INVESTIGATION OF SORTING TECHNOLOGIES FOR SURF CLAMS AND QUAHOGS

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SCeMFiS
Science Center for Marine Fisheries

Investigation of Sorting Technologies for Surf Clams and Quahogs: Final report

About the Project

This project addresses the commercial fishing industry's challenges regarding sorting surf clams and quahogs. It summarizes applicable technologies used in the fisheries sector and other sectors outside of fisheries that can assist with the grading and sorting of surf clams and quahogs, with consideration for both on-vessel and in-plant operations.

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Executive Summary

This study investigated the technical and economic feasibility of implementing automated sorting technologies for surf clams and ocean quahogs in the Mid-Atlantic fisheries. The research focused on evaluating machine vision-based sorting systems in both processing plants and on fishing vessels, addressing the industry's growing challenges with mixed catches and sorting efficiency. The analysis examined multiple scenarios with varying processing rates (14-18 cages/hour) and mixing ratios (5-35%) for both in-plant and on-vessel implementations. For processing plants, the study found that sorting systems become economically viable when operating at higher processing rates and mixing ratios. Specifically, scenarios with processing rates of 18 cages per hour and mixing ratios of 20% or higher demonstrated positive returns, with payback periods ranging from 4.41 to 5.23 years and operational cost reductions of 39-43%. However, on-vessel sorting systems faced greater economic challenges. While vessel cage capacity had minimal impact on feasibility, the mixing ratio proved crucial for economic viability. All analyzed on-vessel scenarios showed negative net benefits, though higher mixing ratios (30% versus 20%) significantly improved the economic outlook. The break-even analysis revealed that processing plants require a minimum mixing ratio of 12-14% at standard processing rates for the technology to be economically viable. For vessels, the break-even point occurs at approximately 35% mixing ratio with a 192-cage vessel capacity. This research provides valuable guidance for industry stakeholders considering automated sorting technology investments, while acknowledging that actual results may vary based on specific operational conditions, seasonality, labor availability, and other factors not captured in the analysis.

Highlights

- Higher processing rates and mixing ratios improve the economic feasibility and positive net benefit costs of implementing sorting technology in plant scenarios.
- All in-vessel scenarios show negative net benefit cost for implementing the sorting technology.

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Introduction

The Atlantic surf clam (*Spisula solidissima*) and ocean quahog (*Arctica islandica*) fisheries are important to the Mid-Atlantic region, with the majority of landings occurring in New Jersey, New York, and Massachusetts. These fisheries have been managed under an individual transferable quota (ITQ) system since 1990[1]. The surf clam fishery primarily supplies fried clam strips, chowders, and canned clam products. Ocean quahogs support an extensive clam bait market as well as a food fishery producing minced clam products.

In recent years, the industry has faced increasing challenges with sorting and grading of the catch. As ocean temperatures rise, the distribution of surf clams has shifted northward and into deeper offshore waters, where they overlap more with ocean quahogs. This has resulted in a greater unintended catch of quahogs on declared surf clam trips and vice versa. However, current regulations do not allow mixed landings - trips are declared for one target species. Vessels avoid mixing to the extent possible, but it still occurs frequently.

The inability to adequately sort catches onboard vessels coupled with processor constraints creates significant economic losses. Most processing facilities are equipped to handle only surf clams or quahogs since they produce different products. Non-target species are discarded as trash. Vessels also lose profitability with a suboptimal catch. Sorting these species by hand onboard vessels is labor-intensive and inefficient at the pace of fishing operations. Players throughout the supply chain incur losses in productivity and yield due to inadequate sorting solutions.

There is also a critical data accounting issue. ITQ reporting assumes cages contain 100% of the declared species with no mixing. In reality, this is not the case. Unreported mixing undermines stock assessment input and catch limit tracking. Finding solutions to the sorting and reporting issues is vital for improving these fisheries' economic viability and management.

The overall goal of this project is to identify and evaluate potential solutions to address the key sorting and grading challenges currently faced by the Mid-Atlantic surf clam and ocean quahog fisheries. More specifically, the project aims to:

1. Investigate the technical and economic feasibility of different mechanical, electronic, and manual sorting/grading approaches that could improve the separation of catch.

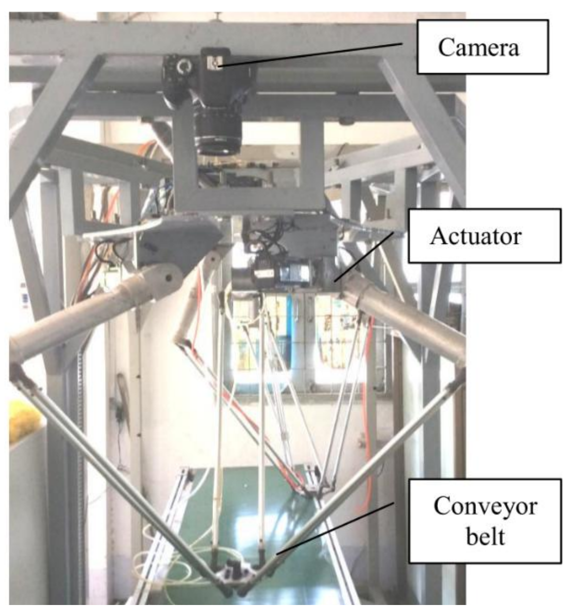
2. Provide guidance to the fishing industry, managers, and policymakers on suitable sorting technologies and revised monitoring/reporting protocols to improve fishery viability.

