

Assessing vulnerability and adopting alternative climate resilient strategies for livelihood security and sustainable management of aquatic biodiversity of Vembanad lake in India

Thankam Theresa Paul, Preetha Panikker, U. K. Sarkar, S. Manoharan, G. Kuberan, K. R. Sreenath, P. U. Zachariah and B. K. Das

ABSTRACT

The present study was carried out at the Thycattussery area in Vembanad lake and assessed the ichthyodiversity, variability in climatic variables, the exploited status of predominant small-scale sector fisheries (SSFs) and impact of climatic variables upon an existing SSF. Fish, as well as clam specimens collected from the study area, were identified. Diversity indices and dominance curves helped to identify monsoon (June–September) as the diverse season in the wetland. SIMPER (similarity percentage) analysis indicated that *Villorita cyprinoides* (clam) was the predominant species in the wetland with a mean relative abundance of 16.1%. Canonical correspondence analysis (CCA) of variables with clam production identified calcium hardness and rainfall with axis loadings of -0.56 and 0.50 respectively as the variables predominantly contributing to clam production. Stepwise regression indicated that temperature and rainfall were the determinants of clam production. A decrease in rainfall and an increase in temperature at an annual rate of 0.02 and 0.8% , respectively, decreased the clam production by 5.37% /year in the study area. Further, the generalized linear model (GLM) indicated stagnancy in clam production until 2035 below $400,000$ kg per year. The study introduced diversification of livelihood systems using clam culture in climate resilient pen structures (CRPS) as an adaptation strategy.

Key words | adaptation, clam fisheries, climate change, climate resilient pen structures, livelihood, vulnerability

HIGHLIGHTS

- The study identified climate change as the major stressor affecting small scale fishers in Thycattussery region of Vembanad lake (wetland).
- The study exposed a huge decline in the production of a predominant single species (*Villorita cyprinoides*) fishery to the tune of 5.37% per year and attributed the decline to climatic variables such as temperature and rainfall.
- The study predicted that the clam production will have a stagnant phase till 2035 below 400 tonnes per year in the study area, which in turn will have an unanticipated loss in catch per unit effort of the fishers.
- The study proposes suitable fishing technology with lesser investments (Climate Resilient Pen Structures) as the appropriate adaptation strategy for restoring the declining fishery in the region.

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (<http://creativecommons.org/licenses/by/4.0/>).

doi: 10.2166/wcc.2020.194

Thankam Theresa Paul (corresponding author)
S. Manoharan

G. Kuberan

B. K. Das

ICAR – Central Inland Fisheries Research Institute,
Kochi,
India

E-mail: thankamtheresa@gmail.com

Preetha Panikker

ICAR – Central Inland Fisheries Research Institute,
Bangalore,
India

U. K. Sarkar

ICAR – Central Inland Fisheries Research Institute,
Barrackpore,
India

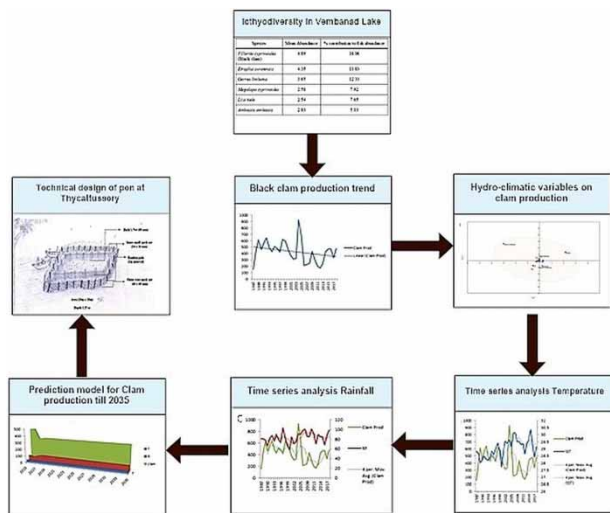
K. R. Sreenath

P. U. Zachariah

ICAR – Central Marine Fisheries Research Institute,
Kochi,
India

- This strategy brought about by Central Inland Fisheries Research Institute helps the small-scale fishers through diversification of livelihood systems, wherein farmers switch between farming in CRPS (Climate Resilient pen Structures) and fishing in response to seasonal and inter-annual variation in black clam fisheries.

GRAPHICAL ABSTRACT



INTRODUCTION

Inland fisheries are declining rapidly due to the increase in anthropogenic pressures which include climate change and overexploitation (Sarkar *et al.* 2019a, 2019b). Anthropological attributes such as growth and development have significantly impacted fisheries and the various assets the system brought in to the communities (FAO 2018). The FAO (2017) revealed that nearly 90% of inland fisheries of the growing economies was contributed by small-scale fishers. Small-scale sector fisheries (SSFs) help in the generation of derived foreign exchange and in greater contributions to the gross domestic product (via income multiplier effects and taxes). They therefore have enabled a stable and growing economy, food and nutrition security, and buffer against extreme poverty and vulnerability (FAO 2017) in emergent nations. The opportunistic nature of SSF has supported the livelihood of the associated local communities during various catastrophic events (Sarkar & Borah 2018). Despite being adept in the fisheries environment, stressors

such as competition for resources, over-harvesting, pollution, environmental degradation and rapid development caused the decline in small-scale fisheries (FAO 2017). Apart from these stressors, climate change was identified by Salagrama (2012) as an additional layer in a complex web of factors affecting fisheries and fishing communities. Some of the principal climatic factors affecting fisheries are sea-level rise, sea level salinity, seasons and seasonality patterns, wind processes, rainfall, tidal amplitude, etc. Frequent incidences of juveniles in the catch, spatiotemporal alteration of inland fishery resources, negative impacts on postharvest and trade arrangements (Salagrama 2012), destruction of traditional breeding grounds, the proliferation of dead fishing zones and pollution sinks (FAO 2017) represent the effects of climate change on the livelihood of SSFs. These vulnerable small-scale fishers required an appropriate adaptation strategy in the form of shifting of fishing operations, using better fishing gear and technologies

with lesser investments in capital and operating costs. Understanding the response of small-scale fishers to this unprecedented challenge is critical for developing more efficient management strategies and alternative options in regional socio-ecological systems.

With this background, the present study assessed the ichthyo-diversity, the variability in hydrological and climatic variables, the exploited status of black clam fisheries and the impact of climatic variables upon the fisheries of a tropical inland wetland in India. The study provided a better adaptation strategy to improve the resilience and productivity of small-scale fisheries of *Villorita cyprinoides* (black clam) associated with Vembanad Lake.

Vembanad, the largest tropical wetland system which is spread over 2,033 km², is bordered by the Alappuzha, Kottayam and Ernakulam districts of Kerala (Kurup *et al.* 1990). The geographical location of the wetland is explained by its extent (latitude 9.51°N–10.19°N and longitude 76.16°E–76.43°E). Vembanad Lake was designated as a wetland of international importance under the Ramsar Convention in 2002 (GOI 2008) and a critically vulnerable coastal area (Singh 2016) after recognizing its ecological

significance as an indispensable ecosystem service provider and an essential habitat. The Thanneermukkom saltwater barrier, a man-made barrier, divided the lake into two sectors based on the salinity of the water as a brackish water zone (towards the north of the lake) and a freshwater zone (towards the south of the lake). The area is noted for two fishery resources (Kurup *et al.* 1990), namely black clam (*Villorita cyprinoides*) and Pearl spot (*Etroplus suratensis*).

