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Removal-Based Valorization of the Invasive Pearl Oyster *Pinctada radiata* (Leach, 1814): Economic Feasibility of Value-Added Seafood Processing in Greece

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Abstract

Invasive non-indigenous species (NIS) are impacting Mediterranean coastal ecosystems, presenting ecological and economic management challenges. This study evaluates the economic viability of processing biomass from wild removals of the NIS pearl oyster, *Pinctada radiata* (Leach, 1814), into value-added seafood products in Greece. The study explored four product formats under two funding scenarios (Scenario A, full private financing; and Scenario B, 60% public co-financing): frozen, vacuum-packed raw oyster meat; frozen, vacuum-packed, breaded raw oyster meat; steamed, brine-smoked, vacuum-packed oyster meat; and steamed oyster meat preserved in olive oil and Mediterranean herbs. In Scenario A, with full private financing, the cumulative net cash flow (NCF) over five years was €165,402.78, with a profitability index (PI) of 2.93 and a payback period (PP) of 1.71 years. In Scenario B, with 60% public co-financing, the owner's contribution reduced to €34,320.00. At the same time, the annual after-tax cash flow reached €50,240.56, resulting in a five-year cumulative NCF of €216,882.78, a PI of 7.32, and a PP of 0.68 years. These findings indicate that utilizing biomass from wild removals can be a financially viable strategy for managing NIS. This approach focuses on removal rather than aquaculture or translocation of *P. radiata* and emphasizes the need for adaptive governance and biodiversity protection to ensure effective population control. The study proposes a replicable bioeconomic model for integrating invasive biomass removal with value-added seafood processing in Mediterranean coastal regions.

Keywords: *Pinctada radiata*; invasive species; value-added seafood; seafood sector diversification; monitored wild removals; economic feasibility; invasive species management; removal-based valorisations

Key Contribution: This study provides the first economic feasibility assessment of the removal-based valorisation of the invasive pearl oyster, *Pinctada radiata*, in Greece. By demonstrating that biomass obtained exclusively through monitored wild removals can be processed into economically viable value-added seafood products, the study proposes a bioeconomic framework that links invasive species management with cost recovery while explicitly excluding aquaculture, cultivation, stock enhancement, and translocation of the species.

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1. Introduction

Global demand for seafood is projected to increase by at least 50% by 2050, placing additional pressure on marine ecosystems and underscoring the need for sustainable, innovative resource management strategies [1,2]. At the same time, biological invasions generate substantial and increasing economic costs globally, including in aquatic systems, reinforcing the need for management approaches that can reduce or partially offset control costs without incentivising further spread. [3–5]. Alongside efforts to improve the sustainability of conventional fisheries and aquaculture, growing attention has been directed to the responsible utilization of underutilized marine resources, including biomass derived from non-indigenous species (NIS). When implemented within appropriate ecological and regulatory safeguards, the removal-based utilization of invasive marine biomass has been proposed as a complementary approach that may simultaneously contribute to ecosystem management, food production, and coastal economic resilience [6–9]. Similar bioeconomic approaches have recently been proposed for invasive marine species in the Mediterranean, emphasizing that commercial utilization should complement, rather than replace, ecological management objectives [10].

Although the present study focuses on the economic feasibility of removal-based valorization of *Pinctada radiata* (Leach, 1814), its findings must be interpreted within the ecological context of biological invasions. Recent invasion risk assessment for the Eastern Adriatic Sea classified *P. radiata* as a high-risk NIS under both current and projected future climate conditions, owing to its broad environmental tolerance, prolonged reproductive period, and climate-enhanced dispersal potential [11]. These findings indicate that any utilization strategy should operate exclusively within a precautionary management framework designed to reduce invasive biomass through controlled wild removals, rather than promote population persistence or expansion. Accordingly, the present study evaluates the economic feasibility of processing oysters obtained exclusively from monitored wild-removal fisheries and does not propose aquaculture, cultivation, stock enhancement, or translocation of *P. radiata*.

The use of invasive marine biomass has increasingly been explored as a complementary management strategy that can generate economic returns while supporting ecological objectives. Rather than creating incentives for the propagation of NIS, carefully regulated removal-based utilization seeks to recover part of the costs associated with NIS management by converting harvested biomass into marketable products [10,12,13]. Such approaches have recently been discussed for several marine invasive species, where commercial utilization has been proposed as a means of supporting long-term control programmes without replacing conventional management measures [4,10,13–19]. Within this context, robust economic feasibility assessments are essential to determine whether removal-based valorisation can meaningfully contribute to management efforts while remaining economically viable, environmentally responsible, and compatible with existing regulatory frameworks.

One such species is *P. radiata*, commonly known as the rayed pearl oyster, a bivalve of Indo-Pacific origin that has established widespread populations throughout the Eastern Mediterranean via Suezian (sensu [20]) migration [20,21]. Recent studies have documented dense, persistent populations characterized by prolonged reproductive periods, asynchronous gametogenesis, and continuous recruitment [22–25]. These biological characteristics, together with the species' documented invasive potential [7], support the evaluation of controlled wild-removal strategies to reduce invasive biomass while generating value from material that would otherwise remain unutilized. Although *P. radiata* remains largely unexploited commercially in Greece due to regulatory constraints and the absence of an organized removal fishery [26], its abundance and favourable biological characteristics provide an opportunity to evaluate whether removal-based utilization can contribute to NIS management without encouraging cultivation or population enhancement [22,26].

A key component of removal-based valorization is the development of value-added seafood products from biomass already harvested through NIS management. Value-added processing encompasses techniques such as freezing, breading, smoking, marination, and innovative packaging that improve shelf life, convenience, product stability, and consumer appeal [16,18]. Recent optimization of brining and thermal processing parameters for *P. radiata* has further demonstrated the technical feasibility of producing safe, stable, value-added oyster products suitable for commercial evaluation [27]. Beyond increasing product value, these processing approaches facilitate more efficient use of harvested biomass, reduce waste, and enhance the economic viability of removal programmes. Consequently, value-added processing represents an important mechanism for linking ecological management objectives to the economically sustainable utilization of invasive marine biomass.

In the present study, four value-added product formats were selected to represent realistic processing options for biomass obtained through monitored wild removals of *P. radiata*: (a) frozen, vacuum-packed raw oyster meat (FVB); (b) frozen, vacuum-packed, breaded raw oyster meat (FBVB); (c) steamed, brine-smoked, vacuum-packed oyster meat (SVB); and (d) steamed oyster meat preserved in olive oil and Mediterranean herbs (OHGC). These products were selected because they can be produced using existing seafood processing infrastructure and address different market segments without requiring the establishment of new production systems. Accordingly, the study evaluates whether existing processing capacity could support removal-based utilization as a complementary invasive species management strategy, rather than promoting expansion of seafood production.

Nutritional and microbiological studies further support the suitability of *P. radiata* for human consumption when appropriately handled and processed post-harvest. Recent investigations have demonstrated favourable biochemical composition, meat yield, and nutritional quality [28–31], while microbiological surveys have confirmed that *P. radiata* meets food safety requirements when harvested from approved production areas and processed under established hygienic conditions [32]. In addition, consumer studies conducted in Greece indicate encouraging acceptance of processed *P. radiata* products, suggesting that value-added formats derived from monitored wild removals may be commercially acceptable while supporting NIS management objectives [33]. Recent studies have also optimized processing methods for *P. radiata*, demonstrating the technical feasibility of producing safe, stable, and high-quality processed seafood products suitable for commercial evaluation [10,27].

