AQUACULTURE PRODUCTION OF THE ZOOPLANKTON SPECIES *AMERICAMYSIS BAHIA*: COMPARING ON-SITE PRODUCTION AT THE WAIKĪKĪ AQUARIUM TO IMPORTATION

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Abstract

An aquaculture production system was constructed at the Waikīkī Aquarium in the fall of 2016 that produces mysid shrimp zooplankton (*Americamysis bahia*). From November 2017 to February 2018, the Waikīkī Aquarium (WAq) required an average of 5,751 live mysids per week that were imported as feed with current import rates of $0.08 per animal or $24,000 annually. Fixed and variable budgets were used to evaluate the economics for the mysid culture system. Sensitivity analyses of labor costs, the sale of excess mysid production, and the discount rate were also conducted using stochastic modeling of in-house domestic yields to estimate the expected the net present values (NPV) of domestic production in comparison with imports. The indirect benefits of domestic production were qualitatively evaluated. Results showed that WAq had a greater (>0) NPV across a variety of cost and benefit scenarios and a less expensive $.05 mysid versus the imported $.08 mysid.

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Table 1. Mysid production parameters and schedule		
Item	Unit	Quantity
Adult Stocking Size	microns	>1000
Naupliar Harvest Size	microns	>200 - <1000
Adult Stocking Density (in a static system)	per liter	15
Adult Stocking Density (in a flow-through system)	per liter	20
Trough Volume to Stock (per trough/12 troughs total)	liter	500
Current Weekly Adult Re-stocking Density (per trough, 2 troughs stocked per week)	individual mysids	1500
Typical Life Span	days	45
Typical Age at Sexual Maturity	days	14
Hypothetical Adult Fecundity	brood size/individual mysid babies incubated	7 to 20
Hypothetical Time Spent Carrying Brood	days	4
Hypothetical Naupliar Survival	percent	50
Naupliar Removal Frequency (to feed or grow out)	days	14
Adult Re-stocking Addition Frequency	days	30-45

Table 2. Artemia sp. requirements for feeding mysids									
# of Adult Mysids Stocked/ L	# of Artemia Required Per Mysid/Day	Volume of a Single Mysid Breeding Trough (MB) (L)	Total # of Mysids/ MB	Average # of Artemia / L	Average # of Artemia/ mL	Volume of Artemia Hatch (mL) Needed Per Mysid to Meet the 150 Artemia/Mysid /Day	# of Artemia Needed Per # Mysids to Meet the 150 Artemia/Mysid/ Day	Volume of Artemia Hatch (L) Needed Per # Mysids to Meet the 150 Artemia/Mysid/Day	Volume of Artemia Hatch (L) Needed Per Feed/ Trough, Depending on Density (@ 2 feeds/day)
1	150	500	500	232244	232	0.65	75000	0.3	0.2
5	150	500	2500	232244	232	0.65	375000	1.6	0.8
10	150	500	5000	232244	232	0.65	750000	3.2	1.6
12	150	500	6000	232244	232	0.65	900000	3.9	1.9
15	150	500	7500	232244	232	0.65	1125000	4.8	2.4
20	150	500	10000	232244	232	0.65	1500000	6.5	3.2

Table 3. Start-up cost budget	
Item	Total ($)
Construction Labor	$7,273.00
Equipment	
Mysid System	$16,895.20
Artemia System	$8,500.60
Miscellaneous Start-up Maintenance Equipment	
Cleaning Supplies	$50.00
Artemia Cysts and Feed (1 bag or can of each required feed)	$137.50
Initial Mysid Stocking (1500 per 6 adult troughs @ .08/mysid)	$720.00
Total Start-up Costs	$33,576.30

Table 4. Hourly labor cost			
UH Pay Scale		Fringe Benefits/ Union	Hourly Salary
APT Band A	Step 24	40%	$44.67
APT Band A	Step 1	40%	$27.82
Contract Hire		N/A	$17.64
Volunteer/Intern		N/A	N/A

Table 5. Federal discount rates (low, mid, high)		
Risk	Year	
	2018	2016
Low	0.022	0.012
Mid	0.023	0.013
High	0.024	0.014

Table 6. Calculations used for NPV simulation model with preset value ranges for labor, yield, and interest rate	
*Year 0 is start up equipment and labor costs. Years 1-20 covers annual costs. Benefits include cost savings from stopping mysid imports and selling excess mysids.	
Start-up Budget	$33,576.30
Current Annual Costs	$25,470.36
Benefits (not importing + selling excess at current import price of .08/mysid)	$35,005.44

Table 7. Annual Labor Classifications and Costs				
Volunteer	Contract Hire	Current Labor Cost	APT Step 1	APT Step 24
$0	$18,617.07	$19,750.15	$29,356.97	$47,143.40

Table 8. Annual profit from selling excess mysids												
Price to Sell Excess Production per Mysid												
$0.00	$0.02	$0.04	$0.06	$0.08	$0.10	$0.12	$0.14	$0.16	$0.18	$0.20	$0.22	$0.24
Total Annual Lost Profit from Selling Least Excess of -896 Mysids per Week												
$0.00	-$931.84	-$1,863.68	-$2,795.52	-$3,727.36	-$4,659.20	-$5,591.04	-$6,522.88	-$7,454.72	-$8,386.56	-$9,318.40	-$10,250.24	-$11,182.08
Total Annual Profit from Selling Average Excess of 2664 Mysids per Week												
$0.00	$2,770.56	$5,541.12	$8,311.68	$11,082.24	$13,852.80	$16,623.36	$19,393.92	$22,164.48	$24,935.04	$27,705.60	$30,476.16	$33,246.72
Total Annual Profit from Selling Highest Excess of 7954 Mysids per Week												
$0.00	$8,272.16	$16,544.32	$24,816.48	$33,088.64	$41,360.80	$49,632.96	$57,905.12	$66,177.28	$74,449.44	$82,721.60	$90,993.76	$99,265.92

Table 9. Calculations used for NPV simulation model without preset value ranges for labor costs and selling excess mysids at the interest rate of 2.3% (mid-range value)	
*Year 0 is start up equipment and labor costs. Years 1-20 covers annual costs. Benefits include selling excess mysids.	
Start-up Budget	$33,576.30
Annual Costs (Mean is average cost and inclulds the cost run over the simulations run previously plus the fixed cost. The standard deviation was chosen to be 12,000 to encompass the highest labor cost but also to ensure that the distribution remains above zero.)	$29,500.00
Benefits (Mean is average profit from selling mysids over the entire simulations run previously (20221.76))	$44,000.00

Table 10. Import NPV at the interest rate of 2.3% (mid-range value)	
*Year 0 has $0 cost due to importation only. Years 1-20 covers annual costs. Benefits include cost savings from stopping extraneous mysid labor.	
Start-up Budget	$0.00
Annual Costs (Current costs of importing the required amount of mysids per week, extrapolated for the year)	$28,242.01
Benefits (labor savings from not harvesting or maintaining mysids each week, extrapolated for the yearly total)	$26,137.63

Table 11. Waikiki Aquarium daily mysid feed usage and costs				
	Live Artemia Cysts (g)	**Algamac (mL)**	**Artemia Decapsulated Cysts (g)**	**Artemac (size 0) (g)**
Mysid Feed Requirements:	Per Breeding Trough Adult/Baby Paired System			
	8	10	1.25	2
	Per Adult Trough (MB)			
	6	7.5	1.00	1.25
	Per Naupliar Trough (MB)			
	2	2.5	0.25	0.75
	Per 2 Grow Out Troughs (MT)			
	8	20.0	N/A	2
	TOTAL FEEDS USED PER DAY			
	56	80	7.5	14
	TOTAL FEEDS USED PER WEEK			
	392	560	52.5	98
Costs of Feed:	Per Economy Grade Can	Per Bag of Red Algamac	Per Can of Decapsulated Cysts	Per Bag of Artemac (size 0)
	$38.50	$42.00	$19.50	$37.50
	Per gram	Per mL	Per gram	Per gram
	$0.0848	$0.0042	$0.0430	$0.0375
Mysid DAILY Feed Costs (With Production):	$4.75	$0.34	$0.32	$0.53
Mysid DAILY Feed Costs (Import Only):	$0.68	$0.08	N/A	$0.08
TOTAL DAILY Feed Costs (With Production):	$5.93			
TOTAL DAILY Feed Costs (Import Only):	$0.84			

Table 12. Weekly labor hours	
Activity	Average Hours/Week
Decapping	2.9080
Making Algamac	0.2563
Artemia Maintenance	5.0170
Making Mysid Feed Cups	0.7246
Feeding Mysids	1.8259
Harvesting/Counting Mysids	4.1126
Wiping/Cleaning Mysid Tanks	4.9391
Acid Wash Mysid Troughs	0.2819
Modifying System	0.1750
Total Hours Per Week	20.2403

Table 13. Actual labor costs per day to maintain on-site mysid system

		Decapping	Making Algamac	Artemia Maintenance	Making Mysid Feed Cups	Feeding Mysids	Harvesting/ Counting Mysids	Wiping/Cleaning Mysid Tanks	Acid Wash Mysid Troughs	Modifying System
Average hours per day/per task:	Per APT Employee:	0.1917	0.0167	0.2964	0.0033	0.0954	0.2764	0.0129	0.0403	0.0250
	Per Contract Employee:	0.2238	0.0000	0.4203	0.0138	0.1348	0.3058	0.4582	0.0000	0.0000
	Per Student Volunteer:	0.0000	0.0199	0.0000	0.0864	0.0306	0.0053	0.2345	0.0000	0.0000
Average hours per task TOTAL:		0.4154	0.0366	0.7167	0.1035	0.2608	0.5875	0.7056	0.0403	0.0250
Average Total Hours for APT Employee per		0.9581								
Average Total Hours for Contract Employee		1.5566								
Average Total Hours for Volunteer per Day:		0.3768								
Cost per day (per APT, Band A step 1		$26.65								
Cost per day (per contract employee)		$27.46								
Cost per day (per volunteer)		$0.00								
Total Cost per Day for Current Mix of Labor:		$54.11								

Table 14. Annualized cost budget			
Item	Cost per Unit ($)	Unit	Total Cost per Year ($)
Operating Expenses			
Hatching Artemia Cysts	4.75	day	1,733.35
De-capsulated Artemia Cysts	0.32	day	117.58
Artemac Enrichment Feed	0.53	day	191.63
Algamac Enrichment Feed	0.34	day	122.64
Labor APT Band A step 24	129.16	day	47,143.40
Labor APT Band A step 1	80.43	day	29,356.97
Labor Contract Hire	51.01	day	18,617.07
Labor Intern/Volunteer	0.00	day	0.00
Actual Current Labor	54.11	day	19,750.15
Miscellaneous Supplies	50.00	quarter	200.00
Fixed Cost			
Electric	4.14	day	1,511.19
Water	0.39	day	143.99
Sewer	0.35	day	128.29
Equipment Depreciation (Annual Expense, Non-Cash, Straight Line)			
Tanks	6,615.16	Total Value	330.76
Pumps	2,285.92	Total Value	114.30
Stands	6,000.00	Total Value	300.00
Plumbing and Construction Materials	16,529.85	Total Value	826.49
Total Operating Expenses (APT step 24)			52,863.61
Total Operating Expenses (APT step 1)			35,077.18
Total Operating Expenses (Actual Mix)			25,470.36
Total Operating Expenses (Contract Hire)			24,337.28
Total Operating Expenses (Volunteer)			5,720.21

