and 68°20'-73°30'E) adjoining the coasts of Gujarat and Maharashtra states has the largest continental shelf covering an area of 400,000 km^2. Along this coast, the stretch between Kutch in Gujarat (excluding the Gulf of Kutch) in the north to Harnai in Ratnagiri district in Maharashtra has many oceanographic and fishery similarities signifying a distinct ecosystem (map, Fig.1).

Fig.1. Map of the NAS ecosystem modelled in the present study.

At present the fish resources in the region are mainly exploited up to 100m depth, therefore, the area of the NAS ecosystem between the shoreline and 100m depth on the continental shelf off Gujarat (22°28'N-68°20'E) and Maharashtra (17°50'N -70°52'E) under the present investigation has been worked out to 1,57,320 Sq Km.

Ecological groups

Initially, 26 ecological groups were considered in the first workshop for NWC but subsequently, in the second workshop, the number was reduced to 23 mainly due to the merging of some groups and inadequacy in getting information on reef fishes and birds even from the secondary sources (Table 1).

Table 1. Components and species in different ecological groups used in the model.

No	Ecological Groups	Components	Main Species
1	Marine Mammals	Dolphins, porpoises and whales	
2	Large Pelagics	Tunas, Seerfish, Barracuda, Pelagic Sharks	*Thunnus albacares, Euthynnus affinis, Scomberomorus commerson, S. guttatus, Sphyraena obtusata, S. jello, Carcharhinus spp, Rhizopriniodon acutus*
3	Large Benthic Carnivores	Eel, Ghol, Koth, Groupers, perches	*Otolithes biauritus, Pseudoscieana diacanthus, Epinephelus diacanthus, Muraenosox talabonoides, Lethrinus sp, Lutjanus sp*
4	Rays & Skates	Rays and Skates	*Dasyatis imbricatus*
5	Medium benthic carnivores	Lizard fish, halibut, Threadfins, Catfishes, Sharks	*Saurida tumbil, Polynemus indicus, O. militaris, T. caelatus, Scoliodon laticaudus*
6	Small Benthic Carnivores	Threadfin breams, Sciaenids, Goatfish, Whitefish, Unicorn cod	*Nemipterus mesoprion, N. japonicus, Johnius vogleri, Johnius gkaucuas, Otolithes cuvieri, Upeneus sulphureus*
7	Mid-water carnivores	Horse mackerel, pomfrets, Queenfish, Ribbonfish	*Megalspis cordyla, Pampus argenteus, Formio niger, S. tol, T. lepturus*
8	Bombay Duck	Bombay Duck	*Harpodon nehereus*
9	Small pelagic herbivores	Sardines, Pellona, Hilsa	*Hilsa toli, Sardinella longiceps, Sardinella sp, Pellona sp*
10	Small pelagic carnivores	Mackerel, Whitebaits, Coilia, Kovala	*Rastrelliger kanagurta, Coilia dussumieri, Escuolosa thoracata*
11	Cephalopods	squid, cuttlefish	*Sepia pharaonis, Sepia aculeate, Loligo duvaucelii, Octopus membraneous*
12	Benthic Omnivores	Soles, Squilla	*Pseudorhombus sp, Oratosquilla nepa*
13	Non-penaeid shrimps	Non-penaeid shrimps	*Exhippolysmata, Acetes indicus, Nematopalaemon*
14	Penaeid shrimps	Penaeid shrimps	*Penaeus semisulcatus, Penaeus monodon, Metapenaeus monoceros, M. affinis, M. kutchensis,, Solonocera crassicornis*
15	Crabs and lobsters	Crabs and lobsters	*Charybdis ferriatus, Portunnus pelagicus, Panulirus polyphagus, P. sanguinolentus*
16	Acetes shrimp	Paste shrimp	*Acetes indicus*
17	Whale Shark	Whale shark	*Rhiniodon typus*
18	Benthic epifauna	Bivalves, Gastropods, Echinoderms	
19	Benthic infauna	Polychaetes and other benthos	*Not commercial*

20	Large Zooplankton	Hydrozoan medusae, Salps, Alima, Phyllosoma, Megalopa, Siphonophores, Ctenophores	*Not commercial*
21	Small Zooplankton	Copepods, Mysids, Crustaceans larvae, fish eggs and Larvae	*Not commercial*
22	Phytoplankton	Diatoms, Dinoflagellates	
23	Detritus	Non-living group	

Fishery Landings Data

A scientific sampling scheme called "Stratified Multistage Random Sampling Design (SMRSD)" has been developed by the ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi, India, to gather data and estimate the landings of marine fisheries and fishing efforts for various maritime states (Sathianandan et al., 2021; Mini et al., 2023) and stored in a database called National Marine Fisheries Data Centre (NMFDC). Estimates of landings for each species were acquired from the NMFDC of CMFRI and based on the ecological groupings, the landings were classified gear-wise (8 craft gear combinations or fleets) and expressed in tonnes per square km. The primary data on landing centre prices of commercial groups maintained in the database were converted into price per tonne per group for each gear.

