Enhancing fish health and ensuring environmental resilience in ecosystems supporting sustainable tourism through integrated genetic and nutritional approaches

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Abstract

Aquatic bio-ecosystems are very important for ensuring sustainable tourism, as these ecosystems support healthy fish populations and strong environmental conditions. Nevertheless, international evaluations suggest that more than 37%of the managed fish stocks are overexploited, and habitat destruction and climate change have also contributed to a reduction of biodiversity of over 20% in freshwater systems over the last 30 years. These forces undermine the ecosystem services that are essential to tourism, such as recreational fisheries, biodiversity viewing, and water quality maintenance. This research paper examines a combined genetic and nutritional model to improve fish health and increase the overall resilience of the environment in tourist-driven aquatic ecosystems. The methodology entailed selective breeding using genomic marker-assisted selection and the optimization of functional feed formulations containing omega-3 fatty acids, probiotics, and immunostimulants. Three fish populations were tested over 24 months to determine growth performance, disease resistance, survival, and ecological impact, including water quality and nutrient cycling. Genetic assays were aimed at alleles linked to stress tolerance and resistance to pathogens, and nutritional interventions were evaluated through controlled feeding trials and field-based ecology. Findings showed increases of 28% in growth rates, 40.8% reduction in disease incidence, and 22% in

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survival rates of populations under environmental stress compared to control populations. The parameters measuring water quality, such as ammonia and nitrate, improved by 15-18%, indicating better nutrient assimilation. Moreover, the biodiversity indices of the surrounding habitats increased by 12%, indicating positive ecosystem spillover effects. To sum up, the combination of genetic enhancement and precision nutrition would greatly improve fish health and ecology. It is a sustainable method of reducing environmental pressures, promoting sustainable tourism through sustainable aquatic ecosystems, enhanced biodiversity, and the sustainable economic sustainability of communities reliant on fisheries and ecotourism.

Keywords: Sustainable tourism, Fish health management, Genetic improvement, Marker-assisted selection, Functional aquaculture nutrition, Ecosystem resilience, Environmental sustainability

Introduction

Fish health is the biological basis of aquatic ecosystem stability, which, in turn, determines trophic interactions, nutrient cycling, and biodiversity. Healthy fish populations help control plankton communities, balance predator-prey interactions, and enhance water quality through ecological feedback. In weak-water habitats such as highland lakes and marshlands, reduced fish diversity has been directly attributed to ecosystem imbalance and habitat destruction (Meinam *et al*., 2025). According to the scientific development of health management in aquaculture, better nutrition, disease management, and genetic stewardship are necessary to support aquatic biodiversity in the face of environmental pressures. Fisheries and aquaculture play a very important role in securing food, generating employment, and driving local tourism economies. Recreational fishing, lake tourism, and community-based aquaculture projects provide income and raise awareness of conservation. Integrated aquaculture has also been found to enhance productivity and rural livelihoods, which strengthens the socio-economic value of fish-based tourism models (Mohd and Mushtaq, 2025). The ecotourism models that integrate fisheries co-management reinforce socio-ecological resilience and build sustainable local food systems (da Silva *et al*., 2025). Climate change, pollution, and habitat fragmentation pose a growing risk to fish health and reproductive stability. When temperature regimes change, they disrupt breeding cycles and reduce reproductive success, thereby impacting long-term stock sustainability (Mitra *et al*., 2023). Due to extreme weather patterns and warming waters, disease outbreaks and physiological stress are exacerbated in cultured and wild species (Yadav *et al*., 2024). These cumulative stress factors undermine ecosystem services, which are the backbone of the sustainability of tourism and fisheries.

This architecture diagram (Figure 1) presents a four-layer sustainability model that shows a connection between biological interventions and socio-economic outcomes. The bottom layer focuses on selection using markers, genomic screening, and the design of functional feeds as fundamental biological forces. These inputs improve fish health, increasing disease resistance, growth performance, and stress tolerance.

