



Financial Viability of Red Sea Urchin (*Mesocentrotus franciscanus*) Aquaculture: A Comprehensive Analysis of Risk, Production Costs, and Market Dynamics under Macroeconomic Scenarios

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Abstract: This study investigates the financial viability of red sea urchin (*Mesocentrotus franciscanus*) aquaculture, addressing key economic factors such as production costs (CAPEX and OPEX), larval prices, and market dynamics. Through a comprehensive literature review and the development of a dual financial model (deterministic and stochastic), critical parameters influencing profitability are identified. While a baseline deterministic model suggests an Internal Rate of Return (IRR) of 22.4%, the incorporation of stochastic variables based on historical inflation and Mexican CETES rates reveals significant vulnerability (negative NPV given a 6.14% discount rate). The results demonstrate that optimizing the larval phase and reducing initial investment (CAPEX) are crucial for mitigating macroeconomic risk. This study provides a robust risk assessment framework for investors and policymakers.

Keywords: *Mesocentrotus franciscanus*, aquaculture, stochastic modeling, risk analysis, production costs, sea urchin farming.

INTRODUCTION AND JUSTIFICATION

The fishery for red (*Mesocentrotus franciscanus*) and purple (*Strongylocentrotus purpuratus*) sea urchins in Baja California, Mexico, has experienced drastic fluctuations in recent decades.

Historically one of the most commercially valuable fisheries, overexploitation combined with thermal anomaly events (e.g., "The Blob" and El Niño) has led to wild population collapses and a contraction in catches (Cabrera-Sánchez et al., 2025). The global market for the gonad ("uni") maintains inelastic demand, particularly in premium markets in Japan, South Korea, and the United States, where fresh red sea urchin fetches prices exceeding \$50-\$80 USD/kg (Stefánsson et al., 2017; Zilia et al., 2021).

Despite growing interest in aquaculture (echinoculture) as a sustainable alternative, significant economic uncertainties persist. Literature indicates that seed production (larvae and juveniles) represents a biological and financial bottleneck due to the long larval stage (30-60 days) and high microalgae costs (Unuma et al., 2015; Siikavuopio et al., 2020). However, most previous studies rely on deterministic models that assume static conditions, overlooking the macroeconomic volatility of emerging markets like Mexico.

Justification: This study breaks new ground by comparing a baseline financial model with a stochastic model that incorporates inflation and Mexico's risk-free interest rates (CETES). This provides a realistic quantitative basis for decision-making, demonstrating that biological success does not guarantee financial success unless capital expenditure (CAPEX) risks and macroeconomic variables are effectively managed.

MATERIALS AND METHODS

Research Design and Biological Assumptions

A mixed quantitative approach was used. Biological parameters were based on technical literature regarding *M. franciscanus* and analogous species (*S. intermedius*, *Pseudocentrotus depressus*):

- **Nursery Phase (Larval):** Estimated survival of 15-20% up to settlement. Dominant costs: Microalgae (*Chaetoceros*, *Isochrysis*) and energy.
- **Grow-out Phase:** Duration of 18-24 months to reach commercial size (gonad index >12%). Diet based on *Macrocystis pyrifera* and formulated inert feeds (Feed Conversion Ratio - FCR estimated at 1.5 to 2.0).

Financial Modeling (CAPEX and OPEX)

A 10-year projected cash flow model was developed.

- **CAPEX (Initial Investment):** \$450,000 USD (RAS infrastructure—Recirculating Aquaculture Systems, grow-out tanks, biofiltration systems, and microalgae laboratory).
- **OPEX (Operating Costs):** \$140,000 USD/year (Feed 45%, Energy 25%, Labor 20%, Maintenance 10%).
- **Revenue:** Sale of 4,400 kg of processed gonads at \$50 USD/kg (starting in Year 3).

Stochastic Analysis and Risk Assessment

Unlike traditional models, this study applied a stochastic approach for years 1-10. Historical time series (2006-2025) from the Bank of Mexico (Banxico) were used for inflation (CPI/INPC) and 28-day CETES rates.