Basic inputs

The major input data provided for the Ecopath modelling includes the estimates of biomass (t/km2), production per biomass P/B (t/km2 /year), consumption per biomass Q/B (t/km2 /year), and ecotrophic efficiency EE for each functional groups. (Table 2).
Biomass: The amount of biomass in the habitat area is estimated using the equation of Gulland (1983) and was expressed in tonnes per square km. For each functional group, biomass estimates were derived from the primary literature, and stock assessments, or were estimated based on catch data and fishing mortality rates. The habitat area of each group was decided based on the depth-wise distribution of the resources and a proportion was assessed.
P/B ratio: The P/B ratio is equivalent to the total mortality rate (Z) (Allen 1971) and includes the mortality due to fishing (F), predation (M2), net migration (NM), biomass accumulation (BA), and other mortality. The P/B of commercial groups were estimated from Z values and for non-commercial groups it was taken from other models (Mohamed et al., 2008) from the region.
Q/B ratio: The Q/B ratio is the ratio of annual food consumption to the biomass of each group and is only entered for secondary consumers as this value is not applicable for primary producers (Pauly et al. 2000). It indicates the intake of food by the groups over the considered time frame. Consumption and production estimates were calculated based on empirical relationships or were acquired from estimates in other models (Mohamed et al., 2008) from the region.
Diet Matrix: Information on the diet composition of the groups is an important parameter for understanding the dynamics of ecosystems, given that food networks connect different ecological groups. The diet matrix helps to identify the trophic levels and the prey-predator relationships existing in the marine ecosystem and forms the major input in Ecopath modelling (Pauly and Christensen, 2000). Diet information was sourced mainly from project reports of CMFRI for the states of Maharashtra and Gujarat.
Fleets: Fishing fleet-wise information is used as a major input in the Ecopath model. The primary gears in the mechanized vessel fishery are multiday trawl nets (MDTN), small mechanized trawl nets (MTN), multiday gillnets (MGN), multiday hook and lines (MHL), mechanized dol nets (fixed bag nets, MDOL), mechanized purse seines (MPS) and artisanal gears (ART). In the 2024 model, another fleet was added – mechanized ring seine (MRS) which

is a miniature version of purse seine operated from a traditional craft, mainly targetting small pelagics.

Table 2. Ecological groups and basic input values used in the NWC model of 2008. P/B – production over biomass ratio; Q/B – consumption over biomass ratio; EE – ecotrophic efficiency; P/Q – production over consumption ratio. Groups 2 to 16 are commercially exploited groups.

No	Group name	TrL	Biomass	P/B	Q/B	EE	P/Q
1	Dolphins & porpoises	4.342	0.010	0.200	14.600	0.000	0.014
2	Large pelagics	4.022	0.080	3.420	17.980	0.774	0.190
3	Large benthic carnivores	4.197	0.080	2.210	6.110	0.896	0.362
4	Rays & skates	4.088	0.063	0.750	5.980	0.711	0.125
5	Medium benthic carnivores	4.033	0.250	3.220	9.590	0.911	0.336
6	Small benthic carnivores	3.756	0.390	4.120	11.690	0.959	0.352
7	Mid-water carnivores	3.771	0.495	4.000	11.410	0.879	0.351
8	Bombay duck	3.986	0.310	3.035	11.770	0.947	0.258
9	Small pelagic herbivores	2.562	0.360	4.200	15.000	0.890	0.280
10	Small pelagic carnivores	3.286	0.550	5.210	12.640	0.991	0.412
11	Cephalopods	3.943	0.420	5.500	18.000	0.870	0.306
12	Benthic omnivores	3.183	0.413	4.560	16.600	0.934	0.275
13	Non-penaeid shrimps	2.715	0.625	7.500	19.200	0.944	0.391
14	Penaeid shrimps	2.950	0.900	7.900	19.200	0.987	0.411
15	Crabs & Lobsters	3.429	0.566	5.000	12.200	0.945	0.410
16	Acetes shrimp	2.163	1.320	10.270	25.000	0.970	0.411
17	Whale sharks	3.503	0.013	2.429	11.000	0.000	0.221
18	Benthic epifauna	2.313	14.500	3.900	15.000	0.210	0.260
19	Benthic infauna	2.250	10.900	5.755	12.500	0.912	0.460
20	Large zooplankton	2.957	0.192	60.000	225.000	0.647	0.267
21	Small zooplankton	2.250	11.760	35.000	125.000	0.884	0.280
22	Phytoplankton	1.000	25.900	118.300	0.000	0.365	
23	Detritus	1.000	16.989			0.000	