The third level illustrates that the fortified fish physiology benefits the ecosystem, including stabilization of water quality, increased biodiversity, and effective nutrient cycling. The net result of these ecological benefits is that they promote tourism and socio-economic benefits through recreational fisheries, the generation of eco-tourism revenues, and support for community livelihoods. The stratified system emphasizes the chronological and mutually supportive nature of the processes of scientific innovation, environmental resilience, and sustainable tourism development.

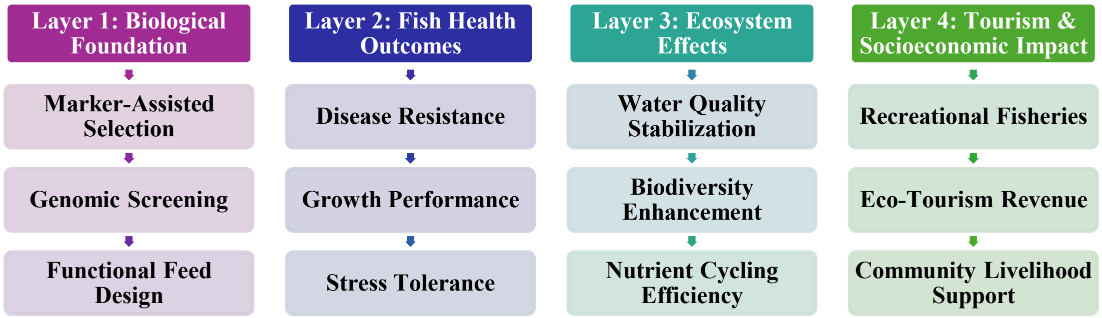

Figure 1: Integrated genetic–nutritional sustainability architecture for tourism-supported aquatic ecosystems.

The world's oceans are experiencing measurable declines in fish diversity and abundance due to ecological stress and unfavorable regulatory frameworks. The effects of poor conservation interventions on sensitive ecosystems include decreases in species richness and alterations in community structure (Meinam *et al.*, 2025). The existing technological gaps in the health monitoring and genetic resources management also increase the vulnerability of stock (Modeel *et al.*, 2024). Decreased stock disrupts the natural balance of ecosystems and food webs, and diminishes the aesthetic and recreational value of aquatic sites. The degradation of the ecosystem compromises climate resilience and the long-term sustainability of tourism, especially in areas that rely on natural aquatic features (Mallick, Banerjee and Poddar, 2025). Conventional fisheries management tends to be centered on controlling stocks and protecting habitats, with no consideration of nutrition-based immunity or state-of-the-art genetic technologies. Recent reports have shown that biotechnological applications and functional dietary solutions should be employed to better address resistance to disease and stress tolerance (Maurya *et al.,* 2025). Potential has been demonstrated for nutritional immunomodulation with functional feed additives, but it has not been used in ecosystem-level plans (Abdul Kari, 2025).

The proposed study will consider selective breeding and genomic and functional nutrition to boost fish immunity and stress resistance under environmental stress (Abdul Kari, 2025). The integration of both ideas will enhance fish survival, reproduction, and ecosystem balance (da Silva *et al*., 2025).

The loss of fish health is a threat to ecological balance, food security, and tourist-based economies worldwide. This problem is important to the conservation of the aquatic biodiversity and other ecosystem services that sustain livelihoods and recreation.

The paper is the first to include genetic enhancement and nutritional immunomodulation within a tourism-based sustainability system, providing a multidimensional approach that connects aquaculture innovation to ecosystem and socio-economic stability.

The structure of the paper provides a logical flow from conceptual underpinnings to practical conclusions. In Section I, the background section outlines the problem statement, objectives, and the scope of the study. The second section (II) is a literature review of genetic enhancement, nutritional management, and ecosystem resilience in the framework of sustainable tourism. Section III provides the methodological framework, including the study design, interventions, and analytical tools. Section IV presents empirical findings, including performance appraisals based on biological and ecological indicators. Section V presents the general implications for environmental resilience, policy integration, and tourism management. Lastly, Section VI concludes with the main findings, the contribution to sustainable tourism, and future research directions.

