Climate Change Effects on Marine Production along the Kerala Coast: Evidence from Ecological Trends and Socio-Economic Analysis

Muhammed Jaffer V., Shukoor.K.H

Assistant Professor, Dept of Economics, MAMO College Manassery

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ABSTRACT

Marine fisheries along the Kerala coast constitute a major component of coastal livelihoods, regional food security, and state-level economic activity. The 590 km coastline along the Arabian Sea supports a large population of small-scale fishers whose income and employment depend heavily on marine resources. However, due to climate change owing to the greenhouse effect a rising sea surface temperature (SST) and changing monsoon dynamics is altering the oceanographic processes that sustain marine productivity. Against this background, the present study analyses the impact of climate change on marine fish production along the Kerala coast.

The study uses linear trend analysis to assess long-term changes in SST and marine landings, followed by regression modelling to check the relationship between climate variability and fish production. The results prove a statistically significant upward trend in SST, confirming sustained warming of the southeastern Arabian Sea. Whereas marine fish landings exhibit increasing interannual variability with a moderate declining tendency over time. Regression results prove a negative link between SST and marine production, indicating that rising ocean temperatures adversely affect fish productivity, particularly small pelagic species such as oil sardine known locally as Mathi or Chala the most beloved fish in the diet of malayalis.

The findings implies that climate change driven ecological instability converts into economic uncertainty for fishing communities through fluctuating catch levels and reduced fishing opportunities. The study underlines the need of climate-sensitive fisheries management, improved ocean monitoring systems, and adaptive livelihood strategies to enhance resilience among coastal populations. By mixing up ecological trends with socio-economic implications, this paper contributes to the growing literature on climate impacts in tropical marine ecosystem.

Keywords: marine fisheries; climate change; Indian oil sardine; sea surface temperature; livelihoods

INTRODUCTION

Marine fisheries are a vital source of renewable income and sustenance for coastal communities worldwide. In developing economies, particularly in tropical regions, marine resources play a vital role in employment creation, nutritional security, export earnings, and poverty reduction. Kerala, located along the southwestern coast of India, is one of the most marine-dependent regions in the country. With a approximate coastline of 590 kilometers along the Arabian Sea, Kerala supports thousands of fishing households whose livelihoods are closely linked to marine ecosystems. The productivity of marine fisheries along the Kerala coast is largely dependent by monsoon-driven oceanographic processes. Seasonal upwelling during the southwest monsoon enriches surface waters with nutrients, leading to enhanced plankton productivity and fish recruitment. Small pelagic species, particularly oil sardine and mackerel, dominate marine landings and are highly sensitive to changes in temperature, nutrient availability, and ocean circulation patterns. Thus, the ecological balance of the Arabian Sea directly influence the stability of marine production in Kerala.

In recent decades, climate change has emerged as a major environmental threat affecting marine ecosystems worldwide. Scientific evidence indicates that the Indian Ocean, including the Arabian Sea, is warming at a rate higher than the global ocean average. Rising sea surface temperature (SST), altered monsoon patterns, increased frequency of extreme weather events, and changes in ocean stratification are destabilizing the marine habitats. These changes influence species distribution, spawning cycles, migration patterns, and overall productivity. As marine ecosystems are temperature-sensitive, even small increases in SST can trigger significant ecological shifts.

For Kerala, the implications of climate variability are particularly serious. Fluctuations in marine landings have been increasingly observed over the past few decades. While interannual variability is a natural feature of marine systems, the growing instability in catch volumes raises concerns about long-term sustainability. Small pelagic species, which form the backbone of Kerala's marine fisheries, exhibit high sensitivity to SST fluctuations. Changes in temperature may affect plankton availability, larval survival, and fish aggregation behaviour, thereby influencing total landings.

Beyond ecological consequences, climate-induced production variability has profound socio-economic implications. A large proportion of Kerala's fishing sector consists of small-scale and artisanal fishers with limited adaptive capacity. Fluctuating fish catches translate directly into income instability, reduced fishing days, and increased financial distress. Since marine fishing is often the primary income source of coastal households, uncertainty production intensifies livelihood risks. In addition, market volatility, rising operational costs, and limited diversification opportunities further escalate economic stress in fishing communities.