Results

The old NWC model was updated with recent landing estimates and the addition of a gear (MRS which is a recent addition to the fishery) to create the NASE model. The model was mass-balanced by tweaking the biomass and diet values keeping EE <1 as the goal. The summary statistics of the NASE model are shown in Table 3. Some of the key parameters and indicators of ecosystem health are discussed below (all parameters are not discussed).

Total system throughput is the sum of all flows in a system, expressed in t/km2/year. Total system throughput represents the 'size of the entire system in terms of flow' and was estimated as 5433 t/km2/year which is relatively low. This may be a reason for the decline in marine fish landings from Maharashtra from more than 400,000 tonnes in the 1990s to 175,000 tonnes in recent years.

The **mean trophic level** (MTL) of the catch functions as an important index of the overall level of exploitation of fish groups low in the food web and its effect on predator and prey species. In the current NASE model, the value was estimated as 3.43 and in the NWC model of 2008, it was 3.49 showing a decline in trophic level of nearly 2%. This may be due to the increasing dominance of small pelagic herbivores in the ecosystem in the last decade.

Table 3. Summary statistics of the NASE model of 2024 showing different ecological indicators of ecosystem health.

Parameter	Value	Units
Sum of all consumption	1982.142	t/km^2/year
Sum of all exports	4.37296	t/km^2/year
Sum of all respiratory flows	1000.552	t/km^2/year
Sum of all flows into detritus	2446.267	t/km^2/year
Total system throughput	5433.334	t/km^2/year
Sum of all production	3649.131	t/km^2/year
Mean trophic level of the catch	3.435818	
Gross efficiency (catch/net p.p.)	0.00142722	
Calculated total net primary production	3063.97	t/km^2/year
Total primary production/total respiration	3.062279	
Net system production	2063.418	t/km^2/year
Total primary production/total biomass	43.67304	
Total biomass/total throughput	0.01291233	t/km^2/year
Total biomass (excluding detritus)	70.15701	t/km^2
Total catch	4.372961	t/km^2/year
Connectance Index	0.4194215	
System Omnivory Index	0.3364932	
Ecopath pedigree	0.4509804	
Measure of fit, t*	2.259685	
Shannon diversity index	1.773085	

The **gross efficiency** is computed as the ratio between the total catch (landings plus discards) and the total primary production in the system. This ratio will vary widely between different systems. Value will be higher for systems with a fishery harvesting fish low in the food chain (e.g., an upwelling fishery) than for systems whose fisheries concentrate on apex predators (e.g., oceanic tuna fisheries). Hence, the index may increase with fisheries 'development'. The index is the ratio between two flows and is thus dimensionless. It is generally much lower than 1.0 (the weighted global average is about 0.0002). The current model value was 0.0014 and in the earlier NWC model, it was 0.0015 indicating a change to a more pelagic fish-driven ecosystem.

The **connectance index (CI**) is for a given food web, the ratio of the number of actual links to the number of possible links. It has been observed that the actual number of links in a food web is roughly proportional to the number of groups in the system. Hence, the connectance index can be expected to be correlated with maturity. The CI did not show much difference between the old and new models (0.42).

The **system omnivory index** is a measure of how the feeding interactions are distributed between trophic levels. The system omnivory index was inspired by the perceived drawbacks of the connectance index. The connectance index is strongly dependent on how the groups of the system are defined. The SOI also did not vary much between the old and new models (0.335). However, the value was much higher than the Karnataka model where it was 0.299 (Mohamed et al 2008) indicating that the number of trophic links in NASE is higher than that in the southern Arabian Sea.