MATERIALS AND METHODS

Sampling area

The sampling area (Figure 1) is geographically located at latitude 9.77°N and longitude 76.34°E and is situated at Thycattussery Panchayat in the Alappuzha district of Kerala, India. The sampling period extended over two years (2016–2018) across six seasons, encompassing two cycles of pre-monsoon (February–May), monsoon (June–September) and post-monsoon (October–January) seasons to establish a relevant relationship between the ichthyo-diversity,

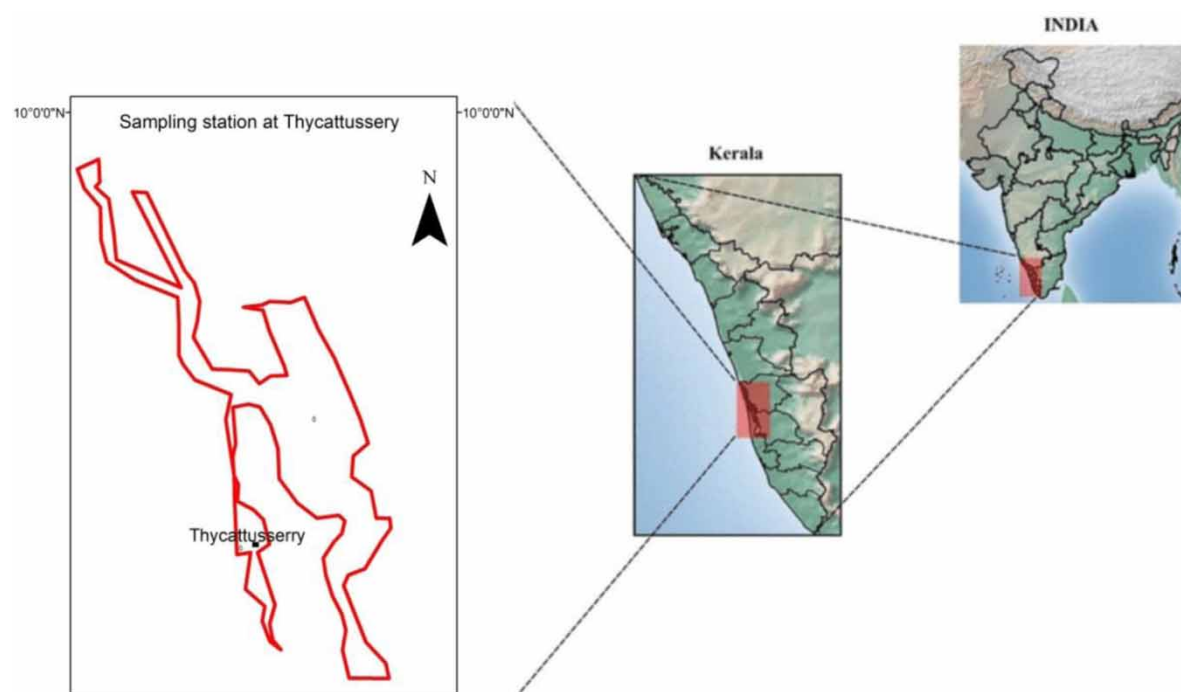


Figure 1 | Sampling station at Thycattussery in Vembanad lake in Kerala, India.

black clam fisheries and associated variables at the sampling site.

METHODOLOGY

Data acquisition

The physical and chemical variables of water were measured monthly during the period 2016–2018. The sampled monthly data were pooled into yearly data for better analysis and interpretation to obtain a more precise estimate of the mean value of each variable (annexure). The time-series data of climatic variables such as temperature and rainfall (in the yearly interval) procured from the Indian Meteorological Department (IMD) during the period 1987–2018 were used in the study taking into consideration its relevance in a tropical monsoon country. The month-wise data of the various fish and clam species collected from the sampling station were pooled together into yearly data to obtain a more precise estimate of the mean value of each variable (Table 1).

The hydrological variables such as temperature, pH and conductivity were measured in-situ using a Eu-tech multi-parameter probe and transparency was measured using Secchi-Disc Depth. The chemical characteristics of water, such as alkalinity, dissolved oxygen (DO) and hardness, were measured using a titrimetric method (APHA 2012). Fish specimens were procured at Thycattussery by

experimental fishing using gillnets (based on the number of hours of operation) and from market surveys monthly. The specimens were then brought to the laboratory for taxonomical identification (Talwar & Jhingran 1991). The black clam was procured by raking (based on the number of hours of operation).

Software used

Plymouth Routines In Multivariate Ecological Research (PRIMER) is a statistical package used for analyzing species sampling data for studies pertaining to community ecology and the environment in the scientific community (Clarke & Gorley 2015). R is a programming language and free software environment widely used among statisticians and data miners for statistical computing and graphics (R Core Team 2013). The pooled year-wise data of all the collected variables in the study (hydrological and climatic variables and abundance data of fish and clam species) were analyzed using various packages in softwares such as Primer 7.0 (Clarke & Gorley 2015) and R (R Core Team 2013).

Data analysis

Data transformation and biodiversity indices

The study describes fish and clam abundance data as a measure of the number of fish or clam in a given area (McLachlan & Brown 2006). The fish and clam abundance data were normalized using $\log(x + 1)$ transformation to moderate the influence of extreme values of fish assemblage (such as zero) on temporal scales and to estimate various indices which assess the status of fish assemblage in the area of study. Four major biodiversity indices, namely dominance index, Pielou's evenness index, Margalef's richness index and Shannon–Weiner's diversity index, were used to estimate the discrepancy of fish communities or populations in this system.

The dominance index is a uniformity index which indicates a high dominance of a species against other species (Harper 1999). The minimum index value is 1. The higher value indicates higher dominance of the species. This index helps to identify the dominant fish species in the selected area of study. It is calculated by the following

Table 1 | Hydro-climatic variables at Thycattussery

Hydro-climatic variables	Max	Min	Mean \pm SD
Specific conductivity (μ S)	79,300.0	241.0	2,6975.5 \pm 3022
pH	7.8	6.8	7.1 \pm 0.3
Carbon dioxide (ppm)	4.3	0.0	1.8 \pm 1.3
Alkalinity (ppm)	120.0	16.0	36.3 \pm 12.0
Calcium hardness (ppm)	7.0	0.0	3.4 \pm 2.8
DO (ppm)	10.4	2.1	4.8 \pm 2.3
Temperature ($^{\circ}$ C)	32.8	27.0	28.8 \pm 1.7
Rainfall (mm)	213.3	5.5	84.3 \pm 71.5
Clam (numbers)	594	273	380.3 \pm 111.7
Fish (numbers)	324	112	256 \pm 53

equation (Harper 1999):

$$D = D = \sum_i^n \left(\frac{n_i}{n}\right)^2 \quad (1)$$

where n_i is the number of individuals of taxon i and n is the total number of individuals in the sample.

Margalef's species richness is a measure of the number of species found in a sample or community and its value ranges between 0 and 1. This index provides details about the species richness of the fish species in the study area selected. It is calculated using the following equation (Margalef 1968):

$$(d) = (S-1)/\ln(N) \quad (2)$$

where N is the total number of individuals; \ln is the natural logarithm; S is the number of taxa; e is the natural logarithm equal to 2.718.

Pielou's evenness index is a measure of biodiversity which indicates homogeneity of species in a sample or community (Ulfah *et al.* 2019). The value of the index ranges between 0 and 1. An evenness value of one indicates all species are equally abundant. It is calculated as (Pielou 1966):

$$(J') = H' / \ln S \quad (3)$$

where H' is Shannon diversity index and S is the number of taxa.

The Shannon diversity index (H') is a measure of species abundance and richness to quantify the diversity of the species. The index ranges from 1.5 to 3.5 in most ecological studies (Ulfah *et al.* 2019). It is calculated as (Shannon & Wiener 1963):

$$(H') = \sum_i^n P_i \log_2 P_i \quad (4)$$

where P_i is the proportion within the sample of the number of the individuals of i th species, n_i is the number of individuals in i th species and N is the total number of individuals.

Data processing

A dominance curve was plotted for the study area employing the transformed data. The dominance curve remains an effective tool for measuring abundance trends in communities over time. The curves are obtained by plotting the cumulative ranked abundance against a log species rank (Jennings *et al.* 2001). The dominance curves across three seasons (monsoon, pre-monsoon and post-monsoon) were plotted to determine the rate of instability of the system during various seasons. The steepest and most elevated curve shows the lowest diversity and the most perturbed system state.