Although numerous studies have examined the biological impacts of ocean warming, relatively fewer empirical investigations have systematically analysed the relationship between climate indicators and marine production using statistical modelling approaches at the regional level. Moreover, the integration of ecological trends with socio-economic implications remains limited in the context of Kerala. Understanding how rising SST influences marine landings is essential for designing climate-sensitive fisheries policies and adaptation strategies.

Against this background, the present study seeks to examine the impact of climate change on marine fish production along the Kerala coast using annual data for the period 1990–2020. The study employs linear trend analysis to assess long-term changes in sea surface temperature and marine landings, followed by regression modelling to estimate the relationship between SST and fish production. By combining ecological evidence with socio-economic interpretation, the study aims to contribute to the growing discourse on climate resilience in coastal economies.

The central argument of this paper is that sustained warming in the Arabian Sea is associated with increasing instability in marine production, which in turn amplifies livelihood vulnerability among small-scale fishers. Identifying and quantifying this relationship is essential for informed fisheries governance, improved climate forecasting systems, and the development of adaptive strategies to safeguard marine-dependent communities

Objectives of the Study

1.To examine long-term trends in sea surface temperature.

2..To analyse trends in marine fish production.

3. To estimate the relationship between SST and marine landings using regression modelling.
4. To assess socio-economic implications for fishing communities.

DATA AND METHODOLOGY

Data Sources and Study Period

This study uses annual time-series data covering the period 1990–2020 to examine the long-term relationship between climatic variability and marine fish production along the Kerala coast. The three-decade span allows for the identification of structural trends, thereby providing a robust basis for climate–production assessment.

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Marine fish production data were compiled from official fisheries statistics and published reports of relevant authorities. The dataset includes total annual marine fish landings (in tonnes) and species-wise landings, with particular emphasis on small pelagic species such as oil sardine. Where available, secondary information on fishing effort was examined to contextualize production variability.

Climatic data consist of annual mean Sea Surface Temperature (SST) for the southeastern Arabian Sea adjoining the Kerala coast. SST is widely regarded as a critical ecological determinant of marine productivity, influencing plankton dynamics, stratification patterns, spawning cycles, and recruitment success. Annual averages were used to ensure temporal consistency with marine production data.

Econometric Framework

Trend Analysis

To examine long-term movements in climatic and production variables, linear trend equations were estimated using the model:

$$Y_t = \alpha + \beta t + \varepsilon_t$$

where Y_t denotes SST or marine fish landings in year t, t represents time, α is the intercept, β is the trend coefficient, and ε_t is the error term.

A positive and statistically significant β in the SST equation indicates warming over time, whereas a negative and significant β in the landings equation indicates declining marine production.

Regression Model

To estimate the climate–production relationship, the following model was specified:

$$LAND_t = \alpha + \beta SST_t + \varepsilon_t$$

where $LAND_t$ represents total marine fish landings and SST_t denotes sea surface temperature. The parameter β measures the marginal effect of temperature on marine output. The expected sign of β is negative, reflecting the hypothesis that rising sea temperatures reduce marine productivity.

Diagnostic Tests and Robustness Checks

Given the time-series nature of the data, standard diagnostic procedures were conducted to ensure econometric reliability.

First, stationarity of the variables was examined using unit root tests. The results indicated that both SST and marine landings were stationary in levels or became stationary after first differencing, thereby reducing the risk of spurious regression.

Second, autocorrelation in the residuals was tested using the Durbin–Watson statistic. The statistic remained within the acceptable range, suggesting no serious serial correlation problem in the estimated models.

Third, heteroskedasticity was examined using appropriate tests. The absence of significant heteroskedasticity indicates that the error variance remained relatively stable over time.

To verify robustness, alternative model specifications were considered, including log-linear forms. The negative relationship between SST and marine production remained statistically significant across specifications, confirming the stability of the estimated climate effect.

RESULTS AND ANALYSIS

Trend in Sea Surface Temperature

The estimated trend coefficient for SST is 0.024°C per year, with an R^2 value of 0.874 and a p-value less than 0.001. This indicates a strong and statistically significant warming trend over the period 1990–2020. The high explanatory power suggests that the majority of SST variation is explained by time, confirming a persistent increase in sea surface temperature in the southeastern Arabian Sea. This finding is consistent with broader evidence of accelerated warming in the Indian Ocean region.

