Ecosystem services of coastal wetlands for climate change mitigation: an economic analysis of Pokkali and Kaipad-based rotational paddy farming systems in India

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Climate change and associated weather aberrations are wreaking havoc on the performance of production systems worldwide. Because of their proximity to the sea and risk of exposure, coastal wetlands are regarded as one of the most climatically vulnerable production systems. As a result, interventions to improve their adaptation and resilience to climate change are critical. We attempted to investigate the multifunctional ecosystem roles and services provided by the Pokkali and Kaipad paddy-based rotational farming systems on the southwest coast of India, which are being revived through a pilot programme implemented by the Kerala Agency for Development of Aquaculture. The physical and economic dimensions of the ecosystem services/disservices are assessed, and policy options for further land revival and area expansion of such wetlands are proposed.

Keywords: Climate mitigation, ecosystem services, ecosystem valuation, market price method, Pokkali/Kaipad ecosystems, replacement cost method, wetland ecosystem.

GLOBALLY, the performance of agriculture and related operations is negatively impacted by climate change and related weather anomalies[1]. Interventions for improving adaptation and mitigation of the negative impacts of climate change have become a matter of priority to sustain food production and livelihoods. Coastal regions are extremely vulnerable to the direct effects of climate change[2–8]. Additionally, it is anticipated that more wetlands in coastal areas are known for their valuable ecosystem services that include maintaining biological diversity, recycling nutrients, fostering water resources through groundwater recharge, controlling soil erosion, mitigating floods, biological nitrogen fixation and carbon sequestration might be affected by sea level rise[9–14]. Farmers involved in agriculture/aquaculture in these vulnerable coastal regions find it difficult to cope with emerging climate change scenarios such as unexpected floods due to uneven monsoons or rise in seawater level due to global warming, tidal flow and moderate changes in temperature, with adverse impacts on the productivity and sustainability of those farming systems.

The ancient brackish water paddy-based rotational farming systems (paddy followed by shrimp/fish) called Pokkali or Kaipad in Kerala – a state in southern India, is known for its multifunctional ecosystem roles, confront similar issues due to climate change. The Pokkali rice farming system in Kerala was once common on over 25,000 ha, but it has since been reduced to about 8000 ha. Currently, only 2200 ha of the 8200 ha of Pokkali filtration fields in central Kerala are being utilized for regular cultivation, and the remaining 5765 ha are still unexplored or partially used. Similar to this, in the last four decades, the cultivable areas of Kaipad land decreased from 2500 ha to 400 ha (ref. 15). The decline in farming over the past few decades is the result of several factors, including the conversion of wetlands for other uses, decreased labour availability, climate change-induced saline water intrusion and increasing tidal surges[16,17]. In order to support climate-resilient farming, it is vital to preserve and restore these coastal wetlands, which are more commonly referred to as an ecosystem that encompasses organisms, energy exchange and nutrient recycling in the environment for climate-resilient farming. In these ecologically sensitive places, integrated farming techniques are recognized as a viable adaptive/mitigation tool to ensure the resilience of the agricultural and fisheries production systems[18–23].

In the above context, the Agency for Development of Aquaculture, Kerala (ADAK), which works to strengthen social security and welfare measures for fisher folk/aqua farmers through inclusive development and empowerment, developed and implemented a project for the promotion of the integrated farming system of Kaipad and Pokkali in the coastal wetlands of Kerala utilizing the National Adaptation Fund for Climate Change (NAFCC) of the Ministry of Environment, Forest and Climate Change at the cost of

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Rs 33.73 crore for a duration of 4 years (2015–16 to 2018–19). The initiative, which aimed to enhance the livelihood support to people through revamping unutilized wetlands and strengthening adaption strategies, was extended through as to October 2021.

These revamped ecosystems provide numerous services, including providing food and other resources, habitat, climate regulation, nutrient recycling, erosion management besides cultural as well as recreational services[24]. Ecosystem services are generally divided into four categories: provisioning services, regulatory services, cultural services and supporting services[25]. Given the importance of ecosystem service instruments in policy development, priority setting and environmental litigation[26], ecosystem valuation is crucial to quantify the market and non-market value of ecosystem services towards ensuring welfare and environmental quality. One of the main priorities of the ADAK project was the assessment of ecosystem services rendered by the farming system under consideration towards climate resilience. This was done by the ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI) as part of a third-party review. In light of this, this paper makes an effort to evaluate the status of Pokkali/Kaipad ecosystem restoration and area extension brought about under the project, as well as to objectively estimate the enhanced ecosystem services realized as a result of the planned interventions of ADAK. The findings of the study can be useful in developing plans and guidelines for the resuscitation of integrated farming systems and towards the overarching goal of resilience building and adaptation to climate change in vulnerable coastal ecosystems.

