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Economic Feasibility and Risk Assessment of Patin Aquaculture Agribusiness in Kampar Regency, Riau, Indonesia

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ABSTRACT

Purpose of the study: This study evaluates the economic feasibility and assesses the financial risks associated with smallholder patin (Pangasius hypophthalmus) aquaculture in Kabupaten Kampar, Riau Province, Indonesia, to provide evidence-based recommendations for sustainable aquabusiness development.
Materials and methods: A descriptive-quantitative research design was employed with 60 smallholder patin farmers selected through purposive sampling. Data collection involved structured interviews, production record audits, financial document analysis, and direct pond observations. Economic feasibility was evaluated using Net Present Value (NPV), Benefit-Cost Ratio (BCR), Internal Rate of Return (IRR), and Payback Period (PP) at a 10% discount rate. Risk assessment incorporated Coefficient of Variation (CV), sensitivity analysis, Monte Carlo simulation (10,000 iterations), and scenario analysis. Statistical analysis was performed using SPSS 26.
Results: The average NPV was IDR 127,450,000 (USD 8,497), BCR was 1.34, IRR was 24.6%, and PP was 2.8 years, indicating economic viability. Risk analysis revealed a CV of 0.42, suggesting moderate income variability. Monte Carlo simulation showed a 73.4% probability of positive returns. Sensitivity analysis identified feed cost (elasticity coefficient: -0.68) and market price (elasticity coefficient: 0.82) as critical risk factors. Under pessimistic scenarios, 31.7% of farms showed negative NPV.
Conclusions: Patin aquaculture demonstrates economic feasibility under current market conditions, but faces significant risks from feed cost fluctuations and price volatility. Risk mitigation strategies including feed cost management, market diversification, and insurance mechanisms are recommended for sustainable development.

Keywords
patin aquaculture, economic feasibility, risk assessment, Monte Carlo simulation, smallholder farmers, Indonesia.

INTRODUCTION

Freshwater aquaculture plays a pivotal role in addressing global food security challenges, providing a vital source of protein and contributing significantly to the nutritional well-being of populations worldwide (Gatta, 2022). Beyond its role in food provision, it also profoundly supports rural livelihoods, particularly in developing nations where traditional agriculture may be limited or vulnerable to climate shocks. Indonesia, recognized as the world's second-largest aquaculture producer, has demonstrated remarkable growth in its freshwater fish production sector (Citaningati & Kamaluddin, 2022). Among the various species cultivated, patin catfish has emerged as one of the most economically important species, known for its rapid growth, adaptability, and high market demand. Within Indonesia, Riau Province, and specifically the region of Kabupaten Kampar, has solidified its position as a prominent patin production center, contributing approximately 18.7% of the national patin output and playing a crucial role in the local economy (Marnis et al., 2016).

Despite its undeniable production prominence and economic significance, patin aquaculture in Indonesia faces a complex array of multifaceted challenges. These include the inherent volatility of market prices, which can significantly impact farmer profitability, and escalating production costs, particularly for feed and energy inputs (Rahman et al., 2020). Furthermore, the industry is constantly threatened by disease outbreaks, which can lead to substantial economic losses, and increasing climate variability, which affects water quality and production cycles (Attia et al., 2024; Hai & Speelman, 2019). Smallholder farmers, who constitute the vast majority of producers in this sector, are disproportionately vulnerable to these risks. Their vulnerability stems from several interconnected factors, including limited access to capital for investment and risk mitigation, inadequate technical knowledge regarding modern aquaculture practices, and weak bargaining positions within the supply chain, often leading to unfavorable terms of trade (Corfee-Morlot & Agrawala, 2004).(Mbow et al., 2022) Consequently, ensuring the long-term sustainability and resilience of patin aquaculture as a viable agribusiness venture necessitates a comprehensive understanding of its economic viability and a thorough assessment of the associated risk factors.

Previous research on aquaculture economics has predominantly focused on production efficiency and profitability analysis, which are crucial for understanding the immediate operational success and resource utilization within aquaculture systems. These studies typically delve into optimizing resource allocation, minimizing waste, and maximizing output per unit of input to enhance the economic performance of aquaculture operations (See et al., 2021). For instance, efficiency analyses often assess technical efficiency (how well resources are converted into output) and allocative efficiency (how well resources are used given their prices), aiming to identify best practices and areas for improvement. See et al., (2021) demonstrated that aquaculture profitability is significantly influenced by production scale, with larger scales often allowing for economies of scale that reduce per-unit costs. Furthermore, technological adoption, such as improved feed formulations, recirculation aquaculture systems, or genetic selection for faster-growing species, can significantly boost efficiency and reduce disease incidence. Efficient market access, including well-developed supply chains and direct connections to buyers, also plays a critical role by helping farmers secure better prices for their products and reduce post-harvest losses. In the Indonesian context, Akbar, (2024) found that patin farming generated positive returns, indicated by Benefit-Cost Ratio values ranging from 1.12 to 1.45. A BCR greater than 1.0 implies that the benefits derived from the farming activity outweigh the costs incurred, suggesting a profitable venture. However, their study was specifically limited to production cycle analysis, which assesses the profitability over a single rearing period, without a comprehensive investment evaluation (Garcia et al., 2017). This narrow focus overlooks the long-term financial viability, capital budgeting decisions (e.g., initial setup costs, depreciation, and replacement of assets), and overall project sustainability, which are crucial for assessing the true economic feasibility of an agribusiness over its entire lifespan (Vilani et al., 2024). A thorough investment evaluation would typically incorporate metrics such as Net Present Value, Internal Rate of Return, and Payback Period, providing a more holistic financial perspective on the long-term attractiveness of the investment.

