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ELEVATED RACK HEIGHT TO CONTROL BIOFOULING ON AN INTERTIDAL OYSTER FARM: EFFICACY AND ECONOMICS

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ABSTRACT Biofouling is an ever-present problem for shellfish farmers. Among the many biofouling agents are mud worms, genus Polydora. Mud worms can cause significant economic loss on oyster farms. This project evaluated the efficacy of elevated rack height as a strategy to control mud worm biofouling on an intertidal oyster farm employing rack and bag culture methods. During the study oyster production and cost data were collected for oysters grown at each rack height (15″, 20″, and 30″) in an experimental farm field trial. This information, along with past business records for the rack and bag farm operation, was used to inform an economic cost model. Rack height had a significant effect on oyster growth, mortality, and mud worm fouling during the experiment with higher growth, mortality, and fouling with decreasing rack heights. Oyster condition, shell strength, shell height, shell width, and shell depth did not significantly differ among rack heights. Economic analyses indicated that each rack height is practicable and can be financially viable. Some labor cost was saved by using elevated racks because of reduced biofouling; however, labor increased overall because of the increased time to grow-out on the elevated racks. Higher capital and labor costs, and lower growth rates associated with higher rack heights, were more than offset by increases in survival, thus increasing overall revenue and profits when using higher rack heights. The economic model presented here suggests that even small improvements in survival can greatly improve profitability. Conversely, small reductions in survival could lead to consequential cash flow problems. This study combined experimental results and economic modeling to demonstrate that for this intertidal farm increasing the height of oyster racks might prove an effective strategy to control fouling pests.

KEY WORDS: biofouling, mud worm, oyster farming, aquaculture, enterprise model

INTRODUCTION

Biofouling is an ever-present problem for shellfish farmers (Fitridge et al. 2012, Bannister et al. 2019, Bullard et al. 2021). The gear used by farmers, and the animals that they culture, provide substrate upon which surface-associated communities grow and often thrive (Adams et al. 2011, Hopkins et al. 2021, Shumway 2022). The biofouling community can be diverse, can cause damage to farms and crops, and is challenging and costly to control (Adams et al. 2011, Bullard et al. 2013, Sievers et al. 2019, Shumway 2022). Among the breadth of biofouling organisms, mud worms, members of the genus *Polydora*, are recognized as an important pest on shellfish farms worldwide (Fitridge et al. 2012, Spencer et al. 2021). Along the east coast of the United States, two species, *Polydora cornuta* and *Polydora websteri*, are widespread and have long been known as particularly problematic to oyster producers (Nelson & Stauber 1940, Medcof 1946). The mud worm *P. cornuta* settles on the exterior of oysters and forms thick mats of mud that inhibit oyster growth and cause oyster mortality (Silverbrand et al. 2021). In contrast, *P. websteri* burrows through the oyster shell, weakening the shells and causing unsightly blisters on inner shell surfaces (Blake & Evans 1973, Zottoli & Carriker 1974, Dorgan et al. 2021) that are unappealing to consumers and decrease product marketability (Cilenti et al. 2018, Spencer et al. 2021).

Methods used to grow oysters can vary greatly from one location to another. In the lower Delaware Bay, NJ, oyster farmers use rack and bag oyster culture methods, rearing seed oysters in plastic mesh bags that are secured to low-lying rebar racks. The racks are located on intertidal mudflats that are exposed to the air at low tide. The time the oysters are aerially exposed will impact their ability to feed, as the oysters must be submerged to have access to the naturally occurring plankton in the water. Tidal aerial exposure has also been investigated as a means for controlling mud worm infestations (Littlewood et al. 1992, Handley & Bergquist 1997, Morse et al. 2015, Spencer et al. 2021), thereby setting up a possible trade-off among costs of lower growth relative to potential pest control by moving oysters higher in the tidal zone for longer air exposure.

Although, mud worm biofouling is problematic in many areas around the world (Spencer et al. 2021), it is particularly challenging in the highly turbid Delaware Estuary, where high sediment loads, intertidal conditions, and temperate climate present ideal conditions for *Polydora cornuta* and *Polydora websteri*. Several strategies to control or treat *Polydora* have been tested, including water pump sprays, multiday exposures to air and refrigeration, modulation of tidal exposure, and immersion in freshwater, saturated seawater, or chemical baths (Morse et al. 2015, Spencer et al. 2021). The practicality of multiday exposures or cold storage control is dependent on regulations and infrastructure that may not be advisable or available for many growers. Several chemical treatments have been evaluated, including copper sulphate (Quayle & Newkirk 1989), formalin or chlorine (Ghode & Kripa 2001) and marine dipterenes from algal extracts (Takikawa et al. 1998). Though some of these products may be efficient in the control of mud worms, they are not widely used because they are toxic, expensive, or require careful handling. Saturated brine dips have been used with some success (Mackenzie & Shearer 1959, DeBrosse & Allen 1993, Nel et al. 1996), as have freshwater dips (Martinelli et al. 2022). Farm management strategies used

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on farms today involve labor-intensive frequent washing of oysters and gear using high-volume trash pumps.