Nonetheless, the use of biomass from wild removals of *P. radiata* must be approached with caution due to its ecological implications. As an invasive species, its uncontrolled harvesting or widespread cultivation could pose risks to native biodiversity, especially to vulnerable native bivalves such as *Ostrea edulis*. Potential impacts include habitat alteration, competition for space and resources, and shifts in benthic community structure. Such concerns are consistent with pan-European evidence showing that invasive alien marine species can affect both biodiversity and ecosystem services through multiple ecological pathways [34]. While a full environmental risk assessment lies beyond the scope of this study, we recognize the importance of incorporating ecological safeguards into any commercialisation strategy and advocate for future research to comprehensively address these considerations [4].

Within this context, the present study aims to: (1) evaluate the economic feasibility of processing biomass obtained through monitored wild removals of *P. radiata* into value-added seafood products under realistic commercial conditions; (2) assess whether removal-based valorisation can provide a financially viable mechanism for partially offsetting NIS management costs without promoting cultivation, stock enhancement, or translocation; and (3) identify practical recommendations for implementing economically viable utilization strategies within an ecologically precautionary management framework. Despite increasing biological and ecological knowledge of *P. radiata* in the Mediterranean, no previous study has comprehensively evaluated the financial feasibility of removal-based valorisation using empirical cost data from commercial harvesters and seafood processors in Greece.

2. Materials and Methods

2.1. Sampling and Biosecurity

All *P. radiata* used in this analysis were obtained via wild-removal harvests from established Zone A production areas, approved for the harvesting of live bivalve molluscs for direct consumption without depuration, in accordance with EU food safety legislation [35]. The harvesting sites were located in the inner part of the Saronikos Bay, between Megalo Pefko and Salamis Island (Western Attica), where stable populations of *P. radiata* have been previously documented [22,32]. Harvested material was landed at a licenced shellfish dispatch centre on the same day of collection. Harvesting was carried out exclusively from naturally established wild populations during routine commercial removal activities. No cultured oysters were used, and no aquaculture production, reseeding, stock enhancement, or translocation formed part of the present study.

2.2. Study Design and Data Collection

This study employs a financial feasibility analysis to evaluate the processing of biomass derived from monitored wild removals of the invasive pearl oyster, *P. radiata*, into value-added seafood products under realistic commercial operating conditions in Greece. Four product formats were selected because they represent technically feasible processing options that can be implemented using existing licenced shellfish processing infrastructure in Greece while targeting different retail and food service market segments. Product selection was informed by pilot processing experience, consultations with commercial processors, and existing evidence of consumer acceptance for processed *P. radiata* products [27,36]. The proportional allocation of harvested biomass among the four product categories was 35% for FVB, 35% for FBVB, 15% for SVB, and 15% for OHGC, reflecting a modelling assumption developed in consultation with the collaborating processor and adopted to simulate a realistic production scenario (Table 1). Frozen products were assigned a greater proportion because they require simpler processing, have lower production costs, and are expected to constitute the primary commercial output during initial implementation. The remaining biomass was allocated to smoked and herb-preserved products to evaluate the contribution of higher value-added product categories to overall economic performance.

Economic and operational data were obtained through structured interviews and consultations conducted during 2024 with the manager of the largest licenced shellfish dispatch centre in W. Attica, which also performs depuration, processing, and packaging of bivalve molluscs, and with an experienced commercial scuba diver representing the local harvesting sector [22]. The processing facility is one of only two licenced installations operating in the region, each with an overall production capacity of approximately 5 t day^{-1} for all bivalve species. Additional quotations for processing equipment and machinery were obtained from a fisheries and aquaculture engineering consultancy specializing in the design of seafood processing plants and from equipment suppliers through direct communication. Cost components included raw material purchase price, processing consumables, packaging materials, labour, energy consumption, and equipment acquisition costs. The raw material purchase price was based on the actual payment offered by the collaborating processing facility to commercial harvesters during the 2024 harvesting season and therefore represents an observed operational value rather than a hypothetical market estimate.

Table 1. Baseline production assumptions and annual output for the four value-added products derived from *Pinctada radiata* biomass.

Product Form	Raw Input Allocation (%)	Annual Raw Input (kg)	Raw Oyster Required per kg Final Product (kg)	Annual Final Product (kg)
Frozen, vacuum-packed raw oyster meat	35%	15,750.00	6	2625.00
Frozen, vacuum-packed, breaded raw oyster meat	35%	15,750.00	4	3937.50
Steamed, brine-smoked, vacuum-packed oyster meat	15%	6750.00	6	1125.00
Steamed oyster meat preserved in olive oil and Mediterranean herbs	15%	6750.00	5	1350.00
Total	100%	45,000.00	-	9037.50

2.3. Processing Facility and Production Parameters

The feasibility analysis was based on integrating *P. radiata* processing into an existing, licenced bivalve shellfish processing facility operating in Greece. The facility's production capacity was estimated at 300 kg of raw *P. radiata* per operational day, with production planned for 150 operational days annually (5 days a week^{-1} for 30 weeks a year^{-1}), corresponding to an annual input of 45,000 kg of raw material (Table 1). This production volume reflects the observed harvesting capacity under current local wild-removal conditions and was adopted solely as the baseline scenario for the economic modelling; it should not be interpreted as an estimate of sustainable harvest or maximum removal potential. Processing yields and product preparation procedures followed the standardized brining–steaming protocol developed by Makri et al. for *P. radiata* [27]. For the smoked product, the liquid-smoke treatment was adapted from the salting-and-immersion protocol optimized for gilthead sea bream (*Sparus aurata*) fillets by Makri et al. [37]. Its application to *P. radiata* has been integrated into the current processing workflow.

In summary, oysters were manually shucked and processed in accordance with the protocol of [27]. Depending on the desired final product, the workflow incorporated cleaning, brining, steaming, smoking, breading, freezing, vacuum packaging, or preservation in olive oil infused with Mediterranean herbs. The brining concentration, steaming conditions, smoking parameters, and product handling adhered to the optimized protocol outlined by [27], thereby ensuring standardized product preparation throughout the feasibility study. The general production workflow for the four value-added products is shown in Figure 1.

The production process for FVB begins with manual shucking of the oysters, followed by meat acquisition, during which the soft tissues are separated and cleaned. The acquired oyster meat is then frozen to ensure preservation and microbial safety. Once frozen, the product is transferred to the vacuum-sealing station, where individual portions are vacuum-packed to minimize oxygen exposure and prolong shelf life. The vacuum-sealed packages proceed to a labelling unit where product information, traceability codes, and regulatory labels are applied. Finally, the labelled packages are moved to freezer storage until distribution (Figure 2a).

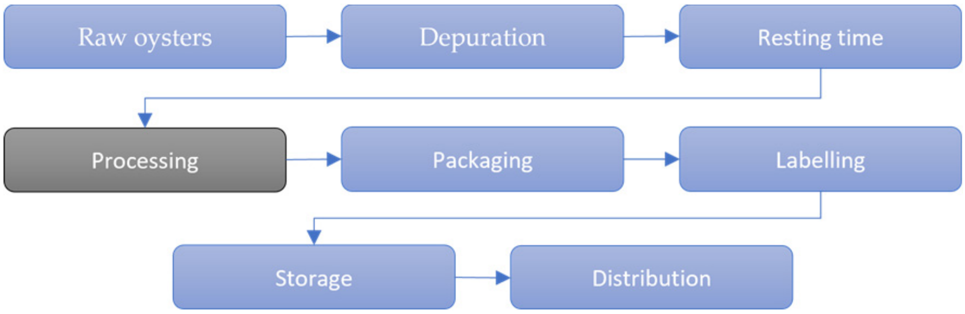

Figure 1. General production workflow for the value-added pearl oyster products.