Table 15. Mysid production over 13-week study	
Greatest Production/Weekly Harvest (mysids/weekly harvest)	13705
Average Production/Weekly Harvest (mysids/weekly harvest)	8415
Least Production/Weekly Harvest (mysids/weekly harvest)	4855
Average LIVE FEED Production Required/Week (mysids/week)	2751
Average TOTAL Production Required/Week (LF mysids + restocking/week)	5751
Greatest Additional # Mysids Produced/Week	7954
Average Additional # Mysids Produced/Week	2664
Least Additional # Mysids Produced/Week	-896

Table 16. Expected NPV, based on actual current labor costs and a range of current 2018 interest rates

Year	0	1	2	3	4	5	...	15	16	17	18	19	20
Cost	-$33,576	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470	-$25,470
Benefit	$0	$35,005	$35,005	$35,005	$35,005	$35,005	$35,005	$35,005	$35,005	$35,005	$35,005	$35,005	$35,005
Net	-$33,576	$9,535	$9,535	$9,535	$9,535	$9,535	$9,535	$9,535	$9,535	$9,535	$9,535	$9,535	$9,535

NPV		
	$119,368.15	0.022
	$117,914.82	0.023
	$116,481.41	0.024

Table 17. Net present values for fluctuating labor costs and selling lowest production at differing 2018 federal discount rates

Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$29,356.97	$29,356.97	$29,356.97	$18,617.07	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$0.00	$0.00	$0.00
Fluctuating Selling Excess Mysids	-$11,182.08	-$6,522.88	-$1,863.68	-$9,318.40	-$4,659.20	-$931.84	-$10,250.24	-$6,522.88	-$5,591.04	-$1,863.68	-$931.84	-$8,386.56	-$3,727.36	$0.00
NPV at 2.2% Discount Rate	-$677,148.48	-$602,414.05	-$527,679.62	-$361,957.07	-$287,222.64	-$227,435.09	-$204,633.97	-$163,021.24	-$129,899.54	-$88,286.81	-$55,165.11	$123,881.06	$198,615.49	$258,403.04
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$29,356.97	$29,356.97	$29,356.97	$18,617.07	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$0.00	$0.00	$0.00
Fluctuating Selling Excess Mysids	-$11,182.08	-$6,522.88	-$1,863.68	-$9,318.40	-$4,659.20	-$931.84	-$10,250.24	-$6,522.88	-$5,591.04	-$1,863.68	-$931.84	-$8,386.56	-$3,727.36	$0.00
NPV at 2.3% Discount Rate	-$671,033.03	-$597,008.75	-$522,984.47	-$358,836.68	-$284,812.40	-$225,592.98	-$203,008.52	-$161,791.21	-$128,984.24	-$87,766.93	-$54,959.96	$122,384.84	$196,409.12	$255,628.55
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$29,356.97	$29,356.97	$29,356.97	$18,617.07	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$0.00	$0.00	$0.00
Fluctuating Selling Excess Mysids	-$11,182.08	-$6,522.88	-$1,863.68	-$9,318.40	-$4,659.20	-$931.84	-$10,250.24	-$6,522.88	-$5,591.04	-$1,863.68	-$931.84	-$8,386.56	-$3,727.36	$0.00
NPV at 2.4% Discount Rate	-$665,001.43	-$591,677.57	-$518,353.71	-$355,759.08	-$282,435.21	-$223,776.12	-$201,405.36	-$160,578.04	-$128,081.49	-$87,254.18	-$54,757.63	$120,909.14	$194,233.01	$252,892.10

Table 18. Net present values for fluctuating labor costs and selling average production at differing 2018 federal discount rates. Simulation index 7 indicates actual current labor costs and selling weekly excess yeild at .08/mysid.

Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$47,143.40	$18,617.07	$29,356.97	$19,750.15	$29,356.97	$18,617.07	$29,356.97	$0.00	$19,750.15	$18,617.07	$0.00	$18,617.07
Fluctuating Selling Excess Mysids	$0.00	$13,852.80	$22,164.48	$27,705.60	$2,770.56	$16,623.36	$11,082.24	$22,164.48	$16,623.36	$30,476.16	$5,541.12	$30,476.16	$33,246.72	$27,705.60	$22,164.48
NPV at 2.2% Discount Rate	-$497,785.84	-$275,584.36	-$142,263.47	-$53,382.88	$4,222.08	$54,153.57	$119.368.15	$143,034.16	$226,423.56	$276,355.05	$347,283.63	$430,450.22	$493,095.34	$702,806.00	315.304.15
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$47,143.40	$18,617.07	$29,356.97	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$29,356.97	$0.00	$19,750.15	$0.00	$0.00
Fluctuating Selling Excess Mysids	$0.00	$13,852.80	$22,164.48	$27,705.60	$2,770.56	$16,623.36	$11,082.24	$11,082.24	$16,623.36	$19,393.92	$33,246.72	$8,311.68	$33,246.72	$22,164.48	$33,246.72
NPV at 2.3% Discount Rate	-$493,374.76	-$273,284.72	-$141,230.69	-$53,194.67	$3,862.90	$53,319.93	$117,914.82	$135,916.93	$205,950.84	$267,970.96	$317,427.98	$387,682.57	$470,058.89	$607,772.62	$783,844.65
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$47,143.40	$18,617.07	$29,356.97	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$29,356.97	$0.00	$19,750.15	$0.00	$0.00
Fluctuating Selling Excess Mysids	$0.00	$13,852.80	$22,164.48	$27,705.60	$2,770.56	$16,623.36	$11,082.24	$11,082.24	$16,623.36	$19,393.92	$33,246.72	$8,311.68	$33,246.72	$22,164.48	$33,246.72
NPV at 2.4% Discount Rate	-$489,024.16	-$271,016.60	-$140,212.07	-$53,009.04	$3,508.65	$52,497.72	$116,481.41	$134,313.19	$203,684.44	$265,117.72	$314,106.79	$383,696.63	$465,293.51	$601,704.19	$776,110.24

Table 18. Net present values for fluctuating labor costs and selling highest production at differing 2018 federal discount rates

Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fluctuating Annual Labor Costs	$47,143.40	$29,356.97	$19,750.15	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$0.00	$19,750.15	$0.00
Fluctuating Selling Excess Mysids	$0.00	$8,272.16	$8,272.16	$16,544.32	$24,816.48	$33,088.64	$41,360.80	$49,632.96	$57,905.12	$66,177.28	$74,449.44	$66,177.28	$99,265.92	$99,265.92
NPV at 2.2% Discount Rate	-$497,785.84	-$79,801.23	$74,293.95	$225,155.74	$357,842.72	$490,529.70	$623,216.68	$755,903.66	$888,590.64	$1,021,277.63	$1,153,964.61	$1,319,898.88	$1,533,850.73	$1,850,646.80
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fluctuating Annual Labor Costs	$47,143.40	$29,356.97	$19,750.15	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$0.00	$19,750.15	$0.00
Fluctuating Selling Excess Mysids	$0.00	$8,272.16	$8,272.16	$16,544.32	$24,816.48	$33,088.64	$41,360.80	$49,632.96	$57,905.12	$66,177.28	$74,449.44	$66,177.28	$99,265.92	$99,265.92
NPV at 2.3% Discount Rate	-$493,374.76	-$79,361.98	$73,268.93	$222,697.18	$354,123.32	$485,549.46	$616,975.61	$748,401.75	$879,827.89	$1,011,254.03	$1,142,680.18	$1,307,037.69	$1,518,956.50	$1,832,742.26
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fluctuating Annual Labor Costs	$47,143.40	$29,356.97	$19,750.15	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$18,617.07	$0.00	$19,750.15	$0.00
Fluctuating Selling Excess Mysids	$0.00	$8,272.16	$8,272.16	$16,544.32	$24,816.48	$33,088.64	$41,360.80	$49,632.96	$57,905.12	$66,177.28	$74,449.44	$66,177.28	$99,265.92	$99,265.92
NPV at 2.4% Discount Rate	-$489,024.16	-$78,928.76	$72,257.96	$220,272.33	$350,454.92	$480,637.51	$610,820.10	$741,002.69	$871,185.28	$1,001,367.87	$1,131,550.47	$1,294,352.83	$1,504,266.46	$1,815,083.19

Table 20. Net present values for fluctuating labor costs and selling average production at differing 2016 federal discount rates. Simulation index 7 indicates actual current labor costs and selling weekly excess yield at .08/mysid, at 2016 discount rates.

Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$47,143.40	$18,617.07	$29,356.97	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$29,356.97	$0.00	$19,750.15	$0.00	$0.00
Fluctuating Selling Excess Mysids	$0.00	$13,852.80	$22,164.48	$27,705.60	$2,770.56	$16,623.36	$11,082.24	$11,082.24	$16,623.36	$19,393.92	$33,246.72	$8,311.68	$33,246.72	$22,164.48	$33,246.72
NPV at 1.2% Discount Rate	-$545,453.95	-$300,435.35	-$153,424.19	-$55,416.75	$8,103.46	$63,162.25	$135,073.50	$155,114.62	$233,080.94	$302,125.78	$357,184.57	$435,396.56	$527,103.26	$680,415.16	$876,430.04
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$47,143.40	$18,617.07	$29,356.97	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$29,356.97	$0.00	$19,750.15	$0.00	$0.00
Fluctuating Selling Excess Mysids	$0.00	$13,852.80	$22,164.48	$27,705.60	$2,770.56	$16,623.36	$11,082.24	$11,082.24	$16,623.36	$19,393.92	$33,246.72	$8,311.68	$33,246.72	$22,164.48	$33,246.72
NPV at 1.3% Discount Rate	-$540,379.51	-$297,789.87	-$152,236.09	-$55,200.24	$7,690.28	$62,203.25	$133,401.61	$153,244.06	$230,437.46	$298,797.84	$353,310.81	$430,747.46	$521,545.03	$673,337.09	$867,408.80
Simulation Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fluctuating Annual Labor Costs	$47,143.40	$47,143.40	$47,143.40	$47,143.40	$18,617.07	$29,356.97	$19,750.15	$18,617.07	$19,750.15	$18,617.07	$29,356.97	$0.00	$19,750.15	$0.00	$0.00
Fluctuating Selling Excess Mysids	$0.00	$13,852.80	$22,164.48	$27,705.60	$2,770.56	$16,623.36	$11,082.24	$11,082.24	$16,623.36	$19,393.92	$33,246.72	$8,311.68	$33,246.72	$22,164.48	$33,246.72
NPV at 1.4% Discount Rate	-$535,376.51	-$295,181.64	-$151,064.72	-$54,986.77	$7,282.91	$61,257.74	$131,753.25	$151,399.82	$227,831.20	$295,516.74	$349,491.58	$426,163.80	$516,065.04	$666,358.66	$858,514.55

Table 21. On-site production NPV simulation model without preset value ranges for labor costs and selling excess mysids, at the interest rate of 2.3% (mid-range discount rate)													
Year	0	1	2	3	4	5	...	15	16	17	18	19	20
Cost	-$33,576	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500	-$29,500
Benefit	$0	$44,000	$44,000	$44,000	$44,000	$44,000	$44,000	$44,000	$44,000	$44,000	$44,000	$44,000	$44,000
Net	-$33,576	$14,500	$14,500	$14,500	$14,500	$14,500	$14,500	$14,500	$14,500	$14,500	$14,500	$14,500	$14,500
NPV						$199,006.39				0.023			

