Optimizing productivity and environmental sustainability in tourism-driven coastal regions through innovative culture systems and pollution control measures

Mavjuda Mominova[1*]; Dilshod Sharipov[2]; Lobar Kamolova[3]; Husnida Ismoilova[4]; Urol Abilov[5]; Komila Asqarova[6]; Turaqul Hasanboyev[7]

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Abstract

The coastal areas that depend on tourism are increasingly under pressure from environmental factors driven by rapid infrastructure development, large seasonal populations, and inadequate waste management systems. The United Nations World Tourism Organization estimates that almost 40% of global tourism income is generated by coastal areas, and the United Nations Environment Program estimates that nearly 80% of marine pollution is land-based. During peak tourist seasons, solid waste may increase by 30-50% at popular attractions, affecting water pollution, biodiversity loss, and reduced local productivity in fisheries and crop production. This paper explores the potential for optimizing productivity and environmental resilience through innovative cultural systems based on sustainable tourism, circular-economy models, and community-based environmental stewardship, alongside sophisticated pollution management strategies. It employed a mixed-methodology, which involved environmental impact analysis, stakeholder survey (n=450), and pilot testing of decentralized wastewater treatment plants and waste-to-resource plants in three coastal areas. A quantitative comparison of pre- and post-intervention water quality indicators, tourism revenue, and employment in the locality was conducted. The outcome shows that there should be a 25% decrease in water

1*- Lecturer, Termez University of Economics and Service, Termez, Uzbekistan.
Email: mavjuda_mominova@tues.uz, ORCID: https://orcid.org/0009-0005-4888-9341
2- Senior Lecturer, Department of Social Sciences, Bukhara State Pedagogical Institute, Bukhara, Uzbekistan.
Email: sharipovdilshod671@gmail.com, ORCID: https://orcid.org/0009-0003-4582-1523
3- Bukhara State Medical Institute named after Abu Ali Ibn Sino, Bukhara, Uzbekistan.
Email: kamolova.lobar@bsmi.uz, ORCID: https://orcid.org/0009-0006-8315-2924
4- Lecturer, Fergana Medical Institute of Public Health, Fergana, Uzbekistan.
Email: ismailovakhusnida1131@gmail.com, ORCID: https://orcid.org/0009-0006-6857-0802
5- Lecturer, Department of Social Sciences, Tashkent State Medical University, Tashkent, Uzbekistan.
Email: uabilov55@gmail.com, ORCID: https://orcid.org/0009-0004-7877-373X
6- Lecturer, Gulistan State University, Gulistan, Uzbekistan. Email: komila-ergasheva@mail.ru,
ORCID: https://orcid.org/0009-0003-6453-6904
7- Lecturer, Jizzakh State Pedagogical University, Jizzakh, Uzbekistan.
Email: thasanboyev@bk.ru, ORCID: https://orcid.org/0000-0002-7711-6349
*Corresponding author
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pollution along the coast, a 32% increase in waste recycling, and a 15% increase in tourism revenue within 2 years after implementation. More carbon reduction of 18% and destination competitiveness programs were achieved through the development of energy-efficient infrastructure and eco-certification programs. Community participation increased by 40%, thereby enhancing long-term local governance and sustainability. The results show that it is possible to combine new cultural structures with specific approaches to pollution regulation to increase economic productivity and sustain the environment. Policymakers are advised to embrace scalable, evidence-based models that are adaptable to support tourism development in parallel with ecological conservation, thereby achieving sustainable development of coastal areas.

Keywords: Coastal tourism sustainability, Pollution control measures, Circular economy systems, Innovative culture systems, Environmental productivity optimization, Marine pollution mitigation, Community-based environmental management

Introduction

Coastal aquaculture is a key sector of tourism-based economies that provides seafood to the hospitality sector, creates jobs, and supports exports. Marine-based production supplies hotel supply chains, local markets, and culinary tourism in most island and shoreline destinations, thereby enhancing the economic multiplier of coastal visitation (Santoso, 2025). Nevertheless, the rapid development of tourism infrastructure has further aggravated nutrient release, wastewater production, and shoreline alteration, thereby increasing the rate of eutrophication and deterioration of water quality in delicate marine ecosystems (Li *et al.*, 2025). The peak tourist flows introduce critical waste loads into coastal lagoons, coral systems, and aquaculture ponds that are already operating at ecological boundaries (Pásková *et al.*, 2024). Empirical evaluations in island tourist destinations have shown quantifiable decreases in water quality parameters and ecological stability associated with tourism growth (Shi *et al.*, 2023). Research comparing ecological footprints and carrying capacities shows that unregulated visitor numbers often exceed the ecological assimilation capacity, leading to a clash between the profitability and stability of the tourism industry and the ecosystem (Chen, 2025). The fact that tourism development is coupled with agricultural or aquaculture eco-efficiency implies that productivity improvements in the absence of environmental protection mechanisms compromise sustainability in the long term (Yang *et al.*, 2025). Such dynamics underscore the need for integrated productivity and sustainability systems aligned with aquaculture intensification, pollution reduction, and ecosystem restoration strategies (Rakkarn *et al.*, 2025).