Materials and methods

Study area

Pokkali and Kaipad are brackish water paddy-based rotational farming systems (paddy-shrimp/fish) in central and northern Kerala respectively. Most Pokkali lands are in the districts of Ernakulam, Thrissur and Alappuzha, whereas Kaipad lands are located in Kannur and Kozhikode districts of Kerala (Figure 1). The intervention was aimed at reviving 600 ha of Pokkali and Kaipad wetlands in Thrissur, Ernakulam, Alappuzha and Kannur districts through adaptive agriculture and aquaculture practices in the context of the reported increase in salinity and flooding of coastal wetlands as a result of climate change. The project was implemented in 105 ha of Kaipad lands in Kannur district and 495 ha of the Pokkali fields in Thrissur, Ernakulam and Alappuzha districts, involving 120 beneficiary groups. It is mandated that each beneficiary group should include five persons and be operating in a minimum area of 5 ha to qualify for inclusion in the project. They should also be following integrated paddy and fish/shrimp farming, as has been traditionally in vogue.

Methodology for impact assessment based on ecosystem services perspective

Given the positive externalities associated with the Pokkali and Kaipad integrated farming systems, particularly those in favour of climate change mitigation, an attempt was made to assess the quantifiable ecosystem benefits associated with the project areas. The ecosystem services valued in this evaluation include provisioning services such as food and fibre; regulating services such as water regulation, erosion control and carbon sequestration besides nitrogen fixation, which falls under support services. However, the valuation of cultural services accrued through the project was overlooked due to inadequate data. A number of standard approaches for ecosystem service valuation, such as the ‘market price method’, ‘replacement cost method’ and ‘benefit transfer method’[25,27–29], were utilized to obtain the results. The total ecosystem services were estimated (in Indian rupees) in the present study based on the following equation.

$$ES_t = PS_t + RS_t + SS_t,$$

where ES_t is the total estimated value of ecosystem services in year t; PS_t the estimated value of provisioning services in year t; RS_t the estimated value of regulating services in year t and SS_t is the estimated value of supporting services in year t.

Valuation of provisioning services

Provisioning services encompass all the outputs of materials, nutrients and energy from an ecosystem, which include food and water supplies, raw materials for construction and fuel, genetic resources, medicinal resources and ornamental resources[30]. ‘Market price method’ is a revealed preference approach for calculating ecosystem services and is estimated using the actual market price of the goods[31]. In the present context, the market value of paddy grain, paddy straw, shrimp and fish produced from the Pokkali and Kaipad project areas was estimated using the ‘market price method’.

Valuation of regulating and supporting services

Regulating services are the benefits obtained from the regulation of ecosystem processes (e.g. climate regulation, water regulation, pest and disease regulation), while supporting services are indirect services, as they are necessary for the production of provisioning, regulating or cultural services (e.g. soil formation, nutrient cycling, photosynthesis)[32]. The set of assumptions, along with the various technical coefficients utilized for estimating the major regulating and supporting services associated with integrated farming in the project areas, are presented in Table 1. For instance,