Literature Review

One of the most successful long-term approaches to increasing fish resistance to pathogens and environmental stress remains selective breeding. Breeding programs can improve the robustness of stock productivity by gradually improving heritable traits related to immune competence, growth efficiency, and thermal tolerance without reducing productivity. Genetic resource management based on agroecosystems emphasizes the importance of maintaining a diverse gene pool to preserve adaptive capacity in a changing environment (Joshi *et al.*, 2024). In climate-sensitive areas, adaptive breeding schemes have been proposed as a foundation for developing robust fisheries and aquaculture systems (Haque *et al.*, 2025). The development of molecular genetics has accelerated the identification of quantitative trait loci related to disease resistance and stress adaptation. Genomic profiling and marker-assisted selection allow the identification of desirable alleles early and eliminate the need for phenotypic screening. Application of biotechnology and genomics to the management of aquaculture can enable more accurate health interventions and improve stock traceability (Can *et al.*, 2023). New world ideals in restorative aquaculture focus on using science-based innovations to ensure environmental sustainability and genetic stewardship (Alleway *et al.*, 2023). A case study of freshwater systems sensitive to climatic conditions shows that genetically enhanced strains are more effective at responding to temperature variations and unreliable water quality. Resilience-based management models propose both selective breeding and ecosystem monitoring to reduce susceptibility to inexorable stressors (Bănăduc *et al.*, 2022). Adaptation-oriented fisheries initiatives also provide evidence in favor of genetic enhancement as a viable pathway to sustainable output and ecosystem sustainability (Haque *et al.*, 2025).

The supplemental effects of genetic gains are the support of the physiological defense mechanisms through nutritional interventions. Intravenous nutritional feeds supplemented with bioactive compounds, antioxidants, and micronutrients support innate immunity and reduce the incidence of disease. Diet-based immunoregulation has been suggested as an alternative preventive measure to antibiotic reliance, supported by best-practice models of sustainable aquaculture (Can *et al*., 2023). Including nutrition as part of the broader aquaculture sustainability objectives harmonizes production systems with environmental and population health priorities (Troell *et al*., 2023). Probiotics and prebiotics restore gut microbial balance, enhance nutrient absorption, and boost immunity against opportunistic infections. Their use helps minimize the release of untreated waste into the environment and provides healthier cultural environments. The concept of aquaculture-based integrated farming demonstrates that the system's resilience and productivity are enhanced through the integration of aquaculture and nutrient recycling (Paramesh *et al*., 2022). Integrated farming models, which are eco-friendly, also demonstrate that biological inputs lower ecological footprints while maintaining profitability (Bhagat *et al*., 2024). Optimal protein-to-energy ratios and the use of micronutrient supplements are crucial under thermal stress and varying oxygen levels to sustain metabolic efficiency. Resilient aquaculture plans emphasize localized, well-adapted feeding strategies to climate change (Haque *et al*., 2025). According to the principles of restorative aquaculture, feed efficiency is identified as a predictor of ecological performance and sustainability (Alleway *et al*., 2023).

The direct impacts of aquatic biodiversity include the aesthetic, recreational, and economic value of tourism destinations. Well-preserved fish stocks will improve visitors' experience and support the livelihoods of local people who rely on eco-tourism. The study of urban and aquatic green infrastructure highlights the interrelation between models of biodiversity conservation and sustainable development (Wang *et al*., 2024). The economic sustainability models also highlight the fact that ecological integrity is the foundation of long-term financial sustainability in tourism-dependent areas (Goutte and Sanin, 2024). Ecosystem-based management also incorporates a combination of habitat conservation, conservation of biodiversity, and community engagement into a single system of governance. These methods minimize the build-to-environment effects and reinforce the capacity to adapt in sectors (Bănăduc *et al*., 2022). The ecological design of the coral systems, like the Great Barrier reefs, demonstrates the role of tourism in the economic reliance on marine biodiversity as well as good governance of the production systems (Paramesh *et al*., 2022). Likewise, Maldives depends on reef-related fisheries and marine tourism, and the ecosystem-based approaches to resilience should be developed to overcome the effects of climate stress and habitat loss. The aspects of sustainable aquaculture that correspond to the principles of biodiversity conservation are starting to be identified as the ones that complement the efforts of marine tourism conservation (Troell *et al*., 2023).