Overview of machine-vision based sorting system

A general sorting system is designed to efficiently and accurately classify objects based on specific criteria such as size, color, weight, shape, or quality. These systems are widely used in various industries, including agriculture, food processing, manufacturing, and recycling. The main objective of a sorting system is to streamline the process of separating objects into different categories, ensuring consistent quality and reducing manual labor. A typical sorting system (Figure 1) consists of several key components that work together to achieve the desired sorting outcome [2].

1. **Feeding mechanism:** The first component of a sorting system is the feeding mechanism, which introduces the objects into the system. This can be a hopper, conveyor belt, or any other device that ensures a steady and controlled flow of objects into the sorting area. The feeding mechanism should be designed to handle the specific characteristics of the objects being sorted, such as their size, shape, and fragility.
2. **Sensing and imaging technology:** Advanced sensing and imaging technologies are at the heart of most modern sorting systems. These components collect data about the objects being sorted, which is then used to make classification decisions. Common sensing technologies include cameras (for color and shape analysis), near-infrared sensors (for internal quality assessment), and X-ray sensors (for detecting internal defects or foreign objects). The choice of sensing technology depends on the sorting application's specific requirements.

Figure 1. Installation of the camera on an existing conveyor belt



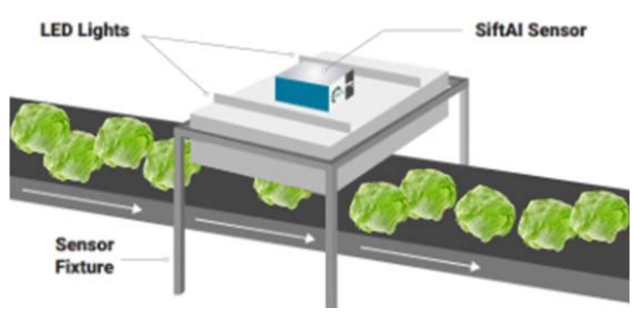
3. **Image processing and analysis software:** The data collected by the sensors is processed using sophisticated image processing and analysis software. This

software employs various algorithms and machine learning techniques to extract relevant features from the sensor data and classify the objects based on pre-defined criteria. The software may also include user interfaces for configuring sorting parameters and monitoring system performance.

4. **Mechanical sorting mechanisms:** Once the objects have been classified, they need to be physically separated into different categories. This is achieved using various mechanical sorting mechanisms, such as air jets, robotic arms, or diverters. The sorting software controls these mechanisms, which are designed to quickly and accurately direct objects into the appropriate output streams.
5. **Material handling and output systems:** After the objects have been sorted, they need to be efficiently transported to their respective destinations. This is typically accomplished using conveyors, chutes, or bins that are specifically designed for the sorted objects. The output systems may sometimes include additional processing steps, such as packaging or labeling.
6. **System integration and control:** A sorting system's various components must be seamlessly integrated and controlled to ensure optimal performance. This is typically achieved using a combination of programmable logic controllers (PLCs), industrial computers, and human-machine interfaces (HMIs). These control systems allow operators to monitor and adjust the sorting process in real time, as well as collect data for quality control and traceability purposes.
7. **Safety and maintenance:** Sorting systems often handle large volumes of objects at high speeds, which can pose safety risks to operators and maintenance personnel. As such, these systems must incorporate appropriate safety features, such as emergency stop buttons, guards, and interlocks. Regular maintenance and calibration are also essential to ensure consistent performance and minimize downtime.

A general sorting system is a complex integration of feeding mechanisms, sensing and imaging technologies, image processing and analysis software, mechanical sorting mechanisms, material handling and output systems, and system integration and control components[3]. The specific design and configuration of a sorting system will depend on the unique requirements of the application, such as the properties of the objects being sorted, the desired throughput, and the level of accuracy required. As technology continues to advance, sorting systems are becoming increasingly sophisticated, enabling

Figure 2. Example of an add-on vision system, photo credit to KPM



more efficient and effective sorting processes across a wide range of industries. Figure 2 is an example of the vision-based sorting system commercialized by KPM; The camera was placed 18 inches above the line.

Design of clam sorting system

Designing a clam sorting system requires careful consideration of the unique characteristics and requirements of clam processing. The system should be capable of efficiently sorting clams based on size, shell condition, and other relevant quality factors. Here's a detailed description of the key components and considerations for designing a clam sorting system:

1. **Conveyor belt:** The objects to be sorted are transported on a mechanical conveyor belt that moves the objects into the camera's field of view. The speed of the conveyor needs to be synchronized with the vision system.

2. **Camera system:** A high-resolution camera is placed above the conveyor belt to capture images of the objects to be sorted. The camera position and field of view are important considerations.

3. **Image Acquisition and Processing** play a crucial role in systems utilizing machine vision. High-resolution cameras capture images of objects on the conveyor, which are then analyzed in real-time by image processing software to identify characteristics such as color, size, or defects. This process often requires adequate lighting and precise synchronization between the conveyor's movement and image capture to ensure accurate and consistent object assessment.