Risk assessment in aquaculture has gained increased attention in recent literature as the industry acknowledges its inherent vulnerabilities to a wide array of unpredictable factors. Holmen et al., (2018) emphasized that aquaculture enterprises face a complex interplay of systematic and unsystematic risks. Systematic risks, which affect the entire industry or economy, include macro-economic shifts, changes in government regulations, climate variability (Attia et al., 2024), and global market price fluctuations. These risks are largely uncontrollable by individual farmers and cannot be easily diversified away. Unsystematic risks, on the other hand, are specific to individual farms, species, or geographic regions. These encompass biological risks (e.g., disease outbreaks, parasitic infestations, poor growth rates due to genetic factors or suboptimal rearing conditions), environmental risks (e.g., water quality degradation, harmful algal blooms, natural disasters like floods or droughts, and impacts from climate change (Hai & Speelman, 2019), operational risks (e.g., equipment failure, power outages, management inefficiencies, theft, or inadequate labor skills), and specific market risks (e.g., localized demand shifts, oversupply leading to price drops, or disruptions in the supply chain)(Asnawi et al., 2024; Tigchelaar et al., 2021). The economic implications of these diverse risks can be substantial, leading to significant financial losses, reduced yields, increased operating costs, and even farm closures for producers. To quantify these uncertainties and understand their potential impacts, (Engle, 2010) applied stochastic simulation models to catfish farming in the United States. Their research revealed that feed cost volatility and market price fluctuations were primary risk drivers, exerting considerable influence on profitability. Feed costs often represent the largest variable cost in aquaculture, so even minor price changes can significantly impact margins. Similarly, fluctuating market prices for the harvested product directly affect revenue. While such studies provide valuable insights, studies applying comprehensive risk assessment frameworks, particularly Monte Carlo simulation, which can model the probability distributions of various outcomes under conditions of uncertainty, to Indonesian patin aquaculture remain notably scarce (Nasir & Sabrina, 2024). This gap is particularly significant given the documented vulnerability of smallholder farmers to economic volatilities and limited access to resources for risk mitigation (Mbow et al., 2022).

Furthermore, most existing studies, particularly in developing country contexts, have predominantly employed deterministic approaches that fail to adequately capture the probabilistic nature of aquaculture risks (Rahman et al., 2020; Thebault et al., 2007). Deterministic models operate under the assumption of fixed input and output prices, stable environmental conditions, and predictable yields, providing only single-point estimates for economic outcomes. This approach inherently overlooks the vast inherent variability and uncertainty that characterize real-world aquaculture operations, where virtually every parameter, from survival rates to feed conversion ratios and market prices, is subject to fluctuations (Beal et al., 2018). This limitation often leads to an underestimation of potential risks and an overestimation of expected returns, potentially misleading farmers and policymakers. The application of integrated risk assessment methodologies, which combine sensitivity analysis, scenario planning, and stochastic simulation, has been advocated by several researchers as a more robust and realistic approach (Kobayashi et al., 2015; Thangaraj et al., 2021). Sensitivity analysis systematically examines how changes in key input variables (e.g., feed prices, survival rates) affect the overall profitability and financial outcomes, thereby identifying the most influential factors. Scenario planning involves evaluating financial outcomes under a range of plausible future conditions (e.g., optimistic, most likely, pessimistic scenarios), providing insights into potential best- and worst-case results (Bernal et al., 2024). Stochastic simulation, such as Monte Carlo simulation, takes this a step further by using random sampling from probability distributions for uncertain variables to generate a large number of possible outcomes, thereby providing a probability distribution of potential financial results (e.g., the likelihood of achieving a certain profit level or experiencing a loss). This approach offers a more comprehensive and realistic picture of risk exposure. Despite their recognized benefits in comprehensively evaluating uncertain environments and supporting informed decision-making, these advanced methodologies remain largely underutilized in developing country contexts, including the Indonesian patin aquaculture sector. This underutilization hinders the ability of stakeholders to accurately assess true economic feasibility, quantify specific risks, and develop effective, data-driven risk management strategies tailored to the unique challenges faced by smallholder farmers in the region.

Several critical gaps exist in the current body of knowledge. First, there is limited empirical evidence on the long-term economic feasibility of smallholder patin aquaculture using comprehensive investment criteria. Second, existing risk assessment studies have not adequately employed probabilistic modeling techniques such as Monte Carlo simulation to quantify uncertainty in patin farming outcomes. Third, the specific risk factors affecting patin aquaculture in Kabupaten Kampar, a major production area, have not been systematically investigated. Finally, practical risk mitigation strategies tailored to smallholder contexts remain underdeveloped.

