Assessing and predicting fishing impacts and temporal shifts in the fisheries of a Tropical Reservoir in India

M FEROZ KHAN (ferosekhan23@gmail.com)
CIFRI: Central Inland Fisheries Research Institute https://orcid.org/0000-0002-4109-0845
Preetha Panikkar
Central Inland Fisheries Research Institute Bangalore Office
Vijayakumar Leela Ramya
Central Inland Fisheries Research Institute Bangalore Office
Salim Sibina Mol
Central Inland Fisheries Research Institute Bangalore Office
Basanta Kumar Das
Central Inland Fisheries Research Institute
Uttam Kumar Sarkar
Central Inland Fisheries Research Institute
Muttanahalli Eregowda Vijayakumar
Central Inland Fisheries Research Institute Bangalore Office

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Abstract

Food Web Modelling is used as a method for an interpretation of ecological processes and for studying the impact of fishing on biodiversity. An overview of ecological dynamics, as well as the significance of interactions between functional groups was obtained by modelling Ecopath with Ecosim in Karapuzha reservoir, in India. The modelling exercise revealed fishing and predator pre-interaction from the main drivers of this ecosystem. This is the first time in the Indian reservoir system, Ecopath with Ecosim was used to predict temporal shifts caused by fishing impacts. The mean trophic level of the catch was 2.53, not varying much throughout the entire time series and the Kempton Index (Biomass diversity) has declined slightly. The values of the L index were between the reference values of the L index 25% and L index 50%, implying overfishing, the favourable impact of gillnet fishing on some indegenous fish was likely due to the predation release of invasive species such as *C. gariepinus* since this fish was caught by gillnets. Such results suggest more work to determine if gillnet fishing in this reservoir will help mitigate the negative effects of invasive fish. Snakeheads, however, which have high market demand, appear not to be investigating the ability of gillnet fishing in this reservoir to contribute to mitigating the negative effects of invasive species. The modelling of Karapuzha reservoir showed a decline in the predicted biomass of some groups (Eels, Snakeheads, Minor Carps and Barbs) because of trophic response and relationships, and failed to give maximum sustainable yield .The new tools are designed to support policy decisions and incorporated into frameworks to integrate the effects of the stressors mentioned above to promote policy decision-making, particularly for ecosystem-based management (EBM), which tests the environment. The Ecosim routine shows that the presence of major carps does not affect other functional environmental organisations in this state and has predicted those groups and are not detrimental. This study will assist Indian Major Carp Stock Managers in enhancing fish productivity. New tools like this support policy-making integration with the impact of aforementioned stressors in reservoirs. This is the first time the Ecopath with Ecosim reservoir system has been predicted to temporarily shift due to fishing effects. This is the first time. This study helps manage resource conservation and management of informed and ecosystem-based fisheries choices. Our study analysed the social and economic elements of Karapuzha Fisheries which might link all these subsystems within a socio-ecological scenario. The modelling of the Karapuzha Reservoir provided an overall understanding of eco-dynamics and the role of interactions among the fish groups particularly since it eliminates the detrimental effects, in particular it eliminates the detrimental effects imposed by the invasive fish (*C. gariepinus O.mossambicus)*. Gillnet fishing has a positive impact on several indigenous fish.

1. Introduction

Artificial water bodies such as reservoirs are unique as they are composed of aquatic systems with lentic and lotic characteristics. While freshwater fisheries' productivity and overall economic values are small compared to marine, inland fisheries have a key social role to play since these are the income and protein source for rural people in rural locations (Bartley et al. 2015; Smith et al. 2005). Fishing in reservoirs is small-scale and spatially dispersed, helping many subsistence fishermen whose catches are sold and consumed locally. The bulk of domestic fishing is carried out in developing countries such as India where fishing is essential to nutritional security and poverty eradication (Cooke et al. 2016). Several fish species are harvested from tropical freshwater fisheries, typically using similar fishing gear (Smith et al., 2005). In the case of fisheries management in reservoirs, conventional input or output restrictions are applied. (Agostinho et al. 2016, Arlinghaus et al. 2016). This ecosystem is affected by the deleterious impact of invasive species, through trophic In this ecosystem, interactions and fishing are important factors. Furthermore, if these fishing activities are not adequately supervised, they might have an influence on the people as well as the structure and function of the ecosystem (Colletal. 2016). However, reservoir ecosystem management should be done in combination with environmental protection (through dam control), taking into consideration the detrimental impact on the recruitment of fish species. (Oliveira et al. 2015; Arlinghaus et al. 2016). In contrast to agriculture, non-native invaders, temperature changes, and ecosystem alterations are some of the other repercussions of dams (Agostinho et al. 2016; Walsh et al. 2016). Food Web Modelling can be used for interpreting environmental processes and studying the effect of fishing on biodiversity for the ecological aspect Ecological models are highly useful in examining such fishery scenarios because multiple degrees of effort and tropical scenarios exist. This methodology provides expertise to help guide and promote management and policy decisions related to fisheries' ecological aspects. Ecopath with Ecosim is a powerful and far-reaching tool for analysing foodweb structure and how ecosystems impact policy decisions. It focuses particularly on how fishing impacts the ecosystem and nutrient regime. (Christensen and Walters 2004). Hundreds of models and their policies have been dramatically released together over the last few years (Christensen and Walters 2004). Ecosim Simulations Allow the Ability to forecast intricate dynamics, which allows the making of informed decision fisheries reservoirs. A key principle of Ecosystem-based Fish Management (EBFM) is the capacity for impacting the whole ecosystem through fishing and the greater compromise interconnectedness of ecosystems (Link 2010). Changes to the ecosystem generally occur through interactions between fisheries or predators. Fisheries Targeting Prey will also influence declining predator population growth and reproductive success at a sustainable pace (Walters and Martell 2004; Walters et al.

2005; Pikitchetal. 2012). EBFM has become a regular goal and environmental managers are provided with an environmental analysis reacting to different policies (Valette-Silver and Scavia 2003). Ecosystem models are increasingly being employed as tools for environmental prediction when they are simulated. Ecosystem Simulation Ecosystem (EwE) software simulates dynamism, trophic interactions, fishing and environmental factors (Christensen and Walters 2004). Ecosystem impacts of small-scale fishing on the structure and function of Karapuzha's ecosystem, located in a tribal-dominated Wayanad district of Kerala, India, are modelled using Ecopath with Ecosim Software. Reservoir Plays an Integral Part in Giving Protein Source and Livelihood to Several Tribal Fishmen. This study aims to (1) develop the Karapuzha Reservoir Food Web Ecopath Model and calibrate it by using the time series of catch and fishing efforts,(2) Evaluate the effect of fishing on the structure and function of reservoir ecosystems using ecological indicators; (3) simulate fisheries effort and predict maximum sustainable yield and (4) Address ecosystem-based management in fisheries.

2. Materials And Methods

2.1 Study Area

Karapuzha reservoir (Lat.11°37'NLong. 76° 10' 30" E) situated at Wayanad District of Kerala State is a major reservoir suited fishing and for farming. (Fig. 1). It has a canal system to irrigate an area of 5221ha acres of land in Vythiri and Sultanbathery Taluks in Wayanad District. The confluence of Mananthavady and Panamaram Rivers forms the Kabini River. Other tributaries, such as Bhavanipuzha, Karapuzha, and Narasipuzha, originate in the Western Ghats and run through the state of Kerala. This reservoir was built in 1979 with the goal of irrigating roughly 9000 hectares. This reservoir was established on about 9000 hectares of land in 1979. The total water spread area of this reservoir is 855 ha (8.55 sq. km) at Full Reservoir Level (FRL).