4. **Computer and software:** A computer runs software algorithms to process the images from the camera. The software detects objects, determines their properties like color and size, locates their position, and outputs control signals.

5. **Algorithms** and decision-making form the brain of the sorting system, where captured data (images, weight measurements, etc.) are processed and analyzed. Advanced algorithms and machine learning models can be employed to enhance sorting accuracy and adaptability, enabling the system to efficiently sort objects based on complex or subtle criteria.

6. **Sorting unit (Rejection):** This includes a class slider conveyors driven by motors. Electromagnets open and close the bowls on the transporter conveyor to drop the secondary catch into the appropriate sliders based on their grade.

7. **Control System:** A Programmable Logic Controller (PLC) controls the motors, opening and closing mechanisms, counting, triggering, and load cell sensors, with

communication to a personal computer (PC) for image capturing, acquisition, and software processing.

8. **User interface:** An interface allows operators to customize parameters in the software like coefficients, brightness, contrast, median values, and sorting criteria to adapt the system to different objects and environments.

A breakdown of capital cost and operational cost of the system with their technical details are listed in Table 1.

Table 1. List of fixed cost items and capacity

Fixed cost items	Descriptions	Approximate cost
2 ft belt imaging system	Maximum processing 15 pieces/second	$120,000
5 ft belt imaging system	Maximum processing 40 pieces/second	$250,000
Shaking-based Singulation system	Compatible with 15 pieces/second	N/A
Rejection system 2ft	Pneumonic, handles 3 pieces rejection/second	$120,000 for a 2ft system
Rejection system 5ft	Pneumonic, handles 8 pieces rejection/second	$250,000 for a 5ft system
System integration	Integrate with current system	$0 (covered)
Software initiation fee for subscription users	One-time upfront cost, monthly fee will continue	$20,000
Software non-shared model	Software ownership, no monthly fees	$500,000
System training		$0 (included)

Table 2. List of operational cost items

Items	Cost	Note
Software subscription fee	$10,000/year	
Maintenance fee	$15,000/year onsite visits	Covers 6 systems maximum per visit
Need-based maintenance rate	$180/hour	
Need-based maintenance rate	$1,500/day	

Considerations between on-vessel and in-plant sorting

No difference between in-plant and in-vessel sorting, as they will remain 18 inches above the line and sit over existing line. The rejection system can also be built upon the existing conveyor belt.

Methods

Feasibility analysis

Eight distinct scenarios were considered when conducting the feasibility analysis for the implementation of a sorting system in both processing plants and fishing vessels. Among these, four scenarios were tailored for processing plants, incorporating varied metrics such as processing capacity (measured in cages per hour) and a mixing ratio. Additionally, the width of the conveyor belt in processing plants was factored in as a variable for scenario differentiation in the economic feasibility analysis. Four scenarios were delineated for the fishing vessel context based on processing capacity and mixing ratio. Given the absence of real operating cost data, certain assumptions were made, including an 8-hour workday, 5 days a week, and 52 weeks a year for labor hours at a cost of $15/h. The assumed production values were derived from processing capacity and mixing ratios. Sales prices were set at $1.10/lb for processed ocean quahogs and $0.90/lb for surf clams. The assumed shucked final product weight for ocean quahogs was 0.3 lb (4.8 oz), while for surf clams, it was set at 0.35 lb (5.6 oz). In processing plants, the number of workers required was calculated based on the ability to manually sort one piece per second, considering rejection estimates from the mixing ratio. It is crucial to note that any alterations in these assumptions, along with factors such as seasonality of fisheries, abundance of species, climate and weather conditions, holidays, and labor shortages, among other variables, may significantly alter the results of the overall analysis. Despite these variables, the estimated costs of implementing sorting systems can guide individual stakeholders in tailoring the models to their specific conditions, providing a valuable framework for decision-making in dynamic operational environments. The assumptions and conversion metrics of production and labor factors for ocean quahogs and surf clams utilized to perform the feasibility analysis are summarized in **Table 3.** We utilized average values for the number of pieces per cage based on a range of pieces per bushel of 150 to 180 for ocean quahogs and 85 to 104 for surf clams.

Table 3. Assumptions and conversion metrics used in the feasibility analysis for implementing sorting technology for ocean quahogs and surf clams in processing plants and fishing vessels.

Dimension	Indicators	Ocean quahog	Surf clam
Production factors	Cage	1	1
	Bushel per cage	32	32
	Pieces per cage (avg)	5280	3024
	Average lb/piece (whole)	1.5	1.75
	Average yield of shucked meat	20%	20%
	Average lb/piece (shucked)	0.3	0.35
	Price/pound ($/lb)	$1.10	$0.90
Labor & supply factors	$/hour	$15	$15
	hours/day	8	8
	days/week	5	5
	weeks/year	52	52
	Sorting (pieces per second)	1	1
	Labor required to operate the sorting system	1	1
Total cost factors	Interest on investments (fixed costs)	5%	5%
	Interest on operating capital (variable costs)	5%	5%
	Useful life of equipment (years)	10	10