Table 22. Import NPV at the interest rate of 2.3% (mid-range discount rate)													
Year	0	1	2	3	4	5	...	15	16	17	18	19	20
Cost	$0.00	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01	-$28,242.01
Benefit	$0.00	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63	$26,137.63
Net	$0.00	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38	-$2,104.38
NPV						-$33,433.90				0.023			

Table 23. Daily costs and equivalent cost per mysid								
Cost of Feed	Cost of Labor (APT, step 24)	Cost of Labor (APT, step 1)	Cost of Labor (Contract Hire)	Cost of Labor (Volunteer)	Cost of Labor (Current Mix)	Cost of Electric	Cost of Water	Cost of Sewer
$5.93	$129.16	$80.43	$51.01	$0.00	$54.11	$4.14	$0.39	$0.35
Total Daily Costs (with APT step 24)		Total Weekly Costs (with APT step 24)			**Cost per Mysid (with APT step 24)**			
$139.97		$979.78			$0.12			
Total Daily Costs (with APT step 1)		Total Weekly Costs (with APT step 1)			**Cost per Mysid (with APT step 1)**			
$91.24		$638.68			$0.08			
Total Daily Costs (with contract hire)		Total Weekly Costs (with contract hire)			**Cost per Mysid (with contract hire)**			
$61.82		$432.71			$0.05			
Total Daily Costs (with volunteer)		Total Weekly Costs (with volunteer)			**Cost per Mysid (with volunteer)**			
$10.81		$75.67			$0.01			
Total Daily Costs (with current mix)		Total Weekly Costs (with current mix)			**Cost per Mysid (with current mix)**			
$64.92		$454.44			$0.05			

Figures

Figure 1. Economic Model (Modified from Leung and Rowland, 1989)