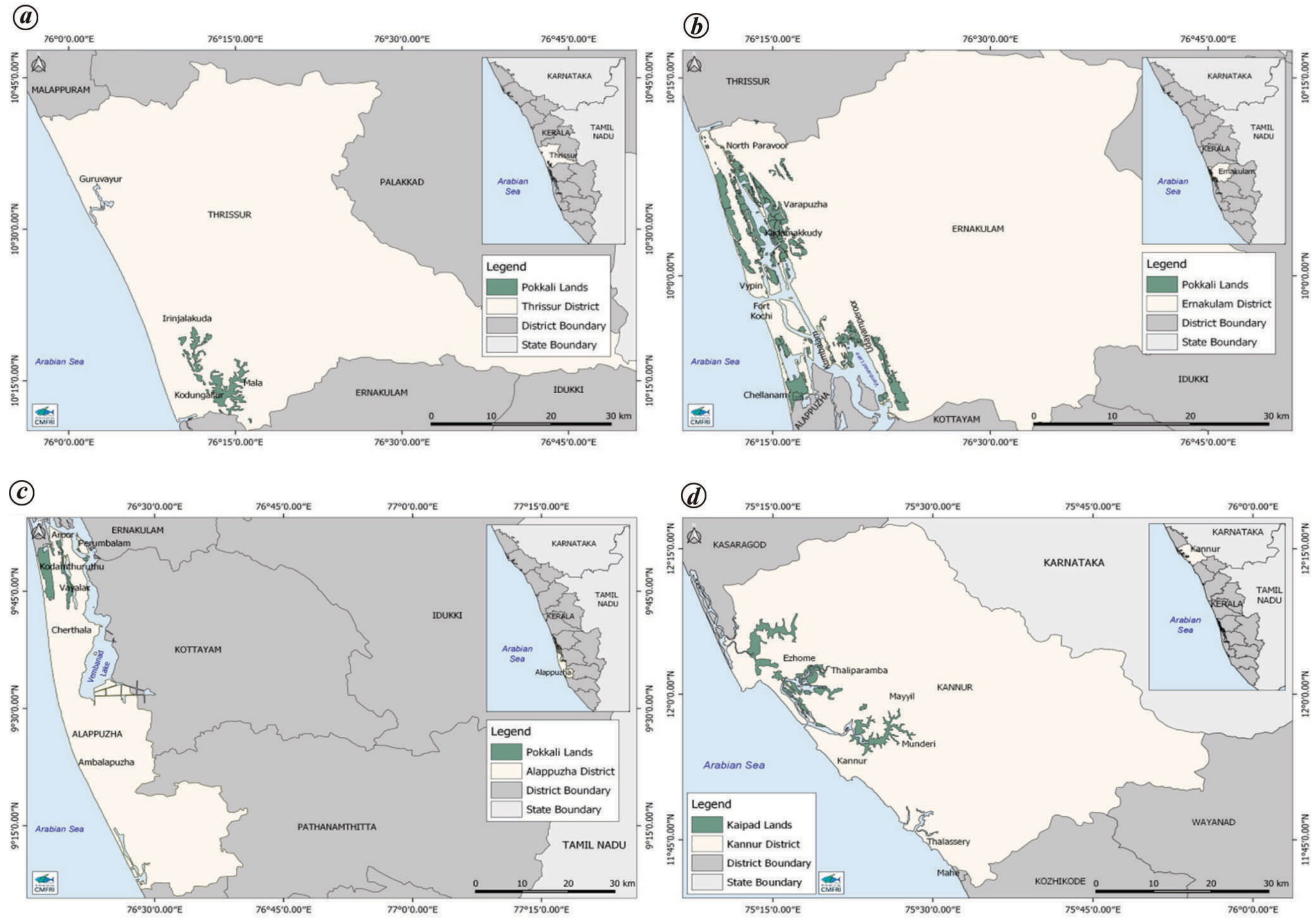

Figure 1 ***a*–*d*.** Pokkali lands in Thrissur, Ernakulam and Alappuzha; Kaipad lands in Kannur.

to estimate the value of the flood mitigation potential of paddy wetlands, replacement cost method was employed. This method determines the cost of replacing ecosystem services by assuming an alternate method for providing the same services and estimating the construction cost of that project[31]. In the present study, it was assumed that the paddy fields act as small reservoirs, as their outer bunds trap significant amounts of water, thereby mitigating the adverse effects of floods. The economic value of the service corresponds to the replacement cost and is estimated in terms of the annual depreciation and maintenance cost of a representative reservoir. The technical coefficient for this calculation, i.e. the annual depreciation and maintenance cost of a representative reservoir (Rs 55.80/m^3), was drawn from a recent study[33]. Similarly, to work out the economic value associated with the groundwater recharge service of wetlands, a stable rate of deep percolation was considered. This was assumed to be the same in both fallow and revived farmlands, except for the paddy growing season covering 150 days in the latter, during which the rate of percolation would be higher by 40% when the porosity of the soil would be greater due to land preparation and other cropping activities. The incremental deep percolation due to project intervention was thus worked out and valued using the price of groundwater for industrial uses in the state of Kerala. Similarly, the economic value of soil erosion control, carbon sequestration, greenhouse gas emission (dis-service) and biological nitrogen fixation were worked out based on reasonable assumptions and technical coefficients obtained from the literature (Table 1).