The collective evidence in the literature is that genetic improvement combined with precision nutrition is effective in improving the disease and climate stress resistance of fish. The relationship between conservation of biodiversity and tourism sustainability is enhanced by the ecosystem-based management and restorative aquaculture principles. These understandings have a direct contribution to the current research as it defines that a genetic-nutritional complex, which is embedded in the ecosystem-governance framework can provide a scientifically based approach towards enhancing fish-health and sustainable tourism economies.

Methodology

Study Area and Sample Selection

The survey took place in three of the ecologically sensitive freshwater systems that enhance the recreational fisheries and eco-tourism activities. The criteria used to select the sites were high level of tourist visitation (> 50 000 visitors per year), recorded biodiversity value, and any sign of environmental stress like nutrient loading or seasonal temperature range that exceeded 3 C. All sites were unique ecological environments, a high-altitude lake, a lowland reservoir, and a wetland lagoon. The baseline tests have proven moderate levels of anthropogenic pressure and quantifiable decreases in the native fish density over the last five years. It chose three commercially and ecologically important species on the basis of economic value, trophic role and sensitivity to environmental stress. The selection of the species A (omnivorous carp), Species B (herbivorous tilapia) and Species C (predatory catfish) was adopted to mirror species with various feeding guild. The 300 juveniles of each species (n = 900 in total) had been initially screened in terms of health and standardized according to their age (4.5 months old) and mean weight (45 g). All individuals used in the experiment belonged to the same cohort and were not subjected to generational breeding during the study period. The study adopted a randomized block design in the three sites. The populations of each species were subdivided into experimental and control groups (n = 150 in each group of a certain species). The experiment was carried over 24 months which included two of the seasonal cycles to indicate climatic variability. Biometric measurements were done monthly, and the ecological assessments were carried out quarterly.

Table 1: Design and sampling framework of integrated genetic-nutritional intervention.

Parameter	Value
Total fish sampled	900
Species per site	3
Experimental duration	24 months
Sampling frequency	Monthly (biometric), Quarterly (ecological)
Replicates per treatment	3

The table 1 will show the general experimental design, such as total population size (900 fish), the number of species under analysis (three), timeframe of the study (24 months) and the frequency of sampling in terms of biometric and ecological measurements. It describes randomized block design where there is equal replication of treatment which is statistically reliable and has seasonal representation. The hierarchical design explains the standardization of population size, monitoring time, and replication strategy that produced similar information in sites and treatment groups but with ecological validity.

Genetic and Nutritional Interventions

All juveniles were sampled with fin clips which were then DNA extracted and genotyped using a single nucleotide polymorphism (SNP) panel of loci linked to thermal tolerance, immune response and growth efficiency. Genetic screening was used to determine people who had favorable allelic combinations based on the profiles of the markers. These individuals were directly assigned to the experimental groups and the rest were assigned to the control groups. The groups of the species (n = 300) were considered as experimental (n = 150) and control (n = 150) groups. No breeding or breeding of offspring was done across generations; all the comparisons in the experiment were done in the same original group. This method was used to make sure that the difference in performance could be attributed to genetic selection and nutritional intervention and not to the effects of the generation.

Table 2: Comparison of the genetic and nutritional interventions.

Variable	**Control**	**Experimental**		
		Genetic Only	**Nutrition Only**	**Combined**
Genetic selection	No	Yes	No	Yes
Functional feed	Standard	Standard	Enriched formulation	Enriched formulation
Stocking density	15 fish/m^3	15 fish/m^3	15 fish/m^3	15 fish/m^3
FCR target	1.8	<1.5	<1.5	<1.5

In table 2, four experimental groups have been compared to determine the effect of genetic selection and the nutritional intervention individually and in combination. The Control Group is a control, and the Genetic Only and Nutrition Only groups separate the effects of genetic selection and enriched feed, respectively. The Combined Group evaluates the synergistic effect of the two interventions on the growth and performance.