Trophic Flows & Links

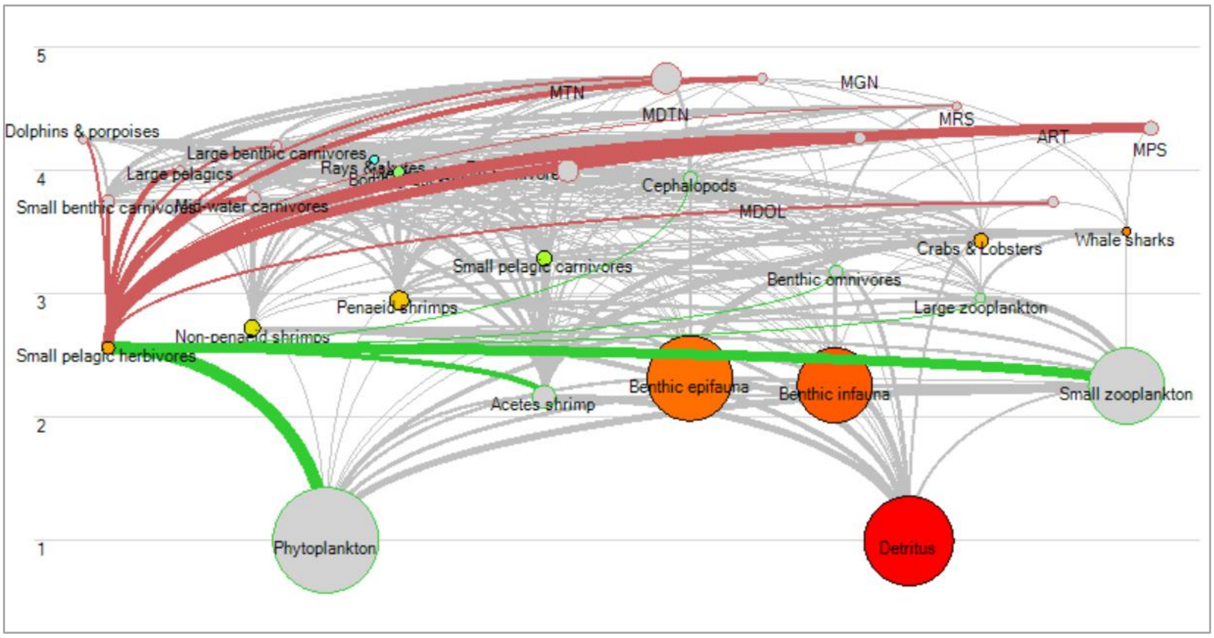


Fig.2. Trophic links in the NASE model show how different ecological groups are connected. The groups (circle diameter) and the links (line thickness) are scaled by the biomass. Trophic levels are from 1 to 5. The highlighted group is small pelagic herbivores (which includes mainly the oil sardine). The Red line indicates usage by other groups including the gears (fleets) exploiting the group and the Green line shows consumption of small pelagic herbivores from different groups.