Results and discussion

Land revival and area expansion

One of the primary objectives of the ADAK project intervention was to revive the traditional Pokkali and Kaipad lands and bring them back under integrated farming of paddy, shrimp and fish. It was observed that most of the lands brought under the project were lying uncultivated for the last 20–30 years. Low economic returns, shortage of labour, high wage rates, high investments associated with maintaining bunds and sluice gates, lack of amenability to mechanization, etc. were cited as the reasons for the above state of affairs. Semi-intensive shrimp farming by stocking

Table 1. Valuation of ecosystem services of Pokkali and Kaipad farming systems: main assumptions and technical coefficients used

Ecosystem service/ dis-service	Main assumptions	Technical coefficients used for valuation	Value	
			Fallow land	Pokkali/ Kaipad land
Flood mitigation	The paddy fields act as small reservoirs, as their outer bunds trap significant amounts of water, thereby mitigating the adverse effects of flood. The economic value of the service corresponds to the replacement cost in terms of annual depreciation and maintenance cost of a representative reservoir.	Height of bund (m) (Source: Field observation)	0.50	2.00
		Depth of standing water (m) (Source: Field observation)	0.15	0.15
		Annual depreciation and maintenance cost of a representative reservoir (Rs/m^3)[33]	55.80	
Ground water recharge	Stable rate of deep percolation is assumed to be same in both fallow and revived farm lands, except for the paddy growing season covering 150 days in the latter, during which rate of percolation is higher by 40% when porosity of the soil is greater due to land preparation and other cropping activities.	Stable rate of deep percolation (mm/day)[42,43]	1.80	3.00*
		Price of ground water for industrial uses (Rs/m^3)[44]	42	
Soil erosion control	Lower soil erosion rate in cultivated fields compared to plain fallow lands is assumed to save significant amounts of nutrient-rich top soil, thereby saving the cost of land reclamation.	Rate of soil erosion per year (m^3/ha)[45]	22.4	4.06
		Cost of reclamation per year to replace nutrients lost due to erosion (Rs/ha)[34]	1631	
Carbon sequestration by mangroves	The rate of carbon sequestration taken here corresponds to that of 12-year-old mangrove plants in Sundarbans area. However, this may be a slight over-estimation as the mangroves in the project area are of maximum five years old.	Net carbon fixed by mangrove plants per year (tonnes/ha of CO_2 equivalent)[41]	0	6.24
		Carbon price in India (implicit price in the form of fuel excise tax) (Rs/tonne of CO_2 equivalent)[46]	1206.3	
Greenhouse gas (GHG) emission (disservice) and carbon sequestration	It is assumed that the rates of GHG emission and soil carbon storage in revived lands beyond the paddy growing season is the same as that in fallow lands. The emission/storage rates used here pertain to paddy growing operations as provided in respective literature. Any additional carbon emission/storage due to shrimp farming operations are overlooked due to lack of reliable information.	Rate of emission of methane per season (tonnes of CO_2 equivalent/ha)[36,47]	–	6.30*
		Rate of CO_2 emission (tonnes/ha)[36,47]	–	0.71*
		Rate of nitrous oxide emission (tonnes of CO_2 equivalent/ha)[36,47]	–	0.28*
		Rate of soil carbon storage due to C sequestration (tonnes of CO_2 equivalent/ha)[36,47]	–	0.31*
Biological nitrogen fixation	It is assumed that biological nitrogen fixation that happens in the paddy rhizosphere during the cropping season due to the activity of bacteria and blue-green algae is over and above what happens normally in submerged wetlands.	Rate of nitrogen fixation per cropping season (kg N/ha)[47]	–	33*
		Market price of nitrogen (Rs/kg)[47]	12	Field data

*Corresponds to the paddy growing season alone.

seeds was not possible due to a lack of effective control over water management in the fields. Even though many landowners were interested in reviving the lands, they could not do so on account of the prohibitive costs associated with the conversion. The ADAK project becomes relevant in this context, wherein necessary financial and technical support was provided to clear the vegetation, construct bunds and sluice gates, and establish mangroves and other infrastructure necessary to bring back cultivation. The area expansion under integrated Pokkali/Kaipad farming is provided in Table 2.