Table 4. Scenario designs with the in-plant system

System	2 ft	4 ft	7 ft	5 ft
Mixing ratio	0.05	0.2	0.35	0.35
Processing rate (cages/hour)	14	18	18	14
Ocean quahog (pieces/second)	20.53	26.4	26.4	20.53
Surf clam (pieces/second)	11.76	15.12	15.12	11.76
Rejection of Ocean quahogs (pieces/second)	1.03	5.28	9.24	7.19
Rejection surf clams	0.588	3.024	5.292	4.116
Number of sorting systems	1	1	1	1
Number of belts/systems	1	1	1	1
Production pieces year				
Ocean quahog (pieces/year)	146,065,920	158,146,560	128,494,080	99,939,840
Surf clam (pieces/year)	83,655,936	90,574,848	73,592,064	57,238,272

In-plant sorting

Under these considerations, the feasibility analysis was performed for different scenario conditions for implementing sorting technology for ocean quahogs and surf clams in processing plants and the results are summarized in **Table 4**. As the processing capacity increases, the total capital investment increases due to the adjustments of the equipment to the size of the conveyor belt. Scenario 3 contains the largest belt of 7 feet, the highest mixing ratio of 35% and the largest amount of workers required to manually sort ocean quahogs and surf clams in a processing facility.

According to **Table 5,** which compares the economic feasibility of four different scenarios for implementing a sorting system in processing plants, the results suggest that processing at a low rate of 14 cages per hour with a low mixing ratio of 5% (Scenario 1) is not economically feasible for sorting system installation. In this scenario, the annual operational cost would increase by 41.12% after implementing the sorting system, and the payback period would be negative at -7.15 years, indicating that the investment in the sorting system would not be recovered within the equipment's useful life.

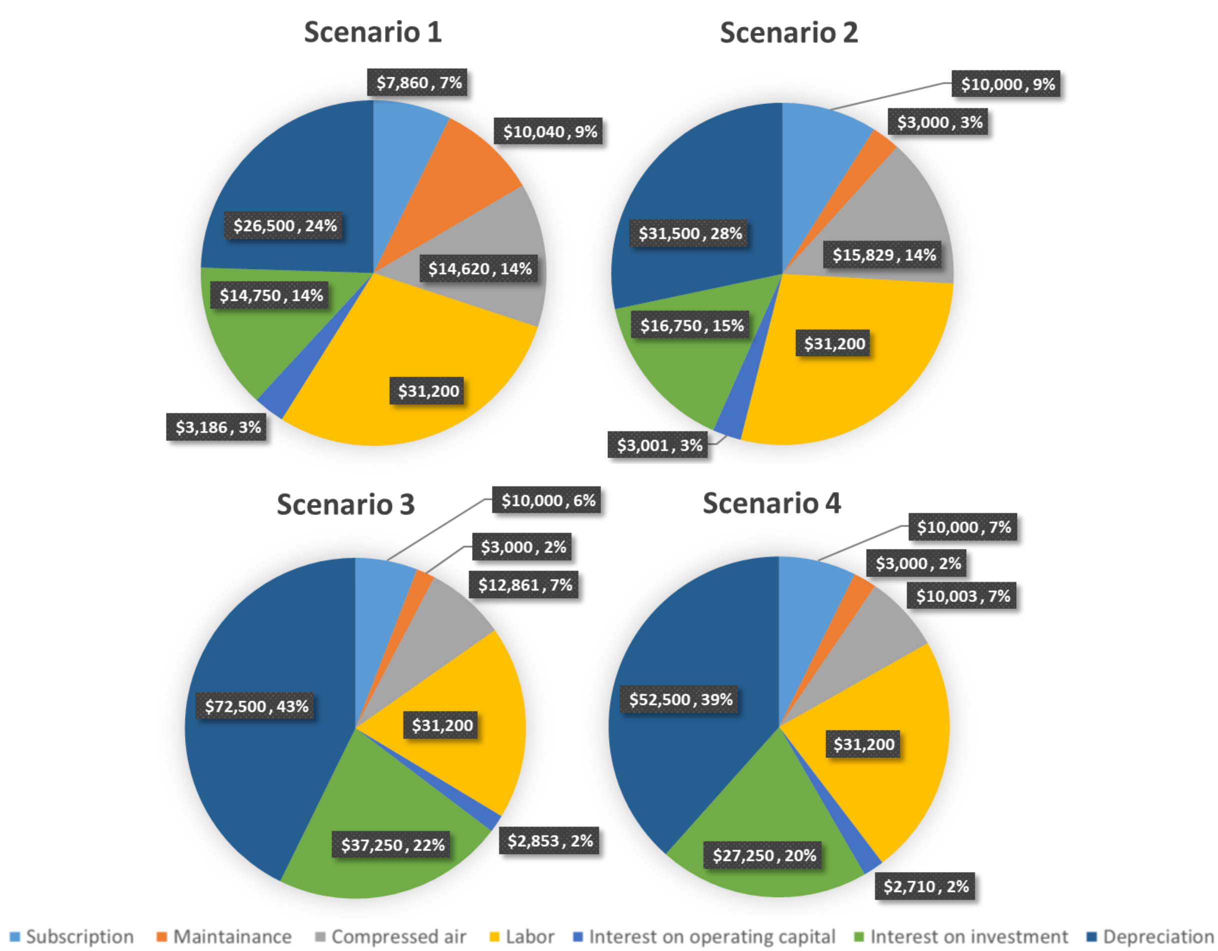
Table 5. Feasibility analysis under different scenario conditions for implementing sorting technology for ocean quahogs and surf clams in processing plants.

