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Economic feasibility of producing oysters using a small-scale Hawaiian fishpond model

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ABSTRACT

Traditional fishpond aquaculture in Hawai'i has declined since global trade provided access to cheaper, imported food. Farming non-native species like the Pacific oyster may prove more profitable than traditional species, and may help maintain the practice of fishpond aquaculture. Little literature exists on the economics of Hawai'i's oyster culture or the unique practices involved in fishpond-based production. Based on information supplied by a currently operating farm, we developed an enterprise budget for a model farm in order to 1) assess profitability, 2) determine sensitive input parameters, and 3) use stochastic modeling to determine the likelihood of different economic outcomes. The budget returned a marginally negative profit, with the bulk of operating costs from labor. Decision reversal analysis showed the model farm can be profitable with an increase in market price from US $1.25 to US $1.35 per oyster or a decrease in mortality rate from 50% to 45.9% – both are within reasonable reach in the near future.

1. Introduction

The people of Hawai'i were food self-sufficient centuries before contact with western civilization created a system of trade with the rest of the world. In addition to farming, hunting, and fishing, Hawaiians practiced aquaculture using fishponds. One type of pond, the loko kuapā, was built with a seawall of coral or lava rock around a portion of the shoreline. Sluice gates built into the wall restricted movement of fish into and out of the pond, allowing the overseer to control stocking and harvesting. Fishponds produced up to 900,000 kg (2 million pounds) of food annually, prior to the arrival of Captain James Cook in 1778 (Keala et al., 2007). Competition from cheaper imports, however, shifted food sourcing away from aquaculture, contributing to a historical decline in fishpond productivity. By 1975–1976, fishponds produced only 9000 kg (20,000 pounds) of food. Recent attempts to grow historically significant species like moi (Pacific threadfin), milkfish and mullet have also had little economic success, and only six structures are used actively for aquaculture today.

Raising species novel to Hawaiian fishponds may prove more profitable than farming traditional species. Hawai'i's waters are particularly well-suited for growing the Pacific oyster, *Crassostrea gigas*. In 2014, fishpond aquaculturists on the east coast of O'ahu began selling the first locally-grown oyster available in decades. Triploid oysters, like those raised on the farm, have been shown to grow faster than diploid counterparts in warm climates (Nell, 2002). Hawai'i-grown oysters are reared from 6 mm spat to 75–100 mm (3–4 inch) market size products in as few as 6 months. Conspecifics from the northwest coast of the U.S. can take 2–3 years to reach the same size (Haws and Howerton n.d.). Fishponds also provide a constant source of natural algal feed for oysters. This allows farmers to avoid the high cost of growing feed, which is characteristic of raceway aquaculture.

High operational costs continue to challenge the aquaculture industry in Hawai'i. The state's labor cost share is 42%, nearly 3.5 times higher than that of mainland operations (Naomasa et al., 2013). Unpredictable environmental stressors can also create additional financial burdens for fishpond aquaculture. Loko kuapā are particularly susceptible to runoff and pollution because of their shoreline locations. Oysters grown in waters that are not classified as "approved" by the State of Hawai'i Department of Health must be depurated at a land-based facility. This activity removes any

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potential contaminants sequestered from pond water. Literature on potentially costly depuration dates back the 1980s (Yamauchi et al., 1983) and no recent characterizations of costs exists. Oysters grown in fishponds are also susceptible to natural disasters, unlike their counterparts that are grown in carefully controlled, indoor raceways. The former are likely to face higher mortality rates and less predictable yield on a year-to-year basis. The state government is interested in developing an oyster industry despite the challenges, and has collaborated with multiple stakeholder agencies to streamline the aquaculture permitting process. Before more efforts are made to advance the industry, however, it is necessary to address the economic unknowns of oyster farming in Hawai‘i.

Several useful budgeting tools have been developed for bivalve producers in the last 15 years (Adams et al., 2001; North Carolina Department of Agriculture and Consumer Services 2001; Hudson et al., 2012a,b). The spreadsheet-based enterprise budget created by the Virginia Institute of Marine Sciences (Hudson et al., 2012a,b) is a comprehensive guideline for cultchless,[1] single-seed oyster production. The budget closely resembles the model case used in this study. Researchers identified labor and oyster seed as the highest operational costs, comprising 64.1% and 10.9% of the overall budget, respectively. They also identified market price and oyster mortality rate as two of the parameters having "the most impact" (on the budget). These figures provide insight on the cost structure of an outdoor farm resembling our model case.

In this study we investigate the economic feasibility of a small-scale oyster farm based at a traditional Hawaiian fishpond in terms of production costs and current market prices. The breakeven price to achieve the desired return and the most limiting factor to production was determined. The profitability, sensitivity of input parameters, and the probability of different outcomes were also investigated.

2. Methods

2.1. Experimental design

To conduct this study, we collected economic and operational (e.g. annual seed plantings) data for the last three years from an active oyster farm. We interviewed employees to create a comprehensive list of activities and equipment involved in the initial construction and daily operation of the facility. The site is located at a traditional Hawaiian fishpond that currently farms the Pacific oyster, *Crassostrea gigas*. Oysters are grown as single-seed individuals and sold as shell stock (i.e. in-shell) products. Depuration is mandatory for this farm due to its low water quality. Output is currently limited by use of a single depuration tank.

To protect confidential information,[2] a model farm case was developed. The model case derives real costs obtained from the current farm, when appropriate. Cost estimates are also based on expert testimony, as well as state and federal government statistics. The model farm uses three depuration tanks and will operate at three times the capacity of the existing farm. It projects a sales volume of 156,000 shell stock oysters a year, assuming a 50% mortality rate.[3] This requires a planting of 312,000 individual seed oysters, known collectively as spat, a year. Spat is planted in cohorts on a staggered schedule. This produces more even temporal distribution of harvest, sales, and labor hours. The model will operate for 10 years on the island of O'ahu, where the existing farm is currently located. As a small-scale farm, it will be run by an owner-operator who actively participates in aquaculture activities, and therefore receives an hourly wage in addition to profits.