2.2 Modelling approach

2.3Ecopath withEcosim(EwE)

Ecopath is a tool designed to build, parameterize and analyse trophic models of aquatic and terrestrial ecosystems (Christensen et al. 2005). It relies on the basic constraints of mass balance to decide the trophic fluxes among functional groups in accordance with its method Polovina (1984) and was developed by Christensen and Pauly (1992). The programme was updated to include a time-dynamic model (Ecosim) and a spatial dynamic model (Ecospace) for direct application in fishery management. This tool has a significant advantage in terms of the applicability of a wide variety of hypotheses, such as thermodynamics, information theory, trophic level description, and network analysis, all of which are important in ecosystem science. It was used to examine a variety of elements of the resulting food web networks (Villanueva et al., 2008). Often, mass-balanced models allow for the comparison of different ecosystems and ecosystems at various times. (Neiraetal. 2004; Panikkar and Khan, 2008; Shannon et al. 2004). Ecosim is a complicated simulation on a system scale, with important parameters inherited from the Ecopath fundamental model. This study examines the transfer of biomass between functional groups as a function of their abundance at certain harvest rates, taking into consideration trophic relationships and foraging behaviour (Pauly et al. 2000). The Ecopath food web model of the Karapuzha Reservoir employs biomass estimates of 14 functional groups, as well as their prey and predators, to depict how the food web linkages within the reservoir system are mass-balanced. This food web model was created from the field data using a similar model criteria and use of Christensen and Walters methods (2004).) Earlier, Ecopath used steady-state assumptions, but is now focused on parameters of equilibrium over a span of one year. With the ecopath parameterization, two master equations are used. The first is to illustrate how to break the production into components for each component. (Christensen and Walters 2004)

Where Bi is its biomass, Bj is the biomass of predator j,(Q/B)j is the consumption/biomass ratio of predator DCji is the fraction of prey i in the diet of predator jYi

is the catch of functional group i, Ei is the migration rate (emigration–immigration), and BAi is the biomass accumulation rate for group i Other mortality is 1 - EEi, where EEi is ecotrophic efficiency of group i, that is, the fraction of yearly productivity P/ Bi expended in the ecosystem by predators and/or exported from the ecosystem by fishing.

$$B_i \cdot \left(\frac{P}{B}\right)_i = \sum_j B_j \cdot \left(\frac{Q}{B}\right)_j \cdot DC_{ji} + \left(\frac{P}{B}\right)_i \cdot B_i \cdot (1 - EE_i) + Y_i + E_i + BA_i \quad (1)$$

$$\left(\frac{Q}{B}\right)_i \cdot B_i = \left(\frac{P}{B}\right)_i \cdot B_i + R_i + UN_i \quad (2)$$

Masterequation 2 shows the energy surplus of each group i, where its consumption rate Q/BI equals the production rate P/ Bi, the non-assimilated food UNi and respiration RI: The Fig. 3 shows Biomass observed (points) and predicted (line) by EwE model for the main species of Karazpuha. Biomass in tonnes /km^2(Fig. 2)depicts the time series of observed total catch (tonnes/km^2/yr), mean trophic level of catch (TLc), L-index for Karapuzha and biomass diversity (Kempton Index).Table 1 List The species and/or functional groups included in the model. Based on The model is mass-balanced on the fundamental assumption that total input equals total output across all groups in the system (Banerjee et al. 2017). Biomass dynamics are described in various coupled differential equations in Ecosim. Since it is well documented, it will not be clarified here. (Christensen et al. 2005). The Static Ecopath Model presupposes the energy balance between functional groups (Alvarado,et al. 2019)and the selected year was 2008 during which information on local fish has begun to be obtained, as the basis for the time dynamic ecosim model).We have been able to calibrate this temporal dynamic model with the time series(2008–2011).We simulated different fishery scenarios with 30 years from 2011(Fig. 3).The following sections describe the theory and methods used in our modelling approach.

Table 1
Input and output parameters of the Karapuzha reservoir model

Group name	Trophic level	Biomass (t/kmÂ²)	Production / biomass (/year)	Consumption / biomass (/year)	Ecotrophic Efficiency	Production / consumption (/year)	FlowToDet (t/kmÂ²/year)	Omnivory index
Aquatic Birds	3.79	0.765	0.33	0.84	0	0.39	0.381	0.147
Clarias gariepinus	3.38	1.493	3.5	10.8	0.144	0.32	7.7	0.097
Eels	3.42	1.395	4.35	9.5	0.232	0.46	7.308	0.069
Snakeheads	3.63	2.734	1.77	4.9	0.362	0.36	5.769	0.026
Major Carps	2.79	3.58	3.06	6.26	0.901	0.49	5.565	0.169
Minor Carps	2.57	3.939	2.55	15.6	0.827	0.16	14.03	0.245
Barbs	2.38	3.288	5.37	50.5	0.418	0.11	43.49	0.236
Minnows	2.75	3.975	2.01	31.5	0.988	0.06	25.14	0.188
O.mossambicus	2.32	2.61	4.65	30.3	0.729	0.15	19.11	0.218
Crustaceans	2	3.7	3.53	25	0.639	0.14	23.22	
Zoobenthos	2	11.88	14.45	43	0.665	0.34	159.8	
Zooplankton	2	14.25	23.5	60	0.361	0.39	385	
Macrophytes	1	9.562	34		0.726		89.14	
Phytoplankton	1	29.7	46.76		0.638		502.1	
Detritus	1	13			0.431			0.364

2.4 Data

The information gathered during field studies conducted was used. The fish lengths were converted into biomass using the isometric growth equation: W = a L^b, with wet weight, l being the standard length, an intercept, and b being the slope when a log transformation determines the weight-length connection. (Alva-Basurto and González, 2014).The values are collected from the field study and some from Fishbase (Froese and Pauly 2006). Biomass (B; tons/km^2) values were derived from single-species stock evaluations, estimated through dividing catch with fishing mortality. The consumption (Q) was estimated using an empirically constructed equation that included morphometric data, ambient water temperature, and nutrition data (Pauly 1989, Palomares and Pauly 1998). Based on our research into food and feeding patterns, a fish diet matrix was created for each species. The Unknown Biomass Non-fish groups were derived from comparable ecosystem research. By Adding Natural Mortality Fishing Mortality, the P/B ratio, the total instantaneous mortality was obtained (Paul 1980). P/B and Q/B Values are for the fish groups derived from Fishbase (Froese and Pauly 2010). There are rather poor catches of various species in Karapuzha. The Nellarachal Fish Cooperative society provided the catch data. Figures for fishing encompass a 7-8-year period of exploitation. This study employed the Karapuzha Reservoir Ecopath model, which covers a period of time. Fishfunctional, one detritus, and two primary producers were among the 14 functional groupings in 2008.

(phytoplankton and macrophytes). While the Ecotrophic Efficiency (EE) values were below one, we considered the Karapuzha Reservoir to be balanced (Christensen et al. 2008). We have made use of evaluation of input parameters, biomass, and vital rates with a pre-balancing tool (Link 2010). The food web was displayed with the following key input variables: biomass (B), production/biomass ratio (P/B), consumption/biomass ratio (Q/B), diet composition, and fishing. In the food web model, the following essential input parameters were displayed: biomass(B), the production/biomass ratio (P/ B),the consumption/biomass ratio(Q/ B).