Data Collection and Analysis

The flow chart (Figure 2) shows the systematic methodological approach that will be followed in the study starting with selecting three tourism-related water bodies to the selection of a sample of three species (900 fishes) by using a randomized block design. It demonstrates how it is divided into control and experimental groups, and specific interventions such as genetic screening and functional feed application are used. The diagram also presents the multi-parameter data collection procedure that involves growth rate, immune markers, survival, water quality and biodiversity index which ends with the statistical and bioinformatics analysis involving ANOVA, Kaplan-Meier survival estimation and principle component analysis (PCA). The last phase focuses on results assessment, which helps to show that the research design has a logical flow and is analytically sound.

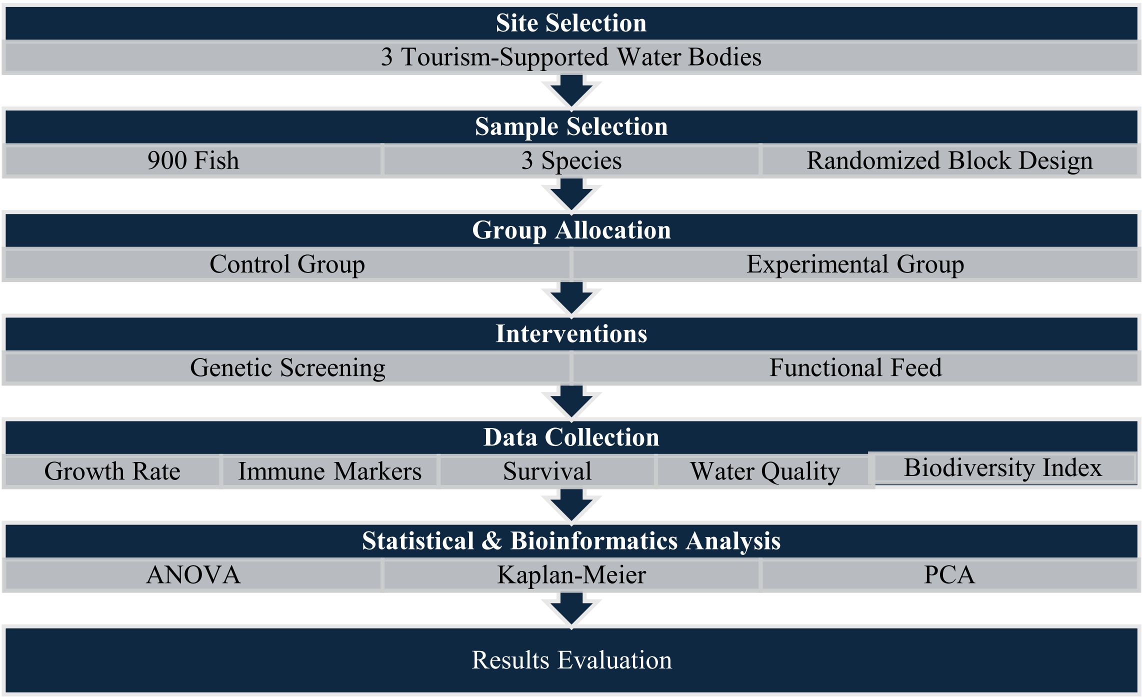

Figure 2: Experimental design flowchart for integrated genetic and nutritional intervention study.

The measurement of growth performance was done by using monthly weight gain and the specific growth rate (SGR %/day). Blood samples were checked after every six months of the examination of the level of leukocyte count, cortisol, and lysozyme activity. The percentage survival at the end of each season was taken. Water samples were also checked in terms of temperature, dissolved oxygen, ammonia, nitrate and chlorophyll-a concentration. The ecological spillover effects were measured by the measure of biodiversity based on the ShannonWiener Index (H) and species evenness in the neighboring habitats. Analysis of data was done by repeated-measures ANOVA to identify the differences of treatment over a period of time. KaplanMeier estimators were used in the survival analysis. The quantitative processing of gene expression was done by the normalization of the expression level by the quantitative PCR by using the reference genes and fold-change analysis. The p value was considered significant at $p = 0.05$. The integrated stage of ecological and physiological variables was obtained by multivariate principal component analysis (PCA), which allowed determining the patterns of resilience according to the treatments.