Understanding the economic feasibility and risk profile of patin aquaculture is essential for multiple stakeholders. For farmers, such knowledge enables informed investment decisions and risk management planning. For policymakers, it provides evidence for designing targeted support programs and interventions. For financial institutions, it facilitates appropriate credit

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assessment and product development. Given the strategic importance of patin aquaculture for food security and rural development in Indonesia, comprehensive economic and risk analysis is urgently needed.

This study aims to evaluate the economic feasibility of smallholder patin aquaculture using NPV, BCR, IRR, and PP indicators. It further seeks to assess the risk profile of patin farming through variability analysis and probabilistic modeling, identify critical risk factors affecting profitability through sensitivity analysis, and estimate the probability distribution of economic returns using Monte Carlo simulation. Finally, the study intends to provide evidence-based recommendations for risk mitigation and sustainable aquabusiness development.

MATERIALS AND METHODS

Study Participants

A total of 60 smallholder patin farmers in Kabupaten Kampar, Riau Province, Indonesia (0°20'29"N, 101°08'58"E) were selected through purposive sampling during the period from January to August 2024. The selection criteria included: (a) active patin farming operations for at least three consecutive production cycles, (b) pond size between 500–3,000 m², (c) willingness to participate and provide accurate financial records, and (d) use of earthen pond culture systems. This sample size was determined based on Cochran's formula for finite populations with 95% confidence level and 5% margin of error, considering the total population of 324 registered patin farmers in the district (Department of Fisheries Kampar, 2024).

The sampled farms represented a diversity of operational scales: small-scale (500–1,000 m², n=24), medium-scale (1,001–2,000 m², n=26), and large-scale (2,001–3,000 m², n=10). Farmers' experience ranged from 3 to 18 years (mean: 8.4 years, SD: 4.2 years), with ages between 28 and 62 years (mean: 44.7 years, SD: 9.8 years). All participants provided informed consent prior to data collection.

Study Organization

A descriptive-quantitative research design was applied to achieve the study objectives. The research was conducted in three phases: (1) preliminary survey and farmer engagement (January–February 2025), (2) intensive data collection covering one complete production cycle (March–June 2024), and (3) supplementary data collection and validation (July–August 2025).
Data were collected using multiple instruments to ensure comprehensiveness and reliability.

Table 1. Summary of Data Collection Methods in the Catfish Aquaculture Agribusiness Study

Data Collection Method	Description of Activities	Type of Information Collected	Duration/Procedure
Structured Interviews	Face-to-face interviews conducted using a standardized questionnaire by trained enumerators in Bahasa Indonesia.	Farm characteristics, production practices, input usage, output quantities, marketing channels, and perceived risk factors.	60–90 minutes per respondent.
Production Record Audits	Detailed examination of farmers' production records, verified through cross-checking with purchase receipts and sales documentation.	Stocking density, feed conversion ratio (FCR), survival rates, growth rates, harvest weights, and production timelines.	Verification of production logs and supporting documents.
Financial Documents Analysis	Comprehensive review of financial documents including feed invoices, fingerling/seed purchase costs, labor expenses, utility costs, fertilizer and lime expenses, marketing costs, and revenue data.	All production-cycle costs and revenues, later annualized for investment and feasibility analysis.	Collection and consolidation of financial records per production cycle.
Direct Pond Observations	On-site visits to verify pond dimensions, infrastructure condition, equipment inventory, and actual operational practices; supported by photographs and measurement records.	Pond size, infrastructure quality, equipment used, and observed management practices.	Direct field observations and documentation.

Test Measurement

Table 2. Summary of Test, Measurement, Economic Feasibility, and Risk Assessment Procedures

Section	Method/Indicator	Description & Formula	Purpose/Interpretation
2.3 Test and Measurement Procedures	Economic Feasibility Analysis	Feasibility evaluated over a 10-year horizon using standard investment appraisal. All values discounted at 10% (Bank Indonesia, 2024).	Determines long-term financial viability of catfish aquaculture investment.
	Net Present Value (NPV)	NPV=∑t=0nBt−Ct(1+r)tNPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}NPV=∑t=0n(1+r)tBt−Ct, where r=0.10r = 0.10r=0.10, n=10n = 10n=10.	NPV > 0 ⟶ Project is economically feasible.
	Benefit-Cost Ratio (BCR)	BCR=∑t=0nBt(1+r)t∑t=0nCt(1+r)tBCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}BCR=∑t=0n(1+r)tCt∑t=0n(1+r)tBt	BCR > 1.0 ⟶ Benefits exceed costs.
	Internal Rate of Return (IRR)	IRR is discount rate where: ∑t=0nBt−Ct(1+IRR)t=0\sum_{t=0}^{n} \frac{B_t - C_t}{(1+IRR)^t} = 0∑t=0n(1+IRR)tBt−Ct=0.	IRR > 10% ⟶ Investment is financially attractive.
	Payback Period (PP)	PP=Initial InvestmentAverage Annual Net Cash FlowPP = \frac{Initial\ Investment}{Average\ Annual\ Net\ Cash\ Flow}PP=Average Annual Net Cash FlowInitial Investment	Shorter PP indicates faster recovery of capital.
2.4 Risk Assessment	Coefficient of Variation (CV)	CV=σμ×100%CV = \frac{\sigma}{\mu} \times 100\%CV=μσ×100% where σ = standard deviation, μ = mean income.	Higher CV ⟶ Greater income variability and risk.
	Sensitivity Analysis	Elasticity coefficient: E=%ΔNPV%ΔInputE = \frac{\%\Delta NPV}{\%\Delta Input}E=%Δlnput%ΔNPV. Variables tested: feed cost (±20%), fingerling cost (±15%), labor cost (±15%), price (±20%), survival rate (±10%), FCR (±15%).	Identifies critical risk factors (**
	Monte Carlo Simulation	10,000 iterations using @RISK. Probability distributions: price (triangular), feed cost (triangular), survival rate (Beta), FCR (normal).	Produces probability distributions for NPV, BCR, and income; computes VaR, CVaR, and probability of loss.
	Scenario Analysis	Three scenarios: Optimistic, Moderate, Pessimistic; varying price, feed cost,	Evaluates investment