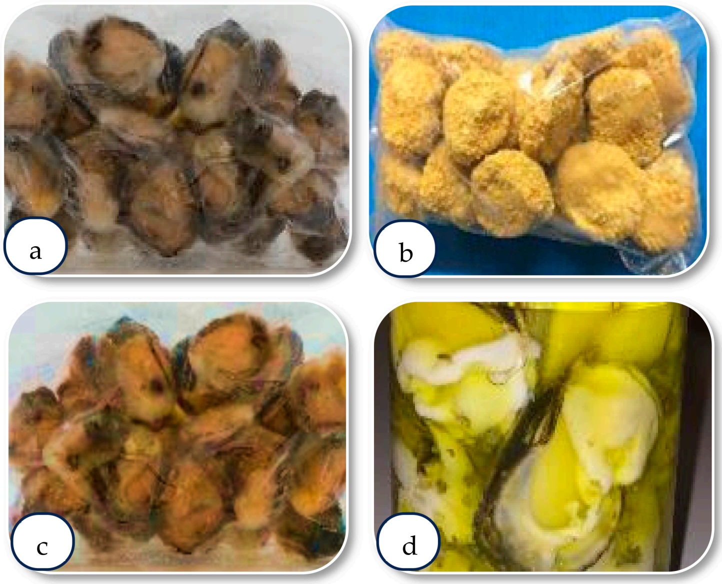

Figure 2. Final product forms developed from *P. radiata* through value-added processing workflows. (**a**) Frozen, vacuum-packed raw oyster meat: Shucked, cleaned meat immediately vacuum-sealed and stored frozen to preserve freshness and minimize oxidation. (**b**) Frozen, vacuum-packed, breaded raw oyster meat: oyster meat washed, tenderized, breaded with seasoned crumbs, then frozen and vacuum-packed for consumer-ready seafood portions. (**c**) Steamed, brine-smoked, vacuum-packed oyster meat: cleaned meat soaked in brine, lightly smoked, vacuum-packed, and frozen to combine flavour with shelf stability. (**d**) Steamed oyster meat preserved in olive oil and Mediterranean herbs: whole oysters steamed, purged, deshelled, rinsed, dried, and packed in glass jars with olive oil and Mediterranean herbs for specialty processed, refrigerated preservation.

The preparation of FBVB begins with shucking the oysters and removing the oyster meat, followed by a washing and tenderizing step to improve texture and remove surface impurities. The cleaned meat then enters the breading process, where it is uniformly coated with seasoned breadcrumbs to enhance flavour and visual appeal. After breading, the product is frozen to ensure microbiological safety and extend shelf life. The frozen, breaded pieces are then placed in vacuum-sealed packaging, minimizing oxidation and preserving quality. Packaged products are directed to the labelling station, where all regulatory and traceability information is applied, and subsequently transferred to freezer storage for preservation before distribution (Figure 2b).

The processing of SVB begins with shucking the oysters and removing the meat, followed by a washing and tenderizing stage to prepare the tissue for further processing. The cleaned meat is then immersed in a brining solution to enhance flavour, preserve texture, and improve microbial safety. After brining, the product undergoes a liquid-smoking process, during which it is exposed to controlled thermal and aromatic treatment to achieve a distinct smoked profile. The smoked meat is then portioned and placed in vacuum-sealed packaging to maintain product freshness and shelf life. Packages are subsequently routed through a labelling station, and the final product is transferred to freezer storage until shipment or retail distribution (Figure 2c).

The preparation of OHGC commences with steam-cooking entire (shelled) *P. radiata* oysters. Subsequently, a purging process is conducted to eliminate any oysters with unopened shells, thereby ensuring food safety and quality. The subsequent phase involves manually detaching the shells from the steamed oyster meat, followed by a rinse to eliminate debris and residual shell fragments. The rinsed oysters are then dried to eradicate surface moisture, preparing the meat for preservation. Once dried, the oysters are packed into glass containers and infused with high-quality olive oil and a blend of Mediterranean herbs, a step that enhances both preservative and culinary attributes. The jars are then sealed, labelled for product identification and regulatory compliance, and ultimately stored in refrigerated conditions to preserve freshness and extend shelf life prior to market distribution (Figure 2d).

2.4. Financial Feasibility Analysis

The economic viability was evaluated using a deterministic cash flow (CF) analysis over a five-year planning horizon, in accordance with established investment appraisal methodologies routinely used in seafood processing and aquaculture economics. The analysis examined the financial performance of processing *P. radiata* biomass obtained through monitored wild removals under operational conditions representative of small- and medium-sized licenced seafood processing enterprises in Greece.

Capital requirements, operating expenses, revenues, and profitability measures were estimated using primary cost information obtained from commercial stakeholders, together with market quotations for equipment, packaging materials, labour, energy, and other processing inputs. Production volumes and operating assumptions were developed in collaboration with the participating processing facility, taking into consideration observed harvesting capacity, available infrastructure, labour requirements, and prevailing commercial practices. The resulting assessment, therefore, represents an operational feasibility scenario based on current conditions rather than a forecast of future production capacity or sustainable harvesting potential.

Project performance was evaluated using standard financial indicators, including gross revenue (GR), net revenue (NR), profit (P), net cash flow (NCF), profitability index (PI), payback period (PP), and benefit–cost ratio (BCR). Equity-based indicators were calculated with reference to owners' private capital, whereas the project-level BCR was calculated using the total initial investment. All calculations followed conventional CF and investment appraisal procedures used in seafood processing, fisheries economics, and agribusiness feasibility studies [38]. The equations applied for each indicator are provided in Appendix A.

Two alternative financing arrangements were considered. The first represented full financing through private capital, while the second assumed partial public co-financing covering sixty per cent of the initial investment. Under the co-financing arrangement, the public contribution reduced the owner's initial equity requirement. Still, it did not change the physical investment, the depreciable fixed-asset base, the production process, the annual depreciation expense, or the operating cash flow before tax. Depreciation commenced in the first operating year and was calculated only for capitalized fixed assets. Consumable materials, operating inputs, and items with a short, useful life were expensed directly and were not included in the depreciable asset base. No residual value or replacement investment was assumed during the five-year planning horizon.

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The subsidy was therefore treated as a financing contribution rather than a reduction in the project's underlying resource cost.

The financial assessment encompassed the initial investment period and the subsequent operational years. At the owner level, the initial cash outflow under the privately financed arrangement corresponded to the entire investment requirement. Under the public co-financing arrangement, the owner-level outflow was restricted to the remaining private contribution. At the project level, however, the full investment was retained in the BCR analysis for both financing arrangements, as public support was regarded as a transfer of funds rather than a reduction in the total resources required for project implementation.

As the feasibility assessment presupposed the utilization of an existing licenced seafood processing facility, no provisions were made for start-up delays or commissioning periods. Although the harvesting areas were approved for direct consumption without mandatory depuration, all oysters were nevertheless subjected to depuration at the dispatch centre as an additional quality-assurance measure. The associated cost was included in the financial model.

Annual depreciation represents the systematic, non-cash allocation of the depreciable cost of the project's fixed capital assets over their assumed useful lives. The depreciable asset base includes the refrigeration and freezing equipment, processing machinery, packaging and labelling equipment, and stainless-steel handling infrastructure listed in Table 2. Depreciation is included in the calculation of annual production costs (APC) and taxable operating P, but it does not constitute a cash outflow. Accordingly, depreciation is added back to the accounting operating result when calculating operating CF.