The scale of the mud worm fouling problem for oyster farmers is substantial. The dry weight of mud accumulated by these worms on farms has been estimated to be 98 tons per acre (Orth 1971), and costs associated with these *Polydora* mitigation strategies for a midsize farm in the Northeast United States (270,000 market oysters) are approximately 700 person-hours, and equipment and supplies cost about $2,000 annually—nearly 30% of production costs. This project evaluated the potential to use rack height as an economically viable (Llorente & Luna 2016) management strategy for controlling infestations of polydorid worms on an intertidal oyster farm. The study evaluated the response of mud worm fouling and the production costs related to oyster growth, mortality, and farm labor, associated with different rack heights on an intertidal oyster farm in Delaware Bay, NJ. These observed benefits and costs were assessed using an economic model to determine whether elevating racks can improve overall farm productivity. This enhanced understanding of the trade-offs related to this fouling mitigation strategy will inform best practices to solve this issue and achieve long-term farm production goals.

MATERIALS AND METHODS

The goal of this study was to compare the efficacy of manipulating rack height and intertidal air exposure as a cost-effective method for controlling *Polydora* biofouling of farmed oysters. Specific objectives were to evaluate the efficacy of elevated rack height in controlling *Polydora* biofouling, compare oyster survival, growth, disease, and condition of oysters grown at different rack heights, and to use experimental data to evaluate economic costs and benefits of elevated rack height for the biofouling control.

These objectives were achieved through an experiment conducted on an active commercial oyster farm. The effects of rack height (three levels) on biofouling, wash frequency, and oyster survival, growth, disease, and condition were statistically compared, and the economic costs and benefits were assessed using an enterprise economic model.

Field Experiment

The field experiment was conducted at a commercial oyster farm located near the Rutgers University Cape Shore Laboratory along the lower Delaware Bay. This area has extensive intertidal mudflats with undulating sloughs and sandbars, experiences semidiurnal tides with an average range of 1.6 m, and is polyhaline with salinity averaging 20–25. The experimental site was located at N 39.07520; W 74.91295.

Hatchery-reared diploid disease-resistant (NEH) 2 mm (approximately 1-y-old) oysters were stocked in plastic mesh bags (6 L of oysters per bag), which were secured on rebar racks following standard farm practices. The bags protect the oyster seed from predators, and the racks keep the oysters elevated off the bottom so the oyster bags air-dry during low tide. Three rack height treatments, 15″, 20″, and 30″ were used in the experiment. The 15″ height represents the standard rack height currently used on farms in the lower Delaware Bay. Four replicate bags were deployed for each treatment (a total of 12 bags for the experiment). Treatments were randomly assigned a location within the farm. The experiment began in May 2024, and racks were monitored weekly through August for *Polydora cornuta* biofouling on the outside of all bags and qualitatively scored (percent coverage) the degree of mud present. The shell height of all oysters from one bag from each replicate was measured to the nearest millimeter at the start of the experiment using digital calipers.

All treatments were washed every 7–10 days using a high-volume trash pump dispensing ambient seawater following standard oyster farm practices used in the lower Delaware Bay. The time required to wash each replicate in each treatment was recorded. This provided a basis for estimating labor costs associated with each rack height treatment (described in the Economic Model section). Water temperature data loggers (Hobo Pendant MX 2201) were deployed on one replicate rack for each treatment. Relative air exposure time was inferred from the temperature data for each treatment.

At the termination of the experiment in August 2024 samples were collected to assess oyster performance metrics. The number of dead and live oysters within each bag were counted, shell height of live oysters was measured to the nearest mm, and 10 randomly selected oysters from each bag were returned to the laboratory for further sampling. In the laboratory, shell height (from umbo to growing edge), fan width, and cup depth were measured to the nearest millimeter using digital calipers. After shell measurements, oysters were shucked, and shells and meat from each oyster was dehydrated in drying ovens for 10 days, after which dry weights were taken. Dry weights and shell height were used to calculate condition [(dry meat weight/shell height) × 100]. The inside of the shells were individually examined for mud blisters associated with *Polydora websteri*, and the percent coverage of the shells was estimated. Shell strength of the right (cupped) valve of each shell was estimated as the maximum force required to break the shell (LaBarbera & Merz 1992) using an Instron 3400 Series Single Column Table Model at a rate of 2.54 mm/min. The maximum force (kiloNewtons, kN) applied in the middle of the shell at which the shell begins to break was assumed the force required to break the shell. Shell breaking strength was standardized to the dry weight of each shell (N/g).

Disease analyses of oysters from each of the treatment groups were performed by Rutgers University. Tissue samples of rectum and mantle from each oyster were incubated in Ray's fluid thioglycollate medium for 7 days, stained with Lugol's iodine and examined to detect *Perkinsus* spp. Infection levels were scored 0–5 according to the Mackin Scale. A cross-section of each of these oysters was preserved in Davidson's fixative, processed into slides using standard histological methods, and stained with hematoxylin and eosin Y. These slides were examined for any parasites, pathogens, and pathological conditions, as well as reproductive status and digestive tubule atrophy as an indicator of general health.