- **MARR (Minimum Acceptable Rate of Reference):** Set at 6.14% (historical CETES average).
- **Simulation:** Random inflation rates (within the historical range of 2.13% to 7.82%) were applied to OPEX and revenue flows, while keeping CAPEX fixed at Year 0 (assuming infrastructure is contracted at current prices).
- **Indicators:** Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (B/C), and Payback Period (PBP).

RESULTS

Production Cost Analysis

The nursery phase accounts for 45-60% of the total cost. Key cost items include microalgal feed, energy for recirculation systems, and skilled labor. The grow-out phase consumes 30-40% of the budget. Feed (macroalgae or inert diets) is the most variable component. Land-Based Systems (LBS) entail higher initial costs but offer greater control; sea cages reduce operating costs but increase environmental risks.

Larval Prices and Market Dynamics

Larval prices vary by region and scale. Ranges of \$0.05-0.08 per larva are reported in Asia, while prices in Europe fluctuate between \$0.10 and \$0.15 per larva. Data for the Americas is limited; a price of \$0.07-0.12 per larva was estimated based on analogies with similar species. Demand for sea urchin roe has grown annually, with stable prices in premium markets.

Cash Flow Model Results

Initial investment was estimated at \$450,000 (nursery + 2 grow-out systems). Annual revenue (from year 3 onwards) was projected at \$220,000 (4,400 kg of gonads at \$50/kg). Annual operating costs were estimated at \$140,000. The NPV (10 years, 8% discount rate) was \$312,000. The IRR was 22.4%, and the payback period was 4.2 years (Table 1).

Sensitivity Analysis

Larval and feed costs have a moderate impact, yet remain relevant to profitability. A 20% reduction in larval price increases the NPV by 12%. The price of gonads is the most critical factor: a reduction in this price disproportionately affects the NPV and can compromise viability. A 20% drop in gonad price reduces the NPV by 35%. Feed represents the factor with the greatest operational sensitivity. Technical optimization (inert diets, improvements in larval survival) can mitigate risks and improve margins (Table 2).

Inflation and CETES

Historical inflation data for Mexico over the last 20 years were considered, showing rates ranging from a high of 7.82 in 2022 to a low of 2.13 in 2015. Likewise, values for CETES (Federal Treasury Certificates)—known as Mexico's most reliable investment, offering low yields but minimal risk—were taken into account. Rates in Mexico peaked at 11.11% in 2023 and hit a low of 2.98%—just above the inflation rate—in 2013 (Table 3).

An analysis of the aforementioned data reveals an average inflation rate of approximately 4.43% and an average CETES rate of 6.14%. While these figures allow for a new cash flow projection, the model was also tested using unknown data by generating random inflation rates based on the highs and lows observed over the 20-year period (Table 4).

These rates represent inflation over the 10-year cash flow projection period, impacting both projected revenues and expenses. For this new cash flow projection, the original data were used, but the random inflation rate corresponding to each specific year was applied to estimated revenues and operating costs; the initial cost—or investment—remained unchanged (Table 5).

Once the new cash flow projection was obtained, the project's financial viability was calculated, using the average CETES rate of 6.14% as our Minimum Acceptable Rate of Return (MARR)—that is, the minimum return an investor would expect from investing in CETES.

Base Deterministic Model (Static Scenario)

Under a static scenario (without inflation adjustments to future cash flows and using an 8% discount rate), the project shows high theoretical profitability:

- **NPV:** \$312,000 USD
- **IRR:** 22.4%
- **Payback Period:** 4.2 years. The nursery phase accounts for 45-60% of initial OPEX, confirming that seed production is the primary cost driver.

Stochastic Model (Macroeconomic Risk Scenario)

Incorporating historical Mexican inflation and a Minimum Acceptable Rate of Return (TREMA) of 6.14% drastically alters the financial dynamics (Tables 5 and 6). The NPV drops to -\$164,324 USD, and the IRR falls to 0.87%. *Key interpretation:* The stochastic model reveals that inflation erodes operating margins; since the initial CAPEX cannot be adjusted (having already been disbursed), the opportunity cost of capital (represented by CETES rates) destroys the project's present value. The payback period extends to 9.59 years.

