Production Economics of Giant Clam (*Tridacna* species) Culture Systems in the U.S.-Affiliated Pacific Islands

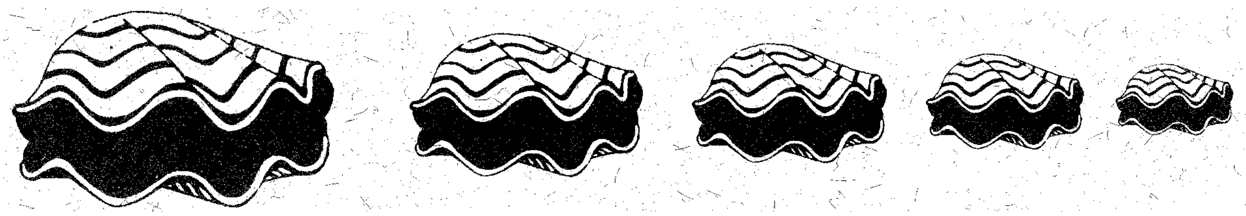

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Table of Contents

Executive Summary

The first part of this report compares production costs of culture systems currently being used or evaluated in the Republic of the Marshall Islands, the Republic of Belau, the Federated States of Micronesia and American Samoa.

At the time this study was initiated, giant clam producers in the Pacific Islands were marketing larger clams, that is, clams more than 3 years old. However, more recently, giant clam producers have been targeting new, higher-priced markets for smaller clams. These smaller animals are being sold to aquarium hobbyists and to food markets for sushi. As more pricing information becomes available, a study could be done to evaluate these markets.

Two distinct systems are undergoing experimentation in the Republic of the Marshall Islands. One system uses raceways in the hatchery phase, and the other system employs floating tanks. Both systems utilize floating platforms with plastic trays for the nursery phase. Clams are then grown out on shallow fringing reefs. The estimated cost of producing 8-month-old, 2.5-cm *Tridacna gigas* in the raceway hatchery system is $0.41 per clam. The cost in the floating tank hatchery system is $0.23 per clam. Raising the clams to about 3 years of age costs an estimated $5.08 per clam for the combined raceway hatchery system and floating platform nursery, and $4.83 per clam for the combined floating tank hatchery system and floating platform nursery. If the clams from the raceway system are grown on the shallow fringing reef for another two years, total costs rise to $9.44 per clam. If the clams from the floating tank hatchery system are grown on the reef for another two years, total costs rise to $9.13 per clam.

The Micronesian Mariculture Demonstration Center (MMDC) in the Republic of Belau uses a land-based hatchery and a combined land-based and ocean-cage nursery system to produce 2-year-old *T. derasa*. The estimated cost of raising 1-year-old clams in the land-based hatchery and nursery part of the system is $0.82 per clam. The cost increases to $1.41 per clam if they are planted in ocean nursery cages for a second year. The MMDC charges a farm-gate price of $1.00 for a 1-year-old clam and $3.00 for a 2-year-old clam.

The systems in Kosrae and American Samoa are similar to the system in Belau but have smaller annual production. The estimated cost of producing 2-year-old *T. derasa* in Kosrae is $1.23 per clam. The American Samoa system produces a 1-year-old *T. derasa* for $0.76 and a 2-year-old *T. derasa* for $3.40.

The second part of the report analyzes the optimal harvest time (replacement cycle) to maximize economic returns for the giant clam, *T. derasa*.

The optimal harvest age ranges from no production to 13.2 years if only the shells are assumed to be saleable, from no production to 9.2 years if only the adductor muscles are assumed to be saleable, and from no production to 10.5 years if only the other meat is assumed to be saleable. If all clam products are assumed to be saleable, the optimal

harvest age ranges from no production to 10.7 years. If only meat is assumed to be saleable, the optimal harvest age ranges from no production to 9.0 years.

The results indicate that clam farming can be profitable if prices of clam products are high or if juveniles are inexpensive and annual operating costs are low. If all clam products can be sold, clam farming is generally profitable. If only meat can be sold, clam farming is profitable only if the production costs are low and the prices of the meat products are high. Marketability of the shell is an important factor affecting the optimal harvest age and the profitability of production.

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The views expressed in this report are those of the authors and do not necessarily reflect the views of the Center for Tropical and Subtropical Aquaculture, the U.S. Department of Agriculture, Cooperative State Research, Education and Extension Service, any of it sub-agencies or staff.

Introduction

The giant clams (*Tridacna* spp.) of the Pacific are popular for food and other uses. The adductor muscle and mantle are consumed as food in raw, cooked or dried forms. Giant clam shells are sold as souvenir items or used in craftware. The market for giant clams as seed, broodstock and aquarium animals is also growing. The animals' high value and easy accessibility have threatened wild populations in many parts of the tropical Pacific Ocean; ineffective protective regulations have done little to deter poaching that is continuing their decimation. Mariculture has belatedly been recognized as an important long-term solution to the continued supply of this threatened species, as it has with many other popular and valuable marine food species.

Because the Pacific Islands have limited land and freshwater, mariculture has considerable potential to diversify their narrowly-based economies. The development of giant clam farming is of particular interest because

- this species is autotrophic, requiring no artificial feeding,
- the ocean grow-out phase appears technically simple and requires little capital investment,
- giant clams are well adapted to the sunlit waters of coral reefs that are low in nutrients, and
- the breeding and rearing techniques are relatively simple and have been developed so that giant clam farming is technically possible now.

It is not unrealistic to envision large-scale commercial giant clam farming in the Pacific by the end of the next decade. Pilot-scale giant clam farming has been practiced in several U.S.-affiliated Pacific islands, the Solomon Islands and Australia. The two fastest growing species, *T. gigas* and *T. derasa,* are being cultured.