2.2. Financial calculations

An enterprise budget (Tables 1 and 2) was specifically designed for a small-scale oyster producer, defined as 50,000–250,000 market size oysters sold per year (Hudson et al., 2012a,b). Annual pre-tax return was calculated by taking the difference between income from oyster sales and cost. It is important to note that the study is a pre-tax analysis. Annualized costs (using a straight-line depreciation scheme) on normally depreciable items, therefore, were used in lieu of depreciation schedules (MACRS) allowed by the Internal Revenue Service (IRS) of the United States. A cash flow was constructed for years zero through ten of operation. Annual net cash flows (cash inflows – cash outflows) were used to calculate modified internal rate of return (MIRR) at a 6% reinvestment rate and a 6% finance rate.[4] Internal rate of return (IRR) was also calculated for comparative purposes, though MIRR is the focus of analysis in this study.[5] Net present value (NPV) was also determined with a 6% discount rate. All monetary values are in USD ($).

A sensitivity analysis was conducted in order to calculate MIRR as a function of percent changes in parameter values. We chose to address seven specific parameters based on the high potential for impacting the economic outcome of the farm. Wage,[6] electricity, and water rates were examined because high costs of labor and energy have been, historically, impediments to the development of the aquaculture industry (Naomasa et al., 2013). We also chose to address the inputs representing high percentage costs of the budget, i.e. oyster seed and rent. Finally, we examined mortality rate and market price because these variables directly affect harvest quantity and income earned, respectively.

2.3. Stochastic model of a small-scale oyster farm

Stochastic modeling was used to address possible outcomes of the operation. Specifically, we used Monte Carlo simulation available through Risk Solver Version 9.6.3.0 (Frontline Systems Inc., Incline Village, Nevada, USA) analytical software to project a range of net present values for the 10-year operation. Three separate simulations were run under the premise that mortality rate and market price are random variables. The first included mortality as a triangularly distributed variable having a minimum value of 30% and a

[1] Cultchless oysters are individuals unattached to hard substrate, in contrast to reef oysters, for example. These are typically intended for half shell consumption.

[2] The currently operating farm is owned by a well-known agri-tourism business; this is atypical of the majority of Hawaiian fishponds. The farm's circumstances represent a unique case, and therefore our study uses a model case that better reflects more general conditions. Scaling up the model to three times the output capacity of the current farm is advantageous for the following reasons: (1) costs are based on real estimates, yet proprietary financial information related to the specific operating structure of the farm is protected, and (2) new farms are expected to operate at a similar capacity.

[3] Mortality in this study is equivalent to total production loss. This includes not only naturally occurring death, but oysters that have been culled, and those infected beyond salability with *Polydora* spp.

[4] The State of Hawai‘i provides a 6% interest rate on farm operating loans for new farmers (State of Hawai‘i Agricultural Loan Division n.d.) A 6% reinvestment rate was used recently in a similar economic feasibility study on aquaponics operations in Hawai‘i (Tokunaga et al., 2015).

[5] MIRR, or modified internal rate of return, is used in lieu of traditional IRR methods. Sullivan et al. (2006) discuss the weaknesses of the latter. MIRR, unlike IRR, is advantageous in several regards by: 1) allowing the user to define the reinvestment rate, 2) avoiding guesswork, and is therefore easier to solve for in a direct manner, and 3) avoiding the potential of generating multiple IRR values.

[6] The study examines the part-time wage rate, as the owner-operator's full-time pay is not likely to change. Other cases may utilize non-owner, full-time employees as well as part-time employees, and thus may choose to address these rates accordingly.

Table 1
Annualized cost enterprise budget.

Item	Unit	Quantity of units	Cost per unit ($)[a]	Total ($)
Gross receipts				
Market oyster revenue	Single oyster	156,000	1.25	195,000.00
Tax collected on sales[b]	Per dollar sales	195,000	0.5%	975.00
Operating expenses				
Oyster Seed (*C. gigas)*	1000	312	35.00	10,920.00
Full-time labor (Owner/operator)	Hour	2080	23.53	48,942.40
Part-time labor	Hour	2808	13.00	36,504.00
Fringe benefits	Proportion of wage	85,446	49.93%	42,659.15
Shipping	Per 30,000 spat	11	50.00	550.00
Fuel (truck and boat)	1 L	2726.21	1.03	2808.00
Artificial seawater	1000 L	31.49	107.32	3380.00
Maintenance	Annual expense	1	1266.67	1266.67
Expendable supplies[c]	Annual expense	1	70.00	70.00
Miscellaneous supplies[c]	Annual expense	1	1300.00	1300.00
Electricity	kWh	6985	21.33 ¢	1489.99
Water	1000 L	545.22	1.31	714.24
General excise tax[b]	Per dollar sales	195,000	0.5%	975.00
Rent on gross receipts	Per dollar sales	195,000	1.5%	2925.00
Total operating expenses				153,529.44
Return over operating expenses				41,470.56
Fixed costs				
Truck insurance	Annual expense	1	400.00	400.00
Business liability insurance	Annual expense	1	700.00	700.00
Business entity structuring fees[c]	Annualized start-up cost	1	11.00	11.00
Other taxes and fees[c]	Annual expense	1	1262.12	1262.12
Rent	1 ha per year	20.23	1235.53	25,000.00
Annualized equipment expenses[c]	Annualized start-up cost	1	7060.10	7060.10
Total fixed costs				34,433.32
Permits and testing costs				
Permits[c]	Annualized start-up cost	1	7146.50	7146.50
Private lab testing[c]	Annualized start-up cost	1	360.00	360.00
DOH certification testing[c]	Total Annual cost (includes year 0)	1	9000.00	9000.00
Total permits and testing costs				16,506.50
Total annual costs				204,469.16
Estimated pre-tax return				−9469.16

[a] Units are in US dollars ($) unless otherwise noted.
[b] General excise tax is passed onto the consumer at the register, netting in a $0 expense.
[c] See Appendix A.

Table 2
Start-up cost enterprise budget.