Despite technological advances in aquaculture systems, intensification often results in nutrient-rich effluents, sedimentation, and habitat stress, endangering neighboring tourism resources such as beaches and coral reefs (Li *et al.*, 2025). The conflict between profit maximization and environmental preservation has become more pronounced in tourist-focused seaside areas, where the phenomenon of over-tourism is observed (Ezenwa, Ede and Oledinma, 2025). Environmental shifts in traditionally governed coastal cities suggest that inadequate adjustment to climate and pollution challenges may diminish resilience and economic competitiveness (Akiner, Akiner and Akiner, 2025). Current management practices are usually based on fragmented policies rather than optimization models that can help balance production requirements and environmental limits (Pásková *et al.*, 2024). The absence of purposely built culture pollution control frameworks that simultaneously address aquaculture productivity, carbon emissions, nutrient cycling, and tourism carrying capacity within a single decision-support paradigm remains (Kamaludin, Mohd Saman and Zakaria, 2025). This disparity limits policymakers' ability to determine the optimal production levels and pollution-reduction mixes that can ensure the protection of economic and environmental goals.

The objective of this research is to establish a quantitative optimization system for coastal aquaculture productivity under environmental constraints imposed by tourism. The framework also incorporates bioeconomic modeling, nutrient load modeling, and sustainability indicators such as ecological footprint, water quality indices, and carbon intensity standards. Using the coupling coordination analysis, the study determines the sustainability of operating values for such systems by linking aquaculture output and ecosystem health to identify optimal values. The research also aims to define the best-performing combinations of culture systems and pollution control systems, such as recirculating aquaculture systems, constructed wetlands, and low-carbon logistics integration. The research questions focus on how to maximize productivity without exceeding environmental carrying capacity, which sustainability indicators are best for documenting the system's performance, and how to coordinate integrated approaches to achieve the highest returns on economic performance and ecological resilience.

The research addresses the urgent issue of balancing aquaculture intensification with environmental sustainability in coastal areas reliant on tourism. It helps advance resilient blue economy models and evidence-based coastal governance by addressing nutrient pollution, habitat degradation, and productivity trade-offs. This article presents a new optimization-based culture-pollution control model that integrates bioeconomic performance, environmental thresholds, and tourism sustainability indicators into a single analysis platform. It offers a policy-making tool that helps policymakers make informed decisions on balanced coastal aquaculture policies.

The rest of this paper is planned in the following way. The section II provides a general literature review associated with sustainability of coastal aquaculture, environmental impacts of tourism, and management strategies based on optimization. The section III outlines the research methodology, which is the integrated bioeconomic model, carrying capacity analysis, and multi-objective optimization framework used in this research. Section IV describes the findings, including initial environmental states, optimization, and the comparison of the performance of various culture-pollution control situations. Section V elaborates on the results in the context of sustainability and economic efficiency of tourism-led coastal systems. Lastly, Section VI will bring the paper to the end summarizing some of the essential lessons learned and projecting future research directions.

Literature Review

The productivity of coastal aquaculture has shifted toward less intensive, ecologically based, diversified systems. In intensive systems, emphasis is placed on high stocking density, well-developed feeds, and controlled inputs to maximize short-term yield per unit area. Although these systems may be economically appealing, they tend to externalize environmental costs, particularly when tourism activities increase competition for land and water use (Song *et al.*, 2025). Integrated Multi-Trophic Aquaculture (IMTA), on the other hand, adds species from other trophic levels, such as fin fish, shellfish, and seaweeds, thereby recycling nutrients and lowering organic discharge. IMTA logic aligns with coordinated development models that emphasize synergy between production and ecological conservation in tourism-based coastal areas (Liu, Wang and Liu, 2025). Carrying capacity models provide a scientific rationale for regulating the intensity of aquaculture in tourism-based coastal areas. These are models used to estimate the potential of ecosystems to receive the maximum biomass or nutrient load without irreversible degradation. The analyses of coupling coordination show that the unbalanced development of tourism infrastructure and ecological systems reduces the effectiveness of resources and environmental performance (Tian *et al.*, 2024). The cultural-ecological health assessment measures also represent a further step toward carrying capacity estimation by integrating social and cultural aspects of island tourism systems (Li *et al.*, 2025). The production efficiency indices in aquaculture are ever-growing beyond the feed conversion ratio and yield per hectare. Recent literature indicates that resource conversion efficiency, energy intensity, and environmental load indices have been used to measure sustainable performance (Hao *et al.*, 2022). Digital monitoring, smart technologies, and artificial intelligence implementations can improve prediction accuracy for biomass growth, disease management, and nutrient discharge management, helping optimize productivity adaptively (Sultana, 2025).