Indicators	Scenarios			
	1	2	3	4
Processing rate (Cages/hour)	14	18	18	14
Mixing ratio	5%	20%	35%	35%
Belt size	2ft	4ft	7ft	5ft
Processing rate - quahog (pieces/sec)	20.5	26.4	26.4	20.5
Processing rate - clam (pieces/sec)	11.8	15.1	15.1	11.8
Rejection - quahogs (pieces/sec)	1.03	5.3	9.2	7.2
Rejection - clams (pieces/sec)	0.6	3.0	5.3	4.1
Number of workers before the system	2	6	10	8
Labor substitution	1	5	9	7
Total capital investment for the system	$285,000	$349,000	$559,000	$559,000
Annual operation cost without system	$65,520	$196,560	$327,600	$262,080
Annual operation cost WITH system	$111,276	$120,640	$185,264	$149,143
Annual operational savings	$(45,756)	$75,920	$142,336	$112,936
Annual operational cost change	41.12%	-39%	-43.45%	-43.09%
Payback period (years)	-7.15	4.41	5.23	4.83

This lack of feasibility can be attributed to the low processing rate and low mixing ratio, which results in a smaller number of clams being rejected per second (1.03 pieces/sec for quahogs and 0.6 pieces/sec for clams). Consequently, the labor substitution is minimal, with only one worker being replaced by the sorting system. The total capital investment for the system in this scenario is $285,000, which is not justified by the small operational savings achieved through the limited labor substitution. In contrast, the other scenarios with higher processing rates and mixing ratios demonstrate better economic feasibility. Scenarios 2, 3, and 4 show positive payback periods ranging from 4.41 to 5.23 years and significant reductions in annual operational costs, ranging from 39% to 43.45%. These results indicate that the sorting system investment becomes more viable as the processing rate and mixing ratio increases, leading to higher labor substitution and operational cost savings. The break-even mixing ratio at 14 cages/hour and 18 cages/hour of processing rate are around 14% and 12%, respectively. The partial financial analysis toolbox we developed can be used for customized adjustment.

Figure 3 shows a breakdown of the operational cost in all four scenarios, where investment interest and equipment depreciation take most of the cost.

Figure 3. Total operating costs in different scenarios for the implementation of a sorting system for ocean quahogs and surf clams in a processing plant.



In conclusion, the feasibility analysis highlights the importance of considering factors such as processing rate and mixing ratio when evaluating the economic viability of implementing a sorting system in clam processing plants. Low processing rates and mixing ratios, as seen in Scenario 1, may not justify the investment in a sorting system, while higher rates and ratios can lead to significant operational cost savings and acceptable payback periods.

On-vessel sorting

Table 6 compares four different scenarios for the on-vessel scenario, with various vessel cage capacity (42 cages to 192 cages) and mixing ratio (20%, 30%). The analysis indicates that the vessel cage size does not significantly impact economic feasibility, while the mixing ratio is the major driving factor. In scenarios 1, 2, and 3, where the mixing ratio is constant at 20%, the annual operational cost change remains similar (ranging from 27.6% to 28.6%) despite the differences in vessel cage capacity and the number of trips per year. The payback period for these scenarios is also consistent at around -10 years, indicating that the investment in the sorting system would not be recovered within the equipment's useful life.

Table 6. Feasibility analysis under different scenario conditions for implementing sorting technology for ocean quahogs and surf clams in fishing vessels.

Indicators	Scenarios			
	1	2	3	4
Vessel Cage Capacity	42	98	196	196
Number of trips per week	4	3	2	2
Number of trips per year	208	156	104	104
Hours per trip	42	56	86	86
Belt size	2ft	2ft	2ft	2ft
Mixing ratio	20%	20%	20%	30%
Processing rate (cages/hour)	6	6	6	6
Required time to process cages (h)	7	16	33	33
Crew members	4	4	5	5
Labor substitution	1	1	1	2
Total capital investment for the system	$375,000	$375,000	$375,000	$375,000
Annual operation cost without system	$131,040	$131,040	$163,800	$163,800
Annual operation cost WITH system	$167,159	168,612	$204,763	$175,393
Difference	$(36,119)	$(37,572)	$(40,963)	$(11,593)
Annual operational cost change	27.6%	28.6%	25%	2.87%
Payback period (years)	-10.38	-9.98	-9.15	-32.35

However, when comparing scenarios 3 and 4, which have the same vessel cage capacity (192 cages) but different mixing ratios (20% and 30%, respectively), the impact of the mixing ratio becomes evident. In scenario 4, with a mixing ratio of 30%, the annual operational cost increase is significantly lower at 2.87%, suggesting that the sorting system investment becomes more feasible and is getting close to the break-even point with a higher mixing ratio.