Item	Unit	Quantity of units	Cost per unit ($)	Total ($)
Business entity structuring fees	One-time fee	1	110.00	110.00
Equipment				
Boat hull	Used 4.3 m (14 feet) boat	1	2500.00	2500.00
Boat engine	11.2 kW (15 horsepower) unit	1	3500.00	3500.00
Truck	Used truck	1	5000.00	5000.00
Cages	25.4 mm (1 in.) wired cage	900	35.00	31,500.00
Refrigerator	780 W refrigerator	1	350.00	350.00
Sorting table	Table	1	300.00	300.00
Depuration tank	Custom-made tank	3	3964.60	11,893.80
Depuration tank equipment	1 set of materials	3	1035.40	3106.20
Driveway	Paved driveway	1	3500.00	3500.00
Air conditioning unit (cold room)	1330 W household air conditioning unit	1	239.00	239.00
Air conditioner converter unit	Converter unit	1	350.00	350.00
Cold room building materials	1 set of materials	1	1200.00	1200.00
Metal trailer (office)	Commercial trailer	1	7000.00	7000.00
Tent frame	9.1 m × 18.3 m (30 × 60 feet) tent	1	1833.00	1833.00
Total equipment expenses				72,272.00
Permits and testing				
Ground and waters leasing	Start-up cost	1	71,465.00	71,465.00
Private laboratory testing	Start-up cost	1	3600.00	3600.00
DOH certification testing	Total annual cost (includes year 0)	1	9000.00	9000.00
Total permits and testing costs				84,065.00
Total start-up costs				156,447.00

Table 3
Production stages for single cohort grow-out.

Activity or measurement of interest	Value
Stocking size	6–8 mm
Duration in 5 mm lined cage	14 days
Duration in 12.7 mm (0.5 in.) lined cage	56 days
Duration in 25.4 (1 in.) unlined cage	112–293 days
Duration in depuration tank	2 days
Harvest size	75–100 mm (3–4 inch)
Harvest frequency	Once per week

Table 4
Weekly labor hours.

Activity	Quantity	Hour/wk	Total hour/wk
Facility maintenance	1	10	10
Pond maintenance	1	8	8
Record-keeping, administration, public relations	1	10	10
Individual tank setup and break down	3	3	9
Packing and transport	3	3	9
Out-of-pond treatment (sort, freshwater dip, dryout)	1	48	48
Total			94

maximum value of 60%, with the most likely value set at 50%.[7] A second simulation examined the array of economic outcomes when market price was triangularly distributed with lower and upper limits of $1.00 and $1.50, respectively, with the most likely value set at $1.25. A final simulation was run using both random variables simultaneously. Each simulation included 1000 trials of the respective model. Output results will help stakeholders determine a range of economic outcomes from worst to best-case scenarios, as well as understand the distribution (or likelihood) of the range of outcomes.

2.4. Production schedule and stocking

Oysters are stocked in 7.6 L (2 gallon) volumes in cylindrical, floating cages. Seed is grown out initially in cages lined with 5 mm mesh (Table 3). After 14 days, oysters are transferred to cages lined with 12.7 mm (0.5 inch) mesh. They are then transferred to unlined cages after another 56 days. Oysters from a single cohort are given 6–12 months to reach market size. It is assumed that the pond itself can support grow-out of the 312,000 seed initially stocked. Market size oysters are depurated for 48 h in batches of 1000. Each depuration tank is run once a week.

3. Results

3.1. Operational costs

The total annual cost of operating the oyster farm is $204,470 (Table 1). The largest cost component is labor, which is 62.7% of the annual budget. Farm activities are listed to provide insight on how hours are allocated (Table 4). Labor cost is the sum of all wages and fringe benefits. Full-time wage of the owner-operator is set at $23.53 per hour, and part-time wage at $13 per hour.[8,9,10] The second most costly item is rent, comprising 13.6% of the budget (when including the 1.5% levy charged by the State of Hawai‘i on gross income earned on its leased agricultural land). The next largest cost component is spat, at 5.3% of the total budget.

3.2. Start-up costs

The total start-up cost in Year 0 is $156,447 (Table 2). The largest cost component is the purchase of all equipment, vehicles, and materials required to establish the farm. This sum represents 46.2% of the entire start-up budget. Cages used for grow-out comprise a large portion of this, accounting for 20.1% of the budget. At $35 per cage and an inventory of 900 units, this cost component totals $31,500. The land-based depuration facility comprises another 9.6% of the entire start-up budget at a cost of $15,000. In both cases, costs are inclusive of both materials and labor in the construction of the items. The initial permitting and fees category comprises another 53.7% of the budget.[11] The remainder of the total budget consists of a small business entity structuring fee.

3.3. Cash flow and financial metrics

The current target sales volume is 156,000 half-shell oysters priced at $1.25. This most accurately reflects the current market price for locally-grown oysters, and is comparable to the retail price of imported oysters in Hawai‘i. Gross annual income at these values totals to $195,000. After subtracting annual costs, net pre-tax return is −$9469. Using a 6% discount rate and a time frame of 10 years, NPV calculates to −$117,165 (Table 5). The cash flow varies from year to year as a result of costs for replacing certain pieces of equipment whose actual usable life has ended (Table 5).[12] Net cash flow values are used to determine IRR, which computes to −12.2%. MIRR is −7.7%, at both a reinvestment rate and a financing rate of 6%. The model farm is not worth considering as an investment option based on these results, but return is marginally negative. Stakeholders may consider options for reducing costs or increasing output in order to capture a positive return.

3.4. Sensitivity analysis and decision reversal

MIRR is most sensitive to changes in market price and mortality rate (Fig. 1). A mere 5% increase in market price, from $1.25 to $1.31, increases the baseline MIRR from −7.7% to 2.3%. A 5% decrease from the baseline mortality rate also increases the MIRR to the same value. MIRR is least sensitive to the price of water, out of the seven parameters examined. Given a 50% decrease in water price, the modified internal rate of return increases from its baseline value to only −7.1%.

[7] These values represent probable range based on current experimental results from oyster growout at the Pacific Aquaculture and Coastal Resources Center.

[8] A farm owner-operator is considered a first-line supervisor (National Center for O*NET Development n.d.).

[9] The average wage of a first-line supervisor is $23.53 (Bureau of Labor Statistics, 2015a).

[10] The State of Hawai‘i pays an average of $14.15 per hour for employees in agricultural and production trades (Bureau of Labor Statistics, 2015b). A full-time employee in the model case would earn $15/hour, while a part-time employee would earn $13/hour. These rates are deemed acceptable values based on the state average.

[11] The total cost of permits necessary for proper fishpond restoration (for the purpose of aquaculture) has been estimated to be between $50,000 and $80,000 (Keala et al., 2007). Where possible, exact costs of permit application fees are used. These fees can be found on the Hawai‘i Department of Agriculture website (Hawai‘i Department of Agriculture, 2011). Site assessment costs are variable. Our study assumes a $5000 cost for each type of assessment necessary, as this allows the total permitting cost to fall between $50,000 and $80,000.