Further, similarity percentage (SIMPER) analysis was carried out using Primer 7.0 to identify (Sandhya *et al.* 2019) the species that was contributing predominantly to the fishery at Thycattussery. SIMPER analysis is a descriptive method which helps in identifying the taxa that are primarily responsible for an observed difference between two or more sample groups (Clarke & Gorley 2015). The SIMPER analysis helped in identifying the predominant fish and clam species that was contributing to the ichthyodiversity of the study region.

On identifying the predominant species in the study area, a vulnerability assessment was conducted using a structured schedule to ascertain the level of vulnerability faced by the species despite assuring food security of the associated local population. Trend analysis of the production of species from 1987 to 2017 was evaluated to substantiate that the species was vulnerable. Canonical correspondence analysis (CCA) was carried out to establish the relationship of the prominent fishery with hydrological and climatic variables (TerBraak & Smilauer 2002) and to identify the variables which impacted the species abundance in the study area (Wei *et al.* 2017).

Stepwise regression was further used to ascertain the level of influence of each hydrological and climatic variable on the species abundance and to identify the predominant variable affecting the predominant fishery in the study area. The stepwise regression excludes one variable at a time, especially one with the lowest F-to-remove statistic during each iteration to find the most influential variable. The variable with the highest regression coefficient usually was considered the most predominant variable among all

the variables represented in the model (Schneider *et al.* 2010). Based on CCA and stepwise regression, the predominant variables were segregated and used for further mathematical analyses.

Trend analysis of the predominant variables was carried out subsequently to predict the future variations in these variables based on recently observed trend data (Radhakrishnan *et al.* 2017). The moving average method was used for the trend analysis. The mathematical model or equations thus retrieved from trend analysis of predominant variables were used for predicting the status of the fishery of the study area. Further, generalized linear modeling (GLM) was carried out to predict the state of the fishery in the event of predicted variations in the chosen predominant variables by fitting the best model.

RESULTS AND DISCUSSION

The ichthyo-diversity at Thycattussery was assessed and it was found that 39 species belonging to 35 genera, 24 families and ten orders were present in the study area. Various biodiversity indices estimates indicated that monsoon season (June–August) was the diverse season, though all the fish and clam species were evenly distributed across all seasons. However, diversity represented on a dominance curve indicated predominance of a single species in all seasons. The analysis using (Similarity Percentage) SIMPER indicated that *Villorita cyprinoides* (black clam) was the major contributor to the species abundance at Thycattussery (16.1%). Further, the vulnerability assessment specified that *Villorita cyprinoides*, despite being a good supplier of provisioning services, was declining in production at Thycattussery by 5.4% per year during the period 1987–2018. Canonical correspondence analysis (CCA) indicated that calcium hardness and rainfall had a predominant role in clam production. The stepwise regression analysis indicated that specific conductivity, pH, carbon dioxide and temperature were the variables influencing clam production. The best fit formula derived from stepwise regression showed the predominance of temperature on clam production (as indicated by the highest regression coefficient of the variable in the model). Thus, this study identified temperature and rainfall as the predictor variables based

on the analysis (stepwise regression and CCA) carried out on hydrological and climatic variables. Taking the predominant inputs from CCA and stepwise regression, i.e. rainfall and temperature, the prediction model was fitted using the generalized linear model in order to identify the future status of clam production. The prediction model indicated that with the combined effect of temperature (increasing at an annual rate of 0.02%) and rainfall (decreasing at an annual rate of 0.8%), the clam production will have a stagnant phase in production till 2035 below 400,000 kg per year. The vulnerability of the species towards climatic variables resulted in stagnancy of the production, which would cause an unanticipated loss in catch per unit effort of the fishers. It was found that small scale sector fisheries (SSFs) based on black clam fisheries exhibited regular fluctuations. The Central Inland Fisheries Research Institute (CIFRI) has come up with an adaptation strategy to cope with climate change by diversification of livelihood systems, wherein farmers switch between farming in CRPS (climate resilient pen structures) and fishing in response to seasonal and inter-annual variation in black clam fisheries.

Ichthyo-diversity

The ichthyo-diversity at Thycattussery was represented by 39 species belonging to 35 genera, 24 families and ten orders. Similar studies were carried out by Narayanan *et al.* (2005), Mogalekar *et al.* (2015) and Ansar *et al.* (2017) at Aymanam, Kumarakom and Panangad-Kumbalam regions of Vembanad lake, respectively. Narayanan *et al.* (2005) reported 37 fish species belonging to 18 families and nine orders from Aymanam panchayath, in the Vembanad wetland. Mogalekar *et al.* (2015) recorded 39 species of fin fishes belonging to 27 families, 11 orders and 31 genera from the Panangad region of Vembanad lake. Ansar *et al.* (2017) recorded 52 fin fish species from the Kumarakom region. A comparative assessment of the studies on the ichthyo-diversity conducted at various areas of Vembanad lake pointed out that diversity was more towards the freshwater side of the wetland represented by the Kumarakom region compared to the brackish water side of the lake represented by Panangad and Kumbalam regions. Saswata *et al.* (2018) examined the diversity status during the periods 1987–88 and 2012–2013 and identified changes in species

richness in Vembanad lake consequent to a top-down trophic cascade effect.

The seasonal variation of the species diversity across two years was represented by a presence or absence table (Table 2) which indicated that diversity in terms of species abundance was more during monsoon. The Shannon diversity index of 2.90 during monsoon followed by post-monsoon (2.30) and pre-monsoon (1.91) indicated that the system was highly diverse during the monsoon season followed by other seasons. This variation in the diversity index (Table 3) may be attributed to the availability of preferred food brought in by the feeding river systems during the monsoon season for the fish and shellfish. This is in accordance with the study by Miranda (2001), which stated that an increase in water levels during monsoon temporarily floods vegetation, increases food and shelter supply and thereby increases the number of species. Similar results were evidenced by Ansar *et al.* (2017) in Vembanad lake and Gbaguidi *et al.* (2016) in Southern Benin, West Africa. Diversity (2.90) and evenness (0.88) indices during monsoon season in the study area indicated a habitat which was characterized by the equitable distribution of individuals in the community among the wide variety of species (Magurran 1988). Gbaguidi *et al.* (2016) had similar findings in a study in the man-made Bewacodji lake in southern Benin in West Africa. Mogalekar *et al.* (2015) studied the diversity indices in Vembanad lake and concluded that Shannon Wiener diversity (H') ranged from 2.9 to 3.4, similar to the findings of the present study. The study pointed out that the proximity of Pielou's evenness index to unity indicated a stable environment with species evenly distributed across the study area irrespective of the seasons. Gbaguidi *et al.* (2016) reported similar results in Pielou's evenness index in the studies conducted at Bewacodji lake in West Africa.

Further, the dominance curve was plotted (Figure 2) to identify the most stable environment based on the season dependent diversity of fish and shellfish in the study area. The dominance curve indicated an unstable ecosystem represented by steep slopes across the seasons. Figure 2 indirectly showed the predominance of a single species to the tune of 94% and above in all the seasons.

SIMPER analysis in Primer 7.0 (Clarke & Gorley 2015) was used to identify the single dominant species contributing to the local fishery in the study area. The mean relative

abundance of distinguishing species in the study area was then compared and species with percentage contributions >10% were identified as major contributors to local fishers (Wakefield *et al.* 2013). Thus, the SIMPER analysis (Table 4) indicated that *Villorita cyprinoides* was the major contributor to the species abundance at Thycattussery (16.1%) followed by *Etroplus suratensis* (13.8%) and *Gerres limbatus* (12.3%). The study thus proved the existence of a local fishery of *Villorita cyprinoides* and *Etroplus suratensis* in the study area.