As evident from Table 2, the beneficiary groups mobilized an excess of 88 ha over and above the project target area of 600 ha using their investment, part of which was leased-in. The total fallow lands revived through the project stands at 248 ha, which is the direct impact of the project.

Valuation of provisioning services

These estimates of ecosystem services, along with the value of employment generated from the system for 2020–21,

Table 2. Particulars of land revival and area expansion through the project interventions

Farming system/district	Total number of project beneficiary groups	Area under the project (ha)	Total area actually revived (ha)	Area brought through leasing (ha)	Total fallow lands revived through the project (ha)
Kaipad–Kannur	21	105	112.1	108	108
Pokkali–Thrissur	33	165	201.4	24.4	20
Pokkali–Ernakulam	33	165	189.6	36.4	40
Pokkali–Alappuzha	33	165	184.8	125.5	80
All	120	600	688	294.3	248

Table 3. Magnitude and value of provisioning services (gross value of marketed goods) as well as employment generated in Pokkali and Kaipad farming systems in Kerala, 2020–21

Provisioning service	Average quantity generated per ha	Total quantity generated from the project area	Average gross economic value per ha (Rs/ha)	Gross economic value from project area (Rs in lakhs)	Additional gross economic value from converted fallow lands (Rs in lakhs)
Paddy grain (tonnes/year)	0.74	524.36	51,012.5	351.0	169.9
Paddy straw* (tonnes/year)	0.89	629.23	5,698	39.2	19.0
Shrimp (tonnes/year)	0.40	282.39	242,240	1,666.6	806.7
Fish (tonnes/year)	0.30	214.80	101,648	699.3	338.5
Employment generation (man-days/year)	214	147,506.40	149,386	1,077.5	466.7
Total			549,984	3,833.6	1,800.7

*This is the notional value as most of the beneficiaries incorporate paddy straw in the field after harvest.

are presented in Table 3. On average, 0.74 tonnes of paddy grain and 0.89 tonnes of paddy straw were generated per hectare of the project area leading to a total production of 524.4 tonnes of paddy grains and 629.2 tonnes of paddy straw. Total shrimp and fish produced from the project area were estimated to be 282.4 tonnes and 214.8 tonnes, with respective average yields of 0.40 tonnes/ha and 0.30 tonnes/ha. The gross economic value pertaining to the above services was estimated to be Rs. 2756.1 lakhs from the total project area of 688 ha, of which Rs 1334 lakhs were generated from newly converted fallow lands alone. Together with the value of total employment generated as a result of project implementation, the direct economic value generated from the project was estimated to be Rs 3833.6 lakhs. The disaggregated estimates pertaining to provisioning services, together with the value of employment generated across the districts are presented in Table 4.

Valuation of regulating and supporting services

The estimated physical and economic values of regulating/supporting ecosystem services/dis-services due to project interventions are presented in Table 5. The net impact in terms of flood mitigation was estimated to be 10,320 thousand m^3/year, valued at Rs 5758.6 lakhs annually. On a per hectare basis, this translates to 15,000 m^3 of flood water mitigated yearly, resulting in a net saving of Rs 8.37 lakhs.

Even though this ecosystem benefit is notional in non-flood years, the project areas contributed to flood mitigation during 2018 and 2019, when large-scale destruction was caused due to flash floods across the state of Kerala. The project interventions are also shown to have resulted in a net increase in groundwater recharge to the tune of 599.4 thousand m^3/year valued at Rs 251.7 lakhs. A lower soil erosion rate observed in cultivated wetlands compared to plain fallow lands is assumed to save significant amounts of nutrient-rich topsoil, thereby saving the cost of land reclamation[34,35]. The net reduction in soil erosions on account of revived fallow lands in the Pokkali and Kaipad regions under the project is quantified to be 6107 m^3/year, thereby saving the cost of soil reclamation at Rs 99.6 lakhs. In other words, the additional lands brought under the Pokkali and Kaipad system of integrated farming have resulted in soil erosion control at the rate of 8.9 m^3/ha resulting in a net saving of Rs 14,483/ha. Studies have shown that paddy soils are rich sinks of soil organic carbon (SOC). Anaerobic conditions induced by flooding slow down organic matter decomposition and thus benefit SOC accumulation. Further, it has been observed that changes in the carbon pool in paddy fields could strongly affect atmospheric CO_2 concentrations[36,37]. On the other hand, paddy fields also emit considerable quantities of greenhouse gases (GHGs) in the form of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) into the atmosphere contributing to global carbon emissions. Due to their potential role in global warming, GHGs from paddy fields do a disservice to the ecosystem[38].