2.5 Ecosim module

This module provides a system-level dynamic simulation capacity that is focused on the Ecopath template with core beginning parameters. Observing time and harvest rates as they change with biomass. Ecosim uses a system of differential equations that expresses biomass flow between groups (Walters et al. 1997; Christensen and Walters 2004; Christensen et al. 2008; Heymans et al., 2016). The root of ecosim is from the basic ecopath equation which is where dBi / dt refers to the biomass transition from the functional group(Bi)overtime t, gi is the net gross efficiency (production/consumption ratio), Qji,

$$\frac{dB}{dt} = g_i \sum_j Q_{ji} - \sum_j Q_{ij} + I_i - (MO_i + F_i + e_i) \cdot B_i \quad (3)$$

consumption job, Qiji The consumption by, Ii is the immigration of group i, MO i, Fi and ei are the non-predation natural mortality, fishing mortality, and emigration of group i ,respectively. The consumption rates, Qij, are estimated based on the foraging arena theory when biomasses are divided into vulnerable and non-vulnerable states. The transfer efficiency, vij, between these two states determines predator-prey interactions (bottom-up, mixed or top-down (Christensen etal.,2008; Ahrenset et al., 2012)

$$Q_{ij} = \frac{a_{ij} \cdot v_{ij} \cdot B_i \cdot P_j}{2v_{ij} + a_{ij} \cdot P_j} \quad (4)$$

While Aij is an active predator rate in search of, feeding on prey I, Bi is a biomass of Prey Pj is a biomass for predators and Vij is a vulnerability of prey in predators. Flow control type i.e., vij = 2, vij = 1 and vij = 2,which represent mixed flow control, a bottom-up, and top-down control, respectively (Walters and Martell 2004; Christensen and Pauly 2004; Ahrens et al.2012). The parameters most relevant for the calibration of Ecosim models are the exchange rates of vulnerability (vij) from prey to predator (Chagaris et al 2015).The rate of predation Once the predator concentrations in its Ecopath base numbers change, mortality remains roughly stable at lower values of vij(2). We conducted a study to alter the vij is to reduce the total squared deviation (SS).)between the predicted and observed biomass (Pranovi and Link 2009).In a follow-up diagnostic, we assessed how communities reacted to exceptionally high fishing and fishing mortalities. Furthermore, the fishing mortality rates in Ecosim were compared to the value estimate in the single-species assessment model at maximum sustainable yield. (the time series the data captured between 1988 and 2011 was used as effort. The Ecosim module compared the data observed with the predicted data for the evaluation of the fit of the model. Ecosim's model shows the number of squared deviations from the predicted log caught (Christensen et al. 2008; Heymans et al. 2016). With a compatible Plug-in, the step by step mounting process was used .The fishing effort was described by the number of days (sum of fishing days of all fishers per year). To evaluate the fit of the model, the predicted and observed catch data was compared using the Ecosim module. The model used by Ecosim is the number of squared deviations from log catches from predicted ones (Christensen et al. 2008; Heymans et al.,2016) The step-by-step fitting process was used with an integrated plug-in (Scott et al. 2016).In this method, the observations are automatically searched to best fit over a set of hypotheses to evaluate fishing effects (via effort timeseries/fishing mortality), shifts in prey predator dynamics vulnerability settings) and primary production variation (PP anomaly: represents changes in primary production that can be either time-series or time observations). The three variables (following Mackinson et al. 2009a) was presented in each hypothesis tested. This method consisted of 7 steps in general (Table 1). This method uses Akaike Information Criteria (AIC

AIC = nlog (minSS/ n) + 2k. (5)

to check statistical hypotheses(Akaike,1974)associated with changes in predatory dynamics (also called vulnerabilities: min SS is the minimum square sum based on the relationship between anticipated and observed data sets; k is the number of data sets. parameters.

Primary Production Changes (P anomalies, given P spline points for time series smoothing); fishing impacts and permutations of the factors mentioned above (Table 1). AIC is a model choice method which penalises the application of too many variables for selecting the "correct" version (one that provides the lowest AIC) which takes into consideration the best fit. The second order, Akaike Information Criterion (AICc), was calculatedas follows and was used in the present study:

AICc = AIC + 2k(k-1)/(n-k-1)(6)

for the dataset's limited sample size in our situation, the fitting process has been performed five times. The indicators in the Karapuzha Reservoir are calculated using the "best"fitted models when the time-dynamic fitting process is done. The protocol begins using ananalysis of reference templates (fishing effects, predator-prey-interactions, PP- anomalies), then measuring different combinations of these three variables (fishing effects, predator-prey interactions, and PP- anomaly). Using a weighted sum of squared differences (SS) and Akaike Information Criterion (AIC), the difference between model.The estimates and time-series observations that best fit are determined (Wagenmakers et al. 2004).During the Fitting Process, we estimated 11 parameters (vulnerability).Once the model with the lowest AIC was established, we determined three metrics for the assessment of the ecological effect of fishing: trophic level of catch (TLc), biomass diversity Kempton index, Q), and loss of production caused by fishing (L index). For the mean trophic level of fishing (TLc) reflected a fishing strategy which accounts for trophic levels of the species in the catch (Christensen1996; Paulyetal.,1998). This indicator is the average TL from the species in the catches:

$$TL_c = \frac{\sum_{i=1}^{m} Y_{ik} \cdot TL_i}{\sum_{i=1}^{m} Y_{ik}} \quad (7)$$

where is the catch of functional group i in year k, and TLi is the trophic level of the functional group i. The index of Kempton (Q) is a biodiversity measure (Kempton 1976) Christensen et al. 2008, describe the slope of the cumulative abundance group curve. The indices calculate mortality impacts in ecological models, whether from fishing or climate change. Biomass diversity, considering only organisms with trophic levels above 3 (Ainsworth and Pitcher 2006; Christensen et al. 2008).According to Libralato et al., 2008,“By calculating the the theoretical loss in secondary production was measured”. For quantifying the secondary production loss because of fishing operations, this index contains both ecological properties (PP and transfer efficiency) and fishing features (trophic level of catch and PP required)w here P1 shows the production of autotrophic and detritus(P1 = PP / FD, PP is the measured net PP and FD is detrital flows) TE is an average transfer efficiency for trophic levels, PR and TL, respectively, are primary production and trophic levels for functional group i. For Ecosystem-based confidence intervals, L index 50 and Lindex75%were used (Libralato et al. 2008). The dynamic module Using the Karapuzha reservoir model, Ecosim was utilised for a set of fisheries simulations to examine probable changes in ecological attributes as a result of increasing or reducing fishing activity.. The various scenarios were simulated by changing, at the same time, the fishing effort of gillnets and by increasing fishing effort by 25,50,75,and100%from baseline adopted in 2008 as a reduced fishing effort value of 10% and 20%.From 2011to2041(30 years)simulation were carried out. We also made two simulations with fishing mortality that yielded maximum sustainable yield MSY) projections from the EwE programme. After the model calibration, Ecosim Estimated the FMSY and MSY for each of the primary target species. For each functional group, we have calculated two kinds of FMSY and MSY: stationary and full compensation with Ewe. In the stationary method, we obtained the MSY and FMSY figures for each group fished using the Ecosim model of equilibrium for a range of fishing mortality values, thus retaining steady other groups of biomass (Fig. 6) This method assumes that the availability of food and the consequences of predation are both predictable, and that the availability of food and the consequences of predation are both predictable. Fish mortality of other groups in the The base values of ecopaths are constant. Differences are allowed with the full compensation method. In the biomasses of all groups and only in response to changes induced by fishing, We determined the FMSY equilibrium and full compensation for each species (Walters et al. 2005).In two further simulations, we used the expected full compensation for FMSY and stationary FMSY. We analysed patterns of biomass and catch in reference (MSY and biomass thresholdand target) for the of these FMSY scenarios on the key targeted organisms overfishing of resources showing fishing mortality above the FMSY (Stationary) reference points were discovered. We came up with FMS equilibrium and full compensation for each species Walters etal.,2005).For each species, we followed the process of Forrest et al. (2015), The biomass limit/target reference points for the classification of stocks in terms of their biomass levels were determined to be 30% and 50% of the biomass in the first year (0.3B19880.5B1988), respectively. The First Year Of The Model. Forrest et al.2015 found the lowest biomass proportions in the first year (20% and 40%). We Raised These Values: We already had pre-built fisheries on the Karapuzha Reservoir before 2008, to represent a higher level of overfishing.