Table 2. Investment cost for the value-added processing facility and financing structure.

Facilities and Equipment	Quantity	Per-Unit Price (€)	Cost (€)
Refrigeration and freezing equipment			
Refrigerator for the preservation of raw pearl oysters	1	2000.00	2000.00
Refrigerator for storing the shucking by-products	1	1800.00	1800.00
Final product refrigerator	1	4000.00	4000.00
Shucked meat refrigerator	1	2000.00	2000.00
Freezer tunnel	1	5000.00	5000.00
Final product freezer	1	3600.00	3600.00
Subtotal			18,400.00
Processing equipment			
Heat-treatment stove	1	2000.00	2000.00
Kitchen hood	1	1000.00	1000.00
Single-waggon smoking chamber	1	37,500.00	37,500.00
Container sterilizer	1	420.00	420.00
Subtotal			40,920.00
Packaging and labelling equipment			
Single-cabin vacuum packaging machine	3	3050.00	9150.00
Bag heat-sealer	3	150.00	450.00
Label-printing machine	2	1000.00	2000.00
Subtotal			11,600.00

Table 2. *Cont.*

Facilities and Equipment	Quantity	Per-Unit Price (€)	Cost (€)
General-use equipment			
Scales	10	250.00	2500.00
Shucking knives	10	20.00	200.00
Stainless-steel mesh work gloves	10	60.00	600.00
Stainless-steel working bench	2	2340.00	4680.00
Stainless-steel strainer	8	350.00	2800.00
Stainless-steel washbasin	4	275.00	1100.00
Stainless-steel breading pans	6	500.00	3000.00
Subtotal			14,880.00
Total investment			85,800.00

3. Results

3.1. Investment Cost and Production Output

The estimated capital investment required to implement the value-added processing workflow for *P. radiata* was €85,800.00 (Table 2). This investment covered refrigeration and freezing capacity, processing equipment, vacuum packaging, labelling infrastructure, safety equipment, and stainless-steel handling facilities. Under the baseline production scenario, 45,000.00 kg of raw *P. radiata* biomass obtained through monitored wild removals was processed annually, yielding 9037.50 kg of final product across the four product formats (Table 1).

3.2. Operating Costs and Revenue Projections

Total APC, including depreciation, were estimated at €154,279.92 and were held constant across both scenarios. Although public co-financing in Scenario B reduced the owner's equity contribution, it did not alter the project's fixed assets or their depreciable cost basis. Therefore, the annual depreciation expense remained €8580.00 in both scenarios. Cash operating costs excluding depreciation were €145,699.92. Annual depreciation was €8580.00, resulting in total accounting production costs of €154,279.92. The acquisition of raw materials represented the largest expenditure (€67,500.00), followed by labour (€37,800.00) and depuration services (€18,000.00). Additional expenses included packaging, breading materials, olive oil and herbs, smoking consumables, energy, water, depreciation, and miscellaneous costs.

Annual depreciation was calculated using straight-line depreciation over a 10-year useful life for all equipment categories (Table 3). The total annual depreciation expense of €8580.00 corresponds to the depreciable fixed-asset base reported in Table 2 and was applied in the same way across Scenarios A and B, as the subsidy affected only the financing source, not the assets acquired.

The annual depreciation expense was €8580.00 in both scenarios, representing approximately 5.58% of total APC, including depreciation. This amount reflects the annual accounting allocation of the depreciable fixed-asset base and does not represent a corresponding annual cash payment. Miscellaneous and unforeseen expenses were estimated at €4230.00 per year, accounting for roughly 2.75% of total APC, including depreciation. All cost and revenue figures were assumed to remain constant throughout the five-year planning period. The analysis was performed using fixed prices and did not consider inflation.

The annual revenue generated from the four processed products was estimated at €213,795.00 based on the projected wholesale prices and quantities provided in Table 4. After deducting the total annual production costs, the estimated annual operating result before tax was €59,515.08 in both scenarios. Applying a simplified income tax rate of 30%

to the positive annual operating result before tax, the corresponding income tax obligation was €17,854.52 in both scenarios. Consequently, the annual after-tax CF was €50,240.56 in both scenarios. The detailed annual operating cost items for the baseline processing scenario are presented in Table 4.

Table 3. Annual depreciation costs.

Asset Category	Depreciable Cost (€)	Useful Life (Years)	Annual Depreciation (€)
Refrigeration and freezing equipment	18,400.00	10	1840.00
Processing equipment	40,920.00	10	4092.00
Packaging and labelling equipment	11,600.00	10	1160.00
General-use equipment	14,880.00	10	1488.00
Total	85,800.00		8580.00

Table 4. Annual operating costs for the baseline *P. radiata* processing scenario.

Cost Item	Unit Price	Annual Cost (€)
Raw pearl oysters	€1.50/Kg	67,500.00
Depuration procedure service	€0.40/Kg	18,000.00
Brining materials	€0.08/Kg	90.00
Smoking chamber consumables	€0.10/Kg	112.50
Vacuum packing consumables	€0.20/Kg	1537.50
Paper and craft packaging consumables	€0.02/Kg	451.88
Labelling consumables	€0.01/Kg	90.38
Product handling consumables	€0.02/Kg	180.75
Breading materials	€1.25/Kg	4921.88
Packaging consumables	€0.01/Kg	78.75
Glass containers (average of 3 sizes)	€1.25/Kg	672.00
Mediterranean herbs mix	€0.78/Kg	1053.00
Cleaning and sanitation materials	---	483.56
Materials and consumables Subtotal		95,172.20
Labour cost	---	37,800.00
Water	---	451.88
Electricity	---	8045.84
Miscellaneous	---	4230.00
Cash operating costs	Excluding depreciation	145,699.92
Depreciation	Table 3	8580.00
Total accounting production costs	Including depreciation	154,279.92

Revenue projections were derived directly from product-specific yields, unit weights, and wholesale prices, thereby reflecting the production allocation assumptions set out in the Section 2. The annual values reported in this section represent a single operating year. The investment indicators and cumulative cash flows reported below are based on five identical operating years following the initial investment at year 0.

The annual production yields, raw material requirements, and revenue contributions for each of the four value-added products are summarized in Table 5.

Table 5. Summary of production and revenue for value-added products derived from *P. radiata* biomass obtained through monitored wild removals.

Product Form	Annual Production Yield (Kg)	Raw Material (RM) Quantity (Kg)	RM Cost (€)	Package Weight (Kg)	Wholesale Price (€/Kg)	Sales Quantity (Kg)	Annual Revenue (€)
P. radiata meat; raw, frozen, and packaged in vacuum-sealed bags	2625.000	15,750.000	23,625.000	0.500	13.200	1312.500	17,325.000
				1.000	24.600	1312.500	32,287.500
P. radiata meat; raw, breaded, frozen and packaged in vacuum-sealed bags	3937.500	15,750.000	23,625.000	0.500	15.800	1968.750	31,106.250
				1.000	29.000	1968.750	57,093.750
P. radiata meat; brine-smoked, steamed, and packaged in vacuum-sealed bags	1125.000	6750.000	10,125.000	0.500	18.000	562.500	10,125.000
				1.000	35.000	562.500	19,687.500
P. radiata meat; steamed and packaged in glass containers with olive oil and Mediterranean herbs	1350.000	6750.000	10,125.000	0.315	18.000	540.000	9720.000
				0.500	35.000	540.000	18,900.000
				1.000	65.000	270.000	17,550.000
Total	9037.500	45,000.000	67,500.000			9037.500	213,795.000

3.3. Scenario Analysis: Financial Indicators

Under Scenario A, the entire initial investment of €85,800.00 was financed by the owner. The annual operating CF before tax amounted to €68,095.08, with annual income tax totalling €17,854.52, resulting in an annual after-tax CF of €50,240.56. Throughout the five-year projection period, the cumulative net CF to equity reached €165,402.78. The undiscounted equity PI was 2.93, the equity PP was 1.71 years, and the project-level operating BCR was 1.25.