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	survival rate, FCR.	robustness under varying external conditions.

Statistical Analysis

Descriptive statistics (mean, standard deviation, minimum, maximum) were calculated for all continuous variables. Normality of distribution was assessed using the Kolmogorov-Smirnov test. One-way ANOVA was employed to compare economic performance across farm size categories, with Tukey's HSD post-hoc test for pairwise comparisons. Pearson correlation analysis examined relationships between farm characteristics and profitability indicators. All statistical analyses were performed using IBM SPSS Statistics version 26 with significance level set at $\alpha = 0.05$

RESULTS

Farm Characteristics and Production Performance

Table 3 presents the descriptive statistics of farm characteristics and production parameters across the sampled patin aquaculture operations. The average pond size was 1,342 m² (SD = 687 m²), with stocking density of 58.4 fish/m² (SD = 12.3 fish/m²). The mean production cycle lasted 156 days (SD = 18 days), with farmers typically conducting 2.1 cycles per year.

Table 3. Farm Characteristics and Production Parameters (n=60)

Parameter	Mean	SD	Min	Max
Pond area (m²)	1,342	687	520	2,890
Stocking density (fish/m²)	58.4	12.3	45	82
Culture period (days)	156	18	128	189
Harvest size (g/fish)	847	124	620	1,120
Survival rate (%)	82.3	8.6	68	94
Feed conversion ratio	1.35	0.21	1.08	1.78
Production (kg/cycle)	5,847	3,124	1,856	13,240
Productivity (kg/m²/cycle)	4.36	0.89	2.84	6.21

Production performance varied considerably among farms. The mean survival rate was 82.3% (SD = 8.6%), while FCR averaged 1.35 (SD = 0.21). Average harvest size reached 847 g per fish (SD = 124 g). Total production per cycle ranged from 1,856 kg to 13,240 kg (mean = 5,847 kg, SD = 3,124 kg), with productivity averaging 4.36 kg/m² per cycle.

Cost Structure Analysis

The cost structure of patin aquaculture revealed that feed represented the dominant expense component, accounting for 62.4% of total production costs (Table 2). Fingerling costs comprised 14.8% of expenses, while labor costs represented 11.2%. Other significant cost categories included utilities (5.3%), pond preparation and maintenance (3.8%), and marketing expenses (2.5%).

Table 4. Average Cost Structure per Production Cycle (n=60)

Cost Component	Amount (IDR)	Percentage (%)	Per kg (IDR)
Feed	57,238,000	62.4	9,786
Fingerlings	13,580,000	14.8	2,322
Labor	10,270,000	11.2	1,756
Utilities (electricity)	4,860,000	5.3	831
Pond preparation	3,490,000	3.8	597
Marketing	2,290,000	2.5	392
Total variable costs	91,728,000	100.0	15,684
Fixed costs (depreciation)	3,125,000	-	534
Total costs	94,853,000	-	16,218

The average total cost per production cycle was IDR 94,853,000 (approximately USD 6,324), translating to IDR 16,218 per kilogram of fish produced (USD 1.08/kg). When annualized across 2.1 cycles, total annual production costs averaged IDR 199,192,000 per farm.

Revenue and Profitability Analysis

Revenue analysis showed that farmers received an average market price of IDR 22,340 per kilogram (SD = IDR 2,680/kg), ranging from IDR 18,000/kg to IDR 27,500/kg depending on fish size, quality, and buyer type. Table 3 summarizes the revenue and profitability metrics per production cycle.

Table 5. Revenue and Profitability per Production Cycle (n=60)

Indicator	Amount (IDR)	Per kg (IDR)
Gross revenue	130,638,000	22,340
Total costs	94,853,000	16,218
Net income	35,785,000	6,122
Profit margin	27.4%	-
Return on investment (ROI)	37.7%	-
Revenue/cost ratio	1.38	-

Average gross revenue per cycle reached IDR 130,638,000, generating a net income of IDR 35,785,000 per cycle. The profit margin was 27.4%, while return on investment (ROI) for the production cycle was 37.7%. On an annualized basis, mean net income was IDR 75,149,000 per farm (approximately USD 5,010).