Trend in Marine Fish Landings

The trend analysis for total marine landings reveals a statistically significant decline. The estimated coefficient of –2,662 tonnes per year indicates a steady reduction in marine production over the study period. The R^2 value of 0.511 suggests moderate explanatory strength, reflecting the presence of substantial interannual variability. While short-term fluctuations remain evident, the long-term downward trajectory suggests increasing ecological and structural stress within the fisheries sector.

Regression Results: SST and Marine Production

The regression analysis reveals a statistically significant inverse relationship between sea surface temperature and marine fish landings. The estimated SST coefficient of –98,270 tonnes implies that a one-degree Celsius increase in SST is associated with an approximate reduction of 98,270 tonnes in marine landings. The R^2 value of 0.461 indicates that 46.1 percent of the variation in marine production can be statistically associated with SST variation.

The coefficient is highly significant ($p < 0.001$), providing strong empirical support for the hypothesis that rising ocean temperatures adversely affect marine productivity. While SST does not account for all variability in landings, its substantial explanatory contribution highlights the central role of climatic factors.

Species-Level Evidence: Oil Sardine

A separate trend regression for oil sardine landings shows a statistically significant decline of –2,958 tonnes per year, with a p-value of 0.002. The R^2 value of 0.295 indicates greater volatility compared to total marine production. This lower explanatory power reflects the higher biological sensitivity of small pelagic species to short-term temperature shifts, nutrient availability, and oceanographic variability.

The species-level findings suggest that climate impacts are uneven across fish categories. Small pelagic species exhibit stronger responsiveness to temperature changes, implying disproportionate vulnerability among fishing communities that depend heavily on these species.

Discussion of Empirical Strength

The empirical evidence demonstrates strong statistical significance across models, with consistent coefficient signs aligned with theoretical expectations. High significance levels ($p < 0.01$) reduce the probability that observed relationships are due to chance. The stability of results across alternative specifications further strengthens confidence in the findings.

Although additional factors such as fishing effort, regulatory changes, and technological improvements may also influence marine production, the consistent negative relationship between SST and landings underscores the central role of climate variability in shaping fisheries outcomes along the Kerala coast..

Overall Interpretation

The combined trend and regression analysis yields three important insights:

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1. Sustained Warming

SST shows a strong and statistically significant upward trend, confirming climate change influence in the Arabian Sea region.

2. Production Instability

Marine landings demonstrate a moderate but statistically significant declining tendency, accompanied by considerable variability.

3.Negative Climate–Production Link

Regression results confirm an inverse association between SST and marine fish production.

Together, these findings suggest that rising ocean temperatures are associated with declining and unstable marine productivity.

Socio-Economic Implications

The empirical findings indicating a warming trend and declining marine production have significant socio-economic consequences for coastal communities in Kerala. Marine fisheries in the region are predominantly small-scale and labour-intensive, with limited technological and financial buffers. Therefore, ecological instability directly translates into livelihood vulnerability.

Income Instability and Earnings Volatility

Marine fishers' incomes are largely dependent on daily catch volumes, making their livelihoods extremely sensitive to changes in marine productivity. The observed decline and increasing variability in marine landings result in fluctuating daily earnings, heightened seasonal uncertainty, and irregular cash flow. Unlike salaried employment, fishing income is directly linked to the quantity and value of the catch, meaning that even moderate declines in productivity can significantly reduce household consumption capacity and limit savings. As variability in production increases, income volatility becomes more pronounced, making financial planning and long-term investment decisions difficult for fishing households. Furthermore, regression results indicating a negative association between sea surface temperature (SST) and marine production suggest that sustained ocean warming could lead to prolonged periods of income uncertainty, thereby intensifying the economic vulnerability of fishing communities.

Reduction in Fishing Days

Climate change often leads to rough sea conditions, unpredictable monsoon behaviour, and an increased frequency of extreme weather events. The extreme weather conditions significantly reduce the number of operational fishing days available to fishers. As a result, fewer fishing days lead to a lower total annual catch, reduced labour utilization, and a decline in crew wages. Since many artisanal fishers work as daily wage earners within crew-based systems, a reduction in fishing days directly decreases their employment opportunities and overall income.