Considering these factors, the annual net GHG emission pertaining to the project areas in terms of CO_2 equivalents was estimated and presented in Table 5. It was assumed that the rates of GHG emissions and soil carbon storage in revived lands beyond the paddy growing season are the same as in fallow lands. The emission/storage rates considered in the estimation pertain to paddy growing operations, as provided in the literature. However, any additional

Table 4. Gross and net (adjusted for costs) value added from provisioning services in Pokkali and Kaipad farming systems in Kerala district-wise, 2020–21

Farming system/ district	Estimated average value per ha (Rs/ha) Gross value of marketed goods	Net value of marketed goods	Value of Employment generated	Net total value added	Estimated value for project area (Rs lakhs) Net value of marketed goods	Value of Employment generated	Net total value added	Additional net value added from converted fallow lands (Rs lakhs)
Kaipad–Kannur	238,357	96,336	84,934	181,271	107.9	95.1	203.0	203.0
Pokkali–Thrissur	493,648	256,007	143,104	399,110	514.6	287.6	802.2	223.5
Pokkali–Ernakulam	535,985	211,557	223,021	434,579	402.0	423.7	825.7	282.5
Pokkali–Alappuzha	334,402	100,302	146,483	246,786	185.6	271.0	456.6	246.8
Entire Kerala	400,598	166,051	149,386	315,436	1,210.0	1,077.5	2,287.5	955.8

Table 5. Estimated physical and economic values of ecosystem service/dis-services due to project interventions in Pokkali and Kaipad farming systems in Kerala

Ecosystem service/dis-service	Total value before project		Total value after project		Net impact due to project		Net impact per hectare	
	Physical magnitude	Economic value (Rs in lakhs)	Physical magnitude	Economic value (Rs in lakhs)	Physical magnitude	Economic value (Rs in lakhs)	Physical magnitude	Economic value (Rs)
Flood mitigation (m^3/year)	2,408,000	1,343.7	12,728,000	7,102.2	10,320,000	5,758.6	15,000	837,000
Ground water recharge (m^3/year)	5,159,160	2,166.8	5,758,560	2,418.6	5,99,400	251.7	871.2	36,591
Net reduction in erosion (m^3/year)	8,901	145.2	2,793	45.6	6,107	99.6	8.9	14,483
Carbon sequestration by mangroves (tonnes of CO_2 equiv./year)	0	0.0	84.2	1.0	84.2	1.0	6.2	7,526
Net GHG emission (dis-service) (tonnes of CO_2 equiv./year)	2,477	9.8	4801	19.1	2324	9.2	3.4	1,343
Biological nitrogen fixation (kg N/year)	11,715	1.4	22,704	2.7	10,989	1.3	16.0	192
All ecosystem services		3,647.3		9,551.0		6,103.0		894,449

Note: Estimates correspond to an area of 688 ha, including the additional area brought under integrated farming by converting fallow lands by project beneficiaries; some studies point to lower GHG emissions in cultivated paddy lands compared to fallow lands[48], however, this aspect is not considered during estimations.