[12] Actual usable life was determined from observations by employees at the currently operating farm.

Table 5
10-year cash flow budget. Units shown are USD ($) unless otherwise stated.

Item[a]	Year 0	1–3	4	5	6	7	8	9	10
Oyster revenue		195,000	195,000	195,000	195,000	195,000	195,000	195,000	195,000
Salvage revenue									12,189
Operating expenses		153,530	153,530	153,530	153,530	153,530	153,530	153,530	153,530
Fixed costs[b]	110	27,362	27,362	27,362	27,362	27,362	27,362	27,362	27,362
Equipment costs	72,272		3500	2483		5000	3500		
Testing and permitting costs	84,065	9000	9000	9000	9000	9000	9000	9000	
Cash flow	−156,447	5108	1608	2625	5108	108	1608	5108	26,297
NPV	−117,165								
IRR(%)	−12.2								
Discount rate (%)	6								
MIRR (%)	−7.7								
Finance rate (%)	6								
Reinvestment rate (%)	6								

[a] General excise tax, as both an operating expense (charged by the State of Hawai'i) and a source of revenue (when passed onto consumers) is excluded, as it nets in $0.
[b] Excluding equipment purchases.

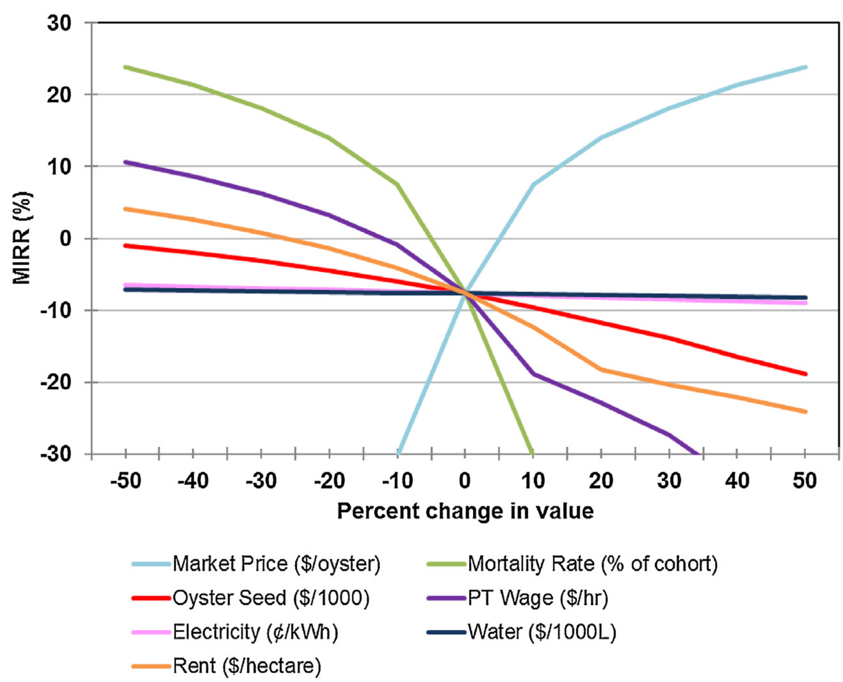

Fig. 1. Modified internal rate of return (MIRR) sensitivity to percent change in key parameter values.

Table 6
Decision reversal values (DRV) and percent change from baseline at MIRR of 6%.

		Model farm case		No depuration facility		No rent	
Parameter	Baseline value	DRV	Percent change	DRV	Percent change	DRV	Percent change
Market price ($/oyster)	1.25	1.35	8.0	1.25	0.0	1.17	−6.4
Mortality rate (% annually)	50	45.9	−8.3	49.95	−0.1	53.07	6.1
Oyster seed ($/1000)	35.00	[a]	−146	34.65	−1.0	73.28	109
Part time wage ($/h)	13.00	9.24	−28.9	12.95	−0.4	15.81	21.6
Electricity (¢/kWh)	21.33	[a]	−1067	18.99	−11.0	192.93	804
Water ($/1000 L)	1.31	[a]	−2227	0.90	−31.1	23.28	1677
Rent ($/ha)	1235.53	450.97	−63.5	1223.17	−1.0	N/A	N/A
Total revenue ($)	195,000	211,139	8.3	195,198	0.1	183,014	−6.2

[a] Negative value.

Decision reversal analysis determines the values at which the MIRR is equal to the minimum acceptable rate, or 6% (Table 6). An increase in market price from $1.25 to $1.35 would raise the MIRR to 6%, making the investment worth consideration. An 8.3% decrease in mortality rate would also provide a return meeting the minimum MIRR value. An overall increase in gross annual income (Table 6) from $195,000 to $211,139 would be required to raise the MIRR value to the reinvestment rate of 6%. This equates to requiring an additional output of 12,912 oysters annually.

The study also examines the outcome of two alternate scenarios, an oyster farm operating without a depuration facility (and associated labor, utility, and materials costs), and one without

Table 7
Cost comparison between model farm and alternate farm with no depuration costs.

Line Item	With depuration ($)	Without depuration($)	Percent reduction (%)
Labor	128,106	118,984	7.1
Artificial seawater	3380	0	100.0
Maintenance	1267	767	39.5
Utilities (water and electricity)	2204	1834	16.8
Equipment	7060	6155	12.8
Permitting and testing	16,507	16,147	2.2

rent costs. Without the necessity of depuration, annual operational costs decrease by 8.7%. A reduction in labor hours is responsible for much of the savings. Fixed costs and permitting and testing expenses also decrease by 2.6% and 2.2%, respectively. The farm that does not require depuration would see a reduction of $14,637 in annual costs, or 7.2% of the total budget (Table 7). Without rent, the farm would achieve a savings of $25,000 from the lease, as well as another $2925 from the surcharge imposed by the state on gross income earned. A decision reversal exercise was also conducted for both alternate farms. Results of the model case as well as both alternate scenarios are summarized in Table 6.

3.5. Stochastic modeling

Using the Monte Carlo method, we run 1000 trials of three separate simulations. Results of the model including stochastic mortality show a worst-case scenario, NPV of −$380,000 and a best-case scenario value of $426,900 (Table 8). The mean value of all trials is −$18,200 with a standard deviation of $174,000. Based on the simulation, 43.3% of trials resulted in the desired 6% return (Fig. 2). When 1000 trials of the stochastic price model were run, results showed a mean NPV of roughly −$118,600 with a standard deviation of $113,900 (Fig. 3; Table 8).