Vulnerability assessment

In order to assess the importance of black clam as a critical food source and a key element in determining the food security and nutrition strategies of the local population, a vulnerability assessment was conducted using a structured schedule. The assessment indicated that *Villorita cyprinoides* (black clam) was a good supplier of provisioning services which was one of the ecosystem services exhibited by the species. All the fishers claimed a considerable decline in clam production at Thycattussery. The trend analysis of black clam production data (Figure 3) obtained from the Thycattussery Black Clam Co-operative societies substantiated the assessment and indicated a declining trend of 5.4% per year during the period 1987–2018. The first decadal analysis (1987–2008) of clam production indicated a huge decline to the tune of 8.8% per year compared to the last decade (2009–2018), which exhibited a gradual decrease to the tune of 0.9% per year.

Influence of hydro-climatic variables on clam production

Canonical correspondence analysis (CCA) was used to identify the predominant hydro-climatic variables influencing the clam production at Thycattussery. Axis 1 of CCA (Table 5) with an eigenvalue of 0.035 explained 66.91% of the variations among the various components compared to axis 2 (23.48%) with an eigenvalue of 0.012. Eigenvalue determines variance in the data in a particular direction. The component or axis with the highest eigenvalue is therefore considered the major component or axis which should be considered for interpretation.

Table 2 | Presence or absence table of species at Thycattusery

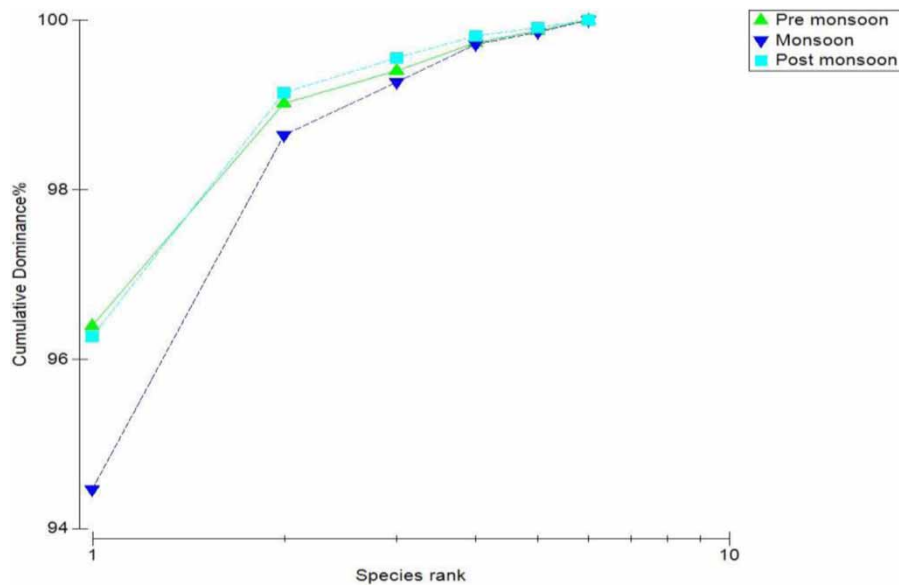
Order	Family	Species	Post-monsoon	Pre-monsoon	Monsoon
Perciformes	Pristolepidae	<i>Pristolepis rubripinnis</i>	x	√	x
	Leiognathidae	<i>Leiognathus dussumieri</i>	√	x	√
	Ambassidae	<i>Ambassis ambassis</i>	√	√	x
		<i>Parambassis sp.</i>	x	x	√
	Gerridae	<i>Gerres limbatus</i>	√	√	√
	Percidae	<i>Eetroplus maculatus</i>	√	√	√
		<i>E. suratensis</i>	√	√	√
	Carangidae	<i>Caranx ignobilis</i>	x	√	x
	Glossogobidae	<i>Glossogobius giuris</i>	√	x	√
	Lethrinidae	<i>Lethrinus sp.</i>	x	√	x
	Lutjanidae	<i>Lutjanus argentimaculatus</i>	x	√	√
	Scatophagidae	<i>Scatophagus argus</i>	x	√	√
	Sillaginidae	<i>Sillago sihama</i>	x	√	x
	Sciaenidae	<i>Johnius dussumieri</i>	x	√	x
Clupeiformes	Clupeidae	<i>Thryssa malabarica</i>	x	x	√
		<i>Stolephorus indicus</i>	x	x	√
		<i>Anadontostoma chacunda</i>	x	√	x
		<i>Nematalosa nasus</i>	x	√	x
Anabantiformes	Anabantidae	<i>Anabas testudineus</i>	√	x	x
	Channidae	<i>Channa striatus</i>	√	x	√
		<i>Channa marulius</i>	√	x	√
	Heteropneustidae	<i>Heteropneustes fossilis</i>	x	x	√
Siluriformes	Mystidae	<i>Mystus malabaricus</i>	x	x	√
	Ariidae	<i>Arius maculatus</i>	x	√	x
	Siluridae	<i>Ompok malabaricus</i>	x	√	x
	Bagridae	<i>Horabagrus brachysoma</i>	x	√	√
Beloniformes	Hyporhamphidae	<i>Hyporhamphus limbatus</i>	x	√	√
	Belonidae	<i>Xenentodon cancila</i>	x	√	√
Pleuronectiformes	Cynoglossidae	<i>Cynoglossus macrostomus</i>	√	√	x
		<i>Euroglossa orientalis</i>	√	x	√
Mugiliformes	Mugilidae	<i>Mugil cephalus</i>	x	√	x
		<i>Liza tade</i>	√	√	√
Cypriniformes	Cyprinidae	<i>Dawkinsia filamentosa</i>	x	√	√
		<i>Gibelion catla</i>	x	√	X
		<i>Puntius sarana</i>	√	√	√
		<i>Puntius mahecola</i>	x	√	√
Elopiformes	Megalopidae	<i>Megalopa cyprinoides</i>	√	√	√
Venerida	Cyrenidae	<i>Villorita cyprinoides</i>	√	√	

√ Monsoon: June–September; Post-monsoon: October–January; Pre-monsoon: February–May. Absence represented by x and presence represented by √.

Table 3 | Season-wise diversity indices at Thycattussery

Seasons	N (number of species)	S (number of specimens)	D (dominance index)	J' (Peilou's evenness index)	Shannon diversity
Pre-monsoon	15	551	2.22	0.71	1.91
Monsoon	27	610	4.05	0.88	2.90
Post monsoon	25	837	3.57	0.72	2.30

Monsoon: June–September; Post-monsoon: October–January; Pre-monsoon: February–May.

**Figure 2** | Dominance curve at Thycattussery.

Since the eigenvalues of axes 1 and 2 were higher compared to other axes, they were chosen for explaining the variations in the study. Table 5 further indicates that axis 1 alone could explain the variations among various components in the study area (Thycattussery) with clam

production. However, a bi-plot diagram (Figure 4) utilizes two axes, mainly those with higher eigenvalues (axis 1 and axis 2) for representation of the findings. The variables of axis 1 and axis 2 in CCA with their respective scores are represented in Table 6.