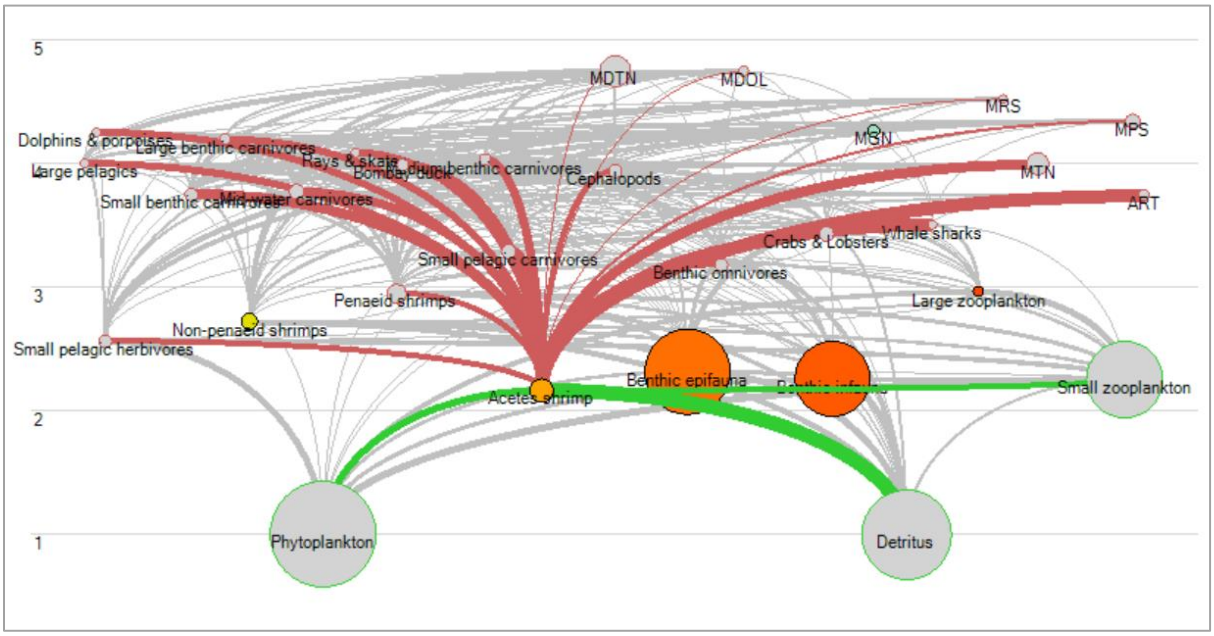


Fig.3. Trophic flows in the NASE model showing links of the Acetes shrimp group which is a keystone species in the ecosystem.

Mixed trophic Impacts

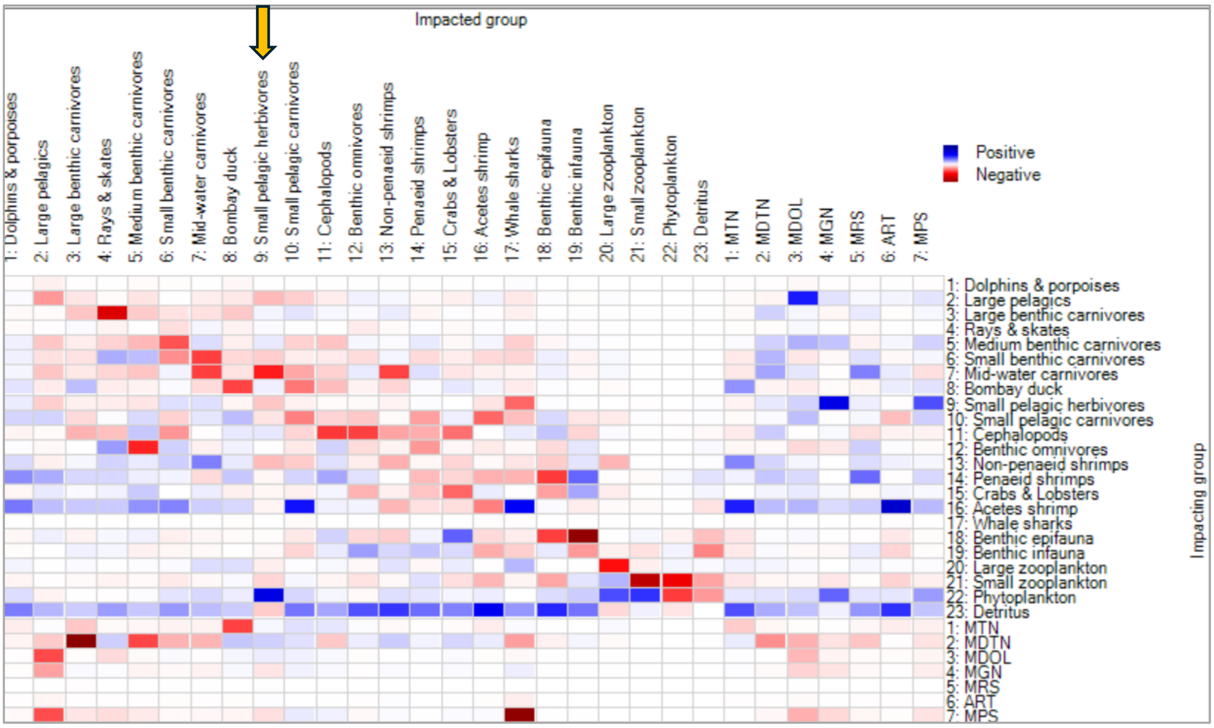


Fig.4. Mixed trophic impact chart showing positive (blue) and negative (red) impacts of different groups. The yellow arrow indicates the small pelagic herbivore group which is highly negatively impacted by the midwater carnivores and large pelagics. Phytoplankton biomass has a positive impact on the small pelagic herbivore group.