Increased Indebtedness and Financial Stress

Income instability frequently leads to a growing dependence on informal credit sources, including borrowing from local money lenders or fish traders, which ultimately results in higher levels of debt accumulation among fishing households. In traditional fishing communities, credit arrangements are often closely integrated with fish marketing systems, where traders or intermediaries provide advance loans in exchange for assured sales of future catch. While such arrangements offer short-term liquidity support, they create structural dependency relationships. When catch levels decline due to ecological or climatic factors, the repayment capacity of fishers weakens significantly, increasing their exposure to financial stress. As a result, ecological shocks translate directly into economic vulnerability by pushing households into recurring cycles of indebtedness.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Production instability also affects fish prices and overall market dynamics. Lower landings may lead to temporary price increases due to reduced supply; however, unpredictable and fluctuating production undermines market stability in the long run. Traders face uncertainty in procurement planning and export commitments, which affects the entire value chain. Despite occasional price rises during periods of low supply, small-scale fishers often possess limited bargaining power and are unable to capture the full benefit of higher prices. Consequently, market volatility combined with production instability intensifies income insecurity rather than alleviating it.

Occupational Diversification and Migration

As marine productivity becomes increasingly uncertain due to climatic variability and ecological changes, fishing households are often compelled to reconsider their traditional livelihood strategies. In response to declining or uncertain fish catches, many households shift to non-fishing jobs such as construction work, transportation services, or other forms of informal sector employment. Some members, particularly younger workers, may engage in temporary or seasonal migration to urban centres or other coastal regions in search of alternative income opportunities. Others attempt to diversify locally by entering small-scale trade, petty business activities, or daily wage labour to supplement household earnings.

Although livelihood diversification can strengthen economic resilience by reducing dependence on a single source of income, such shifts are not always the result of proactive planning. In many cases, these changes reflect distress-driven adaptation, where households are pushed into unfamiliar or less secure occupations due to falling marine resources. Consequently, while diversification may provide short-term coping support, it may also indicate deeper structural vulnerability within fishing communities.

Gendered Impacts

Women play a crucial role in the fisheries sector, particularly in post-harvest activities such as fish processing, marketing, and dry fish production. In many coastal communities, women are actively involved in cleaning, sorting, curing, and preserving fish, as well as selling fresh and dried fish in local markets. These activities not only generate independent income for women but also significantly contribute to household financial stability and food security.

However, when fish landings decline due to climate variability, rough sea conditions, or reduced marine productivity, the availability of raw materials for these post-harvest activities also decreases. This directly affects women’s employment opportunities and earnings, often reducing their daily income and limiting their economic autonomy. Since many households rely on women’s supplementary income to meet basic expenses, declining fish supplies can weaken overall household-level economic stability.

Therefore, the impacts of climate change and ecological stress are not confined to active fishers alone but extend across the broader coastal economy, affecting women workers, small traders, and other stakeholders linked to fisheries-based livelihoods.

Vulnerability of Small Pelagic-Dependent Fishers

The species-level regression results indicate greater volatility in sardine landings, highlighting the sensitivity of small pelagic species to climatic and oceanographic changes. Since many artisanal fishers depend heavily on small pelagic species such as sardines for their daily income, species-specific declines can disproportionately affect particular fishing communities. Specialized fishing groups that rely primarily on targeting these species face higher levels of risk exposure when catches fluctuate or decline. Moreover, adaptive capacity is not uniform across the fisheries sector; it varies depending on gear types, vessel capacity, capital investment, and access to alternative fishing grounds or species. Fishers using highly specialized gear may find it more difficult to shift to other target species compared to those with more diversified fishing methods. As a result, ecological variability creates unequal patterns of vulnerability within the fisheries sector, intensifying disparities among communities and fishing categories

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Social Protection and Institutional Gaps

The findings accentuate the urgent need for stronger institutional mechanisms to mitigate the socio-economic impacts of climate variability on fishing communities. In particular, the introduction of climate insurance schemes could help protect fishers against income losses resulting from extreme weather events and declining marine productivity. Similarly, income stabilization funds could provide temporary financial support during periods of low catch, thereby reducing vulnerability to sudden income shocks. Strengthening weather forecasting and early warning systems would also enable fishers to plan their fishing activities more safely and efficiently, minimizing risks associated with rough sea conditions and unpredictable monsoon patterns. In addition, reinforcing cooperative institutions can enhance collective bargaining power, improve access to formal credit, facilitate better marketing arrangements, and promote savings and risk-sharing mechanisms among members. Without such institutional support, climate-induced production variability may intensify financial insecurity, widen income disparities, and deepen socio-economic inequality in coastal regions, ultimately undermining sustainable development efforts.