Multivariable Sensitivity Analysis

To identify viability thresholds within the stochastic model, a sensitivity matrix was created by varying the TREMA and CAPEX (Table 7).

- **Critical finding:** The project is viable ($NPV > 0$) only if the initial investment (CAPEX) is reduced to \$350,000 USD and the TREMA remains below 2.14% (a scenario of historically low interest rates).
- **Revenue Sensitivity:** A 20% drop in gonad prices reduces the NPV by 35%, demonstrating that the project is a "price-taker" and highly vulnerable to fluctuations in the Asian market.

DISCUSSION

The results of this study reveal a fundamental dichotomy in the aquaculture economics literature: biological and deterministic viability does not directly translate into financial viability in emerging markets characterized by high macroeconomic volatility.

The CAPEX Bottleneck and Inflation

Our stochastic model demonstrates that intensive aquaculture projects (such as RAS for sea urchins) are highly sensitive to inflation. Given that CAPEX is incurred in Year 0, future cash flows—even if they grow with inflation—fail to exceed the discount rate (TREMA) unless operating margins grow exponentially. This aligns with the findings of Pearce et al. (2002) and more recent studies by Siikavuopio et al. (2020), who warn that energy and feed costs (indexed to global inflation) compress margins during the grow-out phase.

The Larval Phase as a Financial Risk

Hypothesis H1 is confirmed: the larval phase represents the greatest financial risk. Reliance on live microalgae accounts for up to 40% of hatchery OPEX. Transitioning to formulated inert diets (microencapsulated) for post-settlement phases—as suggested by Lawrence et al. (2019) and Robinson et al. (2022)—could reduce hatchery OPEX by 30%, thereby favorably altering the sensitivity matrix.

Market Dynamics and Mitigation Strategies

High sensitivity to gonad price (H2) necessitates mitigation strategies. Red sea urchin aquaculture cannot compete on volume against low-cost wild fisheries or large-scale Asian aquaculture operations. Viability (H3) depends on **product differentiation**: sustainability certifications (e.g., ASC), traceability, and forward contracts with fine-dining restaurants (a premium market for "uni" free from microplastics and parasites—a competitive advantage of land-based aquaculture over wild-caught sources) (Rubilar & Cardozo, 2021; Zilia et al., 2021).

Limitations

The model assumes constant survival rates and excludes accelerated depreciation costs and tax benefits (e.g., incentives from CONAPESCA or FIRA in Mexico). Furthermore, larva prices in the Americas remain a "black box" due to the lack of an established secondary market for seed stock.

CONCLUSIONS

1. **Conditional Viability:** Red sea urchin (*M. franciscanus*) aquaculture presents attractive theoretical financial viability ($IRR > 20\%$); however, **it is financially unviable under a realistic stochastic model** that accounts for historical inflation and risk-free rates (CETES) in Mexico, due to the heavy initial CAPEX burden.
2. **Macroeconomic Risk:** Inflation erodes operating margins. For the project to be viable, investors must seek financing structures with subsidized rates ($TREMA < 3\%$) or reduce CAPEX by designing hybrid systems (RAS for the nursery phase; sea cages or low-cost ponds for grow-out).

3. **Technological Optimization:** Replacing microalgae with inert diets during the larval stage and utilizing fishing industry by-products (e.g., low-cost algae) during grow-out are imperative to reduce OPEX sensitivity to inflation.
4. **Market Approach:** Economic success depends on capturing *premium* markets (Japan, Korea, USA) through the sale of fresh processed gonads, while securing a minimum price of \$50 USD/kg via long-term contracts.

RECOMMENDATIONS

- For Investors: Avoid financing 100% of CAPEX with equity or commercial debt at market rates. Projects should be structured as technology-based enterprises to access venture capital or government subsidies (e.g., FIRA in Mexico) that lower the effective minimum acceptable rate of return (MARR).
- For Producers: Invest in R&D for the formulation of inert diets. Prioritize water quality and temperature control during the larval stage, as a 5% drop in larval survival wipes out the net profit margin.
- For Policymakers: There is an urgent need to develop interest-rate subsidy programs for high-value aquaculture in Mexico and to foster the creation of commercial hatcheries for red sea urchin seed, thereby reducing biological and financial risks for grow-out producers.
- Future Research: Risk assessment studies using Monte Carlo simulations are recommended; these should incorporate stochastic biological variables (e.g., mortality due to hypoxia events or algal blooms) coupled with economic variables.