Mortalities

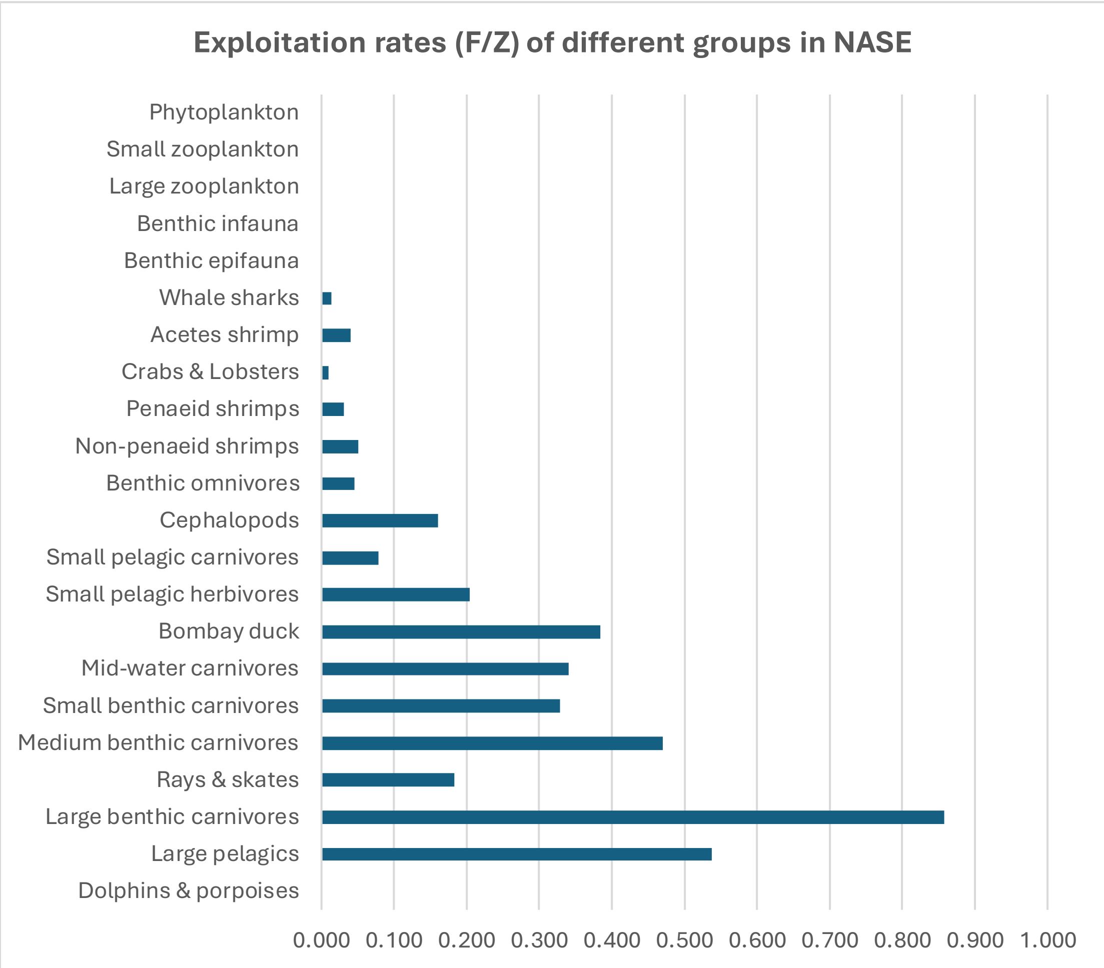
If any component of the system is harvested, a summary of the mortality coefficients can be displayed, which presents total mortality (Z = P/B) and its components. Predation mortality is further broken down on a separate table to show the contribution of each consumer group to the total predation mortality of each prey group.

Table 4. Mortality coefficients (rate/year) of different groups in the ecosystem

	Group name	Prod/ biom Z	Fishing Mortality F	Predation mortality	Other mortality	Fishing mort. / total mort.
1	Dolphins & porpoises	0.200	0.000	0.000	0.200	0.000
2	Large pelagics	3.420	1.837	0.049	1.534	0.537
3	Large benthic carnivores	2.210	1.896	0.073	0.241	0.858
4	Rays & skates	0.750	0.138	0.124	0.488	0.184
5	Medium benthic carnivores	3.220	1.515	1.628	0.077	0.470
6	Small benthic carnivores	4.120	1.353	2.186	0.581	0.328
7	Mid-water carnivores	4.000	1.363	1.992	0.645	0.341
8	Bombay duck	3.035	1.168	1.415	0.452	0.385
9	Small pelagic herbivores	4.200	0.858	3.308	0.034	0.204
10	Small pelagic carnivores	5.210	0.408	4.636	0.166	0.078
11	Cephalopods	5.500	0.885	3.890	0.725	0.161