In a final simulation, both parameters are modeled as random, triangularly distributed variables. One thousand trials of the simulation result in a mean NPV of −$24,500 with a standard deviation of $221,000 (Fig. 4; Table 8).

3.6. Economies of scale

The concept of economies of scale is not directly addressed in the study, but a brief analysis shows that only a portion of line items increase in cost between the existing farm and the model case (operating at three times capacity). This implies that economies of scale may be achieved. The structure of the labor force changes, (i.e. whether an employee is hired at part-time or full-time hours, and at what wage) and thus cannot be compared directly from onefold to threefold production. Total cost of labor, however, can be used for comparison. A threefold output of market-ready oysters requires only a 6.6% increase in total labor cost from roughly $120,154 to $128,106 (Table 9). Fixed costs such as truck insurance and most equipment purchases provide further evidence of economies of scale, as they remain static regardless of the size of the farm.

4. Discussion

We construct an enterprise budget for a model oyster farm operating at a traditional Hawaiian fishpond. Annual costs total to $204,470. The largest expense is labor, comprising 62.7% of the budget. Based on a yearly output of 156,000 oysters, there is an estimated net annual loss of $9469. A small-scale oyster farm appears to be marginally unprofitable, but may still be a viable enterprise if major costs revealed by the budget can be reduced, or if more revenue is generated by increasing production or selling price.

Our model farm requires an initial investment of $156,447. Roughly half of this is the cost of purchasing equipment and materials for facility setup, while the other half consists almost entirely of initial permitting costs and fees. The permitting process entails a multitude of site assessments and applications at the county, state, and federal level. Additionally, the culture of bivalve shellfish requires strict adherence to both Food and Drug Administration regulations and the State of Hawai'i Shellfish Sanitation Plan codes. The budget includes the cost of water quality testing of the grow-out area, estimated at $9000, despite the fact that the State of Hawai'i is currently not charging for this service. There is no guar-

Table 8
Summary of stochastic modeling results.

	Variable mortality	Variable market price	Variable market price and mortality
NPV ($):			
Mean	−18,200	−118,600	−24,500
Standard deviation	174,000	113,900	221,000
Minimum value	−380,000	−394,400	−516,100
Maximum value	426,900	146,300	691,100
Range	806,900	540,700	1,207,200
Percent of trials ≥6% return	43.3	17.0	42.7

Table 9
Comparison of labor structure and hours worked between two production capacities.

Farm type	Maximum annual harvest	Owner/operator hours worked ($23.53/h)	Other full time[a] hours worked ($15/h)	Part time[b] hours worked ($13/h)	Total hours worked	Employees	Total cost (includes fringe benefits) ($)
Current farm[c]	52,000	2080	2080	0	4160	1 Owner, 1 FT	120,154.52
Model farm[d]	156,000	2080	0	2808	4888	1 Owner, 2 PT	128,106.55

[a] Full time (FT) employees work 2080 h per year.
[b] Part time (PT) employees work 1404 h per year.
[c] Values for the currently operating farm are provided as a point of comparison.
[d] The model farm used in this paper is operating at three times the capacity of the current farm.

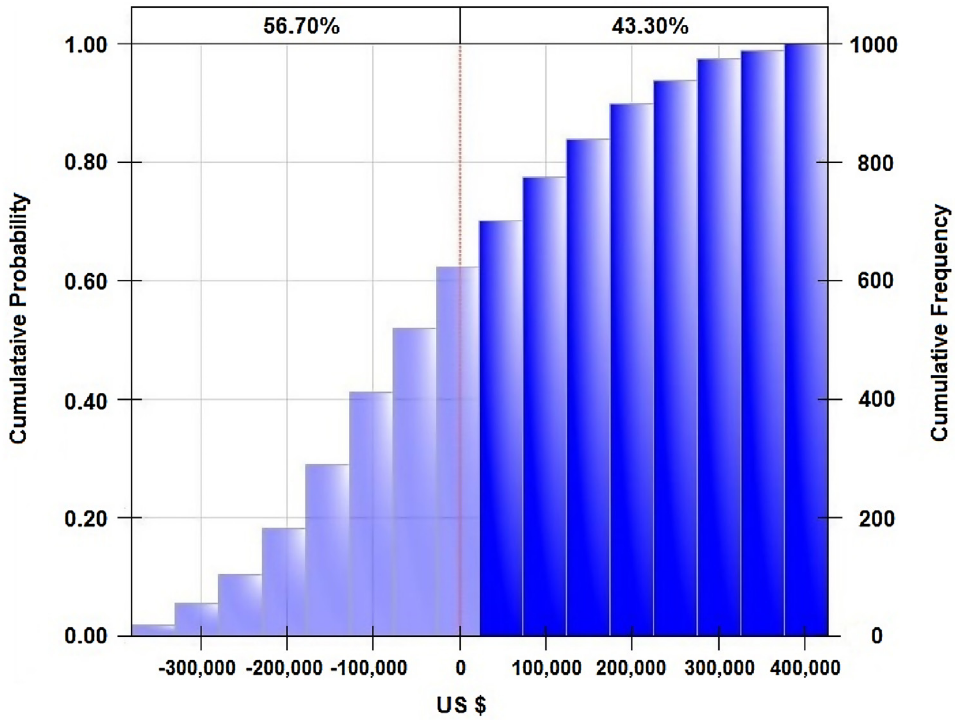

Fig. 2. Cumulative frequency of simulated net present value (NPV) for 1000 trials with mortality modeled as random, triangularly distributed variable.