Statistical comparisons among treatment groups were made using Analysis of Variance, and in cases where rack height had significant effects on the response variable, Tukey *post hoc* testing (TukeyHSD) was used to determine which groups were significantly different.

Economic Model

Economic assessment was conducted using a producer-level enterprise budget analysis (Ahearn & Vasavada 1992, Noren et al. 2025) for each of the three rack height treatments.

Standard capital budgeting, cash flow analysis, and sensitivity analysis were performed following Engle (2010) and Kay et al. (2004). Numerous enterprise budgets have been developed and used for bivalve aquaculture (North Carolina Department of Agriculture and Consumer Services 2001, Hudson et al. 2012, Chen et al. 2017). Chen et al. (2017) used economic data collected from an active oyster farm to investigate the economic feasibility of small-scale oyster farming, employing budgeting analysis to demonstrate profitability with a $0.10 increase in market price or a 4.1% decrease in mortality. The results of the field experiment described above were used to inform an economic cost model. Annual fixed costs were obtained from interviews with the oyster farm operator. In addition, production records were kept during the field experiment to quantify variable costs and yields associated with production at each rack height. This enabled comparison of the benefits that might be gained from reduced labor associated with reduced biofouling, with potential losses, such as reduced growth rate associated with reduced feeding opportunity associated with elevated racks that remain exposed to air for longer durations.

The economic assessment included a producer-level enterprise cost of production budget for a typical "rack-and-bag" oyster operation which uses standard height (15″) racks. This was the baseline used for comparison; changes to the enterprise budget arising from changes in the operation (in this case, changing to new higher heights) were isolated and evaluated.

Enterprise Budget

The enterprise budget model was based on a medium-sized oyster farm with an annual desired production of approximately 270,000 oysters on one acre (average yearly harvest area). The model assumed that 85% of oysters survive the first season, and 79% of the remaining oysters grow out to harvest. Based on desired production, 400,000 2-mm seed oysters are purchased for $0.01 each and planted directly to the field. The number of months to reach harvest size ranges from 16 to 30 mo, with higher proportions of harvest occurring between 22 and 30 mo. The model used a grow-out average of 26 mo.

The average yearly fuel cost of $1,550 was allocated between production costs ($300 for All-Terrain Vehicle operation) and postharvest marketing ($1,200 for local truck delivery). For labor costs, the model used three general laborers who work at an average rate of $17. One crew manager provided supervisory tasks at a rate of $25 per hour. Business liability insurance was estimated at $1,090 per year, and workers' compensation (a legally required insurance program that provides benefits to employees who suffer job-related injuries or illnesses) was estimated at 5% of labor costs.

Lease costs are $111 plus $0.50 per acre per year ($111.50), and three harvest licenses for crew members at $50 each per year ($150 total) were included in the model. Permit fees included a yearly $500 New Jersey Department of Environmental Protection Tidelands fee. Overhead charges (2% of operating costs) included costs such as accounting, legal, payroll services, office supplies, local taxes, telephone, travel, and utilities. Repairs to capital equipment were estimated to be 2% of capital equipment value yearly. The model assumed there are no loans needed to operate the business.

Regarding postharvest marketing, the model assumed 100% of harvested oysters are sold to the half-shell market to retailers at $1.10 per oyster (this price represents the wholesale price of the oysters sold by the farm). Bags which hold 100 oysters cost approximately $.005 each. Marketing expenses were assumed to be $2,100 per year. Postharvest facility rent, including utilities, was assumed to be $1,000 per month. Insurance ($2,500 per year) and operations costs ($5,400 per year, including the fuel costs discussed earlier) for a refrigerated van to deliver oysters were included. Postharvest labor (i.e., washing and packing) entailed two workers, each paid $17 per hour. Many rack and bag operations market oysters through wholesale channels, which can command substantially lower prices. In those cases, postharvest costs can be significantly less expensive.

Capital costs for the rack-and-bag operation are shown in Table 1. These costs included racks (including bungees, hooks, and labor to build), bags that hold oysters during grow out, an all-terrain vehicle with a tow-cart used to transport equipment and oysters on the farm, trash pump washers for cleaning the racks and bags on the farm, power washers for washing oysters postharvest, a refrigerated van to transport harvested oysters to buyers, and a computer record keeping (Table 1). All of these capital cost items were assumed to be 100% used for oyster production. The additional costs associated with 20″ and 30″ racks are $450 and $1,350, respectively, with the rack costs depreciated over 6 y.

RESULTS

Field Experiment

Biofouling, measured as percent coverage of bags, was higher on the lowest racks and lowest on the higher racks (Fig. 1A). Average percent *Polydora cornuta* biofouling coverage on the

TABLE 1.

Intertidal rack-and-bag capital investment costs.