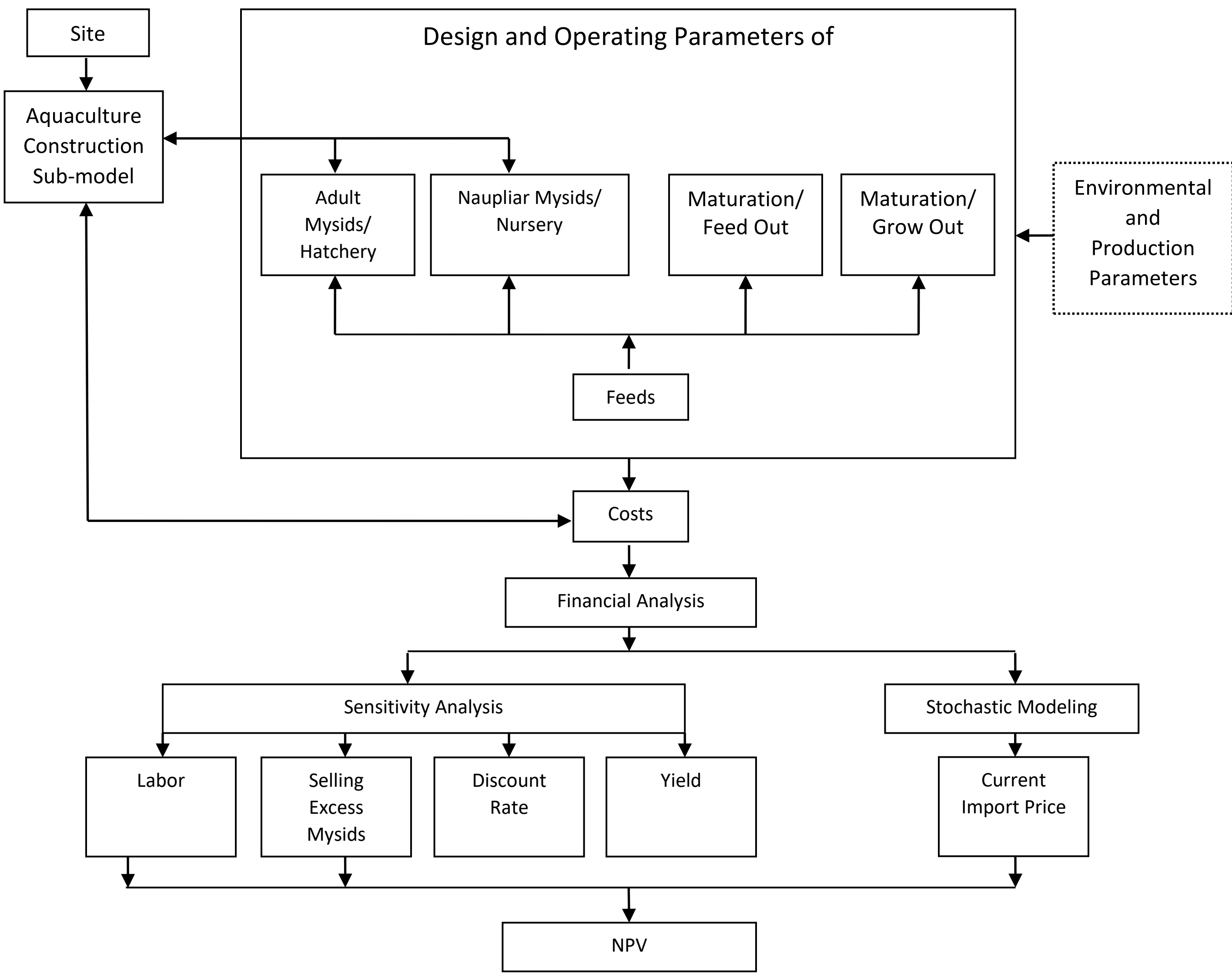


Figure 2. Mysid collection diagram

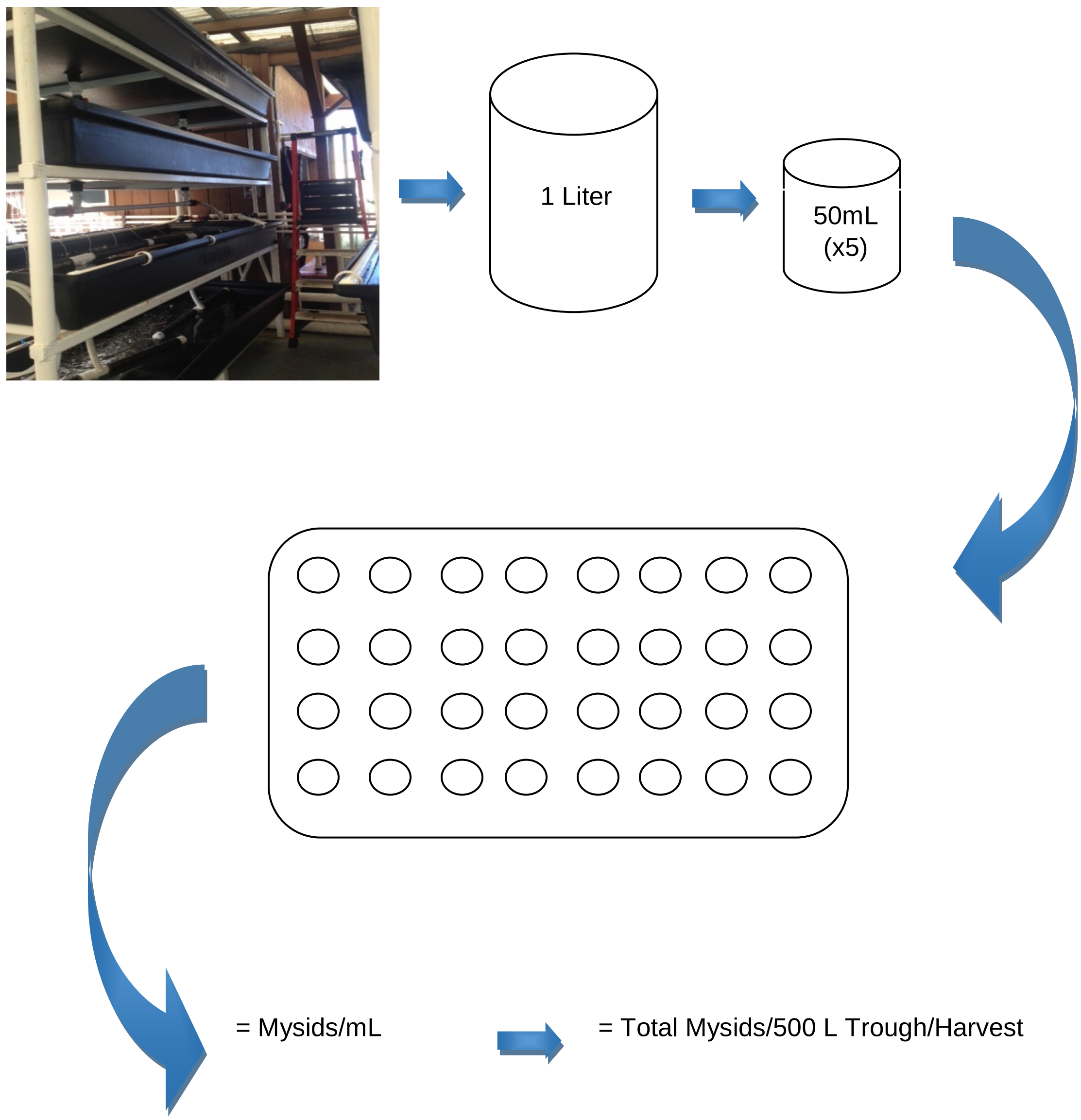


Figure 3. Simulated start-up cost for on-site production random variable NPV

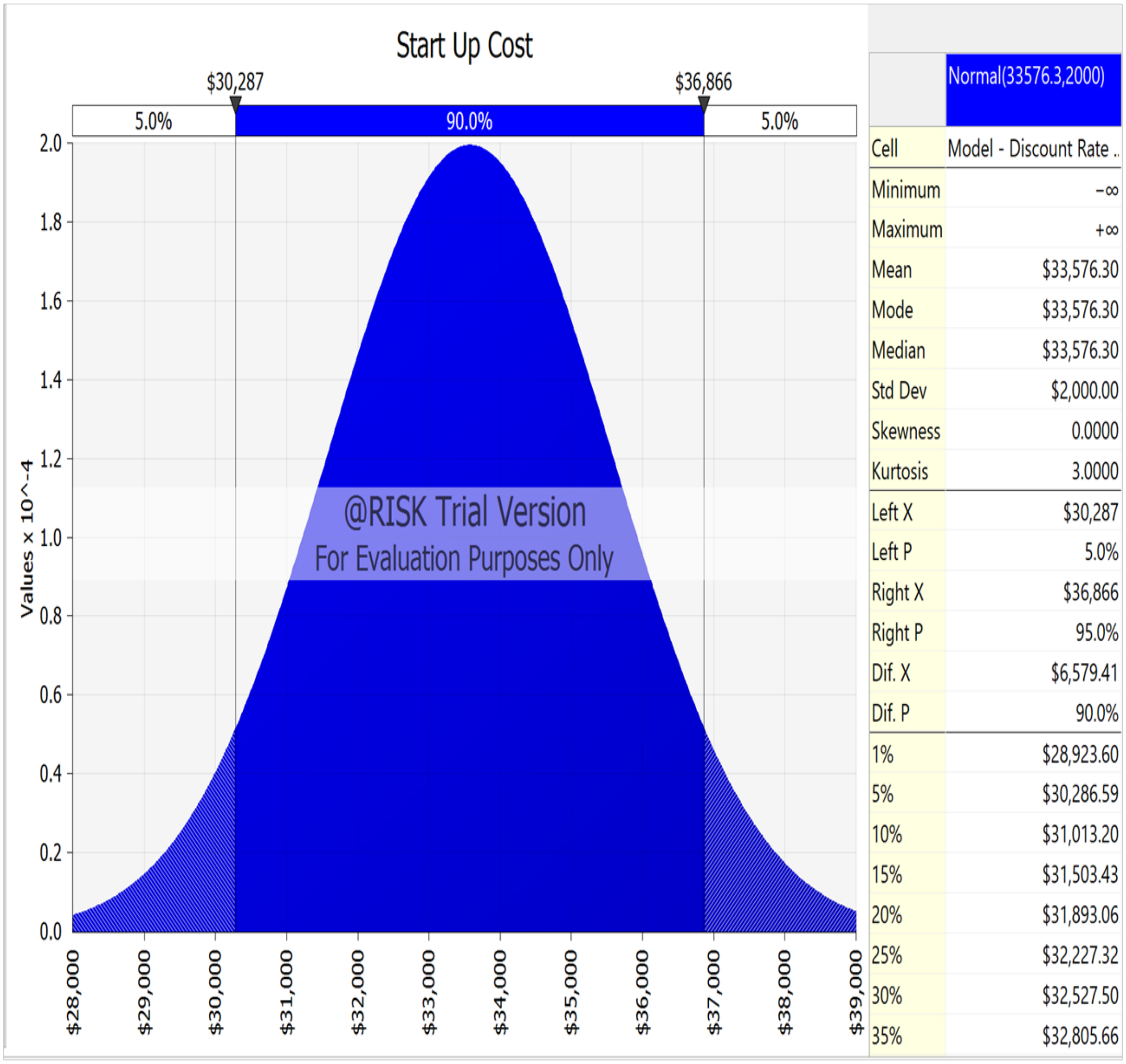


Figure 4. Simulated annual costs for on-site production random variable NPV

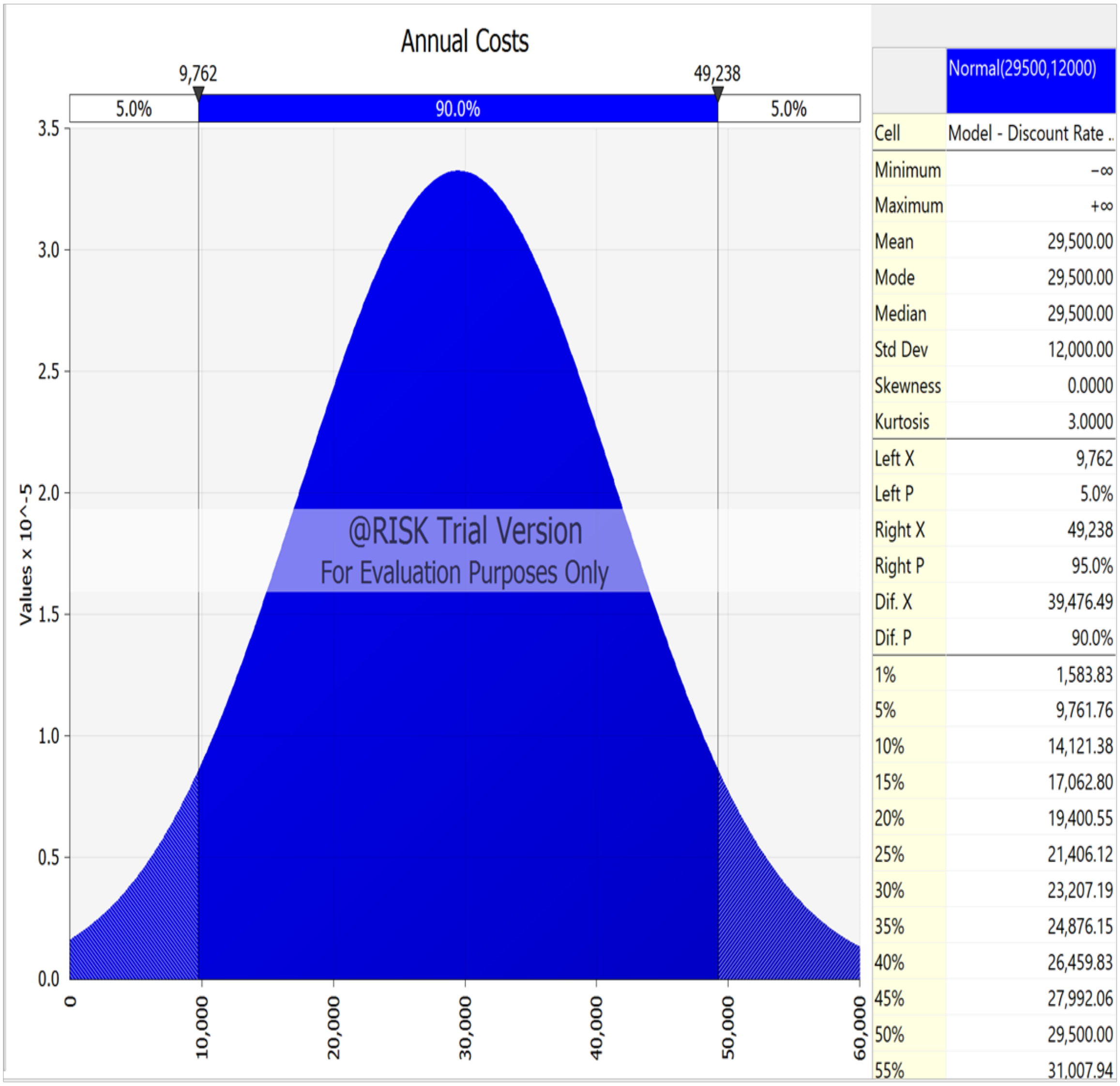
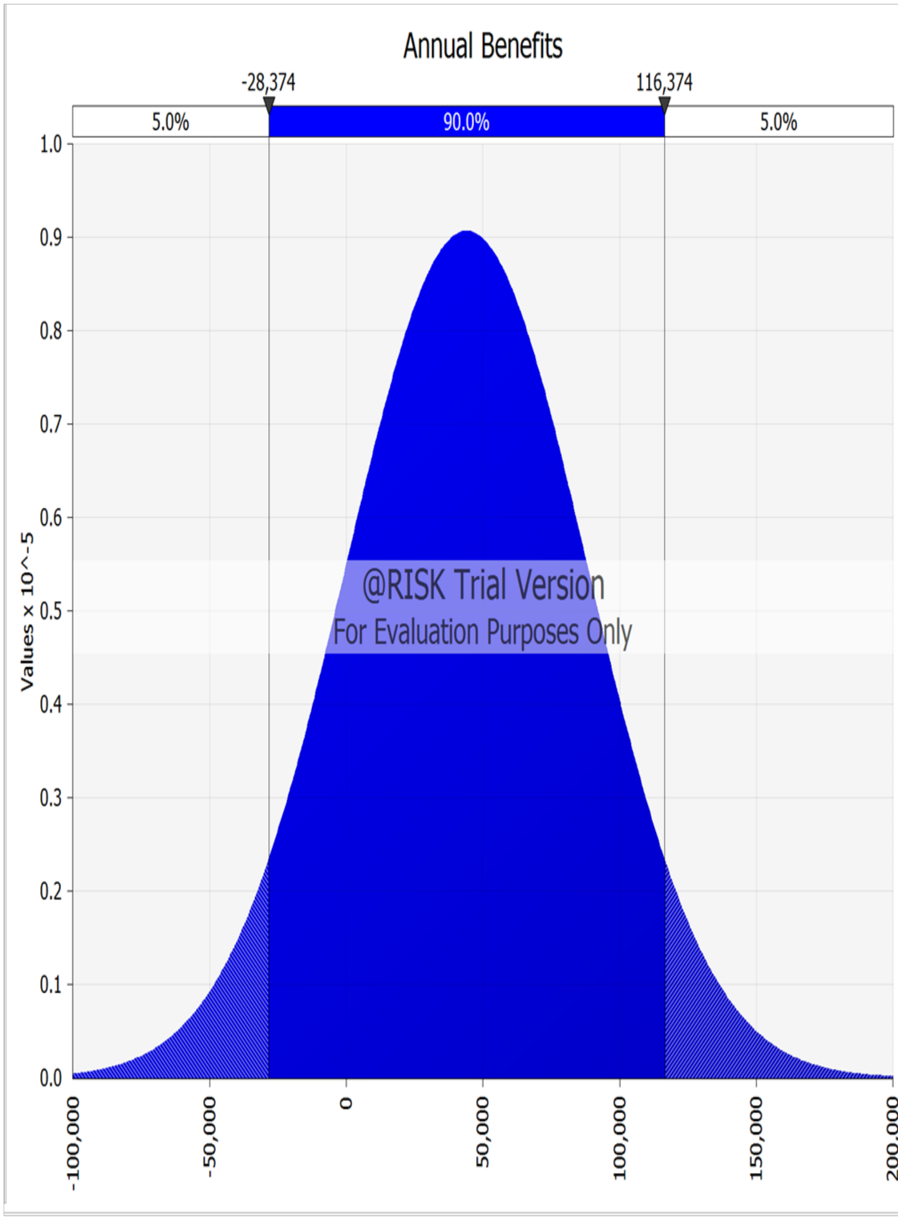


Figure 5. Simulated annual benefits for on-site production random variable NPV



	Normal(44000,44000)
Minimum	−∞
Maximum	+∞
Mean	44,000.00
Mode	44,000.00
Median	44,000.00
Std Dev	44,000.00
Skewness	0.0000
Kurtosis	3.0000
Left X	-28,374
Left P	5.0%
Right X	116,374
Right P	95.0%
Dif. X	144,747.12
Dif. P	90.0%
1%	-58,359.31
5%	-28,373.56
10%	-12,388.27
15%	-1,603.07
20%	6,968.67
25%	14,322.45
30%	20,926.38
35%	27,045.90
40%	32,852.73
45%	38,470.90
50%	44,000.00
55%	49,529.10
60%	55,147.27