The improved feasibility in scenario 4 can be attributed to the increased labor substitution. With a higher mixing ratio, more clams need to be sorted, and the sorting system can replace more manual labor. In scenario 4, the sorting system substitutes two crew members, compared to only one in scenarios 1, 2, and 3. It is important to note that the payback periods for the on-vessel scenarios are generally much longer than those for the in-plant scenarios. This difference can be explained by the lower processing rates and the limited space available on fishing vessels, which may not allow for larger sorting systems that could process clams more efficiently. The break-even point of in-vessel sorting can be calculated in the spreadsheet provided, at around 35% mixing ratio and 192 cage vessels.

In conclusion, the feasibility analysis for the on-vessel sorting system implementation highlights the importance of the mixing ratio in determining the economic viability of the investment. Higher mixing ratios lead to increased labor substitution and improve operational cost savings, making the sorting system more feasible. On the other hand, vessel cage capacity has a limited impact on the system's feasibility. The analysis also suggests that on-vessel sorting systems may face more challenges in terms of economic viability compared to in-plant systems due to lower processing rates and space constraints.

Partial Budget Analysis

Partial budget analysis measures the net benefit from the difference between the benefits and costs for a small change in operation [4]. In this case, the addition of the proposed sorting technology will impact the costs associated with labor, interest on investment and operating capital, subscription, maintenance, interest on investment, and depreciation, following the same criteria and assumptions utilized in the feasibility analysis.

The indicators utilized in the Partial Budget Analysis are described as follows. Additional revenue was estimated based on the difference in gross receipts between the scenarios with and without the sorting system. Reduced costs were estimated based on the difference in the labor and operating interest costs between the scenarios with and without the sorting system. Total additional benefits = Additional revenue + Reduced costs. Additional costs were estimated based on the difference in costs with subscription, maintenance, interest on the investment, and depreciation between the scenarios with and without the sorting system. Reduced revenue was estimated based on the difference between the scenarios with and without the sorting system. Total additional cost = Reduced revenue + Additional costs. Net benefit/cost = Total additional benefits - Total additional costs.

Considering the same scenarios utilized in the feasibility analysis, the Partial Budget Analysis for implementing sorting technology for ocean quahogs and surf clams in processing plants and fishing vessels is presented in Table 6 on a per-year basis. In all of the scenarios for fishing vessels, the PBAs presented a negative net benefit cost for the implementation of sorting technology. Regarding the processing plants, scenarios 2, 3, and 4 presented positive net benefit costs for the implementation of sorting technology, and only scenario 1 presented a negative net benefit cost for it. Scenario 3 for the processing plant had the highest net benefit/cost, at $165,644.

Table 7. Partial Budget Analysis under different scenario conditions for implementing sorting technology for ocean quahogs and surf clams in processing plants and fishing vessels

Scenarios	Benefits			Costs			Net benefit/ cost
	Additional revenue	Reduced costs	Total additional benefits	Additional costs	Reduced revenue	Total additional costs	
In-Plant 1	0	31,377	31,377	52,653	0	52,653	-21,276
In-Plant 2	0	162,357	162,357	93,369	0	93,369	68,988
In-Plant 3	0	293,545	293,545	127,901	0	127,901	165,644
In-Pant 4	0	228,168	228,168	95,043	0	95,043	133,125
In-Vessel 1	0	32,016	32,016	68,135	0	68,135	-36,119
In-Vessel 2	0	31,947	31,947	69,519	0	69,519	-37,572
In-Vessel 3	0	31,893	31,893	70,595	0	70,595	-38,702

Values expressed on a per-year basis

Assumed no changes in revenue happen with the system

Conclusions

Based on the comprehensive feasibility analysis conducted for the implementation of sorting systems in the Mid-Atlantic surf clam and ocean quahog fisheries, it is evident that the economic viability of such systems depends on several key factors, including processing rate, mixing ratio, and the location of the sorting system (in-plant or on-vessel).

For in-plant sorting systems, the analysis demonstrates that higher processing rates and mixing ratios lead to better economic feasibility. Scenarios with processing rates of 18 cages per hour and mixing ratios of 20% or higher show positive payback periods ranging from 4.41 to 5.23 years, significant reductions in annual operational costs, and presented positive net benefit/cost. In contrast, the scenario with a low processing rate (14 cages/hour) and low mixing ratio (5%) is not economically feasible, as it results in increased operational costs, a negative payback period and negative net benefit/cost.

For on-vessel sorting systems, the mixing ratio is the primary factor influencing economic viability, while vessel cage capacity has a limited impact. Higher mixing ratios lead to increased labor substitution and improved operational cost savings, making the sorting system more feasible. However, on-vessel sorting systems generally face more challenges in terms of economic viability compared to in-plant systems due to lower processing rates and space constraints.

The analysis also highlights the importance of considering various assumptions, such as labor costs, production values, and sales prices, when assessing the feasibility of sorting systems. Changes in these assumptions, along with external factors like seasonality, species abundance, labor availability, and different levels of vertical integration, can significantly impact the overall feasibility of the systems.