Table 4 | SIMPER analysis at Thycattussery

Species	Mean abundance	% Contribution to fish abundance
<i>Villorita cyprinoides</i>	4.9	16.1
<i>Etroplus suratensis</i>	4.4	13.8
<i>Gerres limbatus</i>	3.7	12.3
<i>Megalopa cyprinoides</i>	2.6	7.9
<i>Liza tade</i>	2.5	7.7
<i>Ambassis ambassis</i>	2.8	5.0

The CCA showed that clam production was positively influenced by calcium hardness with axis loadings of -0.56 and negatively influenced by rainfall which has an axis loading of 0.50 (Table 6). The study thus indicated that calcium hardness and rainfall had a predominant role in clam production. Robert (2000) found similar results wherein mean abundance (number of clams/sq.m) of *Pisidium casertanum* was found to be positively related to calcium hardness of the water. Similar findings were also reported in land molluscs by Wäreborn (1969). The present study was insufficient to estimate the level of influence of hydrological and climatic variables on clam production. So, a stepwise regression

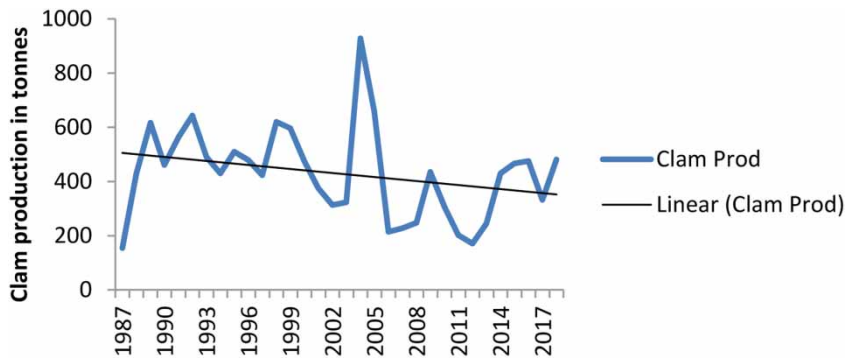


Figure 3 | Black clam production data at Thycattussery (trend analysis).

Table 5 | Eigenvalues of CCA of Thycattussery

Axis	Eigenvalue	Percentage of variation explained
1	0.035	66.91
2	0.012	23.48
3	0.004	6.851
4	0.001	2.383

was used to identify the level of influence of hydrological and climatic variables on clam production and to identify the predominant variable affecting the black clam fishery in the study area.

The stepwise regression between the dependent variable, clam abundance and hydro-climatic variables indicated that a combination of physicochemical variables, such as specific conductivity, pH, carbon dioxide and temperature, impacted clam abundance and the relation was represented with this model:

$$C = -0.881 - 0.122S + 0.409P + 1.313CO + 2.216T \quad (5)$$

where C is clam abundance in thousand kgs, S is specific conductivity in μS , P is pH of the waterbody, CO is carbon dioxide in ppm and T is the temperature ($^{\circ}C$).

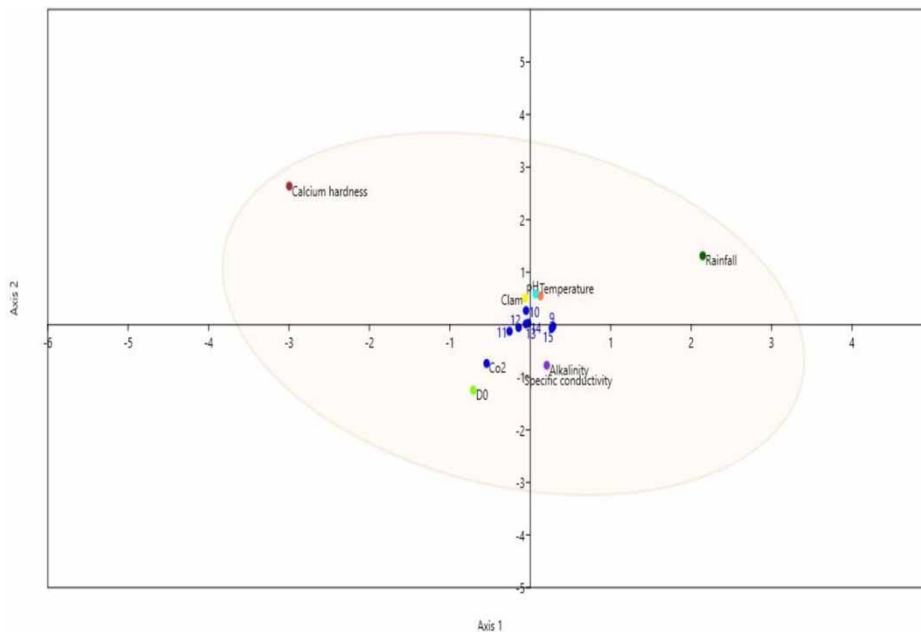


Figure 4 | Canonical correspondence analysis of hydro-climatic variables on clam production.

Table 6 | Components of CCA and their scores

Hydro-climatic variables at Thycattussery	Component scores	
	Axis 1	Axis 2
Specific conductivity	-0.02	-0.11
pH	0.01	0.06
Co2	-0.10	-0.08
Alkalinity	0.04	-0.09
Calcium hardness	-0.56	0.29
D0	-0.13	-0.14
Temperature	0.02	0.06
Rainfall	0.50	0.15
Clam	-0.01	0.06

The stepwise regression carried out in the study (Table 7) indicated that variables with the highest F statistic, such as specific conductivity, pH, carbon dioxide and temperature, could influence the clam abundance as implied by the AIC (Akaike Information Criterion) value of -61.33. This model, which is the best fit formula, indicated the

Table 7 | Stepwise regression in R between hydro-climatic variables and clam production

Step: AIC = -61.33.

$C \sim S + P + CO + T$

	Degree of freedom (Df)	Sum of squares (SS)	Residual sum of squares (RSS)	Akaike information criterion (AIC)
	none		0.129	-61.33
+ CH	1	0.010	0.117	-60.71
+ DO	1	0.002	0.126	-59.66
-S	1	0.039	0.168	-59.39
+ AL	1	9.8×10^{-5}	0.129	-59.34
+ R	1	9×10^{-6}	0.129	-59.33
-T	1	0.040	0.169	-59.30
-P	1	0.064	0.193	-57.3
-CO	1	0.086	0.215	-55.66

Call: $\text{lm}(\text{formula} = C \sim S + PH + CO + T, \text{data} = A)$

Coefficients:

(Intercept)	S	pH	CO	T
-0.881	-0.122	0.409	1.313	2.216

predominance of temperature on clam production (as indicated by the higher regression coefficient of the variable in the model) as evidenced by Kamal *et al.* (2012). Similar findings depicting the predominant role of temperature in seasonal abundance and other attributes of bivalvia was reported by Mark & Brown (2015). Research findings by Garg *et al.* (2009) and Singh (2017) substantiated the role of specific conductivity in the abundance of black clam. Soucek *et al.* (2001) and Garg *et al.* (2009) found clam abundance was positively influenced by water column pH, similar to the findings in the present study. Further, studies carried out by Garg *et al.* (2009) supported the findings that the clam abundance was positively influenced by carbon dioxide concentration which may be attributed to an increase in the temperature.

Normally, the variable with the highest regression coefficient is the most determining independent variable in a study (Schneider *et al.* 2010) and temperature was that independent variable in this study. In India, being a monsoon based tropical country, there always existed an inverse relation between rainfall and temperature (Kamal *et al.* 2012). Since the results from CCA indicated that rainfall was also a determining factor for clam abundance, the study has taken rainfall as a predictor to estimate the level of influence of variation in rainfall on clam production in a climate-changing context along with temperature. Thus the study identified temperature and rainfall as the predictor variables based on the analysis (stepwise regression and CCA) carried out on hydrological and climatic variables.

Changes in seasonal patterns of climatic variables will alter the hydrologic characteristics of aquatic systems, affecting species composition and ecosystem productivity (Poff *et al.* 2002). In India, being a tropical monsoon fed country, the climatic variables have predominant roles in determining the production from aquatic systems (Saud *et al.* 2012). Trend analysis of climatic variables such as temperature and rainfall was also carried out to predict the future variations in these variables based on recently observed trend data (Radhakrishnan *et al.* 2017). The moving average method was used for the trend analysis. The mathematical model or equations thus retrieved from trend analysis were used for the predictions. The study thus investigated the trend in temperature and found an increase in the temperature at an annual rate of 0.02% during 1987–2018, as

represented in Figure 5. Further, the trend of clam production (Clam Prod) was related to the temperature and it was found that for every 0.02% increase in temperature, the clam production decreased by 5.37% (Figure 6).