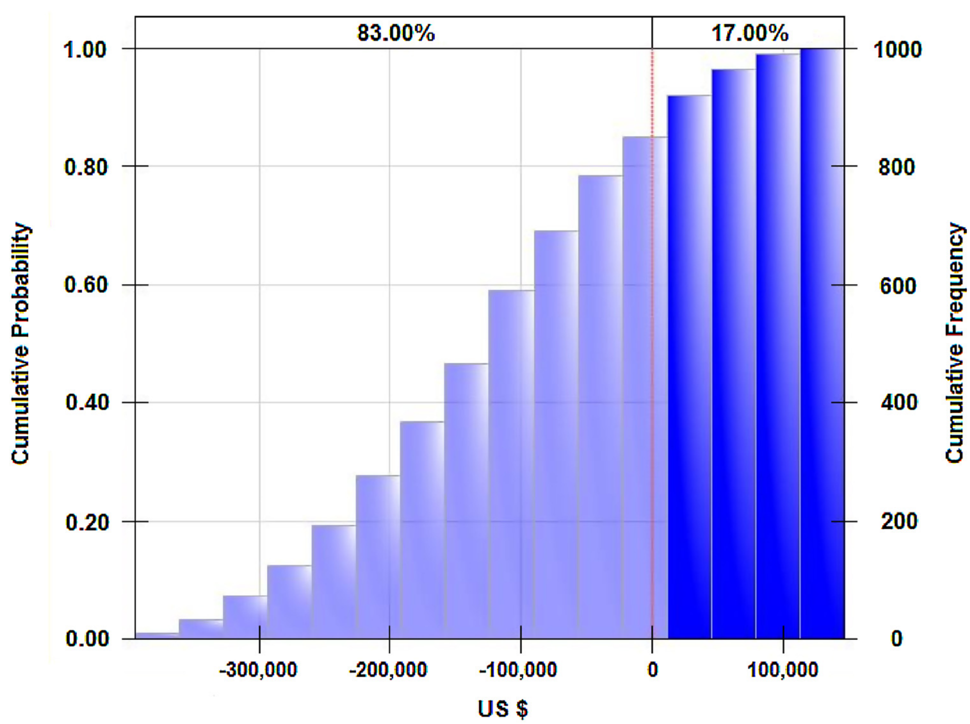

Fig. 3. Cumulative frequency of simulated net present value (NPV) for 1000 trials with market price modeled as random, triangularly distributed variable.

antee that the state will continue to subsidize these costs, thus, we provide an estimate in order to prepare stakeholders for a large initial investment in an oyster farm.

Enterprise budgets structured for shellfish farms on the mainland United States have provided insight on the performance of other operations. One model farm selling market size oysters for $0.25 each achieved an output of 240,000 individuals over the course of 2 years (Hudson et al., 2012a,b). It earned a revenue of $60,000. This case resulted in a negative profit, like our model Hawai‘i farm, with net loss equaling $67,627 in the first year of harvest, and $23,523 in the second year. Despite the similarity in operation size, the mainland-based study had annual expenses in the range of ~$74,000–$78,000. These values are significantly lower than the projected ~$204,000 annual expense on our model farm. In addition to lower overall labor costs, the budget cited a meager $3.71 per hectare ($1.50 per acre) per year lease rate, only

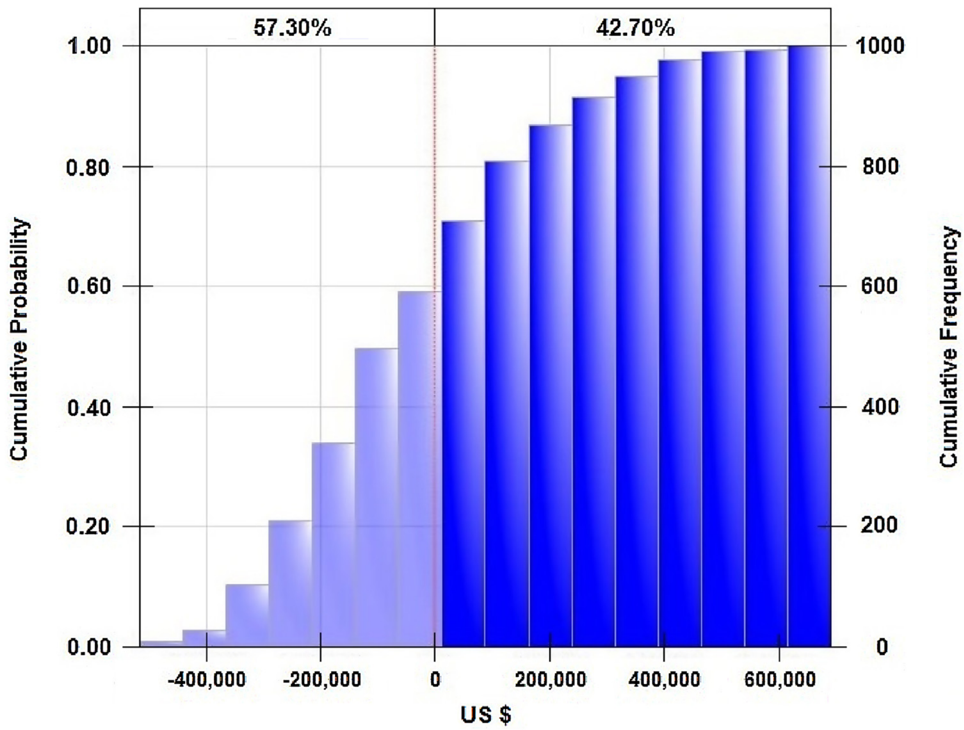

Fig. 4. Cumulative frequency of simulated net present value (NPV) for 1000 trials with market price and mortality modeled as random, triangularly distributed variables.

0.3% of what a Hawai'i fishpond farmer can expect to pay for a coastal agricultural lease. Further research indicates that use of floating cages in fishpond culture is far costlier than other methods of shellfish aquaculture. A model farm in North Carolina using bottom net culture, producing 220,000 *Mercenaria* clams annually, listed only ~$7600 in labor costs (North Carolina Department of Agriculture and Consumer Services, 2001). Growing oysters in a Hawaiian fishpond is a unique farming method, and cannot be expected to perform in a manner similar to other shellfish farms.

Results of the sensitivity analysis offer insight on which inputs should be addressed in order to maximize profit. Success of a fishpond-based oyster farm is largely dependent on two variables. Understanding that MIRR is particularly sensitive to market price, we suggest increasing the target price 10% to $1.38, to achieve a $9738 annual pre-tax return, and an overall MIRR of 7.5%. Understanding the contributors to oyster mortality is also key to reducing loss of profit, since every casualty represents a potential loss of $1.25 in income. Decreasing mortality just 10% a year to an overall rate of 45% would also result in a 7.5% MIRR.