Items	Quantity	Cost per unit ($)	Total cost ($)	Useful years	Yearly depreciation ($)
Racks, bungees, and hooks	300	$70.20	$21,060	6	$3,510
Bags	2,400	$6.00	$14,400	5	$2,880
All-terrain vehicle and cart	1	$8,000	$8,000	3	$2,667
Trash pump field washers	2	$600	$1,200	3	$400
Postharvest power washer	2	$350	$700	3	$233
Refrigeration van	1	$25,000	$25,000	6	$4,167
Computer	1	$2,000	$2,000	3	$667
Total			$72,360		$14,523

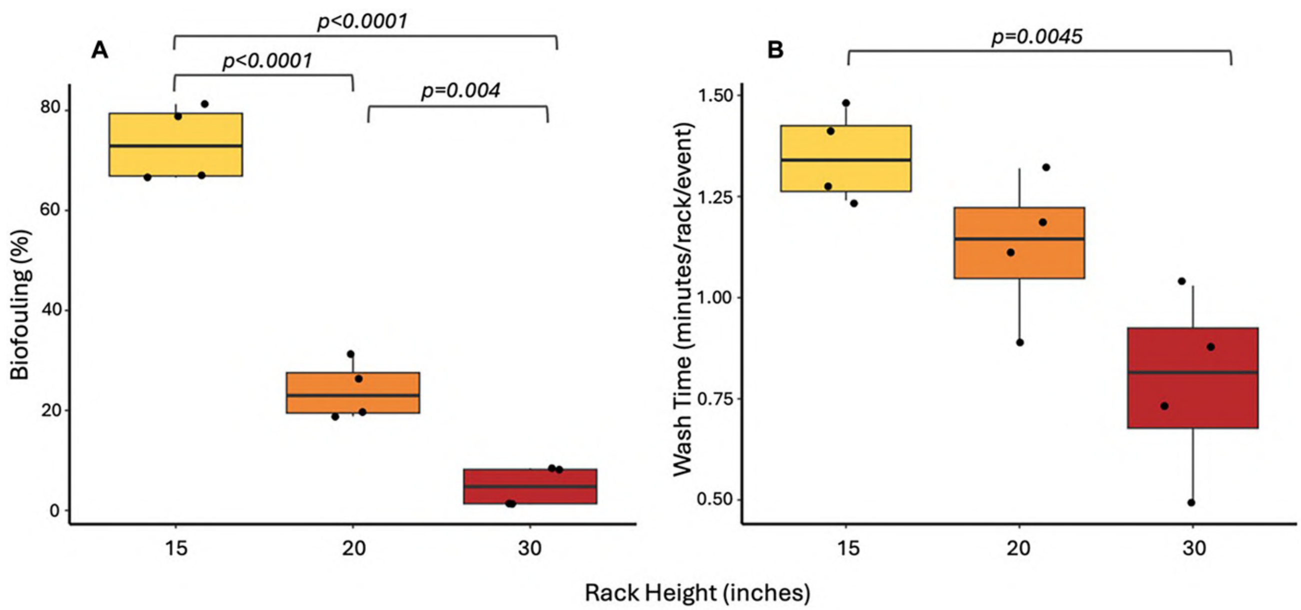

Figure 1. Box and whisker plots of percent mud worm biofouling coverage on oyster shells (A) and time required to wash a rack in a given wash event in minutes (B) across three rack heights (15″, 20″, and 30″). Any significantly different pairwise differences among treatment levels are noted at the top of each panel.

15″ racks was 73% ± 7.7%, whereas percent biofouling coverage on the 30″ racks was 5% ± 4.0% (Fig. 1A). Biofouling significantly differed among rack heights ($P < 0.001$, $f = 111.9$), with all pairs of treatments significantly different from one another (Fig. 1A). Wash time recorded during routine maintenance, as the minutes required to wash a rack in a washing event, also decreased significantly with increasing rack height ($P < 0.056$, $f = 9.7$; Fig. 1B), with a significant pairwise differences in wash time between 30″ and 15″ only.

Higher oyster growth was observed on the lower rack heights ($P = 0.05$, $f = 4.1$), with an average of 0.31 ± 0.05 mm/day on the 15″ racks, and 0.20 ± 0.05 mm/day on the 30″ racks (Fig. 2A). Statistically significant pairwise differences in growth were observed among the 15" and 30" rack heights only (Fig. 2A). Final shell height followed the same pattern as was evident for growth, with smaller final shell heights observed at the 30″ racks ($P = 0.007$, $f = 9.2$); however, no significant difference was evident among treatments for shell width ($P = 0.71$, $f = 0.36$) nor dry shell weight ($P = 0.87$, $f = 0.14$). Oyster mortality from initiation to the end of the experiment ranged from 21% ± 17.6%, to 5% ± 0.9% at 15″ and 30″ rack heights, respectively (Fig. 2B). Despite the large difference from the lowest to highest racks, no significant difference was evident in mortality among treatments ($P = 0.08$, $f = 3.3$). Oyster condition index remained consistent across rack heights ($P = 0.92$, $f = 0.08$; Fig. 2C), with an average condition across all treatments of 2.75 ± 0.3 g/mm. Similarly, standardized shell strength, in Newtons per gram of dry shell weight, did not differ across treatment groups ($P = 0.84$, $f = 0.18$; Fig. 2D).