Under Scenario B, public co-financing covered €51,480.00, equivalent to 60% of the total initial investment of €85,800.00, leaving an owner contribution of €34,320.00. Annual depreciation was €8580.00, identical to Scenario A, and total annual production costs were €154,279.92 in both scenarios. The annual operating result before tax was therefore €59,515.08 in both scenarios; income tax at 30% was €17,854.52, and annual after-tax CF was €50,240.56 in both scenarios. Over the five-year projection period, the cumulative net CF to equity was €216,882.78. The undiscounted equity PI was 7.32, the equity PP was 0.68 years, and the project-level operating BCR was 1.25. When the subsidy is included as a Year 0 project-level financing inflow, the project-level PI is 3.53, and the financing-inclusive BCR is 1.31.

Detailed annual CF projections and cumulative CF are presented in Table 6. Public co-financing improved owner-level viability exclusively by reducing the owner's initial capital contribution. It did not alter physical production, sales revenue, annual operating costs, depreciation, taxable operating P, or operating CF before tax. Accordingly, the improvement in Scenario B's equity-level indicators reflects changes in the financing structure rather than improved productive efficiency.

The main owner-level financial indicators for both financing scenarios over the five-year horizon are summarized in Table 7.

Table 6. Project-level and owner-level cash flow components for Year 0 and five operating years. The projection includes Year 0 and five operating years. In Scenario B, the initial owner-level cash outflow equals the owner contribution after public co-financing. Annual operating costs, depreciation, operating profit, and operating cash flow are identical across the two scenarios; only the financing structure differs.

Cash Flow Item	Year 0	1st Year	2nd Year	3rd Year	4th Year	5th Year
Scenario A: full private financing						
Operating cash flow before tax (€)	0.00	68,095.08	68,095.08	68,095.08	68,095.08	68,095.08
Investment cost (€)	−85,800.00	0.00	0.00	0.00	0.00	0.00
Public subsidy (€)	0.00	0.00	0.00	0.00	0.00	0.00
Income tax (€)	0.00	−17,854.52	−17,854.52	−17,854.52	−17,854.52	−17,854.52
Annual net cash flow to equity (€)	−85,800.00	50,240.56	50,240.56	50,240.56	50,240.56	50,240.56
Cumulative net cash flow to equity (€)	−85,800.00	−35,559.44	14,681.12	64,921.68	115,162.24	165,402.78
Scenario B: 60% public co-financing						
Operating cash flow before tax	0.00	68,095.08	68,095.08	68,095.08	68,095.08	68,095.08
Investment cost (€)	−85,800.00	0.00	0.00	0.00	0.00	0.00
Public subsidy (€)	51,480.00	0.00	0.00	0.00	0.00	0.00
Owner contribution (€)	−34,320.00	0.00	0.00	0.00	0.00	0.00
Income tax (€)	0.00	−17,854.52	−17,854.52	−17,854.52	−17,854.52	−17,854.52
Annual net cash flow to equity (€)	−34,320.00	50,240.56	50,240.56	50,240.56	50,240.56	50,240.56
Cumulative net cash flow to equity (€)	−34,320.00	15,920.56	66,161.12	116,401.68	166,642.24	216,882.78

Table 7. Five-year owner-level financial indicators under full private financing and 60% public co-financing. The analysis includes year 0 and five operating years.

Indicator	Scenario A: Full Private Financing	Scenario B: 60% Public Co-Financing
Total investment (€)	85,800.00	85,800.00
Public subsidy (€)	0.00	51,480.00
Owner contribution (€)	85,800.00	34,320.00
Annual revenue (€)	213,795.00	213,795.00
Cash operating costs (excl. depreciation)	145,699.92	145,699.92
Annual depreciation	8580.00	8580.00
Total annual production costs	154,279.92	154,279.92
Operating result before tax	59,515.08	59,515.08
Income tax at 30%	17,854.52	17,854.52
Annual operating cash flow (CF) before tax (€)	68,095.08	68,095.08

Table 7. *Cont.*

Indicator	Scenario A: Full Private Financing	Scenario B: 60% Public Co-Financing
Annual after-tax CF	50,240.56	50,240.56
Five-year cumulative net CF (€)	165,402.78	216,882.78
Equity profitability index (PI)	2.93	7.32
Equity payback period (years)	1.71	0.68
Operating result margin	27.84%	27.84%
After-tax CF margin	23.50%	23.50%
Project-level PI	2.93	3.53
Project operations benefit–cost ratio (BCR)	1.25	1.25
Financing-inclusive BCR	1.25	1.31

3.4. Sensitivity Considerations

Following the one-variable-at-a-time approach, sensitivity analysis was conducted to evaluate the effect of changes in production yield, wholesale prices, and cash operating costs on the financial performance of the removal-based processing model. The baseline values were varied by ±10%, while all other assumptions were held constant. Additionally, two combined adverse scenarios were examined: a simultaneous 10% reduction in yield and wholesale prices and a 10% reduction in yield combined with a 10% increase in cash operating costs.

The results are presented separately for scenarios involving full private financing and 60% public co-financing, as detailed in Tables 8 and 9. Under conditions of complete private financing, a 10% reduction in yield or wholesale prices resulted in a decrease in annual after-tax cash flow from €50,240.56 to €35,274.91, along with an extension of the payback period from 1.71 to 2.43 years. Conversely, with 60% public co-financing, the respective payback period increased from 0.68 to 0.97 years. An increase of 10% in cash operating costs led to a reduction in annual after-tax cash flow to €40,041.56, thereby resulting in payback periods of 2.14 and 0.86 years under Scenarios A and B, respectively.

Table 8. Sensitivity analysis under full private financing.

Scenario A	Revenue (€)	Accounting Costs (€)	Pretax Result (€)	After-Tax Cash Flow (CF) (€)	Five-Year Cumulative Equity CF (€)	Equity PI	Payback (Years)	Benefit–Cost Ratio
Baseline	213,795.00	154,279.92	59,515.08	50,240.56	165,402.78	2.93	1.71	1.25
Yield −10%	192,415.50	154,279.92	38,135.58	35,274.91	90,574.53	2.06	2.43	1.12
Yield +10%	235,174.50	154,279.92	80,894.58	65,206.21	240,231.03	3.80	1.32	1.37
Wholesale price −10%	192,415.50	154,279.92	38,135.58	35,274.91	90,574.53	2.06	2.43	1.12
Wholesale price +10%	235,174.50	154,279.92	80,894.58	65,206.21	240,231.03	3.80	1.32	1.37
Cash operating costs −10%	213,795.00	139,709.93	74,085.07	60,439.55	216,397.75	3.52	1.42	1.36
Cash operating costs +10%	213,795.00	168,849.91	44,945.09	40,041.56	114,407.81	2.33	2.14	1.15
Yield −10% and price −10%	173,173.95	154,279.92	18,894.03	21,805.82	23,229.10	1.27	3.93	1.01
Yield −10% and costs +10%	192,415.50	168,849.91	23,565.59	25,075.91	39,579.56	1.46	3.42	1.03

Table 9. Sensitivity analysis with 60% public co-financing.