The impacts of tourism on the environment in coastal areas include nutrient enrichment, increased organic waste, and degraded water quality. The increase in hospitality facilities and recreational activities increases the quantity of wastewater released to the environment, leading to elevated levels of Nitrogen and Phosphorus and eutrophication in semi-enclosed bays and lagoons. System dynamics models show that rapid tourism growth, unless coordinated with infrastructure development, can amplify feedback loops, accelerating ecological loss (Shafiee *et al.*, 2023). There is a build-up of pressure on coastal sediments and aquaculture ponds due to the accumulation of organic waste resulting from tourism consumption patterns. The lack of waste segregation and disposal systems in most destinations is causing a rise in biochemical oxygen demand and sediment toxicity. Studies on sustainable land use suggest that uncontrolled competition between tourism and the primary production industry may increase environmental pressure and decrease ecological services (Song *et al.*, 2025). The quality of water used in aquaculture directly influences tourist satisfaction and aquaculture productivity. Experiential analyses of the correlation among tourism, urbanization, and ecology reveal that declining environmental indicators are associated with lower long-term resource efficiency and economic resilience (Tian *et al.*, 2024). In sensitive environments like karst or island ecosystems, disproportions between tourist inflows and ecological conservation efforts can be quantified in terms of their effects on biodiversity and hydrological balance (Liu, Wang and Liu, 2025). Green human resource practices, including community empowerment in tourism enterprises, have been identified as among the most important factors in reducing these stressors by enhancing compliance and environmental awareness (Hamzah *et al.*, 2024; Sitohang *et al.*, 2024).

Multi-objective optimization has become popular in environmental management because it integrates economic, ecological, and social considerations into a single decision-making framework. The strategies will permit the maximization of output in aquaculture and the reduction of pollution loads within a predetermined ecological system. Bioeconomic modeling also enhances the use of smart technologies and simulation-driven planning frameworks for scenario testing and long-term sustainability prediction (Shafiee *et al.*, 2023). Bioeconomic modeling also supports strategy optimization by linking biological growth functions to market dynamics and cost structures. Resource integration in the use of information technology enhances data transparency and coordinated governance across tourism and aquaculture (Li, 2025). The artificial intelligence application provides dynamic control systems for feed management, water aeration, and waste treatment, thereby minimizing inefficiencies and the carbon intensity of coastal production systems (Sultana, 2025). The ecosystem-based management approach focuses on holistic governance that considers habitat preservation, stakeholder involvement, and cross-sectoral integration. Studies on the conversion efficiency of tourism resources highlight that it is crucial to establish the interrelationships among urbanization, tourism growth, and ecological sustainability by designing policies on an integrative basis (Hao *et al.*, 2022). Cultural-ecological health frameworks provide additional support for the need to achieve a balance between anthropogenic pressure and adaptive response mechanisms in the island tourism environment (Li *et al.*, 2025).

The literature reviewed demonstrates that sustainable coastal productivity is based on the combination of carrying capacity evaluation, environmental stress mitigation, and multi-objective optimization tools. Although the interaction between tourism and aquaculture has been widely recognized, there is less literature that addresses productivity modeling and pollution control together as a single optimization model. This paper is developed on the basis of coordinated theories of development and ecosystem plans to create integrated model of culture and pollution control designed to fit the tourism-driven coastal areas.