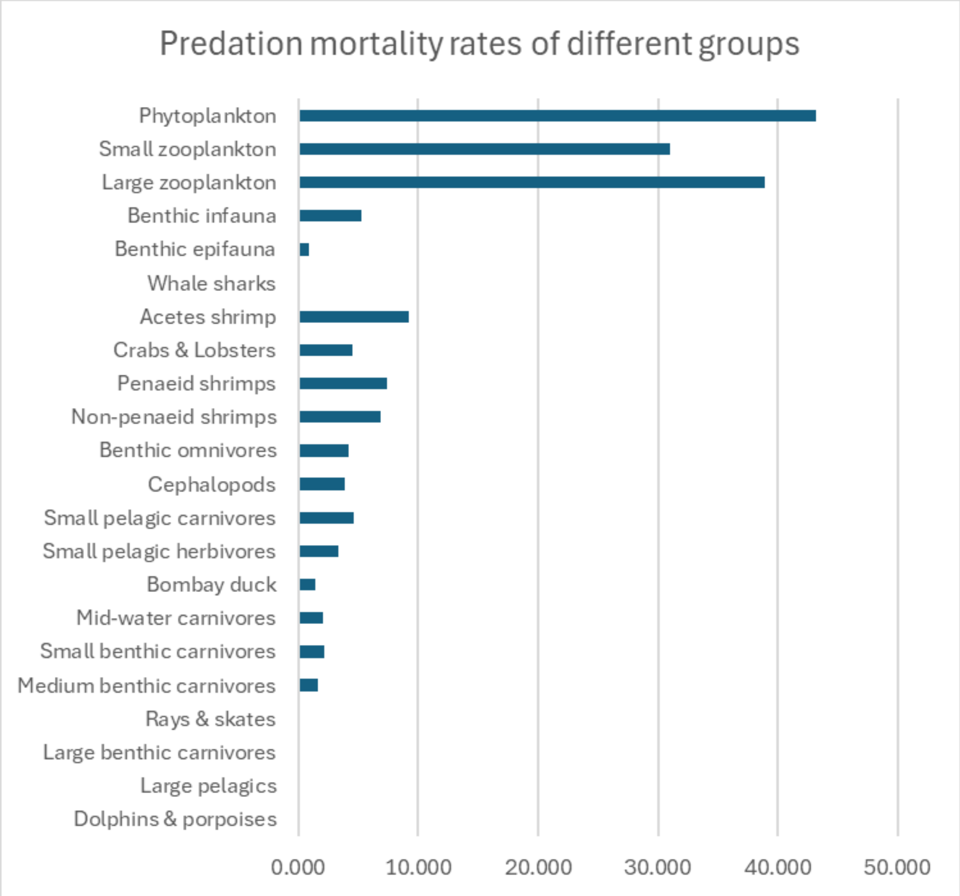
12	Benthic omnivores	4.560	0.208	4.157	0.195	0.046
13	Non-penaeid shrimps	7.500	0.385	6.889	0.227	0.051
14	Penaeid shrimps	7.900	0.239	7.437	0.223	0.030
15	Crabs & Lobsters	5.000	0.046	4.547	0.408	0.009
16	Acetes shrimp	10.270	0.409	9.220	0.641	0.040
17	Whale sharks	2.429	0.032	0.000	2.397	0.013
18	Benthic epifauna	3.900	0.000	0.818	3.082	0.000
19	Benthic infauna	5.755	0.000	5.250	0.505	0.000
20	Large zooplankton	60.000	0.000	38.976	21.024	0.000
21	Small zooplankton	35.000	0.000	30.993	4.007	0.000
22	Phytoplankton	118.300	0.000	43.179	75.121	0.000

Fig.5. Relative exploitation rates (F/Z) of different groups in the NASE



The F/Z values (Fig.5) show that the maximum exploitation rate is for the large benthic carnivore group followed by large pelagics, medium benthic carnivores and Bombay Duck. Small pelagic herbivores comprising principally of oil sardines had low exploitation rates. The predation mortality rates (Fig.6) indicate the high mortality rates of prey groups and the zero mortality suffered by large predators in the ecosystem. Among fishery groups, the Acetes shrimp has the maximum predation mortality as it is the preferred prey of many predators and also because of its relatively high biomass in the ecosystem.

Fig.6. Chart showing predation mortality rates of different groups in NASE.