The trend in rainfall was also investigated and is represented in Figure 7 which clearly shows that rainfall (RF) decreased at the rate of 0.8%/year during 1987–2018. Further, the clam production in relation to rainfall is represented in Figure 8 which indicates that for every 0.8% decrease in rainfall, the clam production decreased by 5.37%.

Relevance of clam culture at Thycattussery

The Thycattussery area had a clam bed of 28 ha area with an estimated production of 296.9 kg/ha in 1988–1989 and this further reduced to 17 kg/ha (Kurup *et al.* 1990). So the clam culture was carried out at the Thycattussery area as a part of the stock replenishment programme. The trophic status of Thycattussery, which was estimated at 48.5, indicated an

oligo-mesotrophic condition (CIFRI 2018) further suggesting that the production from this ecosystem may be enhanced using pens or cages by utilizing the multi-trophic levels in the aquatic ecosystem.

Prediction models for clam production

Taking the predominant inputs from CCA and stepwise regression (i.e. rainfall and temperature), the prediction model was fitted using the generalized linear model to identify the future status of clam production.

The prediction model (Equation (6)) for clam production at Thycattussery is as follows:

$$C = -0.99480 - 0.04951R + 1.36961T \quad (6)$$

where R is rainfall measured in mm (annual) and T is temperature ($^{\circ}\text{C}$).

The prediction model (Figure 9) indicated that with the combined effect of temperature (increasing at an annual rate of 0.02%) and rainfall (decreasing at an annual rate of 0.8%), the clam production would have a stagnant phase in production till 2035, below 400,000 kg per year. The vulnerability of the species towards climatic variables resulted in stagnancy of the production, which would cause an unanticipated loss in catch per unit effort of the fishers. The production is anticipated to decrease, further hampering the livelihood of the fishers.

The climate change-induced vulnerabilities should be combated by developing climate resilient strategies that would accelerate the development of the associated and affected community and by implementing various adaptation strategies in the vulnerable ecosystem (FAO 2017; Sarkar *et al.* 2018, 2019a, 2019b). A crucial part of increasing the resilience of these individuals and communities must be to eradicate poverty and provide food security for them by adopting adaptation strategies based on smart culture-based fisheries to climate change which may be multidimensional and multi-sectoral (FAO 2018). Similar to many fishing communities in tropical countries, it was found that small-scale sector fisheries (SSFs) based on black clam fishery exhibited regular fluctuations (Easterling *et al.* 2007). The Central Inland Fisheries Research Institute (CIFRI) has devised an adaptation

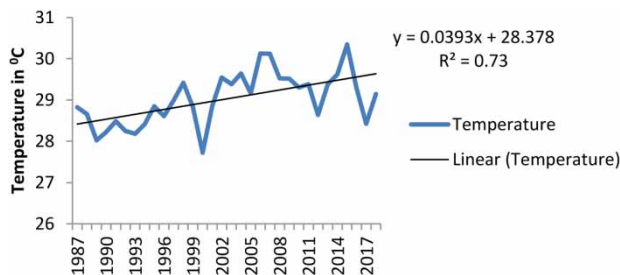


Figure 5 | Trend in temperature during 1987–2017.

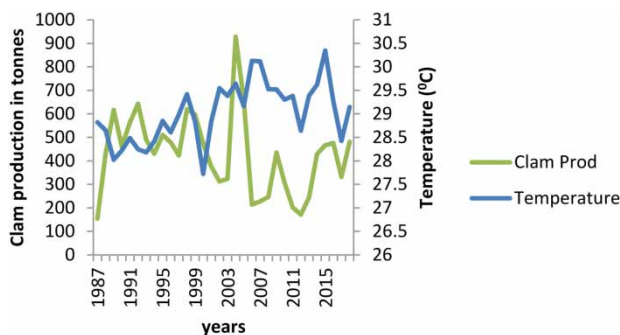


Figure 6 | Time series analysis of clam production and temperature.

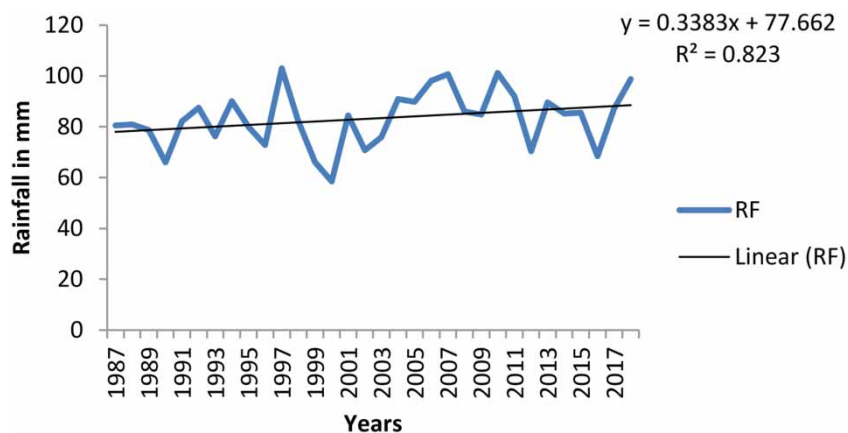


Figure 7 | Trend in rainfall during 1987–2017.

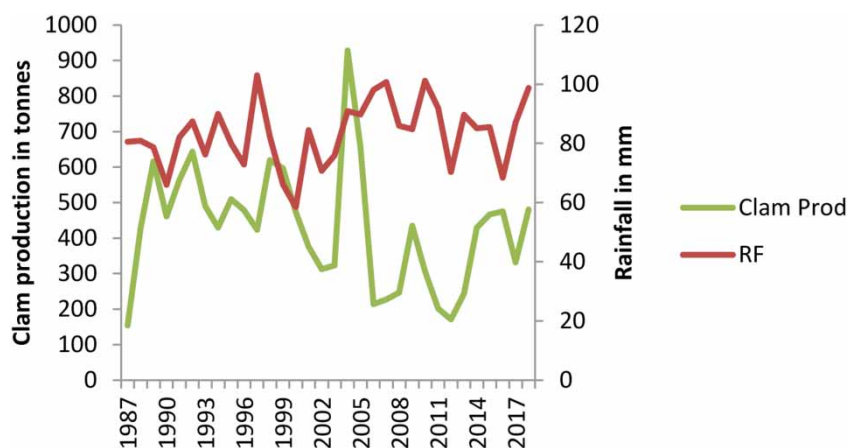


Figure 8 | Time series analysis between clam production and rainfall.

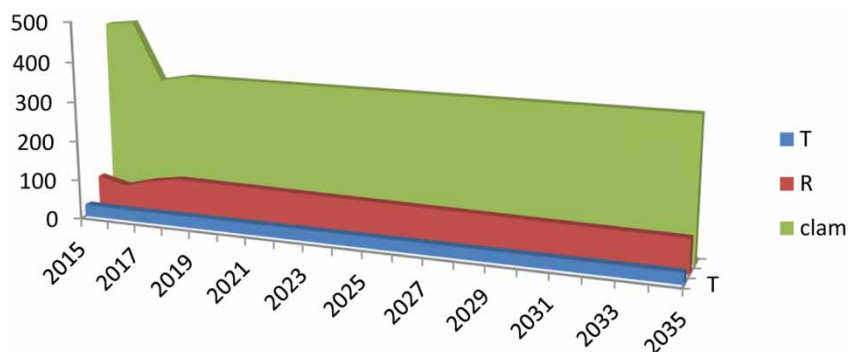


Figure 9 | Prediction model for clam production up to 2035.

strategy to cope with climate change by diversification of livelihood systems, wherein farmers switch between farming in CRPS and fishing in response to seasonal and inter-

annual variation in black clam fisheries (Allison & Ellis 2001). The technical design of CRPS is represented in Figure 10.