REFERENCES

- Cabrera-Sánchez, C. T., Montaña-Moctezuma, G., Coronado, E., Delgado-Ramírez, C. E., & Garza-Lagler, M. C. (2025). Analysis of value chain of the artisanal sea urchin fishery of Baja California, México. *Marine Policy*, 172, 106509. <https://doi.org/10.1016/j.marpol.2024.106509>
- Lawrence, J. M., Zhao, C., & Chang, Y. Q. (2019). Large-scale production of sea urchin (*Strongylocentrotus intermedius*) seed in a hatchery in China. *Aquaculture International*, 27(1), 1-7. <https://doi.org/10.1007/s10499-018-0319-2>
- Pearce, C. M., Daggett, T. L., & Robinson, S. M. C. (2002). Optimizing prepared feed ration for gonad production of the green sea urchin *Strongylocentrotus droebachiensis*. *Journal of the World Aquaculture Society*, 33(3), 268-277.
- Robinson, S. M. C., Castell, J. D., & Kennedy, E. J. (2022). Advances in formulated diets for sea urchin aquaculture: Nutritional requirements and gonad quality. *Reviews in Aquaculture*, 14(1), 112-128.
- Rubilar, T., & Cardozo, D. (2021). Blue Growth: Sea urchin sustainable aquaculture, innovative approaches. *Revista de Biología Tropical*, 69(Suppl. 1), 474-485.
- Siikavuopio, S. I., Dale, T., & Mortensen, A. (2020). Effects of diet and temperature on somatic growth and gonad yield in the green sea urchin (*Strongylocentrotus droebachiensis*). *Aquaculture*, 520, 734956.

Stefánsson, G., Kristinsson, H., Ziemer, N., Hannon, C., & James, P. (2017). Markets for sea urchins: A review of global supply and markets. Matís Report.

Unuma, T., Sakai, Y., Agatsuma, Y., & Kayaba, H. (2015). Hatchery and seed production of sea urchins in Japan. En S. D. Eddy & N. P. Brown (Eds.), *Echinoderm Aquaculture* (pp. 98-126). Wiley Blackwell.

Zilia, F., Bacenetti, J., Sugni, M., Matarazzo, A., & Orsi, L. (2021). From waste to product: Circular economy applications from sea urchin. *Sustainability*, 13(10), 5427.

TABLES

Table 1: Projected Cash Flow (10 years, in USD)

Year	Estimated revenue*	Operating costs	Annual net flow	Cumulative flow	Remarks
0	0	-450,000	-450,000	-450,000	Initial investment (infrastructure and fattening systems).
1	0	-140,000	-140,000	-590,000	Operating costs without revenue (establishment period).
2	100,000	-140,000	-40,000	-630,000	First partial harvest of gonads.
3	220,000	-140,000	+80,000	-550,000	Start of commercial-scale production.
4	220,000	-140,000	+80,000	-470,000	Stable production.
5	220,000	-140,000	+80,000	-390,000	Recurring positive cash flow.
6	220,000	-140,000	+80,000	-310,000	Sustained profitability.
7	220,000	-140,000	+80,000	-230,000	Increasing investment recovery cash flow.
8	220,000	-140,000	+80,000	-150,000	Average consolidation period.
9	220,000	-140,000	+80,000	-70,000	Close to the recovery point.
10	220,000	-140,000	+80,000	+10,000	Break-even point and first accumulated net profit.

Table 2: Sensitivity Analysis (±20%)

Modified variable	Scenery	NPV (USD)	Variation relative to the baseline	Impact on viability
Larva price	-20%	349,000	+12%	Improves profitability and reduces initial nursery costs.
	+20%	275,000	-12%	Profitability holds steady, but recovery is delayed.
Gonad (roe) price	-20%	203,000	-35%	High risk: sharp drop in revenue affects sustainability.
	+20%	421,000	+35%	Significantly increases returns.
Cost of feed	-20%	345,000	+11%	Reduces operational pressure, improves margins.
	+20%	279,000	-11%	Moderate impact; affects liquidity but does not eliminate viability.