The enterprise budget, cash flow, and subsequent analyses in this study provide useful metrics for predicting economic performance. They showcase only one possible outcome of the model farm, however. Stochastic modeling addresses the variability of budget inputs like mortality rate. Of 1000 trials of the Monte Carlo simulation, modeling mortality as a random variable, 43.3% have a minimum 6% return. When market price is modeled as a variable, results are less optimistic, with only 17% of trials giving the same return. The oyster farm can return both a loss and a profit of hundreds of thousands of dollars based on this exercise. Stakeholders should aim to achieve stable survival rates and a consistent selling price prior to establishing their farms. Both parameters are also modeled as variables simultaneously, in order to address the interaction between multiple unknowns in the operation. Output from this simulation demonstrates an even larger range of economic outcomes. The minimum output values for both of the other simulations ranged from −$380,000 to −$394,400; the minimum value in this case is −$516,100. The maximum value also far exceeds that of the other simulations by at least $264,000. The inclusion of a single random variable limits the model to simulating output values based on a specified distribution and range of that variable. The inclusion of two interacting variables, however, further increases the variability of the model. The economic performance of a real farm, therefore, is likely to be less predictable as the number of variables increases.

The influence of individual parameters has been discussed thus far, but the prospective fishpond to be used for production is itself a variable worth discussion. Individual ponds vary greatly in size, structure, and location. Stakeholders must carefully select potential candidates for restoration and subsequent aquaculture activities. A publication by Apple and Kikuchi (1975) listed only 56 structures as potentially productive fishponds. A more recent survey found 248 ponds where at least a partial wall was still visible (DHM Inc., 1990). Of these, 66 were owned by the State of Hawai'i. Others were owned privately, federally, by Hawai'i County, under the Hawaiian Home Lands Trust, or as a combination of the aforementioned. Depending on these attributes, lease rates can vary between ponds. The rate used in this study is a quote from an expert source and fishpond practitioner, but should be considered a baseline value for future studies and farming practice.

This study examines the cost structure of an alternate farm without a depuration facility and related activities. It would be applicable, for example, to a fishpond with sufficiently high water quality that would produce oysters that do not require depuration. Without a depuration unit, overall costs drop by 7.2%. This indicates that creating and operating a depuration center accounts for a sizable percentage of annual costs. Depuration is required for oysters grown in areas that do not meet state standards for "approved" water quality, but there are no specifications for where the activity must occur. As interest in fishpond-based oyster culture grows, planners may consider one or more centralized depuration facilities at strategic locations throughout the state. The transition to this type of system would reduce weekly labor hours by removing the need to prepare and clean in-house tanks. Time would instead be allocated to transporting oysters to and from the central facility. Additional savings would be achieved by eliminating some maintenance activities, as well as private laboratory testing of the depuration water and oyster meat. The facility would also remove the need for state employees, who travel monthly, to do depuration water quality tests at individual sites. In lieu of start-up costs like equipment purchases, and operational costs like electricity usage, users would pay an annual or per usage fee charged by the depuration center. Establishment of a centralized facility would require extensive planning, but it may be a more feasible option than requiring individual oyster farmers to structure their own depuration facilities indefinitely. Like acquiring permits, depuration remains a process that requires a great deal of expert, third-party knowledge for its proper set-up and functioning. Paying a fee and travelling to use a centralized depuration center would remove the complexities of building one's own center. It may also alleviate some of the initial burden on a farm attempting to establish itself.

The intricacies of navigating the permitting process have been another major impediment to restoring fishponds. The state's Ho'āla Loko I'a project is attempting to remedy this problem by streamlining the permitting process. The project consolidates five of the major permits necessary for fishpond restoration into a single permit known as the Statewide Programmatic General Permit (SPGP). The SPGP enables practitioners to avoid major costs incurred in preparation of documents necessary for each of the five individual permits.

Another obstacle in the initiation of a farm is the lack of availability of larger oyster spat that does not require a nursery phase. The existing farm has procured 6 mm (shell length) spat that have been shown, in field trials, to have considerably lower mortality than the 2 mm spat that is generally sold by wholesale seed providers. One author of this paper has observed 35% mortality rate during the 2–6 mm nursery phase alone during research trials. There is a trade-off between larger and smaller spat; the former demonstrates better survival rates but is purchased at a higher price, and the latter accumulates additional rearing-related costs but costs less to purchase. Grabowski et al. (2007) examined this trade-off. They found an increased cost per oyster of 10–30% and 27–47% in winter-initiated and spring/summer-initiated grow-out trials, respectively, when buying larger (25 mm) seed that did not require a nursery phase. This indicated that the savings from avoiding a nursery phase did not outweigh the additional cost of larger seed. This study, however, examined an alternative nursery set-up which did not require a Floating Upweller System (FLUPSY), as a nursery in Hawai'i most likely would require. Because larger spat is generally not grown by hatcheries, it is not likely that hopeful farmers in Hawai'i will be able to acquire the larger seed.

Individual challenges and areas for improvement are examined in the pursuit of achieving optimal performance, but expansion of the entire operation may also be considered. A look at labor provides some insight into how economies of scale may be achieved. At the baseline capacity (the rate of production of the active oyster farm) 4160 h are necessary to produce a total of 52,000 market-ready oysters annually. Only an additional 728 h a year are required to achieve threefold output. Even while the structure of the labor force may change at different capacities, we see that our case demonstrates only a 6.6% increase in overall labor cost. A current farm employee discussed an increase in work efficiency when an additional person participated in certain farm activities. Certain line items, also, do not triple as a result of increased production. Electricity provides an example of this situation. It is used, in part, for operating office appliances, and to keep the cool room at an appropriate temperature. Neither the office nor cool room require expansion (assuming they are not used to capacity at the current production rate), therefore electricity usage is not likely to differ significantly at different production capacities.

This study endeavors to provide a realistic characterization of the challenges and potential for developing a bivalve aquaculture industry in the state of Hawai'i. The challenges that were identified provide opportunity for further study and active pursuits to improve operation efficiency. Biological studies are being conducted at an aquaculture research facility based at the University of Hawai'i at Hilo in hopes of improving growing conditions for shellfish. Marketing research is also needed to determine whether or not locally-grown oysters are able to capture a price premium over the baseline $1.25 used in this study. With results of this study indicating, at the very least, potential for success, it is expected that interest in farming oysters in fishponds will continue to grow.