Figure 6. Simulated annual costs for importation

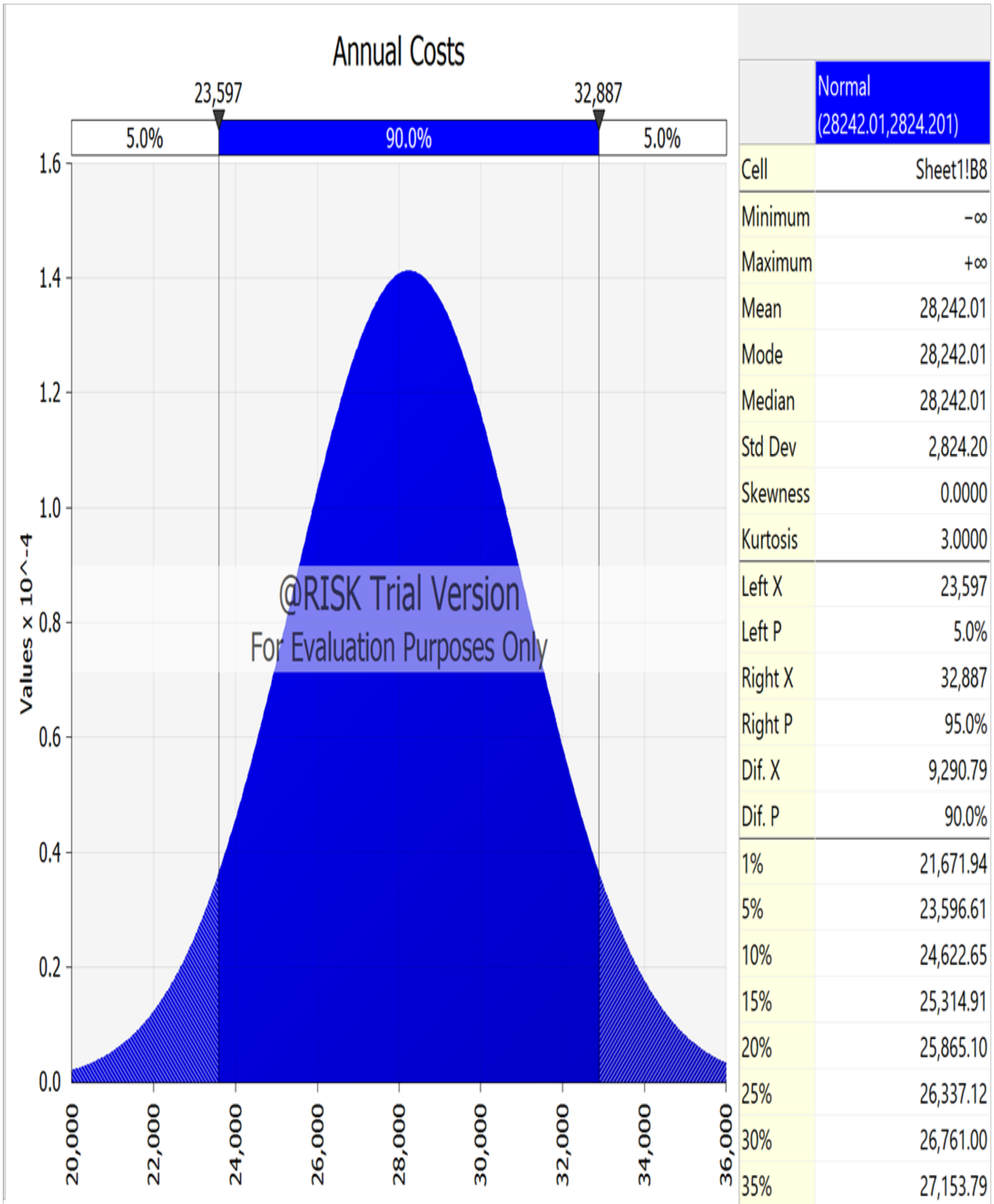


Figure 7. Simulated annual benefits for importation NPV

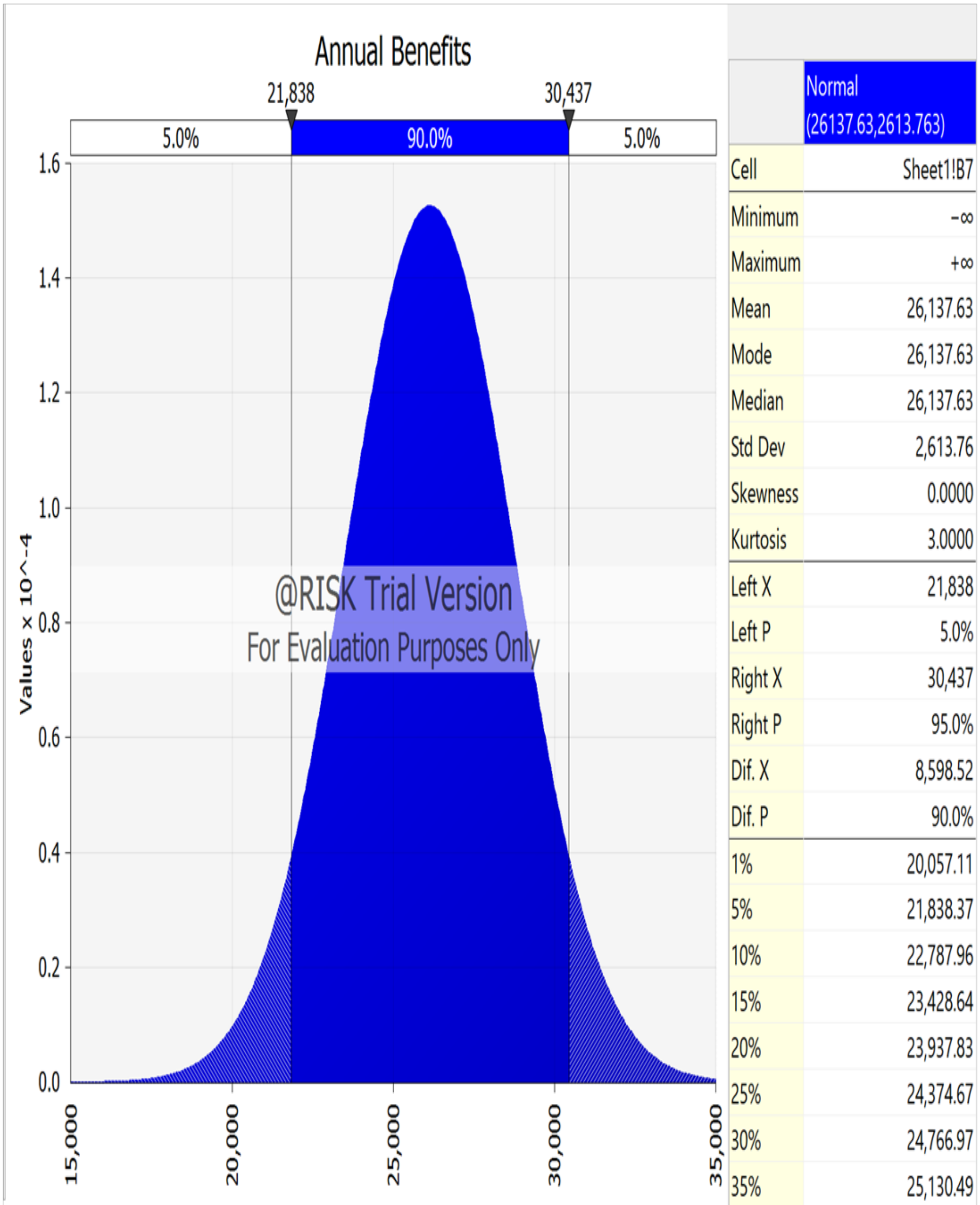


Figure 8. On-site production random variable NPV simulations below and above $0.

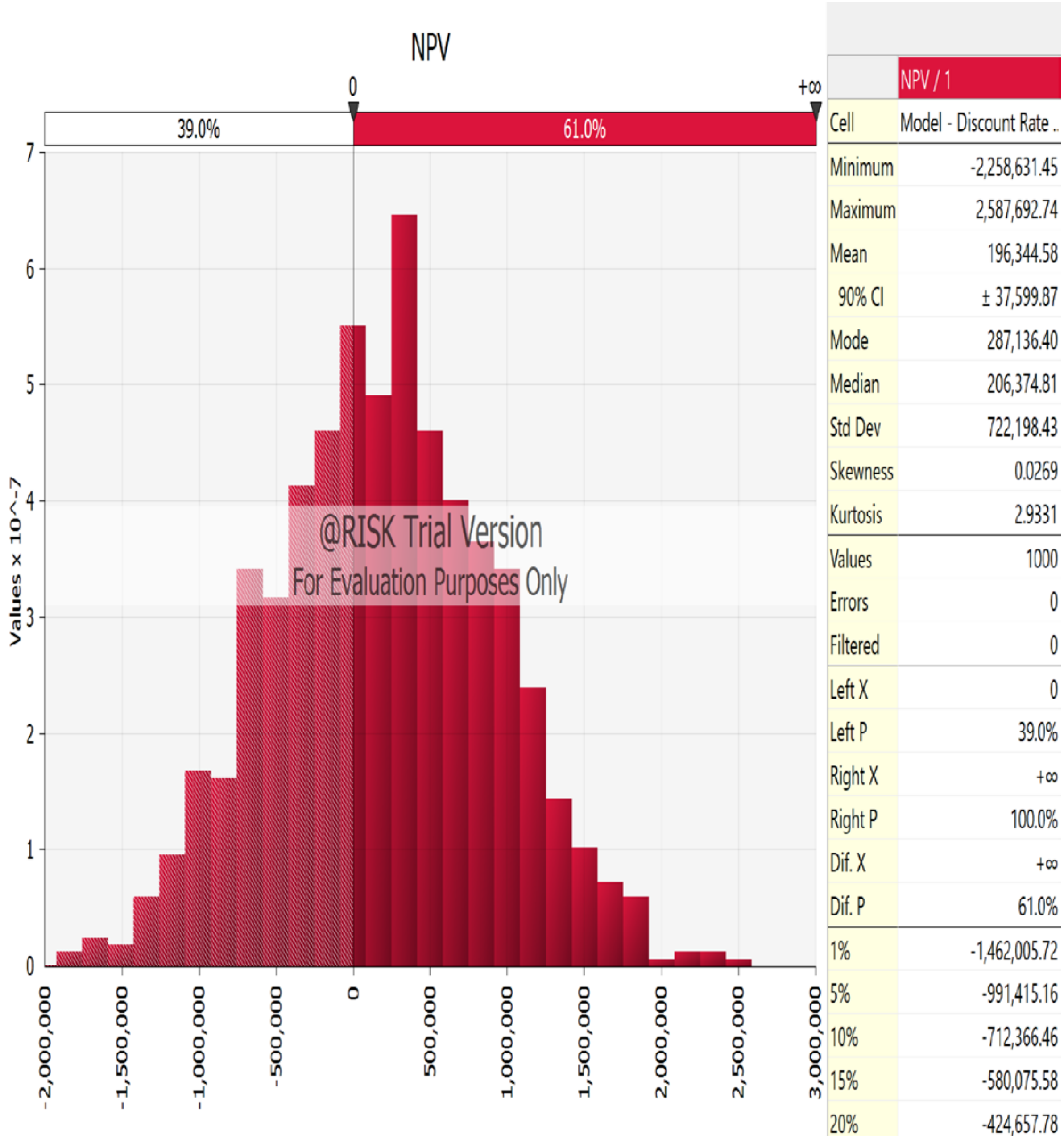


Figure 9. Import NPV simulations below and above $0.