3. Results

3.1 Time series from the model fitting:

When baseline and trophic interactions were combined, we obtained significant results in our model fitting. (Step2 in Table 2 & Table 3). The second major improvement resulted from the addition of trophic linkages to fluctuations in PP anomaly alone (step 4 in Table 3) from the baseline (AIC decreased by 8% more). Bottom-up control interactions and low vulnerabilities drive the Karapuzha reservoir ecosystem, according to Ecosim results. (2). The model with the lowest AICc (23.8) explained nearly 17% of the variance in the catch time series when compared to the baseline model, indicating that fishing and predator-prey interactions (represented by (represented by 2 vulnerability parameters;). Following the fitting procedure, the functional groups with modified vulnerability levels (v) were *Clarias gariepinus* = 8;EelsV = 7; For *O.mossambicus, C.gariepinus*, and Major carps, the model exaggerated catches. Data on minnows was also not a good fit.

Table 2
Steps of model fits following Mackinson, which include trophic interactions, fishery and environmental driver(Primary productivity)

No.	Steps	Description
1	Baseline	Trophic interactions with default vulnerabilities (Prey-predator). Drivers do not include fishery or environmental data
2	Baseline and Trophic interactions	Different vulnerabilities are used to assess trophic interactions. Drivers do not include fishery or environmental data
3	Baseline and Environment	PP anomaly is used as a driver. No fishery data used
4	Baseline, Trophic interactions and environment	No fishery data used
5	Fishery	Driver is Fishing effort. Trophic interactions set at Default and environmental data not used
6	Trophic interaction and fishery	Environmental data not used
7	Trophic interactions, environment and fishery	Jointly all components included as drivers in the model

Table 3
Results of the temporally dynamic fitting procedure of the Ecopath model following the procedure suggested by Mackinson50 (Table 1). Vs is the number of vulnerabilities included in each iteration, sPP the number of primary production spline points (for smoothing of the time series) k is the number of parameters and %IF is the improved fit compared to the baseline AICc. Vs and sPP are shown only for those models with the lowest Akaike Information Criterion (AICc). The "best" models (shown in bold and italics) are the ones yielding the lowest AICc and the one used to calculate model-based indicators

Steps	Vs	sPP	SS (min)	K	AICc	%IF
1. Baseline	0	0	80.92	0	28.7	
2.Baseline and Trophic interactions	2	0	52.05	2	23.8	-17.0
3.Baseline and Environment	0	2	80.86	2	33.5	16.7
4. Baseline Trophic interactions and Environment	2	2	52.50	4	30.9	7.7
5. Fishery	0	0	277.5	0	55.8	94.4
6. Trophic interactions and Fishery	2	0	114.3	2	41.1	43.2
7. Trophic interactions, Environment and Fishery	2	2	4	5	48.2	67.9

3.3 Fishing impact indicators with Ecosim

The total catch changed throughout time, with some maxima in 2006, 2008, 2011, 2013, and 2016. (Fig. 2). Although the catch grows as the fishing effort increases to a certain point (Fig. 4), a 10% reduction in the current fishing effort achieves the maximum catch in this reservoir. The mean trophic level of the catch in 2008 was 2.53, varying from 2.51 to 2.55 until 2008, there was a slight rising tendency over the whole time series (Fig .2). Biomass diversity (Kempton Index) has increased. (Fig. 2). Biomass diversity (Kempton Index) has declined since2015, but with a slight drop. The L index values were between the reference levels of L index 25% and Lindex50%, suggesting overfishing (Librel et al. 2008).

3.4 Simulation of fishing scenarios and maximum sustainable yield

Increased fishing effort scenarios resulted in bigger catches and lower L index values with simulations. (Fig. 5).In Scenes With Improved Fishing Efforts, the Mean Tropical Level (TLC) of the catch was smaller than the baseline. In all situations, biomass diversity increased compared to the baseline scenario. Under all simulated scenarios, the change in total catches did not vary at a significant rate. Figure 4) No significant rate of change was shown in the L index except for lower fishing effort scenarios. In the stationary mode, the estimated maximum sustainable yield (MSY) from the full compensation mode was greater than the estimated MSY, in Crustaceans, Eels, *O.mossambicus*, Snakeheads, and *Clarias gariepinus*, whereas MSY in stationary mode is used for other functional groups. showed higher values. For a decade in the Ecosim equilibrium analysis, catches were over MSY in the case of *C.gariepinus* (Fig. 6). Barbs are overfished, and a 20% reduction in fishing effort isn't enough to save them. Crustaceans produced a yield below MSY in full compensatory mode. (Fig. 6) With increased fishing efforts, the findings of the simulation revealed a small rise in catch for Eels, Minnows, and Crustaceans. These findings could have a big impact. show that the biomass levels for these species are now too low to support higher fishing pressure. The fishing mortality of *O.mossambicus*, *C.gariepinus*, and snakeheads were high at the start of the time series. This increased mortality, combined with the negative consequences of climate change and ecosystem changes, resulted in low biomass levels. Despite the fact that these considerations are sufficient to prevent these species from being overfished, fishermen have not been cautioned because both *O.mossambicus* and *C.gariepinus* are invasive species. Between 2016 and 2045, the simulated biomass of *C.gariepinus*, Eels and Minor carp were higher under decreased effort. The biomass increased with increased fishing efforts ins cenarios(Fig. 7),and for other functional groups, the biomass increased with increased fishing efforts. Biomass generally exhibits considerable changes over simulated years and scenarios. As fishing efforts double, *C. gariepinus* becomes overexploited. This fish will be intensively fished beyond 2020. Over fishing efforts beyond 2035 will lead to a sharp decline and this fish may disappear from this reservoir by 2040. Major carps are overexploited, and frequent stockings are needed to keep the fishery alive. Minor carps are overfished, and a 10% reduction in fishing effort will aid in their recovery. Eels are underexploited and have a lot of room for expansion in this reservoir, but snakeheads are overexploited. Barbs and minnows are also confirm projected biomass within their limit (0.3B 2006) and target (0.55B 2008) (Fig. 7). The stock of crustaceans is very high, and increased fishing efforts will yield more catch throughout the simulated period, except in 2023 and 2035. The stock status was for *C. gariepinus*, which had estimated biomass below both the biomass limit and the target for 15 years beginning 2020. After 2020, the estimated biomass for this stock will go below the biomass target, but only in the scenario is in full compensation mode until 2035, and the decrease is complete by 2040. In the case of Barbs, the biomass will be revived after 2030. Beginning in 2020 and lasting until 2028, the Biomassis will be less than 0.30 percent. However, the biomass is is is below 0.3 percent and in full compensation mode throughout the simulation time. However, under scenarios with decreased fishing efforts for eels, we observed higher biomass levels. In the simulations that used FMSY values, the predicted biomass was lower than the limit for *C. gariepin*us, snakeheads, major carps, Minor carps, and Barbs (Fig. 7*). Puntius ticto* was the most popular of the barbs dominating, followed by *P. dubois, P. sopho*re, and *P. sarana*, resulting in the formation of a fishery in the reservoir. These fishes feed on Zoobenthos, zooplankton, phytoplankton, and benthic algae are all examples of zoobenthos (Panikkar and Khan 2008). Crustaceans remained at or above biomass targets under FMSY full compensation and stationary conditions, respectively, throughout the. simulation period, except for a few years. Estimates of declining mortality that resulted in maximum sustainable yield (FMSY and MSY) were less for the stationary mode than for the full compensation mode with the exception of snakeheads, minor carps and minnows,. The estimated biomass reveals that the only stocks that were below MSY were Snakeheads. major carps, minor carps, and *O.mossambicus* were caught between 2012 and 2016. Eels were caught below the MSY level in 2009, 2012, 2014, and 2019. This is not due to overfishing, as the results show that other variables are at play. Apart from the effects of fishing, it impacted the population dynamics. There was considerable flooding in the state of Kerala in 2018, which may have impacted the Eels.