In conclusion, the implementation of sorting systems in the Mid-Atlantic surf clam and ocean quahog fisheries can be economically viable under certain conditions. For in-plant systems, high processing rates and mixing ratios are crucial for feasibility, while for on-vessel systems, the mixing ratio is the primary determining factor. The results presented in this report contain assumptions from limited data due to proprietary and confidential information not being shared, and this may not reflect all variables a company may encounter in real conditions. Therefore, stakeholders should carefully evaluate their specific operational conditions and tailor the feasibility models accordingly to make informed decisions about investing in sorting technologies. Further research and development may be necessary to address the challenges faced by on-vessel sorting systems and to explore additional solutions for improving the efficiency and profitability of the surf clam and ocean quahog fisheries.

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Appendices

Appendix 1. Surf clam & Ocean quahog conversion table

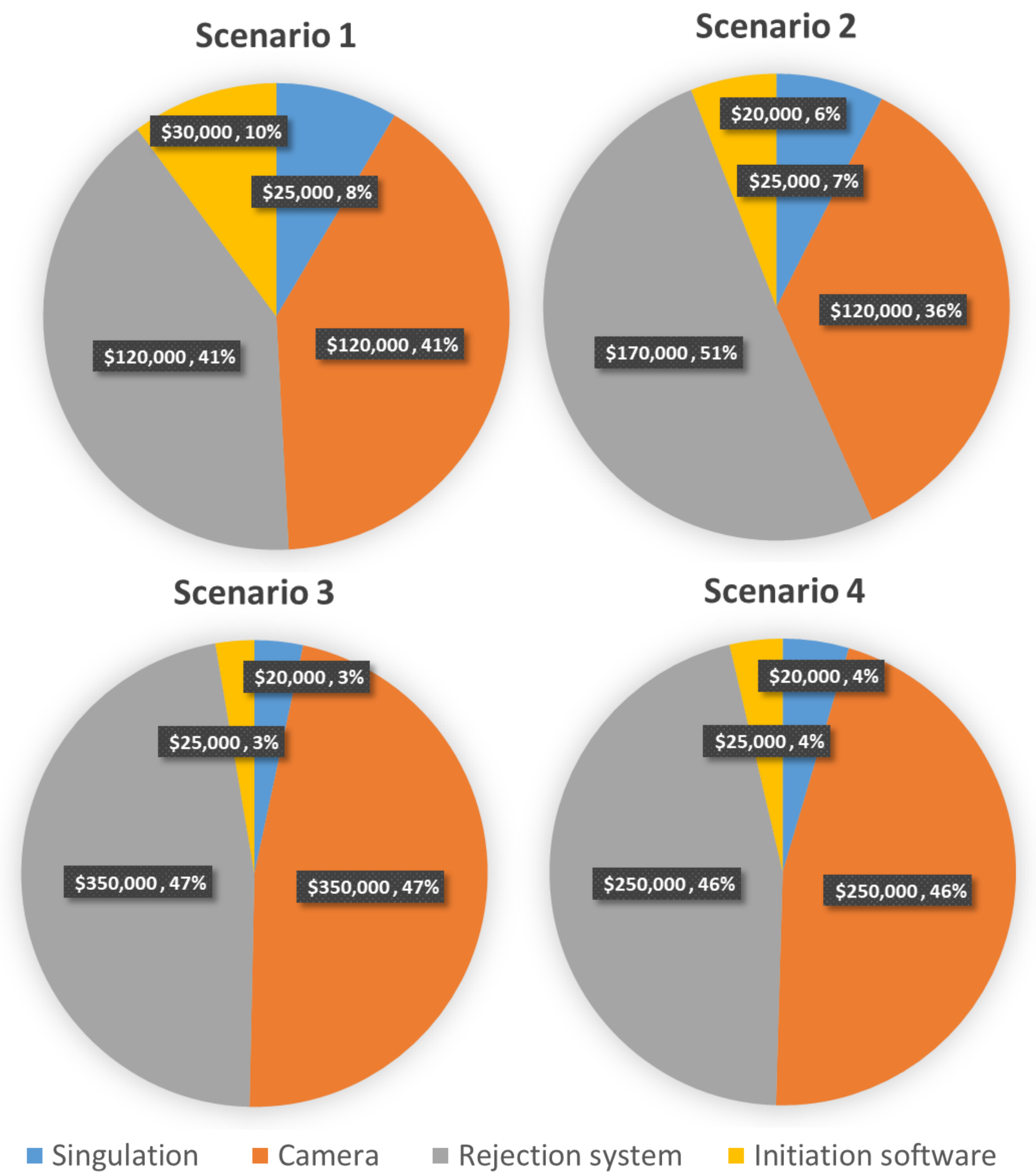
Conversion	Surf clam	Ocean quahog
Cage	1	1
Bushel	32	32
Piece range per cage	2720 3328	4800 5760

Appendix 2. Depreciation calculation (longevity)

Item	Quantity	Useful Life (yr)	Annual Depreciation ($)
Belt	1	20	0
Singulation	1	10	2,500
Camera	1	10	12000
Rejection system	1	10	12000
Initiation software	1	N/A	0

Appendix 3. Capital cost breakdown for the in-plant processing

Appendix 3. Pie chart showing the breakdown of capital cost, operational cost, and fixed cost for in-plant processing.