Mud blister (*Polydora websteri*) coverage and prevalence on shell interiors varied among rack heights with 18% ± 9% shell area coverage and 97% ± 5% prevalence on the 15″ racks, and 9% ± 9% shell area coverage and 62% ± 30% prevalence on the 30″ racks (Fig. 3). Interior shell area covered with blisters significantly varied with rack height ($P = 0.04$, $f = 4.6$) with highest rack having significantly less blister coverage than the lowest rack (Fig. 3A). Prevalence of *P. websteri* blisters measured as the proportion of oyster with at least one blister varied greatly in the 30″ rack treatment, and did not vary significantly by rack height ($P = 0.16$, $f = 2.3$; Fig. 3B).

Weighted prevalences of Dermo disease (*Perkinsus marinus)* were lowest (average Makin score 0.6) at the highest (30″) racks, and highest (average Makin score 2.5) at the lowest racks (15″), although no significant difference was detected among treatments ($P = 0.08$, $f = 3.9$). Very low levels of *Haplosporidium nelsoni* (MSX) parasite infection were observed among all rack heights.

Economic Model

Enterprise Budget

Table 2 shows the enterprise budget for one cohort of 400,000 oysters under baseline farm assumptions. For simplicity, it was assumed that all 268,600 marketable oysters are harvested after a 26-mo grow-out period (a weighted average, which spans several months as oysters reach marketable size of 2.5–3 in.). The model attempts to isolate costs for one cohort of oysters; therefore, the year prior to harvest included no revenue. The traditional breakeven price, which covers fixed and variable costs, is \$0.50 per oyster. Including the additional \$0.20 per oyster postharvest costs (including delivery) raises the breakeven price to \$0.70 per oyster. When sold at a wholesale price of \$1.10 per oyster, the profit (before taxes) is \$0.40 per oyster.

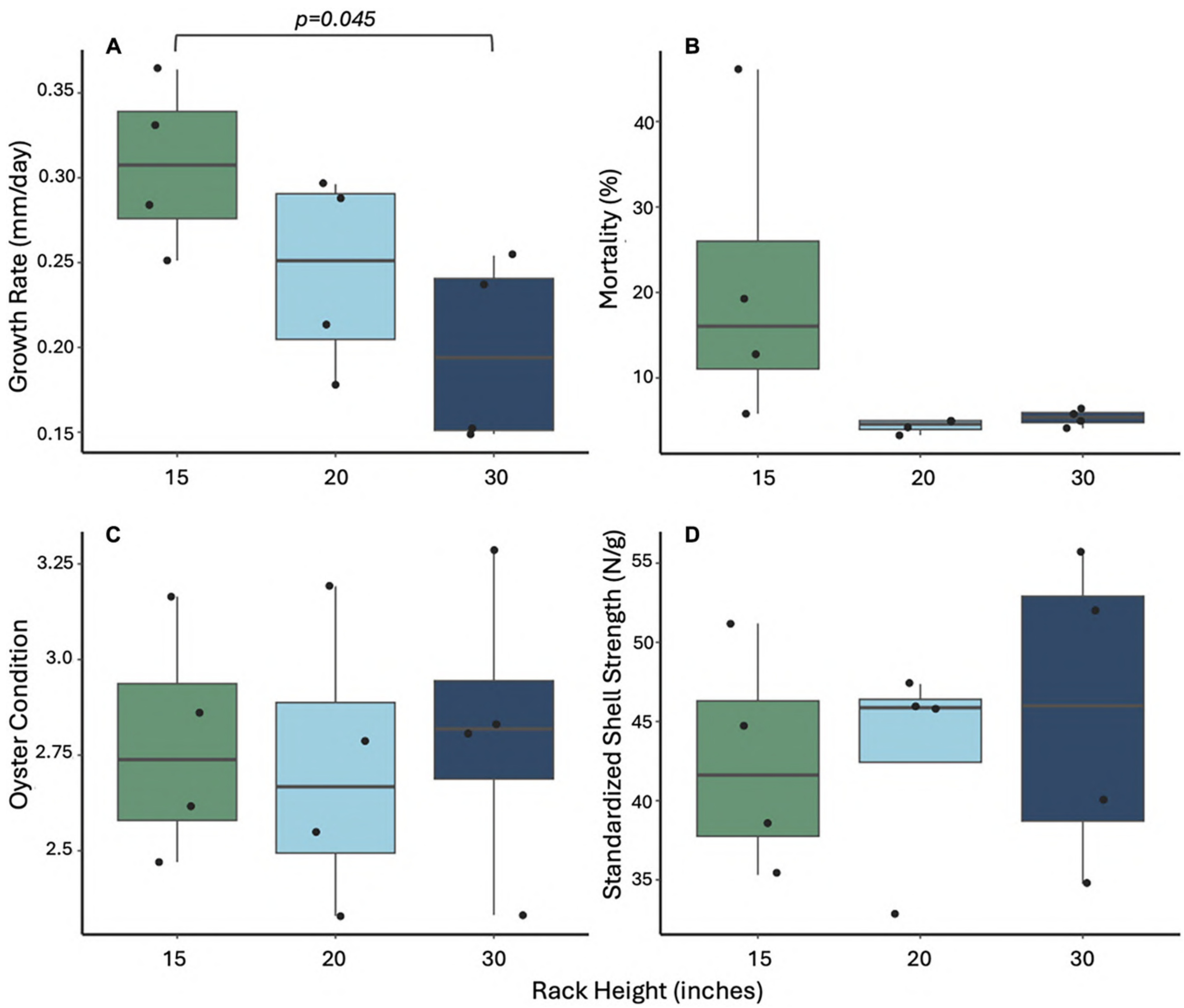

Figure 2. Box and whisker plots of oyster growth rate in mm/day (A), percent oyster mortality (B), oyster condition (C), and standardized shell breaking strength (D) across three rack heights (15″, 20″, and 30″). Any significantly different pairwise differences among treatment levels are noted at the top of each panel.