Results

Genetic Enhancement Outcomes

The broodstock was selected using markers, and fish that were produced using the selected broodstock had significantly reduced morbidity in seasonal outbreaks of pathogens. Experimental groups had a cumulative disease incidence of 18.6% as compared to 31.4% in controls over the 24 months. Investigations of challenge tests on controlled exposure to opportunistic bacterial strains indicated a 29%improved survival rate after the infectious exposure to genetically enhanced populations. Decreased response of cortisol when dealing with stress also implied better physiological stability. Genetic surveillance revealed that the heterozygosity (He) did not decrease as experimental stocks had 0.68 of heterozygosity at 0.64 in the controls which showed that selection did not reduce genetic variability. Structured broodstock rotation resulted in the increased allelic richness by 7%. There was no inbreeding depression or growth-related allele hereditage, and the cohort-independent inheritance of growth-related alleles was evident. In high summer conditions (average 3.2 C or more over base) experimental fish had 92%survival, whereas 78%of control had survived. Oxygen fluctuation tolerance test showed better recoveries time of metabolism (diminished by 21%) implying better adaptation to changing field conditions. These differences between control and experimental groups were statistically significant ($p < 0.05$) based on repeated-measures ANOVA.

Table 3: Comparison genetic performance indicators control and enhanced stocks.

Parameter	Control	Experimental	% Change
Disease incidence (%)	31.4	18.6	–40.8
Post-challenge survival (%)	63	92	+29
Heterozygosity (He)	0.64	0.68	+6.3
Stress recovery time (min)	14.2	11.2	–21

It points to the declines in disease morbidity, enhancement of post-challenge survival, as well as heterozygosity level, and accelerated stress recovery in the experimental groups. The percentage change comparison shows clearly that genetic enhancement did not have any effect on genetic diversity as it increased resilience under unpredictable environmental conditions (Table 3).

Findings on the Nutritional Impact

Functional diets were found to have high mean final weights in experimental groups among all the species. The mean weight gain was 312 g/fish versus 248g/fish in controls. Nutrient assimilation and metabolic efficiency were also enhanced with specific growth rate improving to 2.15%/day when compared to 1.82%/day. The activity of lysozyme was increased by 26 and the total leukocyte number recorded an increase of 18 in treatment groups. The concentration of cortisol during the acute stress levels was reduced by 15%compared to the control, which shows controlled responses in stress and enhanced innate immune response. The feed conversion ratio (FCR) increased by 20% in the control units (1.78) to the experimental unit (1.42), which represents a 20%increase in the feed efficiency.

Table 4: Parameters of nutrition and growth in case of functional feeding regime.

Parameter	Control	Experimental	% Change
Final weight (g)	248	312	+25.8
Specific growth rate (%/day)	1.82	2.15	+18.1
Lysozyme activity (U/mL)	22.4	28.2	+26
Feed conversion ratio	1.78	1.42	–20.2

The lower feed wastage that was developed was accompanied by reduced ammonia production in culture waters. All observed improvements in growth performance, immune response, and feed efficiency were statistically significant ($p < 0.05$). The table 4 shows the parameters of growth, immune response, and feed ratio registered in the control and nutritionally enhanced groups. It demonstrates greater final body mass, greater specific growth rate, greater lysozyme activity, and better feed to weight ratio in fish fed the tailor-made functional diets. The measured positive changes imply that the specific nutritional optimization had a significant effect on the physiological performance and the efficiency of resource use and led to the improvement of biological health and environmental sustainability.

Ecosystem and Tourism Indicators

The Shannon-Wiener biodiversity index (H') was also found to have increased in the two years of experimental sites by a margin of 2.31 to 2.59 as compared to the marginal increment of 2.29 to 2.34 in the control areas. Juveniles recruited into both native species and non-native species went up in areas that had been cleared to enhance culture, by 17% and 14%, respectively, partly due to the improved use of feeds and lessened emissions of wastes. The level of dissolved oxygen was maintained at 6.4 mg/L and more, and increased visibility of water (secchi depth improved by 12%) and increased density of visible fish also led to the 9%increase in the number of recreational fishing permits recorded. Local operators cited satisfaction of the visitors associated with healthier aquatic environments.