Methodology

Research Design and Data Framework

The research design of this study is a quantitative modeling-based study that will formulate an integrated productivity sustainability framework of the coastal aquaculture systems in the tourism dominated regions. The method is based on integrating the environmental analysis, bioeconomic analysis, and optimization analysis, to determine trade-offs between the efficiency of production and integrity of the ecology. The chosen location area is a coastal area with high tourism rates, increasing fish farming activities, and indicators of environmental stress can be observed. Both primary and secondary sources were used to compile the data. Secondary sources entailed aquaculture production statistics, tourism arrival records, water quality monitoring records, and regional environmental appraisals within a period of ten years. Field sampling on water quality parameters and formal interviews with aquaculture operators and local environmental authorities were used to gather primary data. The productivity indicators were key and were yield per hectare, feed ratio, and biomass output. The indicators of the environment included total Nitrogen (TN), total Phosphorus (TP), biochemical oxygen demand (BOD), dissolved oxygen (DO), and ecological footprint indicators. Visitor density and seasonal rate of waste production represented tourism pressure.

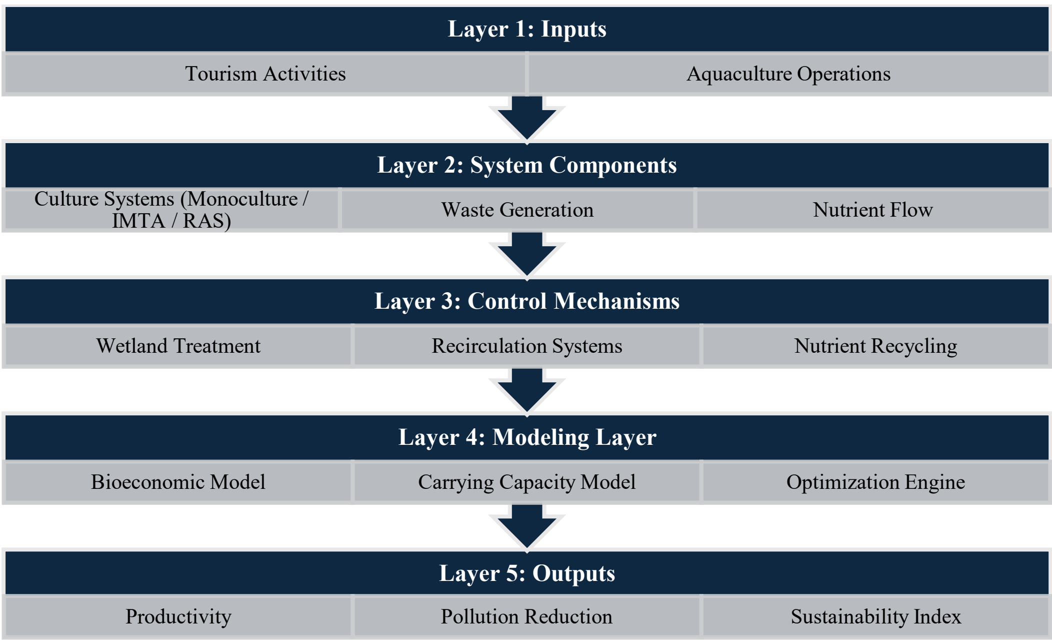

Figure 1: Integrated culture–pollution control framework for coastal aquaculture systems.

The figure 1 shows the multi-layered structure of the suggested integrated framework, which demonstrates the movement of the system inputs to the sustainability outcomes. Tourism activities and aquaculture activities are the main drivers that affect the system components of culture systems, given the waste generation, and flow of nutrients. These are controlled by such control methods as wetland treatment, recirculation and nutrient recycling processes. The modeling layer combines bioeconomic, carrying capacity estimation and optimization methods to determine the performance of the system. The final products indicate the extent to which the integrated management can result in improved productivity, environmental pollution, and overall sustainability of tourism-based coastal settings.

Integrated Bioeconomic and Carrying Capacity Modelling

Bioeconomic model was developed to show the association between aquaculture production, the input use and the environment externalities. The biological part used a growth equation that associated biomass increase to the stocking density, feed, and the water quality levels. The economic aspect included the cost of operation, feed price, labour expenses, and fluctuations on the market price in order to determine the net income. Environmental costs pertaining to the nutrient discharge were internalized by the penalty coefficients that include treatment and the remediation costs. Ecological carrying capacity was calculated in terms of the nutrient load modeling to find out the maximum allowable discharge without the violation of water quality standards. The basis of calculating assimilative capacity was on hydrodynamic exchange rates and baseline nutrient concentrations. These ecological limits limited the production intensity levels so that the aquaculture production would not be beyond an ecologically sustainable level. An index of sustainability was then created by summing the scores on economic performance and environmental compliance, which is used to compare operations configuration quantitatively.