Partial Budget Analysis

A breakdown of rack costs and general labor costs for the three rack heights is displayed in Table 3. Washing times were slightly reduced with higher racks; however, because the higher rack heights decreased growth rates, general labor involved with setting up and breaking down equipment, as well as washing, increased in season 2. Overall, increased rack heights involved additional labor costs of \$170 for 20″ racks and \$2,040 for 30″ racks. A large share of the cost increase for the higher racks was due to increased labor hours associated with a longer growing period to market. It should be noted that in the experiment, all bags were washed within a wash cycle according to the study design; however, some washes were not necessary at the higher rack heights and could have been skipped entirely, realizing additional cost savings. Not shown in the table are small increases in employment taxes and workers' compensation of \$22 and \$258, for 20″ and 30″ rack systems, respectively (Table 3).

Mortality rates for the three rack heights during the first season were held constant; however, mortality during season 2 was assumed to improve for the higher racks. This is due mainly to improved mortality observed in the field experiments during the warm temperature season when biofouling associated with polydorid worms is highest. Overall, increased rack heights reduced mortality in season 2 from 21% to 4.38% in the 20″ rack-height system, and from 21% to 5.33% in the 30″ system (Fig. 2B). The difference in yields translated directly to improved gross revenue (all three rack heights were assumed to yield similar quality oysters and bring the same price received per oyster) that provided \$61,793 and \$55,708 higher income under the 20″ and 30″ rack systems, respectively.

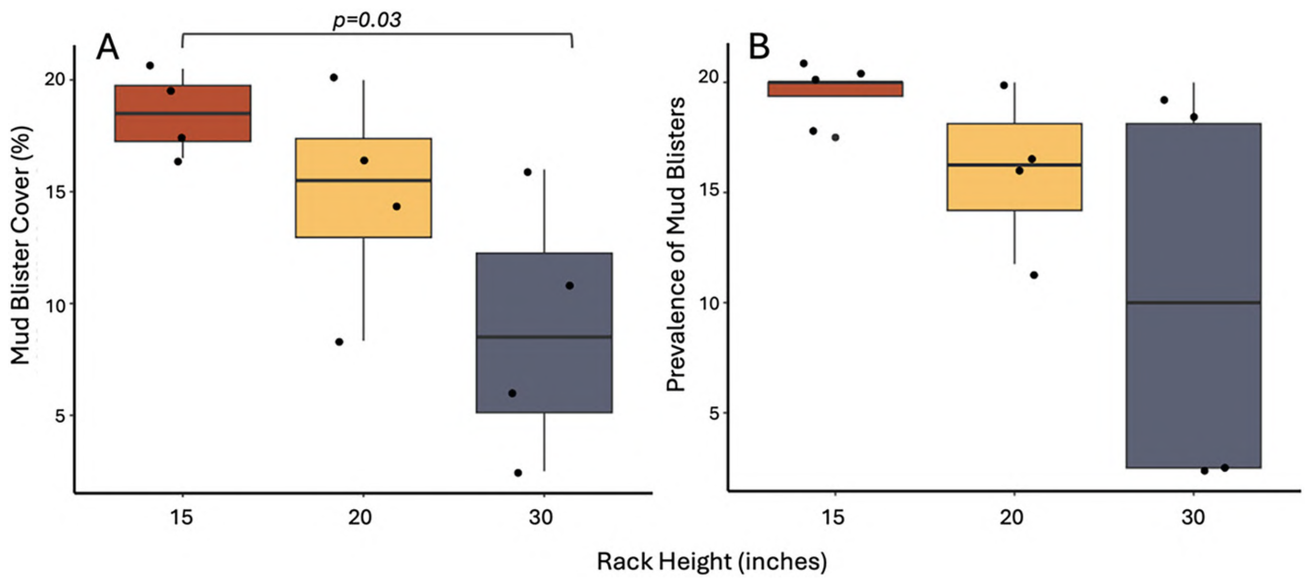

Figure 3. Box and whisker plots of percent interior oyster shell coverage by mud worm blister (A) and prevalence of interior oyster shell mud blisters (B) across three rack heights (15″, 20″, and 30″). Any significantly different pairwise differences among treatment levels are noted at the top of each panel.

Sensitivity Analysis

To illustrate the influence of oyster mortality on revenues at varying price levels, a sensitivity analysis was conducted using the standard 15″ rack-and-bag operation model. The estimated income (before taxes) of the standard rack-and-bag operation varies under several different survival and price levels (Table 4). Net income predicted by the enterprise model was highly sensitive to changes in oyster mortality. For example, holding price constant at $1.10 but increasing survival by 4% (to 83%) yields additional income of approximately $15,000.