Integrated Climate–Livelihood Linkage

The overall socio-economic pathway linking climate change to livelihood vulnerability can be understood as a sequential process in which ecological disturbances translate into economic stress. Rising sea surface temperatures (SST) alter marine ecosystems, affecting fish breeding patterns, migration routes, and overall stock availability. These ecological changes contribute to a decline and increased variability in marine production, making fish catches less predictable and often lower than historical averages. As a result, fishing households have income instability, since their earnings are directly dependent on daily and seasonal catch volumes.

Persistent income fluctuations weaken the financial stability of households, often forcing them to rely on informal borrowing or credit arrangements to meet consumption needs and sustain fishing operations. This growing dependence on debt further reduces repayment capacity when catches remain low, pushing households into cycles of financial stress. Over time, this process deepens livelihood vulnerability, limiting the ability of fishing communities to invest, save, or adapt effectively to changing environmental conditions.

Thus, what begins as an ecological change—such as rising SST—gradually evolves into a broader economic development issue, affecting income security, financial stability, and long-term resilience within coastal communities.

Broader Development Implications

Marine fisheries play a crucial role in ensuring nutritional security, particularly in coastal and low-income communities where fish constitutes a primary source of animal protein. In Kerala, fish is not only a dietary preference but also a culturally embedded and nutritionally significant component of daily food consumption. Marine fish provide high-quality protein along with essential micronutrients such as omega-3 fatty acids, iodine, zinc, calcium, and vitamins A and D. For child growth, cognitive development, maternal health, and the prevention of lifestyle-related diseases these nutrients are vital.

Variations in marine production caused by climate change can directly affect the availability and affordability of fish in local markets. Declining or unstable landings may reduce per capita fish consumption, particularly among economically vulnerable households who are more sensitive to price changes. When supply becomes inconsistent, retail prices may increase, making fish less accessible to poorer sections of society. This can have broader public health implications, especially in regions where fish serves as a key substitute for other costly protein sources such as meat and poultry.

Moreover, marine fisheries support food distribution networks that extend beyond coastal areas into inland markets. Any disruption in marine productivity therefore has implications not only for fishing households but also for broader food systems and state-level nutritional outcomes. Sustained climate-induced instability in

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

marine production may consequently undermine long-term food security objectives and complicate efforts to maintain balanced dietary patterns.

In this context, climate change impacts on marine fisheries should be viewed not merely as sectoral economic issues but as matters of public health and human development. Protecting marine productivity is therefore essential for safeguarding nutritional security and sustaining equitable access to affordable protein sources

Strength of Empirical Evidence

The statistical results show a high level of empirical robustness and reliability. First, the estimated coefficients exhibit strong statistical significance, with p-values less than 0.01 in key models. This indicates that the observed relationships between sea surface temperature and marine production are unlikely to have occurred by random chance. The high significance levels strengthen confidence in the existence of a systematic association between climatic trends and fisheries outcomes.

Second, the models display moderate to strong explanatory power, as reflected in the R^2 values. The SST trend model explains a substantial proportion of temperature variation over time, confirming a clear warming pattern. Similarly, the regression model linking SST to marine landings accounts for a meaningful share of production variability. While marine ecosystems are influenced by multiple biological and environmental factors, the ability of a single climate variable (SST) to explain a significant portion of production variation highlights the importance of temperature as a key driver.

Third, the estimated coefficients consistently show the expected directional relationship. The positive trend in SST aligns with established climate science, while the negative association between SST and marine landings corresponds with ecological theory suggesting that warming can disrupt nutrient dynamics, spawning cycles, and fish recruitment. The consistency between theoretical expectations and empirical findings enhances the credibility of the analysis.

Furthermore, the regression diagnostics indicate acceptable model behaviour. The statistical tests suggest that the models do not suffer from major specification problems within the simplified framework used for seminar purposes. The absence of contradictory coefficient signs or unstable parameter estimates further supports the internal consistency of the results.

It is also important to note that species-level analysis reveals stronger volatility compared to aggregate production trends. This differential sensitivity reinforces the ecological interpretation that small pelagic species are particularly vulnerable to climatic fluctuations. Such species-level consistency adds depth to the empirical evidence by showing that climate impacts are not uniform across fish categories.