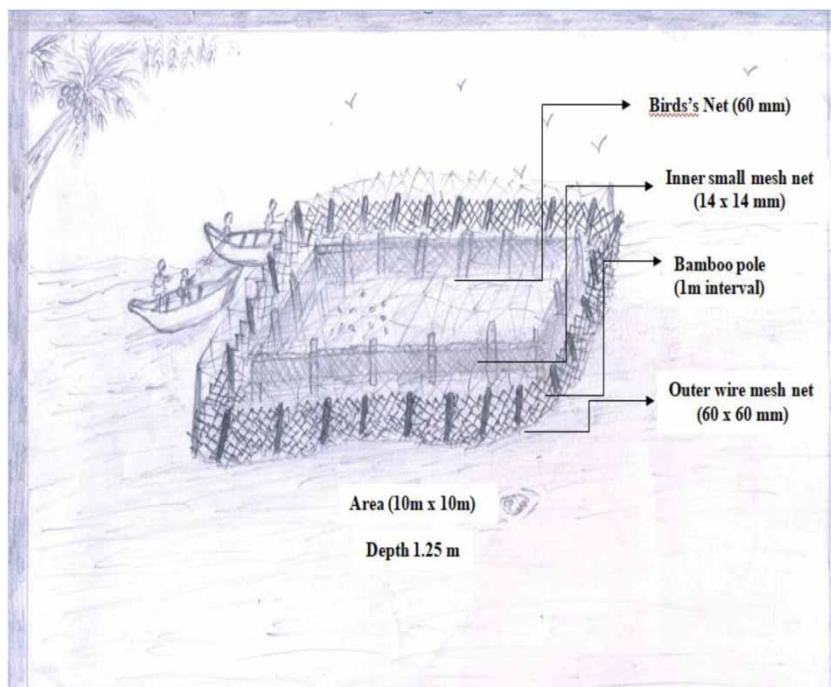


Figure 10 | Technical design of pen at Thycattussery.

The CRPS at Thycattussery was made of bamboo which is a locally available low-cost material. The bamboo was erected at 1 m gaps to withstand the current and wind action in the wetland. This also helped to disperse the wind borne floating weeds such as *Eichornia* sp. out of the culture system. Net walls made of HDPE were used to encircle the bamboo structure to delineate the culture area from the surroundings. The pen height was kept to 1.8–2.5 m to counter the flooded condition of the wetland during peak monsoon. The height of the pen wall is decided based on the highest depth encountered during peak monsoon (July–August). CRPS reduced the fisher's effort in harvesting of clams from the wild and further helped in targeted harvesting.

Particulars of adaptation strategy

In this study, 650 kg of baby clams of mean size of 3 g in total weight and 3 mm in total length were stocked at the rate of 5,000 nos/m² in the Central Inland Fisheries Research Institute (CIFRI) fabricated CRPS for one year of culture. The annual growth rate of clams was assessed

in terms of length and weight as 14.2 mm/year and 48 g/year. The average production obtained from the pen was 2,000 kg. The culture earned a revenue of \$383.43 from sales of clam meat and clam shell. The meat and the shell was separated, washed and sold at \$1.46/kg, whereas the shell was sold at \$51.03/1,000 kg. Thus, in a very short payback period of one year, a benefit cost ratio (BCR) of 1.26 was obtained, thereby substantiating the feasibility of the project. The BCR will act as a stimuli for other small scale sector fishers to use the technology and for researchers to improvise the system by utilizing the column niche.

This culture activity assimilated 915 kg of carbon wherein the carbon cost was estimated at \$ 0.58/1,000 kg. The advantages of the system included protection from adverse climatic events, resilience to fluctuating water levels in wetlands on account of tides and rainfall, better bio-security compared to normal pen enclosures, tapping of natural productivity (food), environmentally viable, low maintenance cost and high shelf life, intensive utilization of space, ease of harvest and greater production in a limited space.

CONCLUSIONS

Improvisation of existing CRPS into integrated multi-trophic pen culture structures by ensuring an ecosystem approach to fisheries and aqua-culture would increase the resilience of the small scale sector fisheries (SSF) and the associated communities in the coming years. Diversification of species in these CRPS would ensure conservation as well as enhancement of the vulnerable category of fishery resources by introducing various fish species in the column niche. Such culture-based fisheries fitted within an ecosystem management perspective can be a sustainable and successful food production strategy with stake-holders' participation.

This study identified this as a location specific suitable technology to support better livelihoods for the associated fisher communities and female family members in the inland aquatic system wherein double income from fish as well as black clams would be ensured. This green technology would not only provide a better livelihood but also act as a carbon sink which would help in reducing the carbon emissions from wetlands so as to curb global climate change. We recommended the application of a participatory approach to relegate the adverse impacts of climate change and the introduction of this new adaptive strategy can withstand the current climatic situation. This clam culture in CRPS in inland waters may be recommended as a context specific and community-based adaptation strategy for sustainable tropical fisheries in India. The study also emphasizes a bottom-up approach wherein the importance of proactive planning at primary stakeholders level is ensured.

ACKNOWLEDGEMENTS

The author would like to thank the Director, ICAR-CIFRI, for his kind support and guidance and financial assistance, and also CRIDA and NICRA for financial support.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

- Allison, E. H. & Ellis, F. 2001 [The livelihoods approach and management of small-scale fisheries](#). *Mar. Policy* **25** (5), 377–388. doi:10.1016/S0308-597X(01)00023-9.
- Ansar, H. S., Mogalekar, C., Sudhan, D. L., Chauhan, A. G. & Canciyal, J. 2017 Finfish and shellfish diversity of Vembanad Lake in the Kumarakom region of Kottayam, Kerala, India. *J. Entomol. Zool. Stud.* **5** (2), 351–357.
- APHA 2012 *Standard Methods for the Examination of Water and Waste Water*, 22nd edn. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, DC, USA.
- CIFRI 2018 *Annual Report*. p. 148. Available from: <http://www.cifri.res.in/AR/Annual%20Report%202017-18.pdf>.
- Clarke, K. R. & Gorley, R. N. 2015 *PRIMER v7: User Manual/Tutorial*. PRIMER-E Ltd, Devon, UK.
- Easterling, W. E., Aggarwal, P. K. & Batima, P. 2007 Food, fibre and forest products. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C. E. Hanson, eds). Cambridge University Press, Cambridge, UK, pp. 273–313.
- FAO 2017 *The State of Food and Agriculture. Leveraging Food Systems for Inclusive Rural Transformation*. FAO, Rome, pp. 122–123.
- FAO 2018 *Small-scale Fisheries. Small-Scale Fisheries Around the World*. FAO Fisheries and Aquaculture Department, Rome.
- Garg, R. K., Rao, R. J. & Saksena, D. N. 2009 Correlation of molluscan diversity with physicochemical characteristics of water of Ramsagar reservoir, India. *Int. J. Biodivers. Conserv.* **1** (6), 202–207.
- Gbaguidi, H. M. A. G., Adite, A. & Sossoukpe, E. 2016 [Ecology and fish biodiversity of man-made lakes of Southern Benin \(West Africa\): implications for species conservation and fisheries management](#). *J. Environ. Protect.* **7**, 874–894.
- GOI 2008 *Report on Visit to VembanadKol, Kerala, A Wetland Included Under the National Wetland Conservation and Management Programme of the Ministry of Environment and Forests*. Planning Commission, Government of India, p. 11.
- Harper, D. A. T. 1999 *Numerical Palaeobiology*. John Wiley & Sons, Chichester, UK, p. 216.
- Jennings, S., Dinmore, T. A., Duplisea, D. E., Warr, K. J. & Lancaster, J. E. 2001 [Trawling disturbance can modify benthic production processes](#). *J. Anim. Ecol.* **70**, 459–475. doi:10.1046/j.1365-2656.2001.00504.x.
- Kamal, A. F. M. C., Ahmmed, S. & Mohammad, A. I. C. 2012 Trends of climatic variables (rainfall and temperature) at Sylhet, Bangladesh. *SUST J. Sci. Technol.* **19** (5), 87–93.
- Kurup, M. P., Sebastian, M. J., Sankaran, T. M. & Rabindranath, P. 1990 Exploited fishery resources of the Vembanad lake. *Mahasagar* **23** (2), 127–137.