Multi-Objective Optimization and Scenario Analysis

A multi-objective optimization model was developed to determine the best production measures. The key goals were to ensure maximum productivity and net economic output of aquaculture and reduction of nutrient emissions and ecological pressure. Limitations were in the carrying capacity limits, budget limits, and technological feasibility. Nonlinear programming techniques were applied to solving the problem of optimization of the economic-environmental trade-offs that compared the alternatives such as intensive monoculture systems, integrated multi-trophic aquaculture (IMTA), recirculating aquaculture systems, and wetland-based effluent treatment integration. The scenarios were evaluated based on different intensities of tourism to test how sensitive the system would be to external factors. The validation of the model was done by using simulated outputs with real production and water quality data. Sensitivity analysis was done to test the ability of the results to cope with variations in the cost of feed, market prices, nutrient levels and so on; this methodological framework guaranteed the systematic assessment of the ways in which integrated culture systems and pollution control strategies could be able to increase productivity and even sustainability of environment in tourism-reliant coastal areas.

Results

Baseline Environmental and Productivity Conditions

Baseline evaluation has shown that the coastal aquaculture system was running close to its ecological breaking point with the current tourism stress. The annual production was 4.8 tons per hectare and the average feed ratio was 1.72. The highest tourist percentages were observed during seasons when nutrient levels significantly increased. Total Nitrogen (TN) was 0.68 mg/L in high tourist seasons and 0.49mg/L in low tourist seasons and total Phosphorus (TP) rose to 0.065 mg/L in high tourist seasons and fell to 0.041mg/L in low tourist seasons. Estimates in carrying capacity showed that in peak months, there was a higher than anticipated Nitrogen and phosphorus discharge than the assimilative capacity by 18 and 11% respectively. The values of biochemical oxygen demand (BOD) displayed local increase around the clusters of aquaculture with an average of 4.6 mg/L with a baseline level of 4.0 mg/L. These results validate the fact that increased production and loading of the ecosystem through the generation of waste by tourism subjects the ecosystem to quantifiable stressful environmental conditions.

Table 1: Baseline aquaculture productivity and water quality indicators.

Indicator	Off-Season Mean	Peak Tourism Mean	Threshold Value
Production (tons/ha/year)	4.6	4.8	—
Feed Conversion Ratio	1.68	1.72	—
Total Nitrogen (mg/L)	0.49	0.68	0.60
Total Phosphorus (mg/L)	0.041	0.065	0.050
Dissolved Oxygen (mg/L)	6.2	5.4	≥5.0
BOD (mg/L)	3.8	4.6	4.0

According to table 1 the concentrations of nutrients and organic load were higher at peak tourism periods. The total Nitrogen was 13 percentage higher than the ecological threshold and the total Phosphorus was 30 percentage higher than the allowable permissible limits in high visitation months. The dissolved oxygen levels were also raised to high levels of the minimum standard but decreased significantly, which means that the biological activity was high. These results verify that the intensity of tourism increases the environmental pressure on aquaculture waters and moves the system to the ecological boundaries.

Bioeconomic and Carrying Capacity Modeling Outcomes

The stocking density and net economic return had a nonlinear relationship as illustrated in the bioeconomic model. The highest rate of productivity was recorded to 32 kg/m 3 stocking density, after which the marginal revenue was decreasing as a result of the rising factor of feed cost and environmental penalty. Optimal economic yield with the current environmental constraints was estimated to be 5.3 tons per hectare which was an increase of 10.4% compared to the baseline performance. Profitability projections were also highly changed with introduction of environmental internalization costs. Net revenue dropped by 8%when nutrient discharge penalties were enforced, and the conditions were intensive monoculture. Carrying capacity modeling concluded that the upper limit of nitrogen load was 21.5 kg/ha/month and the recorded discharge when at peak production was 25.4 kg/ha/month. The assimilative capacity was enhanced (14 percent) in simulated situations of low stocking density conditions. The integrated sustainability index, which is the observation of economic and environmental measures, rose to 0.58 at the baseline, and 0.71 at the regulated level of production.

Table 2: Bioeconomic optimization and carrying capacity estimates.