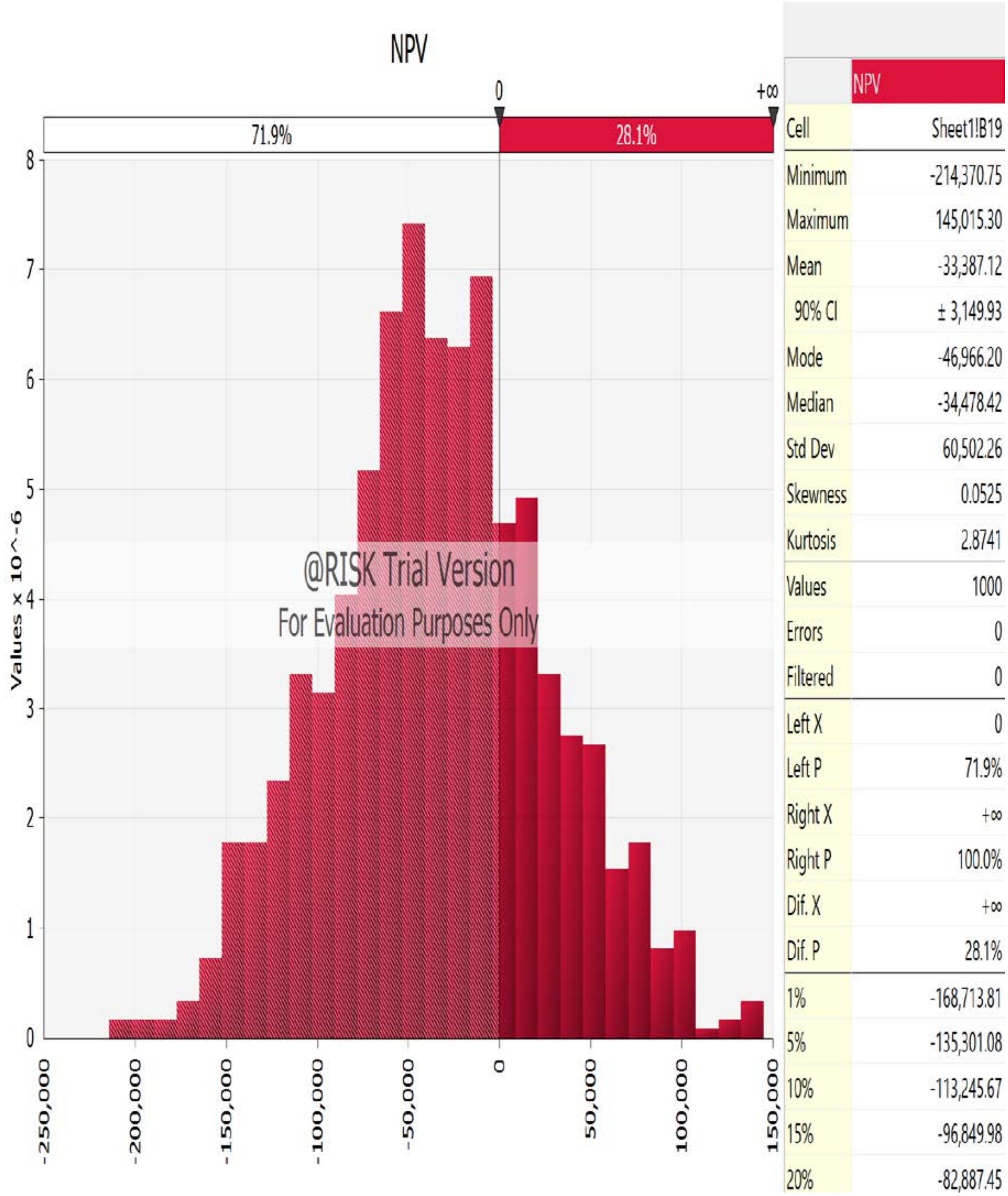


Figure 10. On-site production random variable NPV inputs ranked by effect on output mean.

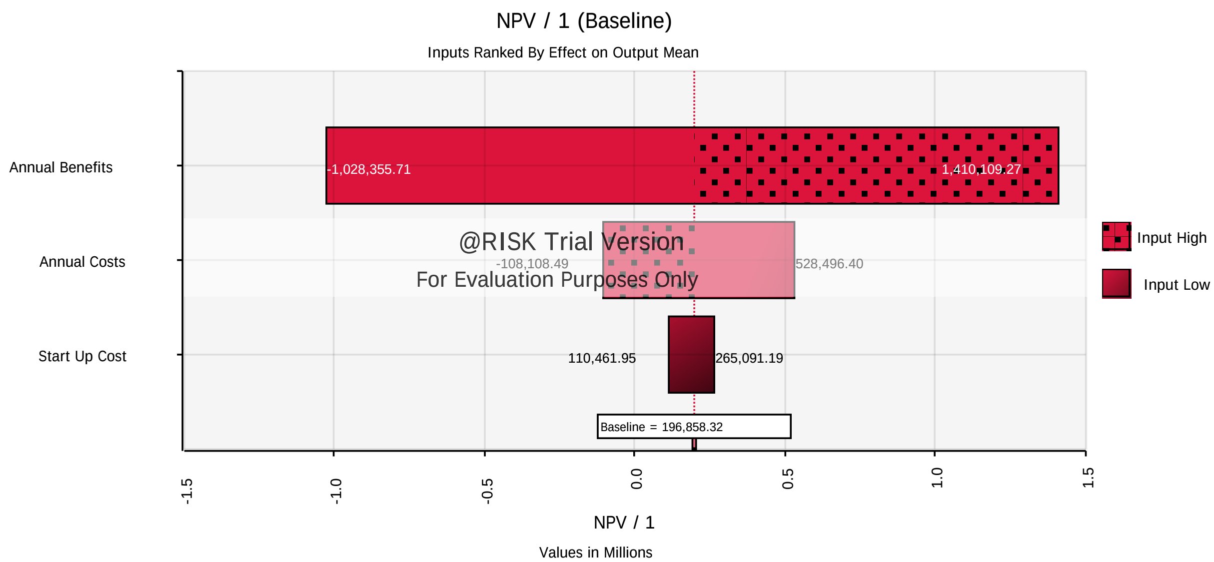
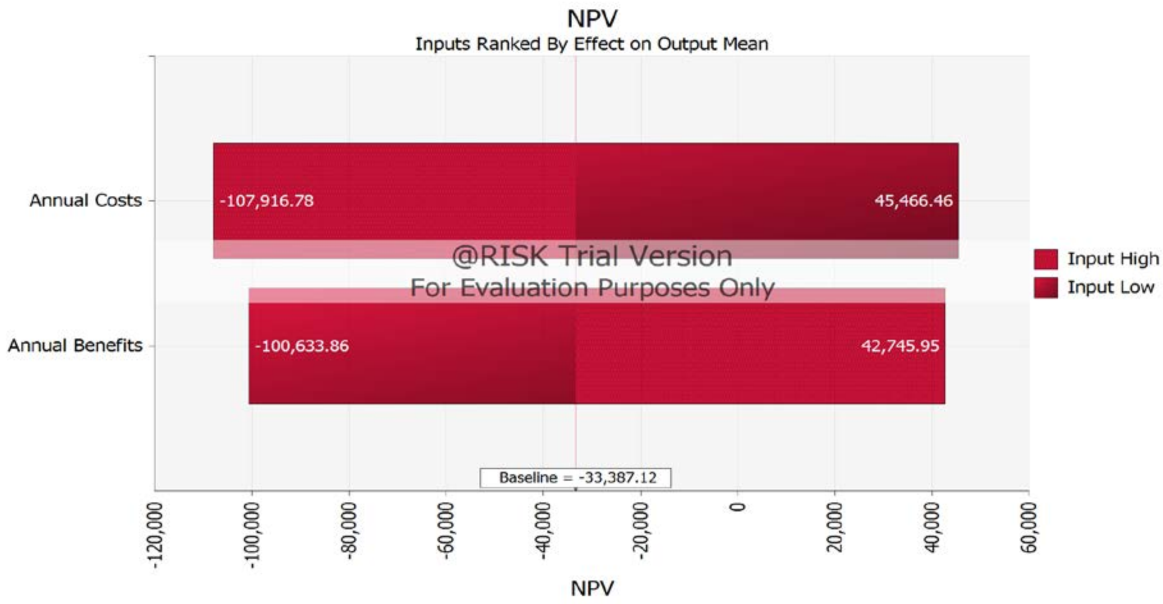


Figure 11. Import NPV inputs ranked by effect on output mean.



Abbreviations

WAq **–** Waikīkī Aquarium

Introduction

Interest in Syngnathidae (the scientific family for the seadragons, seahorses, and pipefishes) culture research and production has recently increased due to the over-exploitation of their wild stocks in most producing countries (Thangaraj and Lipton, 2008; Woods and Valentino, 2003). “These animals are used in traditional Chinese and southeastern Asian medicines and they are also readily collected to supply the aquarium trade world-wide” (Woods and Valentino, 2003). The Waikīkī Aquarium has developed nine new Syngnathidae exhibits to establish a husbandry network to perpetuate their stocks with successively aquacultured generations.

One of the biggest difficulties with Syngnathidae husbandry lies in their unique feeding behavior and diet (Thangaraj and Lipton, 2008). A second difficulty with raising syngnathid species is their lack of a true stomach, forcing them to constantly consume food to maintain energy reserves. The third difficulty in raising seadragons, seahorses, and pipefish is that they must be treated as a true culture, by using nutritional supplementation to create self-perpetuating life cycles within an artificial environment, while maintaining genetic variation.

Due to their high nutritional content and diversity as a prey item, mysid shrimp provide an excellent aquaculture opportunity for the Waikīkī Aquarium to become more self-sustainable in their husbandry practices. *Artemia* sp. (fairy shrimp) are an alternative live zooplankton food source, separate from mysid shrimp (opossum shrimp), used for the rearing and husbandry of aquatic animals, and although they are generally considered easier to produce, additional enrichment is usually required prior to feeding them out to ensure that they match the nutrition provided by the same volume of mysid shrimp (Woods and Valentino, 2003). “Omega-3 highly unsaturated fatty acids (HUFAs) in mysid levels [are] approximately twice that of Artemia” (Woods and Valentino, 2003).

The non-penaeid shrimp, “[*Americamysis bahia,* formerly] *Mysidopsis bahia* is an estuarine mysid found in brackish waters of the northern Gulf of Mexico from southeastern Florida to Mexico” (McKenney and Celestial, 1995). Mysids are cultured in laboratories because they are readily available for broodstock collection, they serve as excellent biological vectors for environmental pollution assays, they have short life spans, and they provide an excellent food source for aquatic animals (Cripe et al., 2000; Thangaraj and Lipton, 2008).

Mysids, particularly *Americamysis bahia*, are cultured as bioassay organisms in several locations across the United States (Cripe et al., 2000); a few of these locations also ship mysids to aquariums to feed their aquatic residents. Select companies also collect wild caught mysids and tend to sell them at more affordable rates. Laboratory cultured mysids can costas much as $.25 per animal, whereas mysids from some culture facilities and the wild can cost as little as $.08 per animal.

Much of the biology of *Americamysis bahia* is known (Wortham-Neal and Price, 2002), including the most efficient feeding density requirements along with other environmental parameters such as dissolved oxygen, temperature and salinity, however many biological factors have not been optimized (McKenney and Celestial, 2003; Modlin and Froelich, 1997). Each aquaculture system is unique relative to flow rates, local water quality, feed quality, cleaning regimens, etc. to optimize zooplankton fecundity, growth, and survival. To elucidate actual production estimates and the net benefits of producing mysids on-site, production optimization and cost-benefit analyses must be performed for each system design.

The Waikīkī Aquarium (WAq) relies on unpredictable air shipments from the United States mainland to obtain live *Americamysis bahia* zooplankton as animal feed for residents such as the weedy seadragon, *Phyllopteryx taeniolatus*. The Waikīkī Aquarium now purchases mysids at a rate of $0.08 per animal. Currently WAq requires and imports ~6,000 mysids per week for an estimated annual total of ~$24,000, not including shipping costs.

The overall goal of the pilot project described in this thesis is to develop a production system capable of producing enough mysids to meet the demand for feed at WAq at a cost that is competitive with the price of imports. The bio-engineering portion of the project involved designing and building a breeding system and optimizing the production of mysid hatchlings. The financial analyses investigated the start-up and maintenance costs based on several economic projected outcomes for the variable production parameters.