Scenario B	Revenue (€)	Accounting Costs (€)	Pretax Result (€)	After-Tax Cash Flow (CF) (€)	Five-Year Cumulative Equity CF (€)	Equity PI	Payback (Years)	Benefit–Cost Ratio
Baseline	213,795.00	154,279.92	59,515.08	50,240.56	216,882.78	7.32	0.68	1.25
Yield −10%	192,415.50	154,279.92	38,135.58	35,274.91	142,054.53	5.14	0.97	1.12
Yield +10%	235,174.50	154,279.92	80,894.58	65,206.21	291,711.03	9.50	0.53	1.37
Wholesale price −10%	192,415.50	154,279.92	38,135.58	35,274.91	142,054.53	5.14	0.97	1.12
Wholesale price +10%	235,174.50	154,279.92	80,894.58	65,206.21	291,711.03	9.50	0.53	1.37
Cash operating costs −10%	213,795.00	139,709.93	74,085.07	60,439.55	267,877.75	8.81	0.57	1.36
Cash operating costs +10%	213,795.00	168,849.91	44,945.09	40,041.56	165,887.81	5.83	0.86	1.15
Yield −10% and price −10%	173,173.95	154,279.92	18,894.03	21,805.82	74,709.10	3.18	1.57	1.01
Yield −10% and costs +10%	192,415.50	168,849.91	23,565.59	25,075.91	91,059.56	3.65	1.37	1.03

The combined adverse scenarios resulted in the weakest outcomes. Under conditions of full private financing, simultaneous reductions of 10% in yield and wholesale prices yielded a benefit–cost ratio (BCR) of 1.01, whereas a 10% decrease in yield coupled with a 10% increase in cash operating costs produced a BCR of 1.03. The corresponding BCR values under public co-financing remained at 1.01 and 1.03, respectively, because the operating BCR is calculated at the project level and is unaffected by the financing structure. These findings suggest that the model remains technically feasible under moderate isolated shocks but exhibits limited financial resilience when adverse production and market conditions occur simultaneously.

4. Discussion

The present study demonstrates that value-added processing of *P. radiata* biomass obtained through monitored wild removals can generate favourable economic indicators under the assumptions evaluated. Across both financing scenarios, the model produced a positive five-year cumulative Net CF, a short PP, and a BCR exceeding 1.0, indicating that removal-based processing could partially offset the costs associated with NIS management. Importantly, these findings should not be interpreted as support for cultivation, stock enhancement, translocation, or deliberate maintenance of *P. radiata* populations. Rather, the economic results are relevant only within a precautionary framework in which biomass is obtained exclusively from controlled removals of naturally established invasive populations. This distinction is essential because market development for NIS can create perverse incentives if not embedded within clear ecological safeguards and containment objectives [10,12,13].

The comparison between the two financing scenarios indicates that public co-financing can improve the financial performance of removal-based processing, primarily by reducing the private capital burden during the initial investment phase. Under the subsidized scenario, the model showed a shorter PP and a higher PI than under full private financing. This does not imply that public support should be used to expand NIS production. Instead, any subsidy or public funding mechanism should be conditional upon measurable management outcomes, such as documented biomass removal, traceability of harvested material, prohibition of reseeding or translocation, and integration with ecological monitoring. Under such conditions, public support could serve as a management instrument to align private processing incentives with invasive species control objectives [11–13].

From the investor's equity perspective, utilizing the €34,320.00 private contribution as the denominator, the undiscounted equity PI for Scenario B was 7.32. From a project-level perspective, using the total investment of €85,800.00 as the denominator and treating the subsidy as a Year 0 project-level financing inflow, the project-level PI was 3.53. The improved Scenario B equity indicators should not be interpreted as evidence of improved operating efficiency; they result from the lower private capital denominator created by the subsidy. Furthermore, although the primary project BCR remains at 1.25 in both scenarios because the subsidy is excluded as a financing transfer, the computed supplementary financing-inclusive BCR for Scenario B is 1.31.

A key strength of the present feasibility assessment is its use of primary cost data from actors directly involved in harvesting, processing, and equipment supply. This improves the model's practical relevance compared with purely theoretical feasibility assessments. Using an existing, licenced seafood processing facility also reduces capital requirements and avoids the need for new production infrastructure. These features make the proposed framework potentially transferable to other localized cases in which invasive or under-utilized marine biomass is already being removed, provided that ecological safeguards, traceability systems, and regulatory controls are in place. Nevertheless, transferability should not be assumed automatically because profitability will depend on local harvesting costs, processing capacity, market prices, labour costs, regulatory requirements, and the ecological status of the target species [13,39,40].

Although the financial indicators are favourable, economic feasibility alone is insufficient to justify implementation. Any removal-based utilization strategy for *P. radiata* must be embedded within an ecosystem-based management framework that prioritizes containment, biodiversity protection, and the prevention of further spread. This requires traceability of harvested biomass, spatially explicit harvest records, monitoring of benthic habitats, and clear prohibition of practices that could enhance population persistence, including reseeding, translocation, or cultivation. In this context, value-added processing should be viewed as a cost recovery mechanism supporting invasive species management, not as a stand-alone seafood development strategy [11,12,20,21].

The results also contribute to the broader discussion on whether market-based approaches can support the management of marine biological invasions. Previous studies have cautioned that commercial use of invasive species should be implemented only when it supports, rather than undermines, control objectives [12,13]. In the case of *P. radiata*, recent Mediterranean evidence indicates both biological potential for spread and possible suitability for value-added processing, creating a situation in which economic opportunity and ecological risk must be evaluated together [10,11,27]. The present findings therefore support a conditional bioeconomic model: processing can be economically feasible, but only if it remains linked to monitored removals, adaptive governance, and explicit prevention of cultivation or redistribution.

4.1. Limitations and Future Research

Despite the favourable financial indicators reported here, the results should be interpreted within the assumptions and boundaries of the feasibility model. The analysis was conducted over a five-year planning horizon. It therefore may not fully capture longer-term variation in market prices, labour costs, energy costs, consumer demand, or ecological conditions affecting *P. radiata* availability. Although the scenario was based on observed harvesting capacity and stakeholder-derived cost data, it assumes relatively stable biomass availability and processing output over time. In practice, local abundance, reproductive dynamics, recruitment, and harvest efficiency may vary spatially and temporally, particularly under changing environmental conditions and climate-driven shifts in invasion risk [11,23,24].

The exclusion of transportation costs also reflects the specific geographic configuration of the present case study. Harvesting sites and the processing facility are located within the same coastal region and are connected through existing local supply chains. This assumption is therefore appropriate for the present feasibility scenario, but it may not apply to more geographically dispersed removal schemes. In other regions, transport distance, cold-chain logistics, landing-site infrastructure, and fuel costs could substantially affect profitability. Future applications of this model should therefore incorporate site-specific transport and logistics costs before extrapolating the economic results beyond the local context examined here.

Food safety and product stability represent another important area for further work. Available evidence indicates that *P. radiata* can meet food safety requirements when harvested from approved production areas and handled under appropriate hygienic conditions. At the same time, recent processing studies support the technical feasibility of producing stable value-added products from this species [27,29,32]. However, the present study did not include independent post-processing microbiological testing, shelf life assessment, or allergenicity evaluation for the specific products modelled here. Such analyses would be required before broader implementation of removal-based processing, particularly for ready-to-eat, smoked, refrigerated, or oil-preserved products.