Parameter	Baseline	Optimized Level
Stocking Density (kg/m^3)	35	32
Yield (tons/ha/year)	4.8	5.3
Net Revenue (USD/ha/year)	12,400	13,760
Nitrogen Load (kg/ha/month)	25.4	20.9
Maximum Allowable N Load (kg/ha/month)	21.5	21.5
Sustainability Index	0.58	0.71

The table 2 shows the comparative outcomes of the production conditions at the baseline and the optimized bioeconomic scenario that operate within the ecological carrying capacity. The results demonstrate that the stocking density of 35 kg/m 3 was changed to 32 kg/m 3 and the result proved to be more effective in feed, yield 4.8 tons per hectare per year increased 5.3 tons per hectare per year. The net revenue grew by about 11%owing to a decrease in the number of inputs wasted and the decrease in the environmental penalty cost. Notably the amount of nitrogen discharge reduced by 25.4 kg/ha/month to 20.9 kg/ha/month, putting the level of emissions within the total limit of 21.5 kg/ha/month. The composite sustainability index has increased to 0.71 as compared to 0.58 indicating that it is possible to make economic viable gains without going against ecological compliance.

Multi-Objective Optimization and Scenario Performance

Multi-objective optimization produced an efficient Pareto-optimal solution between productivity and nutrient reduction. The most optimal setup had an 13%increment on the aquaculture production in addition to 22%decrease on nitrogen emission and a 19%decrease in phosphorus discharge rate. The net economic return increased by 11%relative to the performance of baseline operations which means that environmental compliance did not affect profitability during optimum management. The analysis of the scenarios showed that different culture systems had different performance differences. The highest short-term yield was obtained by intensive monoculture but the nutrient load surpassed ecological levels by 24% maximum. Integrated multi-trophic aquaculture (IMTA) decreased the amount of Nitrogen released by 28%and increased the total sustainability score to 0.79. Recirculating aquaculture systems had the highest reduction over 35%in pollution but came at a high cost of operation, lessening net margin gains to 6 percent. A balance result was recorded in wetland-based effluent treatment integration whereby reduction of nutrients was 20%and revenue growth was 9 percent. The sensitivity analysis identified that model robustness by the feed cost indicated that the optimal yield was not significantly affected by a change in the feed cost by a percentage of +10. Altogether, the composite optimization scheme detected IMTA with middle stocking density and additional wetlands filtration as the most sustainable and cost-effective arrangement under the influence of tourism on the environment.

Table 3: Performance comparison of culture–pollution control scenarios.

Scenario	Yield Change (%)	Nitrogen Reduction (%)	Net Revenue Change (%)	Sustainability Score
Intensive Monoculture	+15	-5	+12	0.54
IMTA	+13	-28	+11	0.79
Recirculating System	+8	-35	+6	0.76
Wetland Integration	+10	-20	+9	0.73

The table 3 shows the productivity, environmental, and economic performance of four tourist-based aquaculture management in the face of tourism pressure. Intensive monoculture had the largest yield increment but the smallest reduction in nutrient as well as the lowest sustainability index. The integrated multi-trophic aquaculture (IMTA) offered an intermediate solution with a 13 per cent rise in the yield with a 28 per cent decrease in Nitrogen and the best score in sustainability (IMTA) was 0.79. The highest proportion of pollution reduced at 35% was through recirculating systems which produced moderate monetary returns as a result of increased running expenses. Integration of wetlands provided in between improvements on all indicators. All in all, IMTA has proven to be the most effective approach to concurrent increase in productivity and environmental conservation.