4. Discussion

4.1 Ecopath model of Karapuzha Reservoir

The modelling exercise showed that in comparison to other reservoirs, the Karapuzha Reservoir Foodweb is maintained by a detritus-based chain with a high recycling rate.. The favourable impact of gillnet fishing on individual species was most likely attributable to the predation release of invasive species, such as *C. gariepinus*, because they were captured in gillnets. Such findings imply that more research is needed to study the possibility of gillnet fishing in this reserve to contribute to minimising the harmful effects of invasive species. Gillnets are multi-species gear that capture both invasive and indigenous species.. Thus, increased gillnet fishing efforts may be investigated to see if they are successful management action based on their impact on species composition, interactions between both species, and capture rates., and catch rates using future simulations. This could aid in reducing the negative effects of invasive species on fishing activities in this reserve (Philippsen et al. 2019). Barbs and tilapia had the highest fishing mortality rates in the

Ecopath models, as predicted. (2006),. However, there was no organised fishing during this period, and the fish are commercially important in this part of Kerala. Fishing mortalities in the Karapuzha Reservoir were low for species that are currently mostly targeted (SnakeHeads, Major Carps, Minor Carps, and Eels), as fishers only began to pursue such species. Following that, major carps were stocked, and a Tribal fishing society was formed, and tribal fishermen were given coracles and nets as part of a government scheme to help them with these fishing tools, resulting in increased fishing efforts. During the impoundment, the reservoir has trophic bursts and fish biomass increases, so fishing mortality was low in this reservoir. Unlike in Italy's Baipur Reservoir in Brazil, where fishing is abundant during the initial heterotrophic phase, the phase is characterised by strong organic matter intake and a growth in terms of species richness and abundance (Agostinho et al. 2016). These circumstances give rise to new possibilities.. These conditions lead to new lentic fisheries being exploited and local fishing opportunities being improved (Petrere 1996).There is an alternate management measure in this period to minimise large fish deaths by the amount of new fishermen entering fisheries right after reservoir construction.

4.2 Ecosim model of Karapuzha Reservoir

The primary factors illustrating capture patterns in the Karapuzha Reserve were fishing impact and predator-prey interactions. There has been a mix of flow control (v = 2) in the model of this reservoir with the lower AICc and AIC bottom-up and top-down controls. The shift from migratory and large species to stationary and medium-sized species in fish assemblage is envisaged after impoundment (Agostinho et al. 2016). Hence we would also predict a decrease in the mean trophic level of catch, yet we are. As a result, a decline in mean trophic level of catch is yet to be predicted; (Philippsen et al. 2018). A large piscivorous (*C. gariepinus* and snakeheads*)* were among the most commonly captured species from the beginning of the time period, along with *O.mossambicus..*It feeds largely on detritus, dipterans, zooplankton and zoobenthos and is among the most prominent in the Region of the south Indian reservoirs (Khan and Panikkar 2009). They will be replaced The is a slight decline in TLc by Major carps after socking this reservoir is of great ecological importance. The three Indian Majors Catla Catala, Labeo Rohita and *Cirrhinus mrigala* are significant but these do not breed Species Indian Reservoirs Production for enhancement of fish production This Fish are stocked in Indian reservoirs.. Although the L-index has not changed substantially over the years, this indicator suggests a significant risk (between 25 and 50%) of overexploitation resulting in ecological consequences (Libralato et al. 2008) .There was not much Change In Biomass Diversity (Kempton's index).

4.3 Simulation of fishing scenarios and highest sustainable yield

For most functional groups, FMSY and MSY achieved complete compensation at greater levels than the MSY reference point (Mackinson et al. 2009), and the model provides increasing surplus output in response to increasing levels of fishing mortality. However, these FMSY estimates were larger in stationary mode compared to full compensation for several taxa, such as snakeheads and carp, likely due to their underestimated sensitivity. (v = 1;low predators influence).The full compensation method contains indirect, compensating reactions to changes in the number of target species (Walters et al. 2005). ecosystem's ability to (Walter et al. 2005). The capacity of the ecosystem to take into account predation loss demands surplus production to reach MSY (Mackinson et al. 2009). The impact of indirect compensatory reactions, which would provide identical FMSY estimations for both the stationary and full compensation modes, might thus be minimal. Ecosim may overstate FMSY if the vulnerability of the groups is calculated at v = 2 and the level of biomass in the Ecopath base scenario is significantly lower than the unfished biomass (Christensenetal.2008). The projected biomass indicates that between 2012 and 2016, major carps, minor carps, and were the only stocks under MSY. There is significant scientific evidence, as well as fishermen's indigenous knowledge, that dam activities have a negative impact on fisheries. (Hoeinghaus et al. 2009; Oliveira et al. 2015). While there are no environmental anomalies in our ecological models, there is solid scientific evidence and fishermen's indegenous knowledge on the negative effect of dam operations on fishing yield. (Agostinho 2016; Philippsenetal. 2016).

In terms of food resources, the ecological overlap between invasive and native cichlid species is quite minimal, owing to differences in dispersal patterns across the day of the several species under consideration. This may be compared to findings made in Parakrama, another tropical reservoir in Sri Lanka, Panikkar and Khan2008). Many state governments in India have banned the culture of *C.gariepinus*. Amid the This fish entered the reservoir via fish culture ponds due to rain and floods. Although this fish is unwanted by many it is more expensive than tilapia since there is a market in some locations.. Snakeheads, on the other hand, which have a high market demand, do not appear to be in a position to sustain greater fishing attempts. Considering, the predicted biomass simulation exercise for the Karapuzha reservoir, the notion of FMSY estimation, which is compensatory owing to tropical response and relationships, the simulation exercise for groups (Eels, Snakeheads Minor Carps and Barbs) did not generate maximum sustainable production after applying for both stationary and full compensation FMSY. Also, higher fishing pressure on the non-native *C.gariepinus* would help manage its harmful effects on indigenous species. Karapuzha showed a general decrease in the mean trophic level of the catch.. The findings show excessive fishing mortality and food web erosion have been observed as a result of fishing. With rapidly increasing anthropogenic pressure on inland water, there is a substantial risk of the system beyond the "point-of-no-return," severely limiting possible ecosystem-service possibilities for future generations, endangering biodiversity and possibly the economy. Climate variability and changes in fishing pressure should improve modelling approaches, as indicated in this projection. They work in tandem with changes in the global climate (Mora,C.et al. 2013). The assessment of their cumulative temporal impact was not reported, which is difficult because human stress fluctuates over time (Halpern,B.et al. 2015). The impact of these stressors is rapidly increasing, and it is important to assess interactions between humans, the environment and organisms, and how these dynamics affect the sustainability of the products and services offered.

Ecosystem modelling techniques can assist in the analysis and identification of possibly relevant choices for sustainable human activities and healthy aquatic environmental protection. Given the fact that climatic variability, as well as changes associated with fishing demands, should enhance methods such as the one presented here are necessary to forecast the effect in the above-mentioned pressures. Despite its shortcomings, this model may be able to describe temporal trends in fisheries across the Karapuzha reservoir.

5. Conclusion

An overview of the complexity of ecosystems and the significance of interactions between the fish groups was obtained by modelling the Karapuzha reservoir ecosystem. In particular, since it eliminates the detrimental effects imposed by invasive fish (*C. gariepinus O.mossambicus*). Gillnet fishing has a positive effect on several indigenous species. Thus, further research is needed to examine how invasive species may be controlled with gillnets.. The decrease in their number in reservoir Karapuzha is a key step forward for invasive species reduction. We recognise that for invasive species this is a significant step towards the eradication of their population in Karapuzha reservoir. as well as invasive species. The decrease in their number in reservoir Karapuzha is a key step forward for invasive species However, our findings are important, including comprehensive evaluation, placing it from an ecosystem perspective by analysis including functional groups and fisheries and the impact of intensive fishing. Our research analysed the biological characteristics of Karapuzha fisheries and further investigations on the social and economic components of Karpuzha fisheries that may connect all of these subsystems within the context of a socio-ecological system for EBFM. However, there should be numerous further stages to develop shortly giving improved information supporting regional conservation policies and strategies First, space-time analysis can detect ecological trends which can help spatial management directly(for example, prioritization and promotion of contacts between scientists and policy-makers, environmental managers, conservationists, politicians and the general public. Second, inclusion is the driving force of human disturbances (e.g., aquaculture, invasive species, climate change, acidification, pollution).This modelling activity is necessary to boost its dependability as simultaneous cumulative impacts affect ecosystems. New scientific tools were created to render this forecasting more effective as habitats have overlapping collective threats. These tools can promote policy decision-making by integrating the effects of the stressors mentioned above in common frameworks (particularly concerning the approach to ecosystem-based management (EBM), which tests the environment.