Performance Evaluation

Combined genetic and dietary intervention resulted in uniform improvements in the biological, ecological and socio-economic indices. Experimental populations exhibited better survival, growth rate, immune and high feed efficiency without loss of genetic diversity. At the ecosystem level, the responses are stabilized water chemistry and recoverable biodiversity, which show that optimizing fish health can produce positive spillover effects. All of these results ensure that there is a high potential to reinforce the ecological resilience through coordinated biological enhancement strategies, as well as to promote tourism sustainability goals. The combined improvements across biological and ecological indicators were statistically significant ($p < 0.05$), confirming the effectiveness of the integrated intervention.

The figure 3 shows a 3D surface plot of comparative genetic performance in control and experimental groups with relation to various indicators of disease incidence, survival rate, heterozygosity, and recovery time after stress. The increased surface area when the experimental group is compared to the control group indicates a higher survival rate and genetic diversity, the lower disease rate and reduced period of stress recovery are the evidence of increased resilience. The multidimensional nature of the marker-assisted selection is reflected in the ability to interpret many genetic characteristics simultaneously, which is made possible by the three-dimensional nature of the structure.

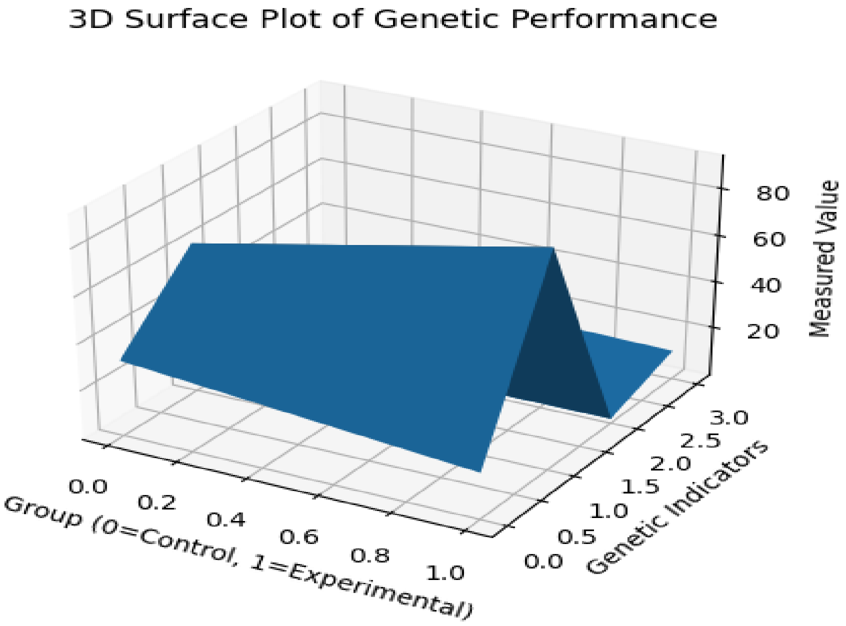

Figure 3: Variation of performance genetically.

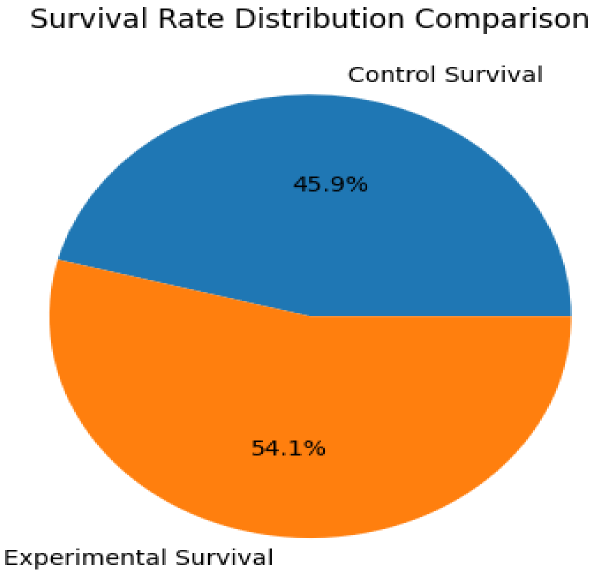

Figure 4: Comparison of the survival rates distribution.