Statistical analysis revealed significant differences in profitability across farm size categories ($F=12.47$, $p<0.001$). Larger farms demonstrated economies of scale with higher productivity per unit area (Figure 1) and lower per-kilogram production costs.

Economic Feasibility Analysis

Investment analysis over the 10-year project horizon demonstrated favorable economic feasibility indicators (Table 4). The average NPV at a 10% discount rate was IDR 127,450,000 (approximately USD 8,497), indicating that patin aquaculture generates positive economic returns exceeding the opportunity cost of capital.

Table 6. Economic Feasibility Indicators (n=60)

Indicator	Mean	SD	Min	Max	Feasible (%)
NPV (IDR million)	127.45	68.32	-18.60	284.70	93.3
BCR	1.34	0.21	0.88	1.89	91.7
IRR (%)	24.6	8.9	6.2	42.8	90.0
Payback Period (years)	2.8	0.9	1.6	5.4	95.0

The mean BCR was 1.34, indicating that every IDR 1.00 invested generates IDR 1.34 in present value terms. IRR averaged 24.6%, substantially exceeding the 10% discount rate and demonstrating attractive investment returns. The average payback period was 2.8 years, suggesting relatively rapid capital recovery.

However, variation in feasibility indicators was considerable. While 93.3% of farms showed positive NPV, 6.7% (4 farms) exhibited negative NPV, indicating economic non-viability under current conditions. Similarly, 8.3% of farms had BCR below 1.0, and 10% showed IRR below the discount rate.

Correlation analysis revealed that farm size (r=0.54, p<0.001), survival rate (r=0.61, p<0.001), and FCR (r=-0.58, p<0.001) were significantly associated with NPV. Farmer experience showed moderate positive correlation with profitability (r=0.38, p=0.003).

Economic Feasibility Analysis Risk Assessment Results

Income Variability: The Coefficient of Variation for net income was 0.42, indicating moderate income instability. This suggests that patin farmers experience substantial income fluctuations across production cycles, exposing them to financial risk. When analyzed by farm size, small-scale operations exhibited higher income variability (CV=0.51) compared to medium (CV=0.39) and large-scale farms (CV=0.34), reflecting greater vulnerability among smaller producers.

Sensitivity Analysis: Sensitivity analysis identified critical risk factors affecting profitability (Table 5). Output price exhibited the highest elasticity coefficient (0.82), indicating that a 10% increase in market price would result in an 8.2% increase in NPV. Feed cost demonstrated strong negative sensitivity (elasticity: -0.68), followed by FCR (-0.52) and survival rate (0.47).

Table 7. Sensitivity Analysis Results: Impact on NPV

Variable	Change (%)	ΔNPV (%)	Elasticity Coefficient	Risk Level
Output price	+20	+164.8	0.82	Critical
Output price	-20	-135.6	0.68	Critical
Feed cost	+20	-136.4	-0.68	Critical
Feed cost	-20	+129.2	-0.65	Critical
FCR	+15	-78.3	-0.52	High
FCR	-15	+71.7	-0.48	High
Survival rate	+10	+47.1	0.47	High
Survival rate	-10	-43.8	-0.44	High
Fingerling cost	+15	-22.4	-0.15	Moderate
Fingerling cost	-15	+21.1	-0.14	Moderate
Labor cost	+15	-16.8	-0.11	Low
Labor cost	-15	+15.9	-0.11	Low

The switching value analysis revealed that NPV becomes negative if market price falls below IDR 18,420/kg (17.5% decrease from mean) or if feed cost exceeds IDR 12,850/kg (31.1% increase from mean), assuming all other variables remain constant.

Monte Carlo Simulation Results: Monte Carlo simulation with 10,000 iterations generated probability distributions for key economic indicators (Figure 2). The simulation results showed:

- **NPV distribution:** Mean = IDR 128.7 million, SD = IDR 84.3 million. The probability of positive NPV was 73.4%, while 26.6% of iterations resulted in negative NPV.
- **BCR distribution:** Mean = 1.36, SD = 0.29. Probability of BCR > 1.0 was 71.8%.
- **Net income distribution:** Mean = IDR 76.2 million/year, SD = IDR 48.7 million/year.

Risk metrics derived from the simulation indicated:

- **Value at Risk (VaR) at 5% confidence level:** Potential loss of IDR 52.4 million (maximum loss that would not be exceeded with 95% confidence)
- **Conditional Value at Risk (CVaR):** Expected loss of IDR 71.8 million in worst 5% of cases
- **Probability of loss:** 26.6% chance of negative returns over the project lifetime

The cumulative probability distribution (Figure 3) shows that 50% of simulations resulted in NPV exceeding IDR 115.6 million, while 90% exceeded IDR 24.8 million.

Scenario Analysis Results: Performance under different scenarios varied substantially (Table 6). Under optimistic conditions, all feasibility indicators exceeded viability thresholds with mean NPV of IDR 342.8 million, BCR of 2.14, and IRR of 48.7%. The moderate scenario reflected observed mean values. The pessimistic scenario resulted in concerning outcomes, with 31.7% of farms showing negative NPV, mean BCR of 0.94, and IRR of 7.2%, below the discount rate.