Declarations

Ethics approval and consent to participate:

The submitted manuscript is not submitted in any other journal.

This manuscript doesn’t involve the use of any live animal or human data or tissue. Fish samples were directly obtained from the commercial catches were used.

Consent to Participate: Not applicable

Consent for publication: The approval for submitting manuscript received from ICAR- Central Inland Fisheries Research Institute.

Availability of data and materials: Data will be available based on request and supporting files are also submitted.

Competing interests: All authors of this manuscript have no conflicts of interest about the submitted manuscript.

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Authors contribution

MFK – Drafted the manuscript and analysed data**, PP –** Collected fish catch data **, VLR –** Analysed phytoplankton**, SSM-** Analysed diets**, UKS –** Analysed Zooplankton **BKD -** Conducted experimental fishing**, MEV-** Collected fish samples from landing centres

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Figures

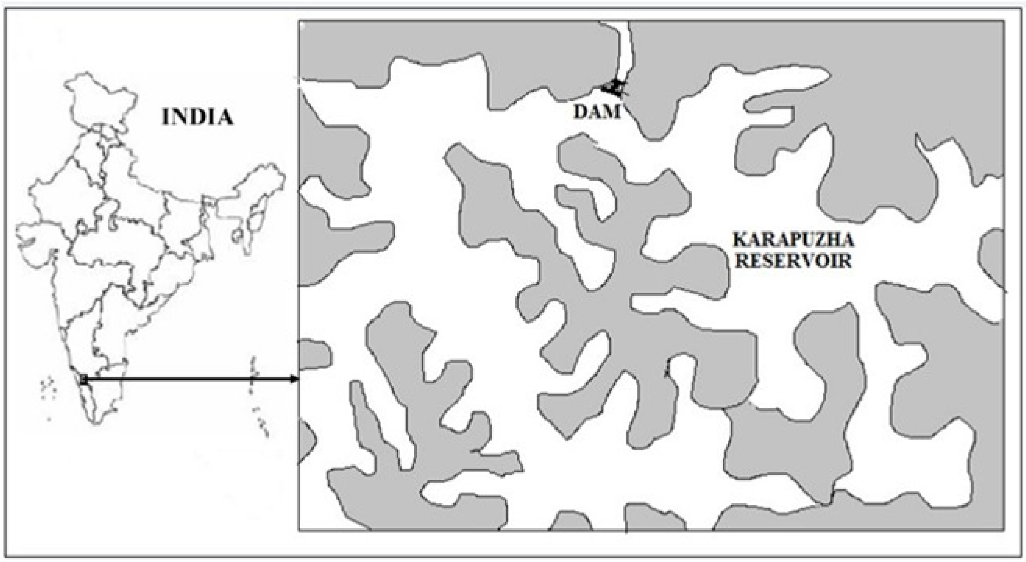

Figure 1

Karapuzha Reservoir, in Wayanad District of Kerala, India

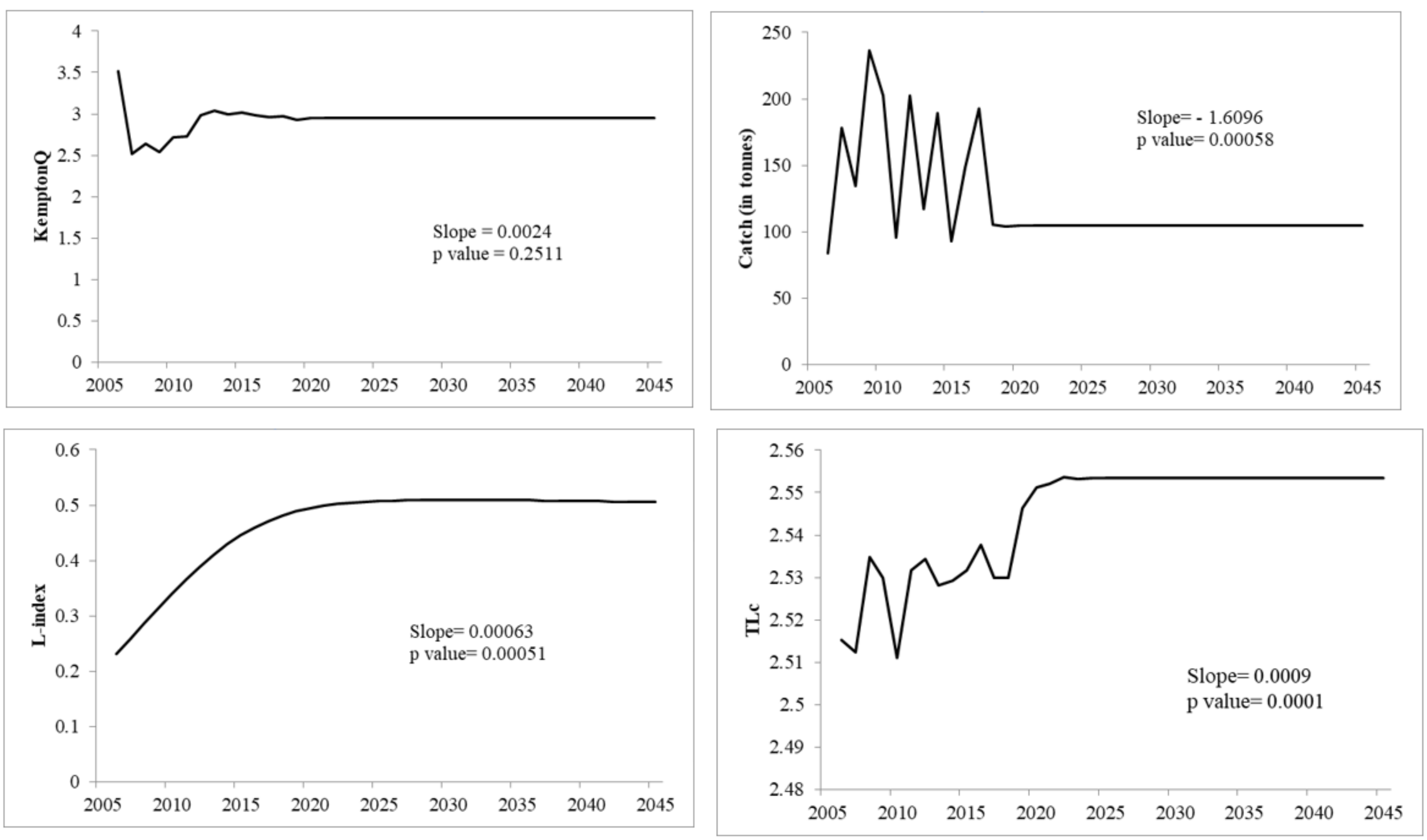

Figure 2

Time series of observed total catch (tonnes/km^2/yr), mean trophic level of catch (TLc), L-index for Karapuzha reservoir model and biomass diversity (Kempton index).