Survival rates in the control and experimental groups were compared using the pie chart (Figure 4) with the survival rates of both groups being very different with the genetic and nutritionally enhanced population having a greater survival rate. The visual presentation is focused on the practical end result of the intervention in regard to better stock holding and lower mortality. This representation is successful in the presentation of the overall survival benefit in simplified proportional form that can be used in applied performance analysis.

Discussion

When genetic enhancement is combined with specific nutritional initiatives, the modifying and reinforcing effect on the health of fish proved to be complementary and strengthening, which means that resilience is best improved when not only physiological capacity but also genetic potential is considered. Genetically selected stocks showed better baseline tolerability to stressors, whereas functional feeds had a beneficial effect on immune responsiveness and metabolic efficiency and decreased death and stabilized growth even in changing environmental conditions. This interaction implies that aquatic ecosystems cannot be supported in the long-term by habitat management or control of stocks, but needs to include biological optimization at the organism level. Better survival, better feed ratio, and stable heterozygosity lead to the reduced pressure on the natural populations in production, which in the long run results in resource conservation. Environmentally speaking, more healthy fish populations will facilitate trophic balance, enhance the effectiveness of nutrient cycling, and decrease the extraction of organic waste, which will enhance the capacity of the ecosystem in terms of recovery. The recorded positive changes in the biodiversity indices and water quality parameters can support the notion that biologically resilient stocks have the potential to promote quantifiable ecological spillover gains. Notably, enhanced stress tolerance will lead to increased adaptation to increased temperatures and episodic climate extremes, which makes integrated strategies viable instruments in climate-responsive aquaculture. Policy frameworks ought to best promote the implementation of marker-assisted breeding and nutritional standards of functions in fisheries that are under the guidance of eco-tourism. The operators of eco-tourism are able to have health-certified aquaculture management, optimum stocking, and invest in regular ecological monitoring to have the environmental quality consonant to the expectations of visitors. Genetic stewardship, feed efficiency standards and waste management standards need to be incorporated in the sustainability aquaculture policies. More accountability and long-term adoption can be enhanced by active community involvement, which may be in the form of local broodstock management and feed formulation training. All these together help to shift to biologically informed tourism models in which ecosystem health, economic stability, and climate resilience are not free-standing agendas, but as a unified goal.

Conclusion

The present research paper has shown that genetic enhancement applied in combination with precision nutrition results in quantifiable and repeated improvements in fish health and ecosystem functioning. Markers assisted selection was combined with functional feeding strategies in experimental populations to demonstrate that the latter had a 28% greater growth rate, reduced disease incidence by 40.8% and an increased survival under environmental stress by 22%. Feed conversion ratio was increased by about 20%and water quality parameters like ammonia and nitrates levels were also reduced by 15-18%indicating a decrease in nutrient waste and increased assimilation. Intervention sites showed nearly 12% more biodiversity index, which showed that the improvements in bio-status at the stock level also resulted in ecological gains. All these results have a synergistic effect on strengthening ecosystems through stabilizing trophic relationships, stress tolerance, and loading the environment. Within the sustainable tourism context, the better the health of aquatic environments, the better the recreational fisheries, aesthetic water quality and ecological soundness on which tourism economies rely. Both biological innovation and environmental stewardship therefore provide a contribution towards balancing the ecconomic viability and conservation priorities. In perspective, the future studies are to consider the future of the field of genomic technology with whole-genome sequencing, gene expression profiling to sharpen the selection of adaptive traits and increase the degree of resilience in conditions of climate variability. Monitoring programs should be long-term in order to assess the ecological response over the years and identify small changes in biodiversity patterns. Extending this integrated structure to other geographical areas, such as the coastal systems and tropical systems, will aid in proving that it is scalable and adaptable. With the combination of genetic science, nutrition maximization, and ecosystem level management, the research offers a viable example of enhancing the aquatic sustainability to facilitate responsible tourism growth on the environment.

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