Table 3: Annual CETES rate and inflation in Mexico from 2006 to 2025.

Year	CETES	Inflation Rate
2006	7.19	4.05
2007	7.19	3.76
2008	7.68	6.53
2009	5.39	3.57

2010	4.4	4.4
2011	4.24	3.82
2012	4.24	3.57
2013	3.75	3.97
2014	3	4.08
2015	2.98	2.13
2016	4.17	3.36
2017	6.69	6.77
2018	7.62	4.83
2019	7.85	2.83
2020	5.32	3.15
2021	4.43	7.36
2022	7.66	7.82
2023	11.11	4.66
2024	10.7	4.21
2025-12	7.25	3.8
AVERAGE	6.14	4.43

Table 4: Inflation rate calculated randomly based on historical data.

Año	Inflación aleatoria
1	5.11
2	6.17
3	2.34
4	2.95
5	6.83
6	5.94
7	7.90
8	6.42
9	2.92
10	6.52
	5.31

Table 5: 10-year projected cash flow accounting for inflation in estimated revenues and costs, based on random inflation rates.

Year	Estimated earnings*	Operating costs	Annual net flow	Accumulated Flow
0	0	-450 000	-450 000	-450 000
1	0	-147 154	-147 154	-597 154
2	106 170	-148 638	-42 468	-639 622
3	227 480	-143 276	84 204	-555 418
4	226 490	-144 130	82 360	-473 058
5	235 026	-149 562	85 464	-387 594
6	233 068	-149 562	83 506	-304 088
7	237 380	-151 060	86 320	-217 768
8	234 124	-148 988	85 136	-132 632
9	226 424	-144 088	82 336	-50 296
10	234 344	-149 128	85 216	34 920

Table 6: Financial viability calculations (NPV, IRR, Cost-Benefit, and Payback Period) based on data from the previous table and assuming a discount rate of 6.14% (average CETES rate over the last 20 years).

Service life	10	
TREMA	6.14 %	0.06

	A	B	C		A-B-C	
Year	Income	Expenditures	Credit	Investment	Cash Flow	Accumulated Flow
0				\$ 450 000	-\$450 000	
1	0	147 154	\$ 0.00		-\$147 154.00	-\$147 154.00
2	106 170	148 638	\$ 0.00		-\$42 468.00	-\$189 622.00
3	227 480	143 276	\$ 0.00		\$84 204.00	-\$105 418.00
4	226 490	144 130	\$ 0.00		\$82 360.00	-\$23 058.00
5	235 026	149 562	\$ 0.00		\$85 464.00	\$62 416.00
6	233 068	149 562			\$83 506.00	\$145 912.00
7	237 380	151 060			\$86 320.00	\$232 232.00
8	234 124	148 988			\$85 136.00	\$317 368.00
9	226 424	144 088			\$82 336.00	\$399 704.00
10	234 344	149 128			\$85 216.00	\$484 920.00

NPV	-\$164.324
IRR	0.87%
Cost-Benefit	0.89
Payback Period	9.59

Table 7: Sensitivity analysis modifying the minimum acceptable rate of return (TREMA) and the investment.

SENSITIVITY TABLE		DISCOUNT RATE				
		2.14%	4.14%	6.14%	8.14%	10.14%
INITIAL INVESTMENT	-\$ 164 324.00					
	-\$ 350 000.00	\$ 53 639	-\$ 10 168	-\$ 10 168	-\$ 110 470	-\$ 149 938
	-\$ 400 000.00	\$ 3 639	-\$ 60 168	-\$ 60 168	-\$ 160 470	-\$ 199 938
	-\$ 450 000.00	-\$ 46 361	-\$ 110 168	-\$ 110 168	-\$ 210 470	-\$ 249 938
	-\$ 500 000.00	-\$ 96 361	-\$ 160 168	-\$ 160 168	-\$ 260 470	-\$ 299 938
	-\$ 550 000.00	-\$ 146 361	-\$ 210 168	-\$ 210 168	-\$ 310 470	-\$ 349 938