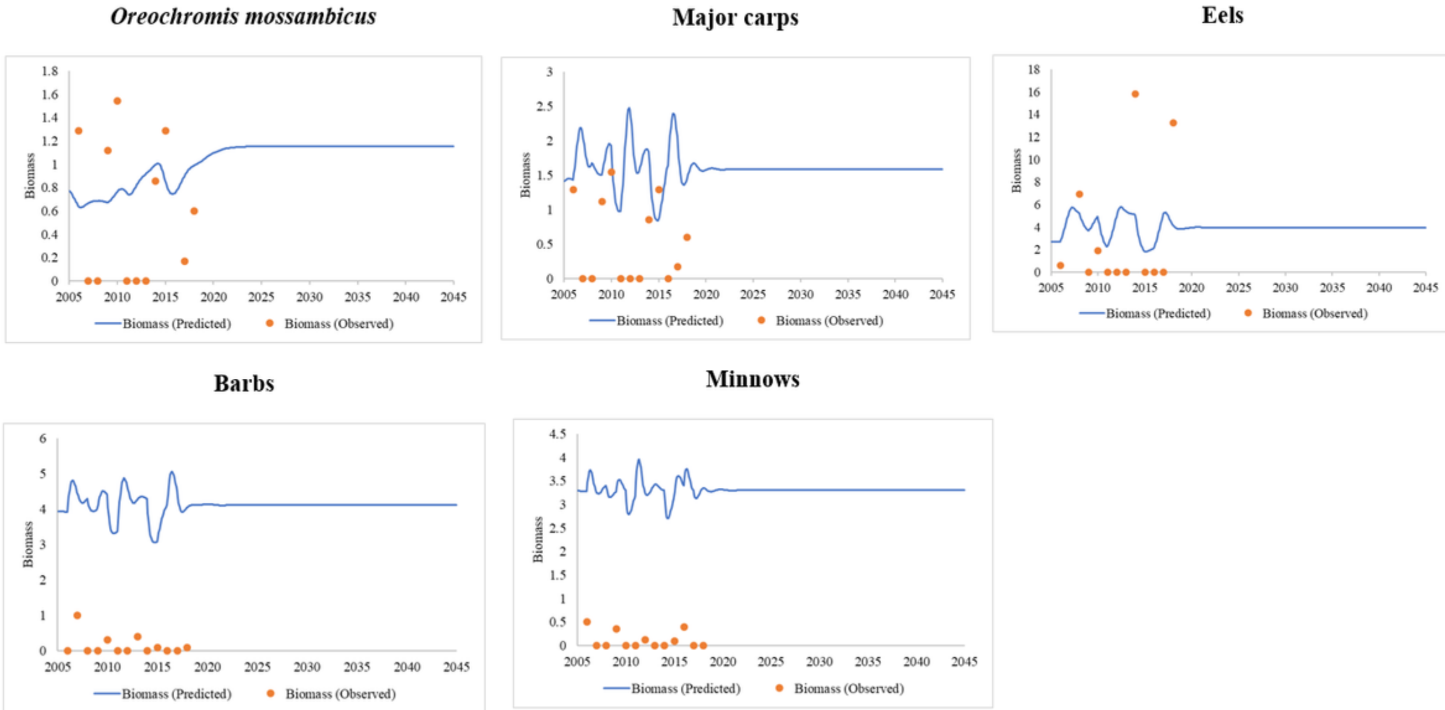

Figure 3

Biomass observed (points) and predicted (line) by EwE model for the main species of Karapuzha reservoir fishery. Biomass in tonnes/km^2.

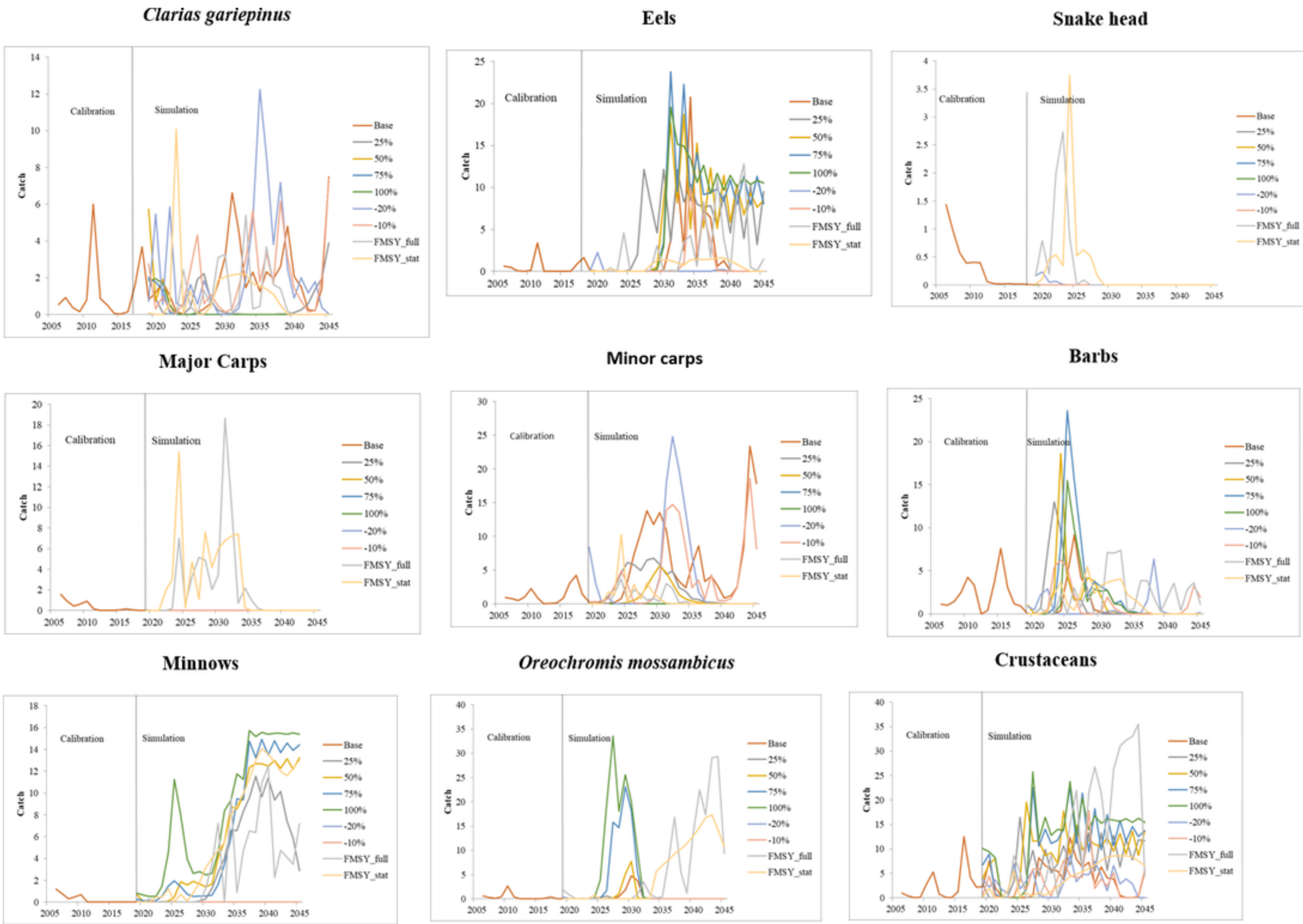

Figure 4

Estimated catches (tonnes/km^2) for the main target species in Karapuzha reservoir under different fishing effort scenarios for 27 years (2019-2045). Base: Baseline (fishing effort value from 2006), Fmsy_full and Fmsy_statare the estimated Fmsy from full compensation and stationary modes, respectively.