DISCUSSION

This project evaluated the efficacy of elevated rack height as a strategy to control mud worm (genus *Polydora*) biofouling on an intertidal oyster farm employing rack and bag culture methods. Findings demonstrated that biofouling associated with *Polydora cornuta* and shell blisters caused by *Polydora websteri* can be significantly reduced by elevating rack heights from 15″ to 20″ and 30″ leading to reduced labor (wash time). Although oyster condition was not shown to be negatively impacted at the elevated rack heights, growth rate was reduced adding, on average, two more weeks of growth at 20″ and 8 wk at 30″ relative to the oysters grown on 15″ racks. It is presumed that the longer air exposure at the elevated heights reduced feeding opportunity. Despite the slight decrease in growth, condition, meat weight, and shell strength were not affected by rack height. Importantly, oysters grown on the elevated 20″ and 30″ racks exhibited lower mortality than those grown on the 15″ racks. This improved survival proved important from a production standpoint as demonstrated by the economic model applied to assess costs and benefits of the potential new biofouling management strategy. Economic analyses indicated that some labor cost was saved by using elevated racks because of reduced biofouling; however, labor increased overall because of the increased time to grow-out on the elevated racks. Higher capital and labor costs, and lower growth rates associated with higher rack heights were more than offset by increases in survival, thus increasing overall revenue and profits when using higher rack heights.

Mud worms are pervasive pests that are an important nuisance on shellfish farms worldwide (Fitridge et al. 2012, Spencer et al. 2021). During the summer months "mudding" associated with *Polydora cornuta* requires oysters to be frequently washed using high-volume trash pumps, an activity constituting a substantial cost of production. The potential of using elevated rack height as passive means to reduce biofouling and the arduous and costly labor involved in controlling *Polydora* mud worms is one that has been explored and proven elsewhere. It has been shown that intertidal oysters had lower mud blister infestation than subtidal oysters (Littlewood et al. 1992, Dorgan et al. 2021). In addition, polydorid worms with dispersive planktotrophic larvae tend to infest intertidal farms at high rates (Simon & Sato-Okoshi 2015); therefore, air drying, when timed to coincide with larval settlement, can be highly effective at reducing infestation because the larval stages are vulnerable and have not yet built protective burrows penetrating the shell (Rawson 2025). Thus, the benefit of elevating racks is 2-fold; it enables desiccation and mortality of the worms themselves, and perhaps positions the oysters above the optimal recruitment zone of the mud worms.

Elevating racks may have the additional benefit of reducing oyster disease load. The highest racks had the lowest oyster disease prevalence and intensity; however, insufficient sampling was performed to make statistical comparisons to confirm this trend. Nonetheless, dermo prevalence and intensity at the higher racks was well below levels that generate oyster mortality (Bushek et al. 2012). In a study also conducted on the Delaware Bay mudflats, Wargo and Ford (1993) found that

TABLE 2.

Intertidal rack-and-bag enterprise budget.

Item	# Units	Unit	Cost per unit ($)	Yr 1 cost ($)	Yr 2 cost ($)	Total cost ($)	Cost/oyster ($)
Variable costs							
2 mm Oyster seed	400,000	Oyster	$0.01	$4,000	$0	$4,000	$0.01
Labor General labor	3,359	$ Per hour	$17.00	$25,551	$31,552	$57,103	$0.21
Supervisory labor	1,248	$ Per hour	$25.00	$14,400	$16,800	$31,200	$0.12
Employment Tax	% of Labor costs		7.65%	$3,056	$3,699	$6,755	$0.03
Workers Comp	% of Labor costs		5.00%	$1,998	$2,418	$4,415	$0.02
Fuel		$ Per year		$300	$350	$650	$0.00
Misc supplies (e.g., boots, etc.)	% of General labor		0.80%	$200.00	$250.00	$450	$0.00
Overhead	2.0%	Of above costs		$990	$1,101	$2,091	$0.01
Total variable costs				$50,495	$56,170	$106,664	$0.40
Fixed costs							
Insurance (business liability)	1	Year		$1,090	$1,090	$2,180	$0.01
Lease fees	1	Year	$111.50	$112	$112	$223	$0.00
Permit and license fees				$751	$751	$1,502	$0.01
Repairs (vessel, cages, and trays)	2%			$1,447	$1,447	$2,894	$0.01
Depreciation				$10,357	$10,357	$20,713	$0.08
Total fixed costs				$13,756	$13,756	$27,513	$0.10
Total production costs (variable + fixed)				$64,251	$69,926	$134,177	$0.50
PostHarvest costs							
PostHarvest facility rent (inc. utilities)					$12,000	$12,000	$0.04
PostHarvest labor	1,600	$ Per hour	$17		$27,200	$27,200	$0.10
Employment tax	% of Labor costs		7.65%		$2,081	$2,081	$0.01
Workers comp	% of Labor costs		5.00%		$1,360	$1,360	$0.01
Retail containers	2,686	Bags and tags	$0.005		$13	$13	$0.00
Trucking (inc. fuel)					$5,417	$5,417	$0.02
Trucking (vehicle insurance)					$2,500	$2,500	$0.01
Marketing expenses					$2,100	$2,100	$0.01
Total PostHarvest costs				$0	$52,670	$52,670	$0.20
Grand total costs				$64,251	$122,596	$186,848	$0.70