This study determines whether on-site production costs are competitive with importation. Fixed and variable budgets were used to evaluate the mysid culture system and the net cost of on-site production versus the cost of importation. Sensitivity analyses of labor costs, the sale of excess mysid production, and the discount rate were also conducted using stochastic modeling of in-house domestic yields to estimate the expected the net present values (NPV) of domestic production in comparison with imports. The indirect benefits of domestic production were qualitatively evaluated.

Methods

An economic model is an important tool that details key design features and the financial matrix of an aquaculture system to predict the behavior of production outcomes as variables change (Salazar, et al. 2018). The mysid production system described in this thesis is based on the Leung and Rowland, 1988 model shown in Figure 1 below.

The biological patterns in the mysid production are discussed below and condensed in table 1. The Waikīkī Aquarium has little vacant space, with the new live feeds deck providing roughly 1,850 square feet. It houses four hatching cylinders of *Artemia sp.* zooplankton and the modular mysid production system. The available space for the mysid production was roughly 120 square feet, with vertical space creating unique potential for system design. Ergonomics and cross-contamination prevention are of the utmost importance as these and other species maintained on the live feeds deck can be responsible for culture crashes from accidental introduction.

Americamysis bahia is a benthic species (Cripe et al., 2000). Imported mysids have been housed in 500 liter bare troughs that are roughly three feet deep, stocked at a density that varies between 12/L and 20/L in a flow-through system however they are rarely seen in the water column unless they are swimming after prey (USEPA, 1990).

<u>System Design</u>

The mysid aquaculture system is composed of four, three feet by eight feet wide, ten-inch-deep troughs, stacked one on top of another fit into the available space. Each trough when filled with salt water weighs 1500 lbs. The four tiers of these tanks are supported by stands of large stainless steel beams welded together with several cross beams for each layer. The top tank is for adults and the one below is for the continual collection of planktonic mysid hatchlings. The system is repeated in the lower two troughs to provide two production systems per four-tiered tank stand module. Three “four-tiered tank stand modules” yields six adult-hatchling collection systems, with the adult tank density stocked with up to 20 mysids per liter, while naupliar and juvenile mysids may be stocked at a higher density (USEPA, 1990). Salt water continually filters into the system in the evening at a rate of not less than two turnovers per tank per day. Each trough is fed a diet of newly hatched *Artemia sp.* enriched with Algamac© preserved micro algae at a recommended density of 150 Artemia per mysid per day, split between two feeds alongside additional non-hatching decapsulated *Artemia sp.* cysts and a prepared micro-algae diet of Artemac© which is a powdered *Artemia sp*. replacement (USEPA, 1990) (see Table 2 below).

Mysids are cannibalistic, voracious predators that continually produce offspring (Wortham-Neal and Price, 2002) and therefore the aquaculture system must ideally continually collect hatchlings. Mysid adults and newly hatched young are continually separated during their nightly brood release using differentially sized micron screens and vigorous flow patterns. Adults are contained in the top tank by1000-micron mesh on the effluent pipes and the planktonic hatchlings are swept into the lower tank and contained by 250-micronscreens on the drains. The young must be removed every two weeks to a separate grow-out tank. Age classes can span no more than two weeks or the chance of cannibalism increases (USEPA, 1990). Mature breeding adults must also be replaced periodically before senescence or losses due to reduced densities and subsequent production will occur. The addition of air from small pumps and the water pressure from the main well-water system at WAq plus the addition of strategic valves dictate currents, flow rates, and patterns. Production of mysid hatchlings for each four-tiered set-up was tracked during each tank's bi-weekly harvests when the young were 14 days old. The system is scheduled to operate with staggered weekly harvests.

<u>Systems Costs</u>

Costs for each tank stand, trough, initial stocking costs of the mysid broodstock for each of the adult production tanks, the PVC used to create the system, manpower, feed and maintenance costs, *Artemia sp.* production, and any indirect costs such as utilities were recorded (see Table 3). Annual totals were extrapolated from quarterly or 13 week costs. These costs do not reflect future changes that may lower initial costs and boost fecundity and survival by further optimization of male to female ratios, feed density and frequency, flow rates, air rates, substrate addition, hypo-salinity water, cleaning protocols, or the handling of adults or nauplii. Many factors affect yields of production, including mysid fecundity, survival, sex-ratios for production optimization, and system maintenance routines. During this trial period, the Waikīkī Aquarium continued to import the required 6,000 mysids per week (for adult re-stocking and as direct feed) to account for the risk of catastrophic failure.

The University of Hawaii (UH) pay scale for “Administrative, Professional, and Technical (APT)” bargaining unit 08 and UH “Casual Hire” pay rates were used to calculate labor costs as employees who worked with the mysid project are in these categories. To protect the identity of employee’s pay rates and to estimate a large variety of labor scenarios, annual labor cost totals for volunteers/un-paid internships, contract hires, UH APT step-1 employees, the current actual mix of labor hours, and UH APT step-24 employees were estimated for the sensitivity analysis. Different hourly labor scenarios were evaluated because large differences exist between employees paid rates negotiated by a union and internship or volunteer labor (see Table 4). Daily labor hours for harvesting, counting, and maintenance were tracked for each labor type. Tracking daily hours were then extrapolated for weekly and then annual costs, per each labor classification and pay rate. Although it was noted that the tallest or highest mysid tanks required the most maintenance due to the proximity to the sun and the subsequent algae growth, this was not accounted for, and all mysid maintenance fell under a general daily total.

To extrapolate weekly yield and annual production totals, the harvests from each tank were counted (see Figure 2). Samples from each bi-weekly harvested baby mysid tank were generally condensed from each 500 liter trough into a 1 liter sub-sample by draining them through a one inch line into a 100 micron screen submerged in a water bath. Each 1 liter sub-sample was then further reduced to 50 mL beakers. The 50 mL beakers were each counted five times, averaged, and then extrapolated for annual harvest totals.

A 2.2% 20-year nominal interest rate was used as the baseline discount rate, based upon federal government funding recommendations for a government owned facility (USWH, 2018) though possible higher discount rates such as 2.3% and 2.4% were also analyzed. Lower nominal rates from 2016 ranging from 1.2%, 1.3%, and 1.4% were also investigated. These 2016 and 2018 discount rates were described as low, mid, and high risk scenarios (see Table 5).

Sensitivity Analysis

Using Palisade version 7.5 Monte Carlo simulation analytical software, sensitivity analyses were conducted to determine how differing assumptions about specific variables such as labor, yield, and discount rate affect NPV. The @Risk software application operates by calculating NPV simulations for every variable combination and allows one to assess the impact of risk. The @Risk software essentially allows the operator to run multiple input variable combinations to assess numerous NPV outcomes simultaneously. The operator creates various tables reflecting the chosen variables to be evaluated and plugs them into the software's NPV calculating formula. Annual net production costs with the current labor mix and benefits of domestic production such as ceasing importation and selling possible surplus mysids were used to calculate the current production's expected NPV by using values in table 6. An annual cash flow was constructed from initial assembly of the system or Year 0 to twenty years of operation or Year 20, similar to the analysis conducted in the Center for Tropical and Subtropical Aquaculture's 2001 publication 146 that details an economic analysis of a fish (*Polydactylus sexfilis*) hatchery in Hawaii (Kam, Lotus E.Y.W., Leung, P., Ostrowski, A.C. et al., 2001). Parameters for each variable were chosen based on the potential for each to impact the economic cost of on-site production. Annual labor totals were compared if solely done with volunteers/un-paid internships, contract hires, UH APT step-1 employees, the current actual mix of labor hours, or UH APT step-24 employees (see Table 7). The sale of excess mysids for the lowest, average, and weekly mysid production were examined. The range of mysid sale prices spanned in $.02 increments from: not selling at $0.0/mysid, to the current WAq purchase price of $.08/mysid and beyond to the highest market price of $.25/mysid (see Table 8). Discount rates from 2016 and 2018 varied from low, mid, and high-risk scenarios (see Table 5). Each simulation consisted of 1000 trials for each model with 65 possible combinations of labor, yield, and discount rate for which to calculate NPV. Results from these analyses were condensed to showcase fourteen to fifteen different outcomes across the entire range of 65 possibilities, from lowest to highest. NPV input and output variables for each category (labor, sale price, discount rate) varied amongst specified ranges within themselves and as combinations between themselves.

"A stochastic model predicts a set of possible outcomes weighted by their likelihoods, or probabilities" (Taylor and Karlin, 1998). Stochastic modeling with Palisade version 7.5 Monte Carlo simulation analytical software addressed scenarios of mysid production to project net present values for the 20-year operation. The stochastic model simulation was completed based on the discount rate of 2.3% and certain cost and benefit values shown in table 9, so that results could be directly compared with the import NPV analysis at a mid-range rate. This simulation did not include a defined range of various values for labor costs, sale of excess mysids, and discount rates and instead allowed the program to assign random variable values contained within a specified and uniformly distributed range to complete the analysis. Triangular parameters were set at minimum, most likely, and maximum values and ran at 1,000 iterations for an average result; Normal parameters are the mean and standard deviation and all choices are based off of the 1,000 realistic input value NPV simulations. The annual benefits are an average profit of these NPV simulations from selling mysids ($20,221.76) plus the simulated fixed benefits ($23,932.20). Standard deviation was chosen to be 44,000 to encompass the highest profit seen in the simulation model ($123,189.12). The annual cost includes average cost from these NPV simulations plus the fixed cost. The standard deviation was chosen to be 12,000 to encompass the highest labor cost but also so that the distribution remains above zero. Stakeholders can determine their expected outcome and standard deviation based upon these scenario estimates. The NPV was also calculated for import costs and benefits using the appointed mid range discount rate of 2.3% (Table 10) to facilitate a comparison with the random variable NPV simulation above. Triangular parameters were set at minimum, most likely, and maximum values; Normal parameters are the mean and standard deviation. Lastly, costs were calculated on a per unit or mysid basis to facilitate a comparison between on-site production and importation cost.

Results

The 13-week pilot study provided more precise and information on the variability of cost and benefit data for which to predict NPVs. Current mysid feed requirements are in table 11. Labor rates are most accurately portrayed by daily maintenance tasks and the time per week required for completing them as shown in table 12. Each task requirement was then extrapolated for each labor classification's hourly cost as shown in table 13. The Waikīkī Aquarium's annualized mysid production cost budget is shown in table 14 and is based upon the variety of maintenance and labor requirements that were clarified in the 13-week pilot study.

Production yields are condensed into table 15 and showcase the minimum required number of mysids for direct live feeds versus those required for weekly adult restocking. Table 15 also describes the lowest, average, and highest weekly mysid production as well as the predicted weekly overage (extra mysids) above dragon feed requirements for each scenario.

The Monte-Carlo sensitivity analyses estimated the expected NPVs for the variety of preset labor and excess mysid sale combinations for the lowest, average, and highest weekly production totals using the 2018 discount rates in table 17, 18, and 19, respectively. Monte-Carlo NPV analysis for the variety of preset labor and excess mysid sale combinations for average production using previous 2016 interest rates are shown in table 20.

Monte-Carlo analysis for on-site production NPVs without preset labor and sale price data are shown in table 21. The import NPV is described below in table 22. Monte-Carlo analysis shows the percentage of NPV inputs (start-up costs, annual costs, and annual benefits) for simulations without preset labor and for importation simulations fall within bell-shaped normal distributions as seen in figures 3-7. Monte-Carlo analysis shows the percentage of NPV simulations below and above $0.00 for on-site production NPVs without preset labor and sale price data along with importation NPV results in figures 8 and 9, respectively. Monte-Carlo analysis showing the NPV inputs ranked by the effect of the output mean for on-site production NPV simulations without preset labor and sale price data along with importation NPV results are in figures 10 and 11, respectively. The on-site cost per mysid for each type of labor is shown in table 23.