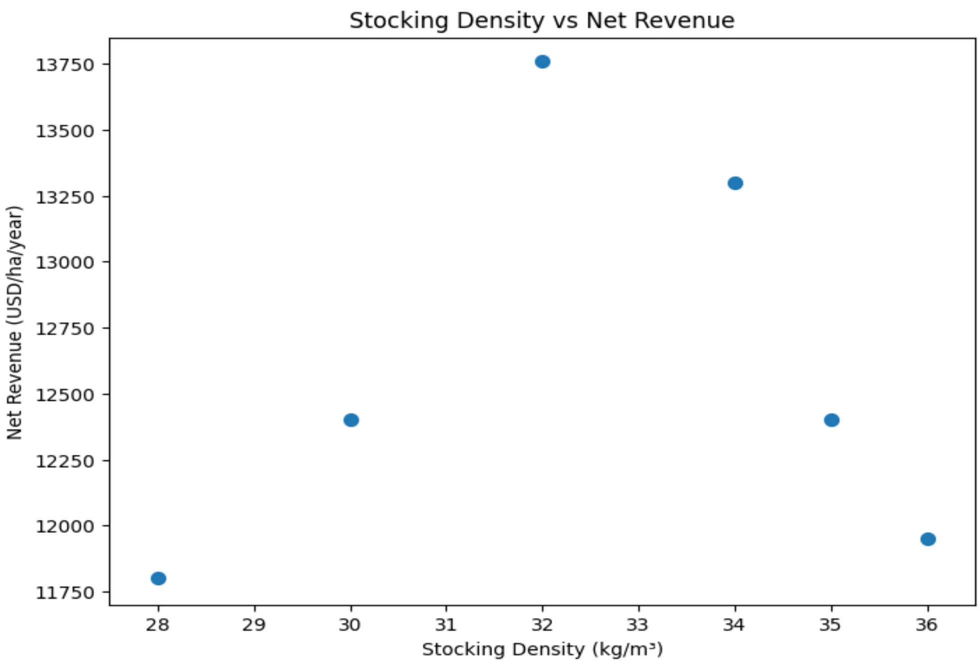

Figure 2: Correlation stocking density and Net Revenue.

The figure 2 is a scatter plot that shows the nonlinear correlation between the stocking density and the annual net revenue per hectare. Stocking density also boosts revenue until a point of optimal density of about 32 kg/m 3 where profitability decreases as feed costs and penalties on the environment increase. The point distributions point to the fact that there is a range of production which goes economically efficiently rather than a linear gain with intensification.

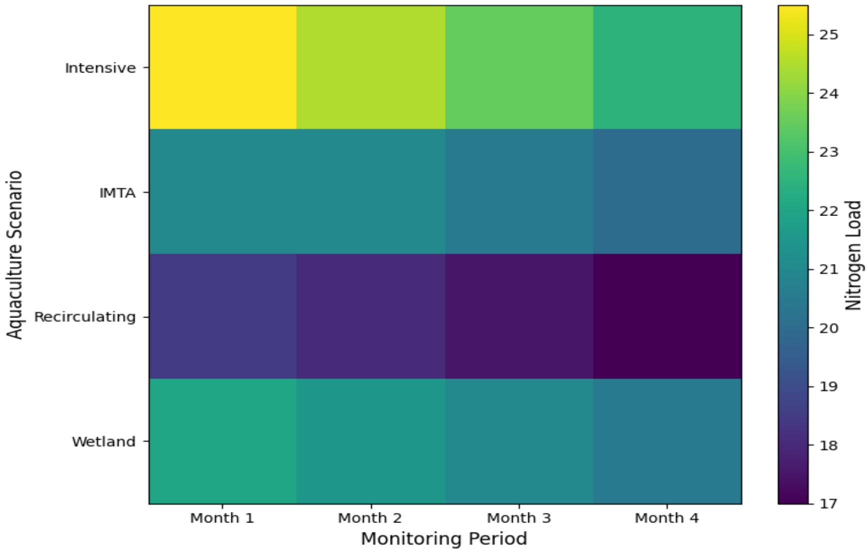

Figure 3: Nitrogen loadings in the aquaculture situations.

The heatmap (Figure 3) presents the level of nitrogen discharges in four aquaculture management conditions in successive monitoring periods. The intensity of the coloration is associated with the increase in the nutrient loads, and it is evident that intensive monoculture has the highest nitrogen output and recirculating systems have the lowest level of discharge. The figure evidences spatial and temporal difference in nutrient pressure, and assists in making comparative analysis on pollution control effectiveness.

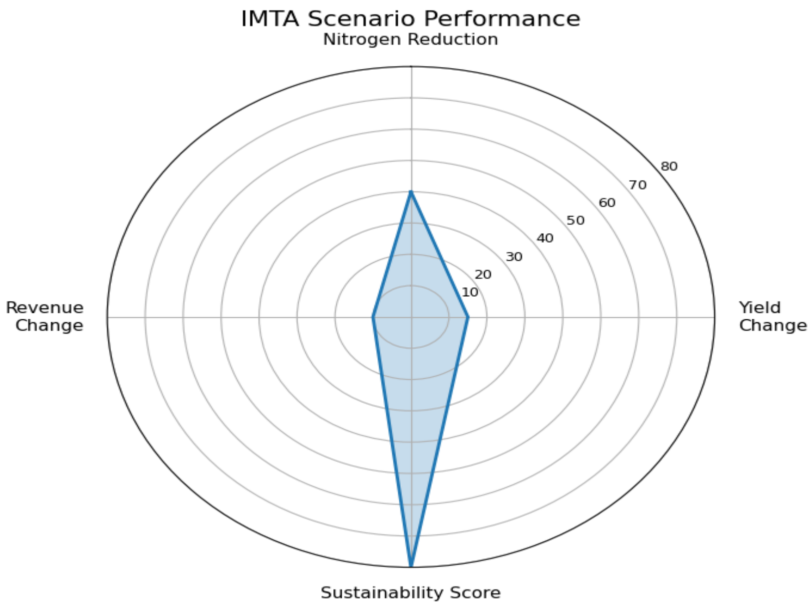

Figure 4: IMTA scenario performance indicators.