The financial analysis also does not include a life-cycle assessment or a comprehensive environmental impact evaluation. While using existing processing infrastructure reduces capital requirements and may limit additional environmental burdens, economic feasibility alone cannot justify the use of an invasive species. A complete sustainability appraisal would need to quantify energy use, water consumption, packaging impacts, cold-chain requirements, waste generation, and shell by-product management. These assessments are especially important because removal-based utilization should demonstrably support containment, biomass reduction, and biodiversity protection rather than create a new commercial incentive around the species [12,21,41].

The model excludes a terminal value, residual asset value, working capital recovery, replacement investments, financing costs, and discounting. The reported annual depreciation should be treated as a model assumption and verified against an asset-level depreciation schedule.

Consumer acceptance was not directly assessed in the present feasibility study. Research on consumer attitudes towards wild and farmed seafood demonstrates that purchasing decisions are influenced by multiple attributes, including taste, freshness, safety, origin, sustainability, price, and knowledge. Market value is determined by both biological availability and social acceptability, with low familiarity or negative associations often leading to lower prices, even for abundant species. These findings suggest that the profitability of processed *P. radiata* will depend not only on production costs and wholesale prices but also on consumer perceptions, product format, and the effectiveness of communication and traceability systems [42,43]. Existing evidence from Greece indicates favourable responses to processed *P. radiata* products, including high acceptance of breaded, oil-preserved, and ready-to-eat formats among consumers previously unfamiliar with the species [32,33]. These findings support the plausibility of the product formats and wholesale price assumptions used in the model; however, they do not negate the necessity for broader market testing. Future research should explore regional consumer segmentation, willingness to pay, sensory preferences, perceptions of food safety, and the influence of sustainability-oriented labelling on purchase intent. It is imperative that consumer-facing communication emphasizes invasive species management and traceable removal, rather than promoting *P. radiata* as a species to be maintained or expanded.

4.2. Recommendations for Future Work and Policy

The implementation of removal-based valorisation for *P. radiata* should be considered only within a precautionary management framework that prioritizes containment, ecological monitoring, and the prevention of further spread. Future management efforts should establish species-specific harvesting guidelines calibrated to local ecological conditions, including population density, reproductive seasonality, recruitment dynamics, habitat sensitivity, and the presence of native or vulnerable bivalves. Spatial mapping of benthic habitats will be particularly important for identifying areas where removal may be appropriate, as well as zones where harvesting should be restricted to avoid disturbance of sensitive assemblages or native biodiversity. This is especially relevant given evidence that *P. radiata* shells can host diverse fouling assemblages in Mediterranean habitats, suggesting that indiscriminate removal could generate unintended ecological effects even when targeting an invasive species [11,21,23–25,44].

From a cost–benefit perspective, the favourable economic indicators reported here must be weighed against the ecological risks associated with *P. radiata* persistence, spread, and habitat alteration. *P. radiata* is classified as a high-risk non-indigenous species under current and future climate scenarios, highlighting the need for management approaches that reduce, rather than maintain, invasive biomass [11]. Under this framing, the economic benefit of value-added processing lies not in creating a new production sector, but in partially offsetting the costs of monitored removals, traceability, ecological surveillance, and post-removal impact assessment. The financial feasibility demonstrated in this study should therefore be interpreted as conditional: processing can support invasive species management only when revenues are linked to documented biomass removal and when practices such as reseeding, translocation, stock enhancement, or cultivation are explicitly prohibited [11–13].

A practical policy framework would need to connect harvesting permissions, product traceability, and ecological monitoring within a single management system. At the European policy level, this approach is consistent with Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species and with the Marine Strategy Framework Directive, which promotes an ecosystem-based approach to marine environmental management [45,46]. Harvested biomass should be traceable from the removal area to the final product, with records of harvest date, location, quantity, processing pathway, and destination. Such traceability would help ensure that market demand is met only through approved wild removals, not through activities that could increase propagule pressure or incentivise population maintenance. In parallel, monitoring programmes should evaluate whether removal activities reduce local biomass, whether benthic habitats recover after harvesting, and whether any unintended ecological effects emerge. These safeguards are essential because market-based approaches to invasive species can fail when commercial demand becomes decoupled from control objectives. [12,20,21].

Stakeholder participation should also form part of any future implementation framework. Harvesters, processors, local authorities, scientists, and coastal communities should be involved in defining acceptable harvesting areas, removal intensity, reporting obligations, and product traceability requirements. Participatory governance can improve compliance and make management more adaptive, particularly in coastal systems where ecological conditions, market demand, and harvesting capacity may change rapidly. For *P. radiata*, this is especially relevant because management decisions must balance biomass reduction, economic cost recovery, food safety requirements, and protection of native benthic communities [20,21,23–25].

Future research should transcend solely assessing financial feasibility and instead evaluate the combined ecological and economic performance of removal-based processing. Key areas of focus include spatially explicit stock assessment, reproductive monitoring, quantification of removal efficiency, validation of post-harvest food safety, life-cycle assessment, valorisation of shell waste, sensory evaluations, willingness-to-pay studies, and market research prior to broader commercialisation. Additionally, consumer research should concentrate on management-oriented communication. These analyses aim to determine whether the economic advantages of value-added processing sufficiently outweigh the direct and indirect costs associated with ecological monitoring, traceability, habitat assessment, and regulatory oversight. Consequently, the model proposed herein should be regarded as a bioeconomic mitigation instrument rather than a traditional seafood development pathway.

Overall, the economic feasibility demonstrated in this study supports the further evaluation of *P. radiata* processing only under strict removal-based conditions. The proposed framework should not be used to justify aquaculture, stock enhancement, translocation, or deliberate maintenance of invasive populations. Instead, it provides a basis for assessing whether value-added processing can help recover part of the costs of invasive species management while remaining aligned with ecosystem-based governance, biodiversity protection, and the precautionary approach [11–13,21].

5. Conclusions

The present study provides an economic feasibility assessment of the value-added processing of *P. radiata* biomass obtained through monitored wild removals in Greece. Our evaluation showcases that processing within an existing licenced seafood processing facility generated favourable financial indicators, suggesting that removal-derived biomass can be incorporated into value-added product workflows with positive economic performance. These findings indicate that processing may contribute to partial cost recovery within invasive species management, particularly where harvesting, handling, and processing can be integrated into existing regional infrastructure.

The proposed framework should be interpreted as a conditional bioeconomic model for the management-linked utilization of invasive biomass, rather than as a production-oriented development pathway for *P. radiata*. Its relevance lies in assessing whether material already targeted for removal can be converted into value-added seafood products while remaining consistent with ecological precaution, traceability, biodiversity protection, and ecosystem-based governance. Future implementation should therefore depend on evidence that removal-based processing contributes to invasive biomass reduction, remains embedded within adaptive monitoring systems, and avoids incentives that could promote population persistence, redistribution, or further spread.

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Appendix A

The financial indicators utilized in this study to evaluate the investment's financial viability are outlined in the following section. Year 0 denotes the year of investment and subsidy, whereas Years 1 through 5 represent the operational period. The analysis employs a five-year operational horizon, with prices and costs held constant, and excludes the application of a discount rate. Consequently, all cumulative cash flows, profitability indices, benefit–cost ratios, and payback periods are presented without discounting.