5. Conclusion

We conducted a thorough economic analysis of a model farm growing *C. gigas* in a traditional Hawaiian fishpond on the island of O'ahu, with a projected output of 156,000 market size oysters. Net pre-tax return was estimated at −$9469 at a selling price of $1.25 per oyster. The bulk of annual costs derived from labor. Using a finance rate and reinvestment rate of 6% MIRR was determined at −7.7%. A sensitivity analysis revealed mortality rate and market price to have the greatest impact on economic performance. A Monte Carlo exercise demonstrated a large range of returns when the two line items were modeled as random variables in two separate simulations. This range increased when the variables were modeled simultaneously in a single simulation. All three cases demonstrated profits and losses reaching hundreds of thousands of dollars. An oyster industry may be an economically viable pursuit if stable mortality rates below 45.9%, and or a minimum selling price of $1.35 per oyster can be achieved.

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Appendix A.

See Table A1–A7.

Table A1
Equipment expenses to be annualized.

Item	Cost per unit ($)	Usable life (yrs)	Times purchased over 10 yrs[a]	Usable years left on last purchase	Total cost over 10 yrs ($)	Salvage value[b] ($)	Annualized cost per item[c] ($)	Quantity of units	Total ($)
Boat hull	2500.00	25	1	15	2500.00	1500.00	100.00	1	100.00
Boat engine	3500.00	4	3	2	10,500.00	1750.00	875.00	1	875.00
Truck	5000.00	7	2	4	10,000.00	2857.14	714.29	1	714.29
Cages	35.00	10	1	0	35.00		3.50	900	3150.00
Refrigerator	350.00	5	2	0	700.00		70.00	1	70.00
Sorting table	300.00	5	2	0	600.00		60.00	1	60.00
Depuration tank	3964.60	20	1	10	3964.60	1982.30	198.23	3	594.69
Depuration tank equipment	1035.40	10	1	0	1035.40		103.54	3	310.62
Driveway	3500.00	40	1	30	3500.00	0[d]	350.00	1	350.00
Air conditioning unit (cold room)	239.00	10	1	0	239.00		23.90	1	23.90
AC to cold room converter	350.00	10	1	0	350.00		35.00	1	35.00
Cold room building materials	1200.00	20	1	10	1200.00	600.00	60.00	1	60.00
Metal trailer office	7000.00	20	1	10	7000.00	3500.00	350.00	1	350.00
Tent frame	1833.00	5	2	0	3666.00		366.60	1	366.60
Total						12,189.44	3310.06		7060.10

[a] Equipment is purchased the minimum number of times to last through 10 years of operation.
[b] Salvage value is determined by total cost divided by number of years in operation, multiplied by however many usable years are left on the item; Assume item can be sold for whatever salvage value is determined to be.
[c] Annualized cost = (total cost – salvage value)/10 years.
[d] Not salvageable.

Table A2
Other taxes and fees.

Item	Unit	Quantity of units	Cost per unit ($)	Total annual cost ($)
Boat registration fee	Annual expense	1	15.00	15.00
Truck registration fee and weight tax	Annual expense	1	425.00	425.00
Annual business report filing fee	Annual expense	1	15.00	15.00
Accounting fees (tax accounting)	Annual expense	1	300.00	300.00
Electric company base user fee	Monthly fee	12	33.00	396.00
Water company billing fee	Monthly fee	12	9.26	111.12
Total				1262.12

Table A3
Ground and waters permits to be annualized.

Item	Filing, application, hearing fees ($)	Site review, etc. costs ($)	Quantity	Total start-up cost ($)	Annualized cost ($)
Environmental assessment (federal, state, & county)		5000.00	1	5000.00	500.00
U.S. Dept. of the Army Permit – Navigable Waters[a]	100.00	5000.00	1	5100.00	510.00
"Conservation District" Permit – land	2600.00	5000.00	1	7600.00	760.00
"Conservation District" Permit – marine waters	2600.00	5000.00	1	7600.00	760.00
Historic Properties and Sites Review (concurrently Burial Sites Review) (federal & state)	2300.00	5000.00	1	7300.00	730.00
NPDES Permit	1000.00	5000.00	1	6000.00	600.00
Zone of Mixing Review		5000.00	1	5000.00	500.00
Water Quality Certification (Clean Water Act)[a]	1500.00		1	1500.00	150.00
Federal Consistency Review: CZM			0		
Underground Injection Control			0		
Well Construction and Pump Installation			0		
Water Use Permit – Windward Oahu	25.00	5000.00	1	5025.00	502.50
Special Management Area Use Permit: Coastal Zone Management	15,000.00	5000.00	1	20,000.00	2000.00
Shoreline Setback Variance Permit	1000.00		1	1000.00	100.00
Grading, Grubbing, and Stockpiling Permit	90.00		1	90.00	9.00
Building Permit	250.00		1	250.00	25.00
Total				71,465.00	7146.50

[a] Items are contingent on each other; If the Department of the Army Permit is required, this operation becomes a federal matter and requires full National Environmental Policy Act (NEPA) review, as opposed to general environmental impact assessment review; If it is not a federal matter, the water quality certification is also unnecessary, unless a fishpond is the grow-out site.

Table A4
Shellfish quality permits and testing to be annualized.

Item	Site review, etc. costs ($)	Total cost ($)	Annualized cost ($)
Private laboratory meat and depuration tank quality testing	3600.00	3600.00	360.00
Total			360.00

Table A5
DOH Certification (quality testing) costs to be annualized.

Item	Unit	Quantity of units	Cost per unit ($)	Total annual cost ($)
Shellfish grow-out area survey – pond waters	Bi-Monthly (also start-up)	6	500.00	3000.00
Shellfish meat and depuration tank testing	Monthly (also start-up)	12	500.00	6000.00
Total				9000.00

Table A6
Individual budget items to be annualized.

Item	Cost per unit ($)	Annualized Cost ($)
Business entity structuring fees	110.00	11.00
Expendable supplies		
Tools (rakes, pliers, etc.)	500.00	50.00
Protective gear (gloves, waders, etc.)	200.00	20.00
Total expendable supplies		70.00

Table A7
Miscellaneous supplies.

Item	Cost per unit ($)	Quantity of units	Times purchased per year	Total annual cost ($)
Tent tarp	350.00	1	2	700.00
Replacement lids for cages	2.00	300	1	600.00
Total				1300.00

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