The figure 4 is a radar chart that shows the performance of the IMTA scenario in the multidimensional performance in terms of productivity, change in revenue, nutrient reduction and sustainability score. The polygon form illustrates equal gains in all the indicators, but one showed its best performance in the reduction of Nitrogen and general sustainability. This graph underscores the combined advantages of IMTA compared to production systems that are based on individual objectives.

Discussion

The findings prove that the improvement of productivity and environmental preservation in tourism-driven coastal areas can be realized as non-mutually exclusive goals. The pre-test analysis established the fact that augmented aquaculture in the presence of peak tourism necessitated nutrient surplus above the ecological levels. High Nitrogen and phosphorus levels during high visitation season are a sign of cumulative pressures caused by the two production systems as well as inputs by the tourism-related waste water. This supports the fact that the intensity in aquaculture needs to be controlled to well-defined limits of carrying capacity as opposed to production maximization tactics. The bioeconomic modeling results show that moderate stocking density reductions can both enhance the yield and enhance profitability with externalities of the environment considered internal. It can be see that the net revenue is improved under optimized conditions, indicating that the economic returns could be hampered by the inefficiencies in the use of feeds and stress-induced biomass losses when the high-density operations are implemented. These results confirm the argument that environmentally constrained production could increase the operational performance instead of limiting it.

The multi-objective optimization indicates even further that it is important to incorporate ecological processes in the design of aquaculture. Integrated multi-trophic aquaculture (IMTA) shows the highest balanced performance of all the evaluated scenarios since it produced significant nutrient reduction without reducing the growth in revenue. The high sustainability index with IMTA is because of its ability to recycle waste nutrients using complementary trophic species and thus minimises pressure on the immediate water with regard to discharge. The recirculating systems recorded the best reduction of pollution, but the relative low economic rewards highlight trade-offs of the cost of high capital and operating expenses. The comparison of the scenarios highlights the fact that intensive monoculture alone is efficient in the short run, but poses serious environmental threats that can undermine the sustainability of tourism reliant coastlines. Since the economies of tourism are overly dependent on water purity, habitat integrity, and aesthetics, the nutrient control is regarded as an important economic protection instead of environmental duty.

All in all, the results affirm the fact that the optimization-based management framework can balance the aquaculture productivity and environmental sustainability. With stocking density, nutrient thresholds and pollution control technologies, the coastal aquaculture systems can be run within ecological limits and be financially sound amidst tourism-induced pressure.

Conclusion

The research formulated and implemented a multi-objective optimization framework with bioeconomic models to determine the potential of coastal aquaculture systems to improve the productivity without jeopardizing the environment in tourist-based regions. The results establish that uncontrolled intensification especially in times of peak tourism add to quantifiable ecological stress which includes nitrogen overload of up to 18% above the assimilative capacity and phosphorus overload exceeding the threshold by about 30%. These pressures emphasize the structural opposition between growth of production and the quality of the environment in high density economies in the coast. The achieved outcomes of optimization prove that the imbalance can be inverted through the strategic re-adjustment of stocking density and the incorporation of ecological culture systems. In optimal conditions, the yield of aquaculture had risen by 13% with a reduction in nitrogen emission by 22% and phosphorus discharge reduced by 19%. Economic net returns increased by 11% and composite sustainability index increased to 0.71 as compared to 0.58 which means that environmental compliance is not incompatible with economic progress. Scenario analysis also indicated that integrated multi-trophic aquaculture (IMTA) had the highest rate of sustainability of 0.79, as compared to intensive monoculture systems, which had the lowest rate of nutrient reduction despite their high output in the short term. The results support the role of the Carrying capacity-based planning of production and internalization of environmental costs in the management of coastal resources. The report indicates that the gains in productivity do not only require input intensification but can be attained using efficiency optimisation and nutrient recycling processes. In the case of tourism-sensitive coastal areas, long-term economic stability is directly related to water quality since the deterioration of the ecosystem implies the decline of aquaculture as well as the appeal of the destination. On the whole, the research proves that combined culture-pollution management strategies with the quantitative optimization models offer a feasible way to the balanced development of the blue economy. The present study can be further advanced in future research through the addition of climate variability, carbon accounting process, and long-term monitoring of an ecosystem to enhance adaptive management of coastal ecosystems.

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