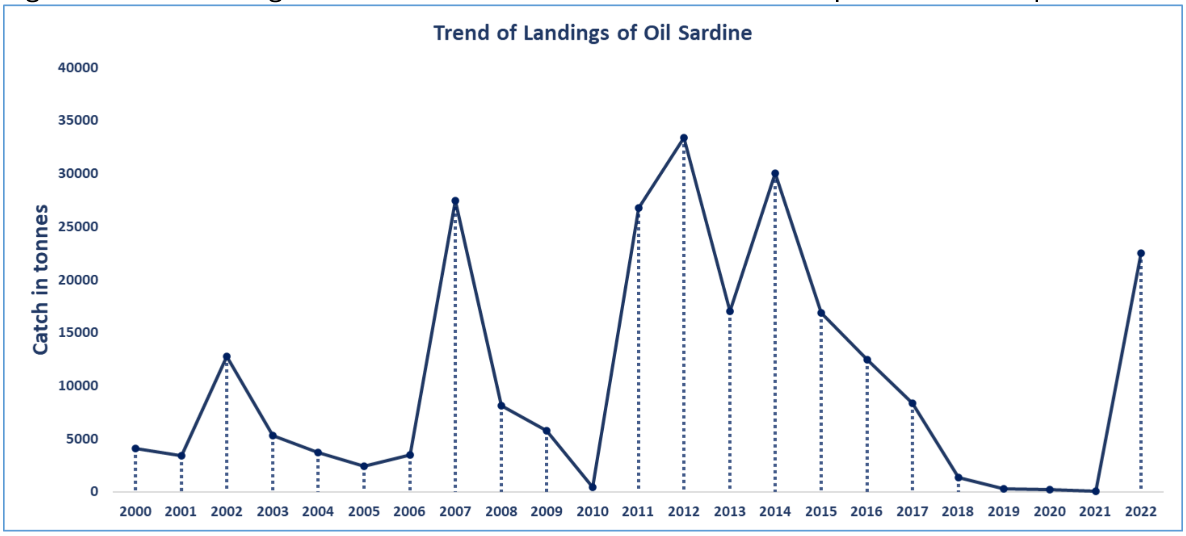
Change in fishery pattern in the NASE

Fig.7. Change in the landings (tonnes per sq km) of different ecological groups between 2008 and 2024. The green box indicates the most significant change.

There has been a significant change in the fishery exploitation pattern as evident from the landings during the two periods (Fig.7). In general, the landings have decreased for almost all groups. Total landings declined by 8% from 4.75 to 4.36 t/km2 during 2008 to 2024. The most significant increase (by 17 times) has been in the small pelagic herbivore group which is mainly composed of oil sardines. The introduction of the MRS gear has played a significant part in this apart from the increased demand and use of oil sardines in the fish meal industry. However, there is no significant change in the average biomasses of the groups.

The landings of oil sardines show a very fluctuating trend (Fig.8), which is quite normal in most small pelagic fishes throughout the world. The recruitment successes of these resources are greatly influenced by the climatic and oceanographic features of the area (Kripa et al., 2018, 2019).

Fig.8. Trend in landings of oil sardine in Maharashtra. Source: compiled for CMFRI publications.



Inferences

From the above results, the following inferences can be made:

1) The NASE is a subtropical marine ecosystem with low ascendancy and high overheads indicating a highly resilient ecosystem.
2) The NASE supports a large number of carnivorous fishes and its current mean trophic level was estimated as 3.43 showing a 2% decline in MTL from that of 2008 (after 15 years).
3) The shift in MTL was mainly because of increased abundance and capture of small pelagic herbivores (particularly the oil sardine, *Sardinella longiceps*). The catches increased by 17 times in 15 years.
4) The gross efficiency of the current model was 0.0014 and in the earlier model, it was 0.0015 indicating a change to a more pelagic fish-driven ecosystem. This also indicated that the ecosystem was becoming more mature.
5) The system omnivory index was relatively high for NASE indicating that the number of trophic links in NASE is higher than that in the southern Arabian Sea.

6) The trophic impacts analysis showed that the small pelagic herbivore group is highly negatively impacted by the midwater carnivores and large pelagics. Phytoplankton biomass has a positive impact on the small pelagic herbivore group.
7) The maximum exploitation rate was estimated for the large benthic carnivore group followed by large pelagics, medium benthic carnivores and Bombay Duck. Small pelagic herbivores comprising principally of oil sardines had low exploitation rates.
8) The current NASE trophic model indicates that the exploitation level of oil sardines is not high, but these resources are subject to fluctuations in abundance caused by climatic and oceanographic parameters, and therefore, excessive fishing effort can result in economic crisis in the sector.
9) Based on this ECOPATH model, simulations can be carried out for better policy decisions.

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