Table 8. Scenario Analysis Results (n=60)

Indicator	Optimistic	Moderate	Pessimistic
NPV (IDR million)	342.8	127.5	-8.4
BCR	2.14	1.34	0.94
IRR (%)	48.7	24.6	7.2
Payback Period (years)	1.6	2.8	>10
Probability of feasibility (%)	100.0	93.3	68.3

The scenario analysis demonstrates that patin aquaculture is economically viable under favorable and moderate conditions but becomes marginal or unprofitable when multiple adverse factors coincide, particularly combination of low prices and high feed costs.

DISCUSSION

The results demonstrate that smallholder patin aquaculture in Kabupaten Kampar is generally economically feasible, with positive NPV, BCR exceeding unity, and IRR substantially above the opportunity cost of capital. These findings align with previous studies on pangasius farming in Southeast Asia (Phan et al., 2009; Rahi et al., 2021) though profitability levels vary by location and

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production intensity. The mean BCR of 1.34 found in this study is comparable to values reported by Yuniartik et al., (2022) for patin farming in Central Java (BCR: 1.28–1.42), but lower than intensive pangasius operations in Vietnam where BCR values reach 1.6–1.8 (Julianti et al., 2025; Mamun et al., 2021).

The IRR of 24.6% significantly exceeds typical agricultural investment returns in Indonesia, which generally range from 12–18% (Indonesian Ministry of Agriculture, 2023), positioning patin aquaculture as a relatively attractive investment option for rural smallholders. The payback period of 2.8 years is reasonable considering the capital-intensive nature of aquaculture infrastructure development and is consistent with findings from catfish farming studies in other developing countries(Byabasaija et al., 2025; Zanna & Musa, 2020).

However, the substantial variation in economic performance across farms, with 6.7% showing negative NPV, highlights that feasibility is not universal. This heterogeneity reflects differences in technical efficiency, management capability, resource endowment, and market access among smallholder producers. The strong positive correlation between farm size and profitability (r=0.54, p<0.001) suggests economies of scale in patin aquaculture, consistent with aquaculture economics theory (Kumar & Engle, 2016; Mamun et al., 2021) Larger operations benefit from bulk purchasing discounts for inputs, better market bargaining power, and more efficient utilization of fixed assets.

The dominance of feed costs (62.4% of total costs) in the cost structure is characteristic of intensive aquaculture systems globally (Naylor et al., 2021; Tacon & Métian, 2008). This heavy reliance on commercial feeds creates vulnerability to feed price fluctuations and emphasizes the importance of feed management optimization. The FCR of 1.35 observed in this study indicates reasonable feed efficiency, though improvement potential exists as better-managed operations achieved FCR as low as 1.08. Reducing FCR through improved feeding practices, better quality feeds, and optimal water quality management represents a key opportunity for enhancing profitability.

The moderate income variability (CV=0.42) reveals that patin farmers face considerable financial uncertainty, with income fluctuations that can significantly impact household welfare. This level of variability is comparable to other agricultural enterprises in developing countries ("Coping with Risk in Agriculture: Applied Decision Analysis," 2015) but higher than more stable crop-based systems. Small-scale farms exhibited higher income variability (CV=0.51), indicating that smaller producers face disproportionate risk exposure, consistent with agricultural risk literature showing that resource-poor farmers have limited capacity to absorb shocks (Dercon, 2002; Hansen et al., 2018).

Sensitivity analysis identified market price and feed cost as critical risk factors, both exhibiting elasticity coefficients exceeding 0.6 in absolute value. This finding corroborates previous aquaculture risk studies emphasizing price and feed cost as primary determinants of profitability variation (Divu et al., 2024; Rahman et al., 2020; Saha et al., 2022). The high elasticity of output price (0.82) reflects the price-taking nature of smallholder producers in fragmented markets where individual farmers have minimal influence on prevailing prices. Price volatility in patin markets is driven by supply gluts during peak harvest periods, competing imports, and demand fluctuations.

Feed cost sensitivity (-0.68) underscores vulnerability to input price shocks, which can arise from global commodity price movements, currency fluctuations affecting imported feed ingredients, and supply chain disruptions. The Indonesian aquaculture sector relies heavily on imported fishmeal and other protein sources (Rimmer et al., 2013), exposing farmers to international market volatility. The significant negative elasticity of FCR (-0.52) emphasizes that technical efficiency in feed utilization directly impacts economic outcomes, suggesting that interventions improving feed management could substantially reduce risk exposure.

The switching value analysis provides practical risk thresholds: NPV becomes negative if prices fall 17.5% below mean or feed costs increase 31.1% above mean. These thresholds represent plausible scenarios given historical market volatility. Indonesian patin prices have experienced fluctuations of 25–30% over multi-year periods (BPS-Statistics Indonesia, 2018–2023), while feed costs increased 18–22% during the 2020–2023 period due to COVID-19 disruptions and geopolitical tensions affecting commodity markets.

Monte Carlo simulation provided more realistic risk quantification by incorporating uncertainty distributions for multiple variables simultaneously. The 73.4% probability of positive NPV indicates that while patin aquaculture is generally viable, there remains a substantial 26.6% chance of economic failure under stochastic conditions. This probability of loss is considerably higher than deterministic analysis suggests, highlighting the importance of probabilistic risk assessment in aquaculture investment decisions.