Overall, the empirical findings provide coherent, statistically significant, and theoretically consistent evidence of a climate–production linkage. While the models are intentionally simplified for seminar presentation, the results offer a solid quantitative foundation for further advanced research and policy discussion

Policy Implications

The empirical findings of a sustained warming trend and its negative association with marine production underline the urgent need for climate-sensitive fisheries governance in Kerala. Traditional fisheries management approaches that focus primarily on stock regulation and licensing must now integrate climate variability as a central planning parameter. This includes incorporating sea surface temperature monitoring, climate forecasts, and oceanographic data into fisheries decision-making processes. Adaptive management frameworks that allow flexible seasonal regulations, dynamic fishing zones, and climate-responsive advisories can help reduce ecological stress while maintaining production sustainability.

The development and strengthening of early warning systems are equally critical. Accurate and timely dissemination of weather forecasts, ocean condition alerts, and extreme event warnings can reduce risk exposure for fishers. Technological interventions such as mobile-based alerts, satellite-based SST monitoring, and real-time marine advisories can improve preparedness and minimize economic losses caused by adverse weather conditions. Enhancing coordination between meteorological agencies, fisheries departments, and coastal communities will be essential to ensure that scientific information translates into practical decision-making at the grassroots level.

Sustainable harvesting practices must also be prioritized to prevent the compounding effects of climate stress and overfishing. Measures such as regulated fishing effort, mesh size control, protection of spawning grounds, and promotion of selective gear technologies can help maintain stock resilience. Climate change may alter species distribution and reproductive cycles; therefore, fisheries regulations must be periodically reviewed and adjusted based on scientific assessments. Strengthening community-based fisheries management and cooperative institutions can promote compliance and participatory conservation.

In addition, diversification of livelihood strategies is necessary to enhance the adaptive capacity of fishing households. A single climate-sensitive occupation dependence increases vulnerability to environmental shocks. Encouraging supplementary income activities such as aquaculture, value-added fish processing, small-scale entrepreneurship, eco-tourism, or skill-based non-fishing employment can provide income buffers during periods of low catch. Access to institutional credit, insurance schemes, and financial literacy programs can further reduce reliance on informal debt systems and improve economic resilience.

Social protection mechanisms also deserve attention. Climate insurance schemes, disaster relief funds, income stabilization support, and targeted welfare programs can mitigate the socio-economic consequences of production variability. Policies should particularly focus on small-scale fishers, women engaged in fish processing and marketing, and marginalised coastal households who face higher vulnerability.

Overall, the findings suggest that marine climate adaptation must move beyond ecological management to encompass integrated socio-economic planning. A combined policy framework that incorporates scientific monitoring, regulatory reform, financial inclusion, and livelihood support is essential to strengthen resilience among fishing communities in a warming ocean context.

CONCLUSION

Climate change is progressively reshaping marine production systems along the Kerala coast, altering both ecological dynamics and the economic foundations of coastal livelihoods. The trend analysis clearly indicates a persistent warming pattern in sea surface temperatures, while regression results establish a statistically significant link between rising SST and variability in marine fish production. These findings confirm that climatic factors are not peripheral influences but central drivers of change in marine resource availability and productivity.

The decline and increasing unpredictability of fish landings have direct implications for income stability, employment opportunities, and financial security among fishing households. Given the high dependence of marine fishers on daily catch volumes, even moderate ecological shifts translate into substantial socio-economic consequences. Income instability, debt dependence, occupational shifts, and heightened vulnerability are emerging as structural challenges within coastal communities. The impacts are multidimensional, extending beyond active fishers to include women engaged in post-harvest activities, small traders, and other stakeholders within the fisheries value chain.

These findings underscore the need for integrated adaptation strategies that combine ecological sustainability with socio-economic resilience. Strengthening fisheries management, promoting climate-resilient fishing practices, improving access to institutional credit and insurance, and enhancing early warning systems are critical policy priorities. At the same time, livelihood diversification and cooperative strengthening should be supported in ways that reflect planned adaptation rather than distress-driven responses.

In conclusion, climate change in the marine sector must be viewed not only as an environmental issue but also as a developmental and social justice concern. Ensuring sustainable coastal livelihoods along the Kerala coast

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requires coordinated efforts that bridge environmental science, economic policy, and community-based resilience planning.

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