Income (before taxes)—Wholesale market

# Market oysters	Price/ oyster ($)	Gross income ($)	Net income ($)	Net income/ oyster ($)
268,600	$1.10	$295,460	$108,612	$0.40

lower conditioned oysters tended to have higher MSX disease, and that young oysters (<1-y-old) with MSX disease were four times more likely to have mud worm blisters. By reducing disease load, elevated racks may improve the susceptibility of young oysters from being infested with mud worms.

In addition to demonstrating reduced mud worm biofouling with elevated rack height and increased drying, this study used an economic enterprise model to evaluate the overall production costs and benefits associated with using higher racks. A similar economic modeling strategy was used to evaluate the viability of a higher capital cost scallop farming approach (ear-hanging), to demonstrate that higher initial costs were offset by labor savings and improved productivity (scallop growth) (Noren et al. 2025). Economic analyses indicate that all three rack heights are practicable and can be financially viable for the farm. Higher capital and labor costs, and lower growth rates associated with higher rack heights were offset by significant increases in survival, thus increasing overall revenue and profits when higher racks are used.

Although the analysis used here was intentionally cohort-specific to align with the biological experiment design, future modeling could incorporate overlapping cohorts and multiyear cash flow projections to more fully capture operational realities. Even so, sensitivity analysis demonstrated that methods to reduce biofouling on rack and bag intertidal farms would dramatically shift profit margins. This study took place during the summer season; no weather-related damage to the racks occurred. It is presumed that elevated racks may experience a greater risk of damage by ice and winter weather; these potential costs were not evaluated nor included in our analysis. Nonetheless, the economic model presented here suggests that even small improvements in survival can greatly improve farm profitability. Conversely, even small reductions in survival could lead to serious cash flow problems.

TABLE 3.

Rack and general labor costs by rack height.

	Rack height		
	Std 15″	**20″**	**30″**
Rack costs			
Cost per rack	$28.20	$29.70	$32.70
Bungies and hooks	$12.00	$12.00	$12.00
Labor cost per rack	$30.00	$30.00	$30.00
Total cost per rack	$70.20	$71.70	$74.70
Total rack cost (300 racks)	$21,060	$21,510	$22,410
General labor costs			
Avg time to grow-out (months)	26	26.5	28
Set-up, Break-down, etc.			
1st season labor (h)	1,392	1,392	1,392
2nd season labor (h)	1,624	1,682	1,856
1st season labor cost @ $17/h ($)	$23,664	$23,664	$23,664
2nd season labor cost @ $17/h ($)	$27,608	$28,594	$31,552
Washing			
Wash-time / rack (minutes)	2.021	1.688	1.181
Season 1 # washes	11	12	13
Season 2 # washes	23	23	26
Season 1 washing labor (h)	111	101	77
Season 2 washing labor (h)	232	194	154
Season 1 washing labor cost @ $17/h ($)	$1,887	$1,717	$1,309
Season 2 washing labor cost @ $17/h ($)	$3,944	$3,298	$2,618
Total general labor			
Total season 1 labor (h)	1,503	1,493	1,469
Total season 2 labor (h)	1,856	1,876	2,010
Season 1 labor cost ($)	$25,551	$25,381	$24,973
Season 2 labor cost ($)	$31,552	$31,892	$34,170
Total general labor cost ($)	$57,103	$57,273	$59,143

TABLE 4.

Price and yield (oyster survival) effects on net income from sensitivity analysis.

		Survival (Yr 2%)					
Avg price received per oyster ($)	**67%**	**71%**	**75%**	**79%**	**83%**	**87%**	**91%**
$0.80	-$4.6	$6.3	$17.2	$28.0	$38.9	$49.8	$60.7
$0.85	$6.8	$18.3	$29.9	$41.5	$53.0	$64.6	$76.1
$0.90	$18.2	$30.4	$42.7	$54.9	$67.1	$79.4	$91.6
$0.95	$29.6	$42.5	$55.4	$68.3	$81.2	$94.2	$107.1
$1.00	$41.0	$54.6	$68.2	$81.8	$95.4	$109.0	$122.6
$1.05	$52.3	$66.6	$80.9	$95.2	$109.5	$123.7	$138.0
$1.10	$63.7	$78.7	$93.7	**$108.6**	$123.6	$138.5	$153.5
$1.15	$75.1	$90.8	$106.4	$122.0	$137.7	$153.3	$169.0
$1.20	$86.5	$102.8	$119.2	$135.5	$151.8	$168.1	$184.4
$1.25	$97.9	$114.9	$131.9	$148.9	$165.9	$182.9	$199.9
$1.30	$109.3	$127.0	$144.7	$162.3	$180.0	$197.7	$215.4

Annual income shown in $1,000 s. The center income level (shown in bold) represents the baseline case used in this study.

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