Appendix A.1. Definitions and Assumptions

i = cash flow year, where $i = 0, 1, 2, 3, 4, 5$.
n = total number of operating years; here, $n = 5$.
p = product category.
GR_i = gross revenue in year i.
OC_i = total annual production costs in year i, including depreciation.
NR_i = annual operating result in year i.
D_i = annual depreciation in year i.
T_i = income tax paid in year i.
OCF_i = operating cash flow before tax in year i.
NCF_i = net cash flow in year i.
I_0 = total initial investment at Year 0.
S_0 = public subsidy received at Year 0.
E_0 = private owner contribution at Year 0.

Appendix A.2. The Analysis Assumes

Annual gross revenue: €213,795.00.
Cash operating costs, excluding depreciation: €145,699.92.
Annual depreciation: €8580.00.
Annual production costs, including depreciation: €154,279.92.
Annual income tax: 30% of the annual operating result before tax.
Total initial investment: €85,800.00.
Public subsidy under Scenario B: €51,480.00.
No discount rate or inflation adjustment.
Constant annual production, revenue, and cost values throughout Years 1–5.

The subsidy is received at Year 0 and treated as a financing inflow rather than taxable operating income.

No terminal value, residual value, working capital recovery, or additional replacement investment is included.

Scenario A represents full private financing. Scenario B represents the same total investment with a 60% public subsidy. The subsidy reduces the private owner contribution but does not change annual production costs, depreciation, operating profit, or operating cash flow.

Depreciation was calculated using the straight-line method according to:

$$D_j = \frac{C_j - S_j}{L_j}$$

where D_j is the annual depreciation expense for the asset j, C_j is its acquisition cost, S_j is its estimated residual value, and L_j is its useful life in years. Unless otherwise stated, residual values were assumed to be zero.

Appendix A.3. Gross Revenue

Gross revenue was calculated as the sum of the revenue generated by each product category:

$$GR_i = \sum_{p=1}^{m} Q_{p,i} P_{p,i}$$

where $Q_{p,i}$ is the quantity sold of product p in year i, and $P_{p,i}$ is its selling price.

Under the baseline production scenario:

$$GR_i = €213,795.00$$

Cumulative five-year gross revenue is therefore:

$$GR_{\text{cum},5} = \sum_{i=1}^{5} GR_i = 5 \times €213,795.00 = €1,068,975.00$$

Appendix A.4. Annual Operating Result

The annual operating result before tax was calculated as gross revenue minus total annual production costs:

$$NR_i = GR_i - OC_i$$

$$NR_i = €213,795.00 - €154,279.92 = €59,515.08$$

The five-year cumulative operating result is therefore:

$$NR_{\text{cum},5} = \sum_{i=1}^{5} NR_i = 5 \times €59,515.08 = €297,575.40$$

Appendix A.5. Operating Cash Flow Before Tax

Depreciation of fixed capital assets is a non-cash accounting expense. It reduces the reported operating result and, under the assumed tax treatment, the taxable operating profit; however, it does not generate an annual cash payment. Therefore, depreciation is added back to the after-depreciation operating result when calculating operating cash flow before tax:

$$OCF_i = NR_i + D_i$$

$$OCF_i = €59,515.08 + €8580.00 = €68,095.08$$

Appendix A.6. Income Tax and Annual After-Tax Cash Flow

Income tax was calculated at 30% of the annual operating result:

$$T_i = 0.30 \times NR_i$$

$$T_i = 0.30 \times €59,515.08 = €17,854.52$$

Annual after-tax cash flow was calculated as operating cash flow before tax minus income tax:

$$NCF_i = OCF_i - T_i$$

Therefore:

$$NCF_i = €68,095.08 - €17,854.52 = €50,240.56$$

Appendix A.7. Initial Investment and Year 0 Cash Flow

For Scenario A, no public subsidy is received:

$$S_{0,A} = €0.00$$

$$NCF_{0,A} = S_{0,A} - I_0 = €0.00 - €85,800.00 = -€85,800.00$$

For Scenario B, the public subsidy is received at Year 0:

$$S_{0,B} = €51,480.00$$

$$NCF_{0,B} = S_{0,B} - I_0$$

$$NCF_{0,B} = €51,480.00 - €85,800.00 = -€34,320.00$$

Appendix A.8. Five-Year Cash Flow

Cumulative undiscounted cash flow through year t was calculated as:

$$CUCF_t = NCF_0 + \sum_{i=1}^{t} NCF_i$$

For Scenario A:

$$CUCF_{5,A} = -€85,800.00 + 5 \times €50,240.56 = €165,402.78$$

For Scenario B:

$$CUCF_{5,B} = -€34,320.00 + 5 \times €50,240.56 = €216,882.78$$

Appendix A.9. Equity Payback Period

The undiscounted payback period is the time required for cumulative net cash flow to become non-negative.

For Scenario A, the investment is recovered during Year 2:

$$PP_A = 1 + \frac{€35,559.44}{€50,240.56} = 1.71 \text{ years}$$

For Scenario B, the investment is recovered during Year 1:

$$PP_B = \frac{€34,320.00}{€50,240.56} = 0.68 \text{ years}$$

Appendix A.10. Equity Profitability Index

The undiscounted equity profitability index compares total five-year after-tax cash inflows with the private capital contribution:

$$PI_{equity} = \frac{\sum_{i=1}^{n} \; NCF_i}{I_0 - S_0}$$

For Scenario A:

$$PI_{equity,A} = \frac{5 \times €50,240.56}{€85,800.00} = 2.93$$

For Scenario B:

$$PI_{equity,B} = \frac{5 \times €50,240.56}{€34,320.00} = 7.32$$

These values indicate that the total undiscounted after-tax cash inflows equal approximately 2.93 times the private investment in Scenario A and 7.32 times the private contribution in Scenario B.

Appendix A.11. Project-Level Profitability Index

For the project-level perspective, the full investment is used as the denominator. The subsidy is included as a Year 0 project inflow under Scenario B:

$$PI_{project} = \frac{\sum_{i=1}^{n} \; NCF_i + S_0}{I_0}$$

For Scenario A:

$$PI_{project,A} = \frac{5 \times €50,240.56}{€85,800.00} = 2.93$$

For Scenario B:

$$PI_{project,B} = \frac{(5 \times €50,240.56) + €51,480.00}{€85,800.00} = 3.53$$

Equity PI and project-level PI are not interchangeable because they use different capital bases and financing perspectives.

Appendix A.12. Benefit–Cost Ratio

The principal project-level BCR excludes financing transfers from project benefits and is calculated as total five-year revenue divided by total five-year production costs plus the initial investment:

$$BCR_A = \frac{5GR}{I_0 + 5OC}$$

For Scenario A:

$$BCR_A = \frac{5 \times €213,795.00}{€85,800.00 + (5 \times €154,279.92)}$$

$$BCR_A = \frac{€1,068,975.00}{€857,199.60} = 1.25$$

For Scenario B, annual operating costs are identical to Scenario A because the subsidy changes only the financing structure and does not alter the physical investment or operating cost base.

As a supplementary financing-inclusive measure, the subsidy may be included as a Year 0 benefit:

$$BCR_B = \frac{5GR + S_0}{I_0 + 5OC}$$

$$BCR_B = \frac{(5 \times €213,795.00) + €51,480.00}{€85,800.00 + (5 \times €154,279.92)}$$

$$BCR_B = \frac{€1,120,455.00}{€857,199.60} = 1.31$$

The principal BCR omits the subsidy from the project's benefits because it is considered a financing transfer rather than an operational advantage.

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