carbon emission/storage due to shrimp farming operations is overlooked due to a lack of reliable information in this regard. The results showed that the GHG emissions from the study areas in terms of CO_2 equivalents were greater than that of SOC storage, resulting in net ecosystem dis-service. In terms of physical magnitude, the net GHG emission was estimated to be 2324 tonnes of CO_2 equiv./year which was valued at Rs 9.2 lakhs. On a per hectare basis, these estimates translate to 3.4 tonnes of CO_2 equiv./year and Rs 1343 respectively. Mangroves planted along the bunds are another major source of carbon sequestration in the project sites. Several studies have shown that tropical mangrove cover is an excellent carbon sink, increasing SOC in the long run[39,40]. The rate of carbon sequestration in comparable ecosystems, as obtained from the literature[41] was utilized for estimating carbon storage in the project areas. However, the technical coefficient considered for the estimation corresponds to that of 12-year-old mangrove plants in the Sundarbans area, which may be a slight overestimation as the mangroves in the project area are a maximum of five years old. Based on field accounts, only 50% of the mangrove saplings planted were considered to be successfully established around the bunds. Considering a total length of 1.5 km bunds per unit and 1.5 m mangrove stand width, the total mangrove cover established in the entire project area was worked out to be 13.5 ha. Accordingly, the net additional quantity of carbon sequestered per annum as a result of project implementation was estimated to be 84.2 tonnes CO_2 equivalent, valued at Rs 1 lakh, given the carbon tax rate of Rs 1206/tonne CO_2 equivalent in India. Taken together, the net ecosystem economic value generated through the implementation of the project was estimated to be Rs 8.94 lakhs per hectare per annum, which translates to Rs 6103 lakhs at an aggregate level for the area under the project. It may be noted that the above estimates are over and above the annual value of provisioning services estimated at Rs 3834 lakhs (2020–21).

The key economic and financial indicators pertaining to the multidimensional ecosystem benefits accrued from the project interventions are presented in Table 6. As evident, the net total benefit inclusive of provisional regulating and supporting services adjusted for the cost incurred is estimated to be Rs 6860.8 lakhs per annum. Similarly, the return on

Table 6. Economic and financial indicators of direct and indirect ecosystem benefits accrued from the ADAK Project, 2020–21

Economic and financial indicator	Code	Value (Rs in lakhs)
Direct benefits from provisional services	A1	2,896.2
Indirect benefits from regulating/supporting services	A2	6,103.0
Total benefits (B = A1 + A2)	B	8,999.3
Initial capital cost	C1	1,250.0
Operational cost[#]	C2	685.9
Labour cost	C3	1,077.5
Gross cost (D = C2 + C3)	D	1,763.4
Depreciation on capital assets (20%)	E	250
Interest (10%)	F	125
Total cost (G = D + E + F)	G	2,138.4
Net cash flow (H = A1 – D)	H	1,132.8
Net direct profit (I = A1 – G)	I	757.8
Net direct profit margin (%) (J = I/A1)	J	26.2
Gross Value Added (GVA) to direct benefits (K = H + C3)	K	2,210.3
Net total benefit (L = B – G)	L	6,860.8
Value of fixed tangible assets*	M	400
Return on fixed tangible assets (ROFTA) (%) (N = I/M)	N	1,715.2
Return on Investment (ROI) (O = I/C1)	O	548.9

[#]Includes the overhead cost of project administration over and above input costs borne by the beneficiaries.
*Assuming the average duration of project implementation in 2020–21 as 3.4 years.

investment of the project was estimated at 548.9%, which is quite high as per accepted standards for projects intended for the greater common welfare.

Conclusion

Integrated farming systems such as paddy-fish-based rotational ecosystems have been identified as effective means for ensuring the resilience of extremely climate-vulnerable fragile regions such as coastal wetlands. Given the importance of coastal wetlands restoration and management for resilient climate farming, the ADAK implemented a project from 2016 to 2021 to promote the integrated farming system of Kaipad and Pokkali coastal wetlands in Kerala. Large stretches of idle fallow paddy lands in four coastal districts of Kerala have been revived and used for integrated farming as part of the project. Against this backdrop, this paper primarily aimed to quantify the extent of land revival and area expansion of Pokkali/Kaipad lands under the project and objectively estimate the ecosystem service and benefits provided by these coastal wetlands towards climate change adaptation and resilience. The findings indicate that various ecosystem benefits of the revival of paddy wetlands included flood mitigation, groundwater recharge, soil water erosion control, carbon sequestration, biological nitrogen fixation, etc. The net economic value of ecosystem services generated by revitalization and expansion was estimated to be Rs 6103 lakhs per year or Rs 8.94 lakhs per hectare. This works out to a net enhancement of about 162% in ecosystem value as a result of the project implementation. Even though farmers in Pokkali/Kaipad farming frequently face physical, economic and technical constraints, our findings suggest that the ecological benefits derived far outweigh the constraints, given proper policy and institutional support are in place. In the context of the increasing vulnerability of coastal ecosystems due to the impending climate change scenario, the study's outcomes are encouraging, given its overarching potential in integrating inbuilt resilience-building mechanisms and ecosystem service potential, in addition to sustainable and integrated farming interventions.

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