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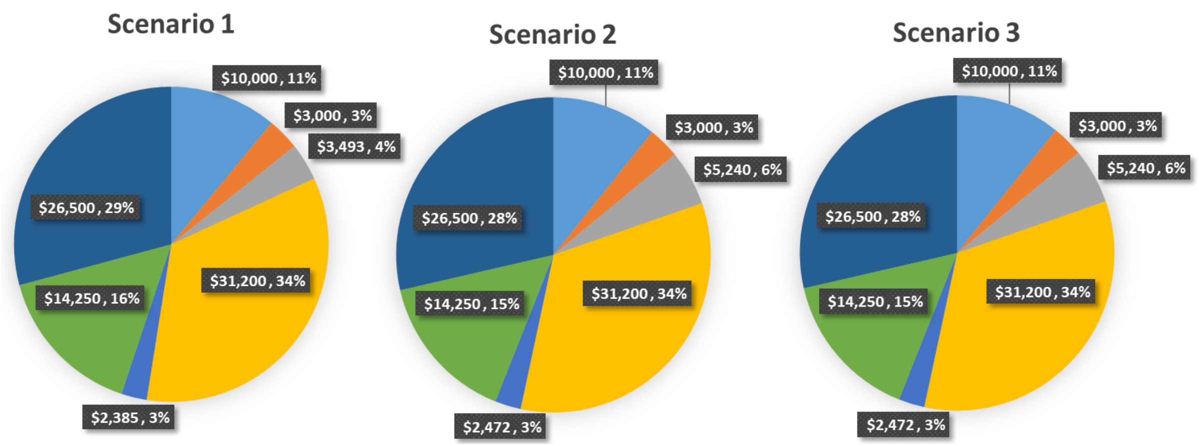
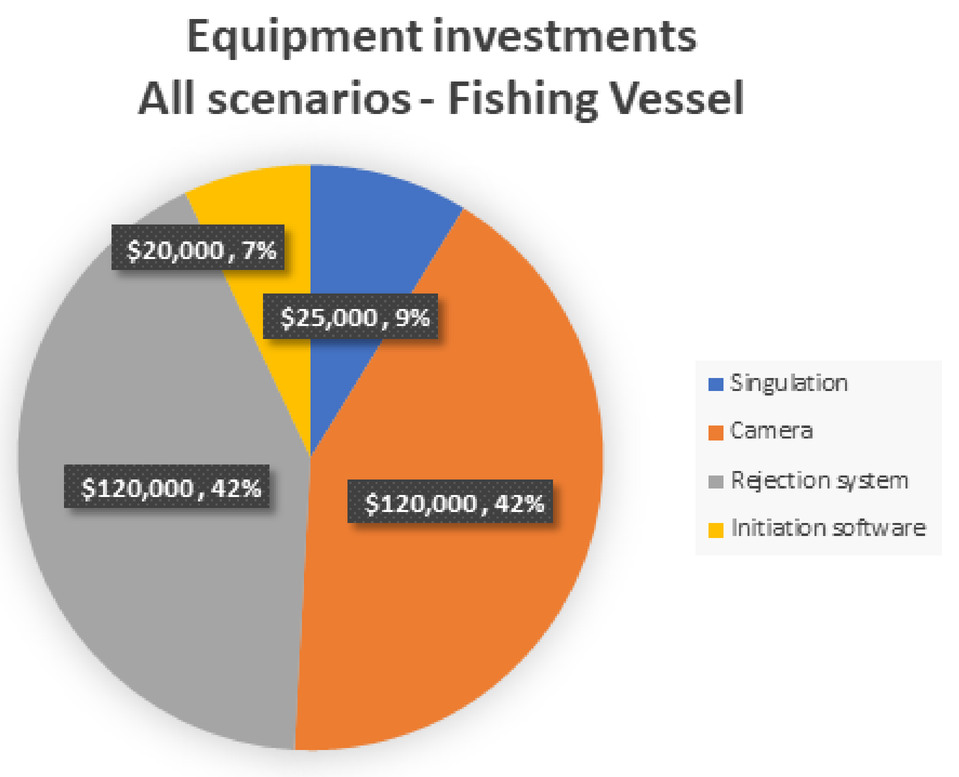


Appendix 5. Equipment investments in different scenarios for the implementation of a sorting system for ocean quahogs and surf clams in a fishing vessel.



Appendix 6. Cost break-down table

System #	1	2	3	4
Mixing ratio	5%	20%	35%	35%
Processing rate (pieces/s)	20.5	26.4	26.4	20.5
Rejection Pieces/sec	1.0	5.3	9.2	7.2
Number of lines	1	1	1	1
Dimension of the belt	2 ft	4 ft	7ft	5 ft
Singulation (shaker)	yes	yes	yes	yes
Camera	2 SiftAIs	4 SiftAIs	7 SiftAIs	5 SiftAIs
Rejection	4 inch fingers	4 inch fingers	4 inch fingers	4 inch fingers
System integration	$0	$0	$0	$0
Subscription (per year)	$7,860	$13,120	$21,010	$15,750
Initiation software	$30,000	$30,000	$30,000	$30,000
Maintenance (per year)	$10,040	$10,040	$10,040	$10,040
Maintenance (per day visit)	2	2	2	2
Total capital investment	$375,000	$450,000	$700,000	$500,000