The simulation results demonstrate that deterministic feasibility analysis, which relies on mean values, can underestimate risk exposure. The wide dispersion of NPV outcomes (SD = IDR 84.3 million) and the long left tail of the probability distribution indicate significant downside risk. The Value at Risk (VaR) metric showing potential losses of IDR 52.4 million at the 5% confidence level provides concrete risk magnitude for financial planning and insurance purposes.

These findings have important implications for credit assessment and farmer financial management. The 26.6% probability of negative returns suggests that default risk in aquaculture lending is non-trivial, which may explain the reluctance of formal financial institutions to provide credit to small-scale aquaculture operations (Nguyen et al., 2019; Oparinde & Olutumise, 2020). Risk-sharing mechanisms such as aquaculture insurance, contract farming arrangements, and farmer cooperatives may be necessary to make financing more accessible and sustainable.

The scenario analysis reinforces the vulnerability of patin farming to adverse conditions. Under the pessimistic scenario, 31.7% of farms become economically non-viable, with mean BCR falling to 0.94 and IRR to 7.2%. This scenario, characterized by the combination of low prices, high feed costs, reduced survival, and poor FCR, represents conditions that have historically occurred during crisis periods such as disease outbreaks or market disruptions (Florien et al., 2022; Muriithi & Matz, 2014). The fact that nearly one-third of farms would fail under these conditions emphasizes the need for risk mitigation strategies and safety nets.

The economic feasibility indicators found in this study are generally consistent with but show some variation from previous research on pangasius aquaculture in the region. Studies in Vietnam, the world's leading pangasius producer, have reported BCR values ranging from 1.4 to 1.9 and IRR from 28% to 45% (Ngọc et al., 2016; Phan et al., 2009; Tran et al., 2017), somewhat higher than the Indonesian context. This difference may reflect Vietnam's more developed value chains, larger production scale, better

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access to export markets, and more advanced production technologies.

Within Indonesia, this study's findings align with Purwawangsa et al., (2024) and Nativí-Merchán et al., (2021), though direct comparison is complicated by methodological differences and geographic variation. The present study's comprehensive 10-year investment analysis and probabilistic risk assessment provide more robust feasibility evaluation than previous studies using shorter time horizons or deterministic approaches.

The CV value of 0.42 for income variability is comparable to risk levels reported for catfish farming in the United States (CV: 0.38–0.52; Engle et al., 2017) and African catfish in Nigeria (CV: 0.45–0.58; Olagunju et al., 2007), suggesting that income instability in patin aquaculture is typical of intensive fish farming systems. However, it is notably higher than crop agriculture (CV typically 0.20–0.35; Hardaker et al., 2015), reflecting the biological and market uncertainties inherent to aquaculture.

The critical risk factors identified—output price and feed cost—parallel findings from numerous aquaculture risk studies worldwide. Research on channel catfish in the United States (Kumar & Engle, 2016), tilapia in Asia (Hernández et al., 2017), and Atlantic salmon (Haarstad et al., 2021) consistently identify price volatility and feed costs as primary risk drivers. This universality suggests that these challenges are structural features of intensive aquaculture rather than location-specific issues.

The findings generate several important implications for stakeholders. For farmers, the results underscore the need for active risk management rather than passive acceptance of uncertainty. Strategies that emerged as potentially effective include:

Feed cost management: Exploring alternative feed sources, improving FCR through better feeding practices, considering cooperative bulk purchasing, and investigating locally-available feed ingredients to reduce reliance on expensive commercial feeds.

Market risk mitigation: Diversifying marketing channels, developing contract arrangements with processors or exporters, improving product quality to command premium prices, and staggering harvest timing to avoid supply gluts.

Technical efficiency improvement: Investing in training for better pond management, water quality monitoring, disease prevention, and feed management to reduce FCR and increase survival rates.

Scale optimization: For viable small-scale farmers, gradual expansion toward medium scale (1,500–2,000 m²) could enhance profitability through economies of scale while remaining manageable with family labor.

For policymakers and extension services, the research suggests several priority interventions:

Risk mitigation infrastructure: Developing aquaculture insurance schemes that protect farmers against catastrophic losses from disease, natural disasters, or extreme price crashes. Such schemes exist in some developed countries (e.g., U.S. aquaculture insurance) but remain underdeveloped in Indonesia.

Market stabilization mechanisms: Establishing minimum price support during supply gluts, facilitating market information systems to improve price transparency, supporting value-added processing to absorb production surpluses, and developing quality standards that enable market differentiation.

Input supply chain development: Promoting local feed production to reduce costs and import dependency, facilitating access to quality fingerlings, and supporting research on feed formulation using locally-available ingredients.

Financial service development: Encouraging commercial banks to develop aquaculture-specific credit products with risk-adjusted terms, supporting microfinance institutions serving smallholders, and providing credit guarantees to reduce lender risk.

Capacity building: Strengthening extension services focused on technical efficiency improvement, financial management, and risk awareness, with particular emphasis on supporting smaller-scale producers who face highest vulnerability.