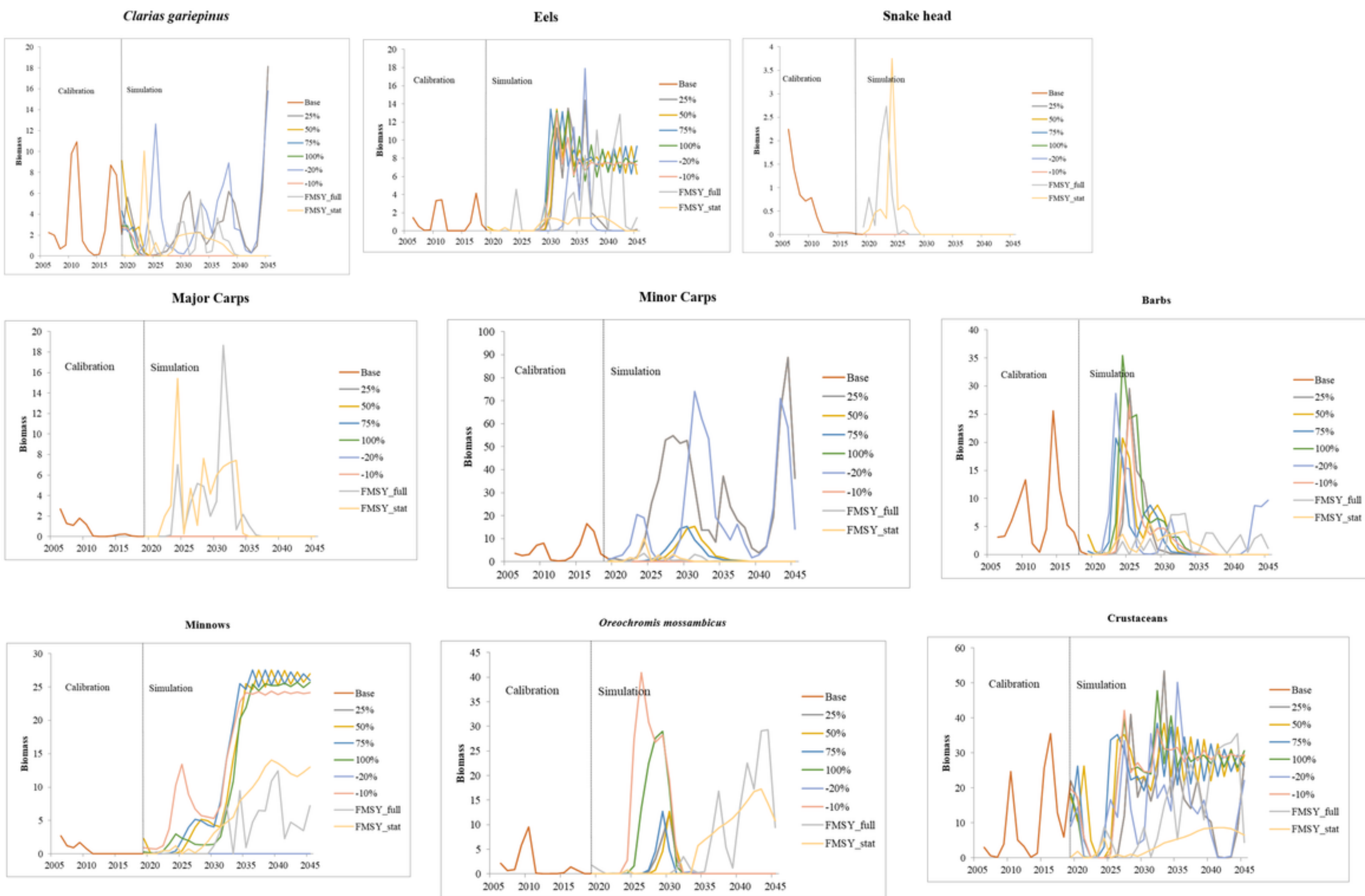

Figure 5

Biomass estimates (tonnes/km^2) from Ecosim simulations for the main target species in Karapuzha reservoir fisheries. Base: Baseline (fishing effort value from 2006), Fmsy_full and Fmsy_stat are the estimated Fmsy from full compensation and stationary modes, respectively.

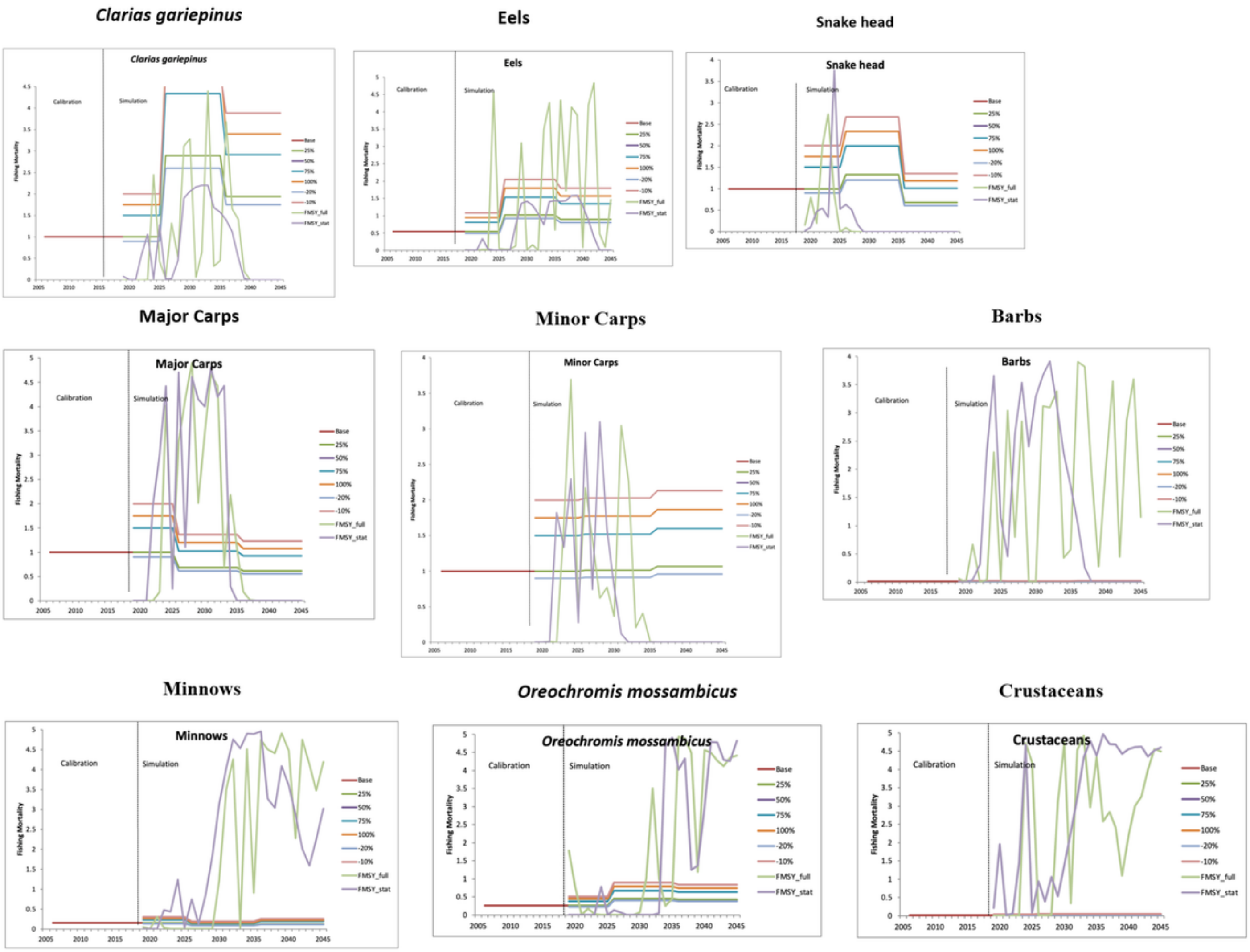

Figure 6

Fishing mortality (year^{-1}) estimated by the foodweb model of Karapuzha reservoir under different scenarios of fishing effort for the 27 years simulations (2019-2045). Base: Baseline (fishing effort value from 2006), Fmsy_full and Fmsy_stat are the estimated Fmsy from full compensation and stationary modes, respectively.

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Figure 7

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