- Magurran, A. E. 1988 *Ecological Diversity and its Measurement*. Princeton University Press, Princeton, NJ.
- Margalef, R. 1968 *Perspectives in Ecological Theory*. University of Chicago Press, Chicago, IL, p. 111.
- Mark, P. & Brown, K. M. 2015 Introduction to Mollusca and the class Gastropoda. In: *Thorp and Covich's Freshwater Invertebrates*, 4th edn. Ecology and General Biology. (P. Mark & K. M. Brown, eds). Academic Press, Inc, USA, pp. 383–421.
- McLachlan, A. & Brown, A. C. 2006 Beach and surf-zone. In: *The Ecology of Sandy Shores*, 2nd edn (A. McLachlan & A. C. Brown, eds). Academic Press, USA, pp. 55–64.
- Miranda, L. E. 2001 A review of guidance and criteria for managing reservoirs and associated riverine environments to benefit fish and fisheries. In: *Dams, Fish and Fisheries: Opportunities, Challenges and Conflict Resolutions* (G. Marmulla, ed.). FAO, Rome, pp. 91–138.
- Mogalekar, H. S., Ansar, C. P., Raman, N. N., Jayachandran, K. V. & Kolhe, S. 2015 Fish diversity of Vembanad lake in the Panangad- Kumbalam region of Kochi, Kerala, India. *Pollut. Res.* **34** (2), 345–349.
- Narayanan, S. P., Thapanjith, T. & Thomas, A. P. 2005 *A study on the ichthyofaunal of Aymanam Panchayath in Vembanad lake, Kerala*. *Zoo's Print*. **20** (9), 1980–1982.
- Pielou, E. C. 1966 *The measurement of diversity in different types of biological collections*. *J. Theor. Biol.* **13**, 131–144.
- Poff, N. L., Brinson, M. E. & John, W. D. 2002 *Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States Aquatic Ecosystems & Global Climate Change*. Pew Center on Global Climate Change, Copenhagen, Denmark, p. 34.
- Radhakrishnan, K., Sivaraman, I., Jena, S. K., Sarkar, S. & Adhikari, S. 2017 *A climate trend analysis of temperature and rainfall in India*. *Clim. Change Environ. Sustainable* **5** (2), 146–153.
- R Core Team 2013 *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical computing, Vienna, Austria. Available from: www.R-project.org/.
- Robert Jr., T. D. 2000 *The Ecology of Fresh Water Molluscs*. Press Syndicate of university of Cambridge, Cambridge, UK, pp. 334–335.
- Salagrama, V. 2012 *Climate Change and Fisheries: Perspectives From Small-Scale Fishing Communities in India on Measures to Protect Life and Livelihood*. SAMUDRA Monograph. International Collective in Support of Fishworkers, Chennai, India, p. 53.
- Sandhya, K. M., Lianthuamluaia, L., Karnatak, G., Sarkar, U. K., Suman, K., Mishal, P., Vikash, K., Debabrata, P., Yousuf, A. & Naskar, B. K. 2019 *Fish assemblage structure and spatial gradients of diversity in a large tropical reservoir, Panchet in the Ganges basin, India*. *Environ. Sci. Pollut. Res.* **26**, 18804–18813.
- Sarkar, U. K. & Borah, B. 2018 *Floodplain wetland fisheries of India: with special reference to impact of climate change*. *Wetlands Ecol. Manage.* **26**, 1–15.
- Sarkar, U. K., Koushik, R., Gunjan, K. & Saurav, K. N. 2018 *Adaptive climate change resilient indigenous fisheries strategies in the floodplain wetlands of West Bengal, India*. *J. Water Clim. Change*. **9** (3), 449–462.
- Sarkar, U. K., Roy, K., Naskar, M., Srivastava, P. K., Bose, A. K., Verma, V. K., Gupta, S., Nandy, S. K., Sarkar, S. D., Karnatak, G., Sudheesan, D. & Das, B. K. 2019a *Minnows may be more reproductively resilient to climatic variability than anticipated: synthesis from a reproductive vulnerability assessment of Gangetic pool barbs (*Puntius sophore*)*. *Ecol. Indic.* **105**, 727–736.
- Sarkar, U. K., Mishal, P., Karnatak, G., Sarkar, S. D., Das, A. K. & Das, B. K. 2019b *Climate resilient pen system in floodplain wetlands: an adaptive strategy for fisheries enhancement and biodiversity conservation*. *Indian Farm.* **69** (4), 41–44.
- Saswata, M., Harikrishnan, M., Shibu, A. V., Sureshkumar, S., Ranjeet, K. & Nandan, B. 2018 *Studies on temporal variations of exploited fishery resources and their trophic levels in a tropical estuary*. *Reg. Stud. Mar. Sci.* **22**, 61–69.
- Saud, B. J., Bhattacharjya, B. K., Verma, V. K., Kumar, D., Debnath, D., Das, M. & Sharma, A. P. 2012 *Effect of climate change on aquatic life with special reference to north-east region of India*. *Environ. Ecol.* **30** (4A), 1534–1537.
- Schneider, A., Hommel, G. & Blettner, M. 2010 *Linear regression analysis: part 14 of a series on evaluation of scientific publications*. *Deutsches Arzteblatt Int.* **107** (44), 776–782.
- Shannon, E. R. & Wiener, W. 1963 *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, Illinois, p. 117.
- Singh, A. 2016 *Coastal ballads and conservation ironic*. *Econ. Polit. Wkly.* **51** (7), 70–75.
- Singh, Y. 2017 *Relationships between environmental factors and biological parameters of Asian wedge clam, *Donax scortum*, morphometric analysis, length-weight relationship and condition index: a first report in Asia*. *J. Mar. Biol. Assoc. UK* **97** (8), 1617–1633. doi:10.1017/S002531541600103X.
- Soucek, D. J., Schmidt, T. S. & Cherry, D. S. 2001 *In situ studies with Asian clams (*Corbicula fluminea*) detect acid mine drainage and nutrient inputs in low-order streams*. *Can. J. Fish. Aquat. Sci.* **58** (3), 602–608.
- Talwar, P. K. & Jhingran, A. G. 1991 *Inland Fishes of India and Adjacent Countries*, Vol. 2. A.A. Balkema, Rotterdam.
- TerBraak, C. J. F. & Smilauer, P. 2002 *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5)*. Microcomputer Power, Ithaca, New York, USA, p. 500.
- Ulfah, M., Fajri, S. N., Nasir, M., Hamsah, K. & Purnawan, S. 2019 *Diversity, evenness and dominance index reef fish in Krueng Raya Water, Aceh Besar*. *IOP Conf. Ser. Earth Environ. Sci.* **348**, 012074.
- Wakefield, C. B., Lewis, P. D., Coutts, T. B., Fairclough, D. V. & Langlois, T. J. 2013 *Fish assemblages associated with natural and anthropogenically-modified habitats in a marine embayment: comparison of baited videos and opera-house traps*. *PLoS One* **8** (3), e59959. doi:10.1371/journal.pone.0059959.

Wäreborn, I. 1969 [Land Molluscs and their environments in an Oligotrophic Area in Southern Sweden](#). *Oikos* **20** (2), 461.

Wei, L., Lijuan, C., Baodi, S., Xinsheng, Z., Changjun, G., Yan, Z., Manyin, Z., Xu, P., Yinru, L. & Wu, M. 2017

[Distribution patterns of plant communities and their associations with environmental soil factors on the eastern shore of Lake Taihu, China](#). *Ecosyst. Health Sustainability* **3** (9), 1385004. doi:10.1080/20964129.2017.1385004.

First received 3 September 2019; accepted in revised form 5 May 2020. Available online 3 September 2020