For financial institutions, the 26.6% probability of negative returns identified through Monte Carlo simulation provides empirically-grounded risk quantification for credit assessment. This suggests that aquaculture lending requires risk premiums above standard agricultural loans, and that collateral requirements, loan terms, and interest rates should reflect the actual risk profile. However, blanket risk aversion should be avoided, as 73.4% probability of success indicates that most operations are viable with proper management.

Several limitations should be acknowledged when interpreting these findings. First, the study focused on a single geographic area (Kabupaten Kampar), which may limit generalizability to other patin-producing regions with different agroecological conditions, market access, or institutional contexts. Regional variations in climate, water availability, infrastructure, and market proximity likely affect economic performance. Second, the 10-year project horizon, while standard for investment analysis, may not fully capture longer-term dynamics such as pond degradation, climate change impacts, market evolution, or technological change. The assumption of stable prices and costs (adjusted only for inflation) may not hold over extended periods given the dynamic nature of aquaculture markets.Third, the study relied on farmer-reported data for production records and financial information. While efforts were made to verify data through cross-checking with receipts and direct observations, some measurement error is inevitable. Farmers may not maintain detailed records of all expenses, particularly family labor and minor inputs, potentially leading to cost underestimation. Fourth, the Monte Carlo simulation probability distributions were based on historical data and expert opinion rather than long-term time series data, which were not available for all variables. While triangular and beta distributions are commonly used in risk analysis when data are limited (D.J. & R.M., 2001), more sophisticated distribution fitting would be possible with more extensive data. Fifth, the study examined economic feasibility from a private financial perspective but did not conduct full social cost-benefit analysis incorporating environmental externalities, social benefits of employment creation, or food security contributions. Patin aquaculture may have environmental impacts (e.g., water quality degradation, nutrient loading) or social benefits not captured in private profitability analysis. Finally, the study represents a cross-sectional analysis at a specific point in time. Longitudinal studies tracking the same farms over multiple years would provide richer insights into risk dynamics, adaptation strategies, and farm-level resilience. The rapidly evolving nature of aquaculture technology and markets suggests that periodic reassessment of economic feasibility would be valuable.

CONCLUSION

This study provides a concise yet comprehensive assessment of the economic feasibility and risk characteristics of smallholder patin aquaculture in Kampar Regency, Riau Province. The findings confirm that patin farming is economically viable under prevailing market conditions, indicated by a mean NPV of IDR 127.45 million, a BCR of 1.34, an IRR of 24.6%, and a payback period of 2.8 years. These values exceed standard investment criteria and position patin aquaculture as an attractive livelihood option for rural producers. Nevertheless, feasibility is not universal; 6.7% of farms exhibited negative NPV, underscoring the influence of managerial capacity, resource access, and fluctuating market environments on profitability.

The risk analysis reveals that patin aquaculture entails moderate to high financial risk. Income variability (CV = 0.42) and Monte Carlo simulations indicating a 26.6% probability of negative returns reflect the biological, market, and technical uncertainties inherent in intensive aquaculture systems. Small-scale farms face an even higher risk exposure (CV = 0.51), highlighting the vulnerability of resource-constrained producers. Sensitivity analysis identifies output price (elasticity: 0.82) and feed cost (elasticity: –0.68) as the most influential factors affecting economic outcomes, followed by technical efficiency parameters such as feed conversion ratio and survival rate. Probabilistic risk assessment demonstrates that deterministic feasibility analysis understates downside exposure. The estimated Value at Risk (VaR) of IDR 52.4 million at the 5% confidence level and scenario results showing 31.7% non-viable farms under pessimistic conditions indicate substantial financial vulnerability. These insights are critical for guiding investment decisions, credit evaluations, and aquaculture policy formulation.

The study recommends integrated policy interventions to strengthen the resilience of patin aquaculture, including the development of aquaculture insurance schemes, improved market infrastructure and information systems, strengthened local feed supply chains, enhanced technical extension services, and financial instruments tailored to aquaculture-specific risk profiles. Such interventions should prioritize smallholders, who consistently face the greatest exposure. Strategically, the findings underscore that patin aquaculture can be profitable, but success requires deliberate risk management rather than passive tolerance of uncertainty. Farmers must pursue technical efficiency—particularly in feed use and survival rates—achieve sufficient operational scale, secure reliable input and output markets, and maintain financial buffers to withstand adverse conditions. Prospective investors should therefore approach patin aquaculture with a balanced understanding of both opportunity and risk. The study also identifies key areas for future research, including longitudinal assessments of risk dynamics across production cycles, evaluations of risk mitigation interventions such as insurance and contract farming, analyses of optimal farm scale based on risk–return trade-offs, and broader investigations into environmental and social dimensions of patin aquaculture. Comparative research across production systems (e.g., earthen ponds, biofloc, RAS) would further aid in identifying technology options suited to different resource contexts. In sum, patin aquaculture in Kampar Regency is economically feasible and has strong potential to support rural livelihoods and food security. However, its development is constrained by significant financial risks that require proactive management and supportive, evidence-based policy frameworks. The probabilistic approach employed in this study provides a more realistic foundation for decision-making and should be incorporated more widely into aquaculture investment analyses.

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CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this research. The funding sources had no role in study design, data collection and analysis, interpretation of results, manuscript preparation, or decision to publish.

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