Discussion

Annual volunteer labor totals $0.00 per year. Contract hire labor costs $18,617.07 per year. Projected annual labor costs for APT step 1 and 24 are $29,365.97 and $47,143.40, respectively. The Waikiki Aquarium's actual mix of current volunteer, contract hire, and APT labor equals $19,750.15 per year, which is slightly more than contract hires that do not receive any fringe benefits (see Tables 7, 12, 13).

Annual general operating expenses totaled $1,933.35. Utilities cost $1,511.19 per year while depreciation is $330.76 per year. Labor is the highest annual cost with differing totals for each type of labor (see Table 14).

Annual costs vary as labor costs vary (see Table 14). Volunteer labor plus current general annual expenses total $5,720.21, while annual costs for contract hire labor plus current general annual expenses total $24,337.28. The Waikīkī Aquarium's actual current mix of volunteer, contract hire, and APT labor plus general annual expenses is slightly larger than the annual contract hire cost total, at $25,470.36 per year. Projected annual costs for APT step 1 and 24 plus general annual expenses are $35,077.18 and $52,803.61 per year, respectively. Importation with reduced overall maintenance needs costs $28,242.01 per year, which means that volunteer, contract hire, and the current labor mix are under this annual import cost, whereas APT step 1 and 24 are above it.

Production (see Table 15) was on average 8,415 mysids per week. On average, the minimum amount required per week is 2,751 mysids as direct animal feed needs. Restocking amounts require 3,000 additional mysids per week. In total, weekly feed use and restocking requires 5,751 mysids per week. The Waikīkī Aquarium can be self sustainable with supporting both direct animal feed and restocking needs for continued production as the average weekly yield allows for an average excess of 2,664 extra mysids produced each week. Theoretically, these extra 2,664 mysids could be sold for a profit. In comparison, WAq's lowest weekly production of 4,855 mysids per week didn't support the weekly 5,751 required mysids and had -896 total mysids for the week. The greatest weekly production in this trial was 13,705 mysids produced, with an excess of 7,954 extra mysids per week. A larger excess of production yield is possible: it can either be sold, frozen for later use (which could further reduce imports of mysids, albeit frozen feeds), or used to expand the mysid production area.

The current projected NPV for this 20-year project is $119,368.15 at the current 2018 discount rate of 2.2%. Increased discount rates to the mid and high risk scenarios total $117,914.82 at 2.3% and $116,481.41 at 2.4%, respectively (see Table 16). The difference among NPV results between 2018 discount rates for the current projected NPV is minor with the 2.3% rate at ~$1453 less than the 2.2%, while 2.4% is ~$1433 less than the 2.3%.

The Monte-Carlo NPV sensitivity analyses results for the variety of preset labor and excess mysid sale combinations for the lowest, average, and highest weekly production totals using the 2018 respective range of discount rates in table 17, 18, and 19 have varying outcomes. For selling the least, average, and highest production per week, the mysid sale prices range from not selling them ($0.0/mysid) to the current WAq purchase price of $.08/mysid and above to the most expensive price on the market of $.25/mysid, represented at $.24/mysid (see Table 8). Annual profits range from $0.00 (not selling/selling at $0.0/mysid) to $99,265.92 for selling the highest excess production at $.24/mysid. Table 17 shows the lowest possible weekly production scenario with fluctuating labor and sale costs and has NPVs that range from -$677,148.48 to $252,403.04: The lowest NPV reflects APT step 24 labor and lost profit from selling -896 mysids per week at $.24/mysid, with the highest NPV reflecting volunteer labor and not selling the lack of excess production. For the lowest production using 2018 discount rates, there is ~$6,000 difference in NPVs between low, mid, and high risk rates. Table 18 shows the average possible weekly production scenario with fluctuating labor and sale costs and has NPVs that range in quantity from -$497,785.84 to $776,110.24: The lowest NPV reflects APT step 24 labor and zero profit from not selling excess mysids per week at $0.00/mysid, with the highest NPV reflecting volunteer labor and selling the excess production at $.24/mysid. For the average production using 2018 discount rates, ~$4,350 difference exists in NPVs between low, mid, and high-risk rates. Table 19 shows the highest possible weekly production scenario with fluctuating labor and sale costs and has NPVs that have a range from -$497,785.84 to $1,850,646.80: The lowest NPV reflects APT step 24 labor and zero profit from not selling excess mysids per week at $0.00/mysid, with the highest NPV reflecting volunteer labor and selling the excess production at $.24/mysid. For the highest production using 2018 discount rates, ~$4,350 difference exists in NPVs between low, mid, and high risk rates. High labor rates and lack of profit reduce the NPV, whereas volunteer labor and selling excess mysids at the highest price are primary factors in making the expected NPV positive. All production scenarios (least, average, highest) have the capability of achieving a positive NPV.

The Monte-Carlo NPV sensitivity analyses for the variety of preset labor and excess mysid sale combinations for average production with fluctuating labor and sale costs and previous 2016 interest rates have NPVs that range from -$545,453.95 to $876,430.04: The lowest NPV reflects APT step 24 labor and zero profit from not selling excess mysids per week at $0.00/mysid, with the highest NPV reflecting volunteer labor and selling the excess production at $.24/mysid (shown in table 20). Nominal differences exist between the low and high NPV results for current 2018 discount rates and the previous 2016 discount rates: the low, mid, and high risk rates carry an decrease of ~$47,000 per scenario in the higher 2018 versus the lower 2016 rates. High labor rates and lack of profit reduce the NPV, whereas volunteer labor and selling excess mysids at the highest price are primary factors in making the expected NPV positive.

The Monte-Carlo results for the on-site production NPV stochastic modeling analysis without preset labor and sale price data equals $199,006.38 (shown in table 21). The import NPV based off of the equivalent 2018 mid risk discount rate of 2.3%, equals -$33,433.90 (see Table 22). On-site production at the Waikiki Aquarium has a current projected NPV of $119,368.15, with the on-site random variable NPV equaling $199,006.38, versus the import NPV with a negative outcome at -$33,433.90. With the current projected NPV at greater than or equal to zero, the Waikīkī Aquarium's mysid operation remains a viable option for mysid acquisition. The import NPV on the other hand is negative, and unless the qualitative non-market benefits outweigh this, importation alone is not a viable option into the future for mysid needs at the Waikiki Aquarium. The current annual costs of $25, 470.00, annual benefits of $35,005.00, and a projected NPV of $119,368.15 is similar to the simulated annual costs of $29,500.00, annual benefits of $44,000.00, and a simulated on-site NPV of $199,006.38. Each of the simulated input values for on-site production and importation were within a normal distribution (figures 3-7).

Monte-Carlo stochastic NPV analysis models on-site production without preset labor and sale price data and the import NPV analysis by showing the percentage of NPV simulations below and above $0.00 (Figures 8, 9). The on-site production at the Waikiki Aquarium predicts having NPVs in the positive range in 61% of the projected scenarios, with 39% as negative outcomes. The import only NPVs are predicted to have 28.1% positive and 71.9% negative results, with the positive results due to large labor savings when not required to produce or maintain mysids on site. Monte-Carlo analysis showing the NPV inputs ranked by the effect of the output mean for on-site production NPV simulations without preset labor show that the variables with the greatest effect on NPV, ranked from highest to lowest, are: the sale of mysids (annual benefits), annual costs (labor), and the start up cost. Although labor is the highest annual cost for on-site production, the ability to sell excess mysids has the greatest effect for the on-site production NPV. Monte-Carlo analysis showing the NPV inputs ranked by the effect of the output mean for import NPV simulations show that the variables with the most effect on NPV, are greatest with annual costs (the cost of importing required mysids, annually) and lowest with savings on labor from not producing mysids on-site (annual benefits). This tells us that the import price per mysid has the greatest effect on the import NPV.

If mysids could be sold for profit and with each differing labor scenario and weekly required mysid totals, the equivalent price per mysid is extrapolated (see Table 23). Annual volunteer, contract hire, current actual, APT step 1, and APT step 24 labor costs plus additional general annual costs reflect $.01, $.05, $.05, $.08, and $.12 per mysid, respectively. For current production costs, the price per mysid produced at the Waikīkī Aquarium is $.05, whereas the current import cost is $.08 per mysid purchased. On-site production NPVs are either greater than the import NPV or they have the capability of becoming so and the on-site cost per mysid is $.03 cheaper than importing, so it appears that the Waikīkī Aquarium should continue producing mysids on-site.

Conclusion

The Waikīkī Aquarium's production target is between the minimum and desired needs of syngnathid populations. Currently, the absolute minimum amount of live mysid feeds for the weedy seadragons equals 2,751mysids per week. Production at the Waikīkī Aquarium requires a minimum of 3,000 mysids per week to support restocking of the adult populations for a weekly total of 5,751 mysids per week if on-site production is to continue. Currently, only 3,000 mysids per week are still imported as the results of this study were compiled. With average weekly production at 8,415 mysids per week and an average of 2,664 extra mysids produced per week, the Waikīkī Aquarium should cease importing mysids all together in order to take advantage of the additional cost savings.

With a sustainable, productive, and on-site mysid aquaculture system established at the Waikīkī Aquarium, other future prospects are possible. The Waikīkī Aquarium can produce their own food for the husbandry of their syngnathids and may also do so for other aquarium residents; instead of selling excess mysids, cost savings from reducing frozen mysid imports could be realized. Invertebrate and larval fish rearing opportunities may also increase. The WAq is home to many endemic Hawaiian animals that could benefit from aquaculture and affordable mysid production can lead the way to additional possibilities. Local aquaculture provides relief to wild collection and contributes to a subsequent environmental balance through the rearing of successive generations that are born in captivity rather than collected from the ocean.

Additional benefits to on-site mysid aquaculture include reducing WAq's carbon footprint as imports decline, providing a secure food supply for WAq and increasing cash flows by selling excess mysids to hobbyists or further reducing frozen mysid imports. Mysid culturing facilities have crashed for months at a time. Mainland United States winter storms, holidays, and other shipping delays are also a frequent problem when considering providing a sustainable resource of live food for aquatic animals. On-site production increases food security for WAq and eliminates shipping from importation. The on-site sustainable production of a main food source for WAq's rare Syngnathidae conservation project and its conferred security is likely to have large non-market benefits.

The largest non-market benefits may come from creating either an un-paid or paid student internship by embracing the Waikīkī Aquarium's status as a part of the University of Hawaiʻi. The Waikīkī Aquarium has a complete live feeds aquaculture manual for mysid production and all used species of zooplankton. This manual is the basis for a local aquaculture training center that provides internship opportunities.

Future research could investigate how to reduce the cost of on-site mysid aquaculture and reducing imports; this benefits the Hawaiʻi state economy by reducing monetary leakages to out of state vendors. Further investigations into more widely ranging interest rates would be useful, especially those commonly used for private loans (5+%) so that entrepreneur businesses could assess their risk for starting mysid production. For the on-site mysid production, many risk factors affect yields of production, including mysid fecundity, survival, sex-ratios for production optimization, and labor costs. Further optimization will come from refining feeding and maintenance needs along with possible future modifications that may lower initial costs and boost fecundity and survival by further optimization of male to female ratio, stocking density and harvest frequency, flow rates, air rates, substrate addition, hypo-salinity water, or the handling of adults or nauplii.

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