The key to the success of the giant clam industry, like that of any other industry, is coordination of the marketing and production operations. To evaluate the potential of the giant clam industry, information on market and production economics is urgently needed. The markets for giant clam products have been studied (Shang et al. 1991, 1992); however, information on production economics is very limited. The purposes of this production economics study were to:

- document and compare production costs of giant clam culture systems in the U.S.-affiliated Pacific Islands;
- identify .the optimal harvest age for the giant clam *T. derasa.*

At the time this study was initiated, giant clam producers in the Pacific Islands were marketing larger clams, that is, clams more than 3 years old. However, more recently, giant clam producers have been targeting new, higher-priced markets for smaller clams. These smaller animals are being sold to aquarium hobbyists and to food markets for sushi. As more pricing information becomes available, a study could be done to evaluate these markets.

Production Cost Comparisons of Giant Clam Culture Systems in the U.S. Affiliated Pacific Islands

Two distinct culture systems are undergoing experimentation in Pacific island countries. One system uses land-based tanks/raceways, and the other system uses floating tanks in the hatchery and nursery phases. Figure 1 summarizes the major production phases and the associated ages and sizes of clams at the various culture stages in the systems used in American Samoa, the Republic of Belau, the Federated States of Micronesia and the Republic of the Marshall Islands. Production cost data were collected during 1991 and 1992 from giant clam culture facilities in the U.S. affiliated Pacific islands named above. Wherever possible, information was collected for the three phases of clam production, i.e., hatchery, nursery and growout. Information was obtained through personal interviews with facility managers at each site. Discounted costs were estimated at the various stages of production using a discount rate of 10 percent and assuming an operation life of 20 years. The analysis also assumed that 100 percent of the required capital was obtained through a 10-year loan at an annual interest rate of 10 percent. Sensitivity analyses were also performed on key production and financial parameters. Detailed results of the analysis are given in the following sections.

Republic of the Marshall Islands

Mr. Neal Skinner experimented with two systems of culturing *T. gigas* in the Republic of Marshall Islands. One system used raceways in the hatchery phase while the other system used floating tanks. Both systems were designed for small operations and mainly rely on solar energy to generate electricity. In the nursery phases, both systems utilized floating platforms with plastic trays. Clams were then grown-out on shallow fringing reefs (Figure 1).

Hatchery

For the hatchery phase, this report assumes a target production level of 40,000 2.5-cm clams in eight months. The capital costs for both the raceway system and the floating tank system are shown in Tables 1a and 1b, respectively. Total capital costs for the raceway system proved higher than the floating tank system: $12,330 versus $10,135. Typical annual operating coats for the raceway system are estimated to be $16,881.

Typical annual operating costs for the floating tank system are estimated to be $9,753. A breakdown of the annual operating costs for the raceway hatchery system and floating tank hatchery system is shown in Tables IIa and Ilb, respectively. The breakdown of annual operating costs is similar for the two systems, with labor costs (wages and salaries) accounting for more than 70 percent of total operation costs (Figures 2 and 3).

Throughout this publication, the term ‘Wages” refers to labor costs for technical support related to production, and the term “salaries” refers to annual salaries for professional staff. Producing 8-month-old *T. gigas* using the raceway hatchery system costs an estimated $0.41 per clam. Producing the same animal in the floating tank system costs an estimated $0.23 per clam.

Figures 4 and 5 show, respectively, the sensitivity of production cost to the changes in major cost items for the hatchery phase of both systems. Changes in labor costs most affect the cost of production. A 10 percent increase in labor costs would raise the production cost per clam by 7.3 percent (from $0.41 to $0.44 per clam) for the raceway system and 8.7 percent (from $0.23 to $0.25 per clam) for the floating tank system.

Nursery

The nursery phase assumes an annual target production of 800 clams to be raised from 2.5 cm to 20 cm in 28 months. Survival rate is assumed to be 80 percent, i.e., stocking rate is assumed to be 1,000 clams. This report assumes that 15 floating platforms are used, each of which can hold 9 trays; each tray can hold 12 3-year-old *T. gigas*. Nursery capital costs are shown in Table III. The nursery's annual operating costs are shown in Table IVa (assuming juvenile clams are from the raceway hatchery system) and Table lVb (assuming juvenile clams are from the floating tank hatchery system). The estimated cost of raising a 3-year-old clam is about $5.08 each if the stocking cost per clam is $0.41 (i.e., juvenile clams from the raceway hatchery system). However, if the stocking cost per clam is $0.23 (i.e., juvenile clams from the floating tank hatchery system), the estimated production cost decreases to about $4.83 per clam.

The breakdown of annual operating costs for the nursery phase is very similar for both the raceway and floating tank systems. The only difference is in stocking costs, which are higher for the juveniles from the raceway hatchery system (Figures 6 and 7). Percentage changes in major cost items also similarly affect the production cost per clam for both hatchery systems; as expected, labor costs are the most sensitive factor (Figures 8 and 9).

Growout

The ocean growout phase assumes a 2-year cycle with an annual target production of 720 clams. Three-year-old, 20-cm clams are assumed to grow to 32 cm in two years with 10 percent mortality. The capital cost for ocean growout is shown in Table V. Table VIa shows annual operating costs, assuming the stocking cost of a three-year-old *T. gigas* is $5.08. Table VIb shows the annual operating costs assuming the stocking cost of a three-year-old clam is $4.83. The estimated total cost of producing a five-year-old clam is $9.44 if the raceway hatchery system is used. The cost goes down to $9.13 per clam if the floating hatchery system is used.

As in the nursery phase, the percentage breakdown of annual operating costs for the ocean growout phase using either hatchery system are almost identical (Figures 10 and 11). As a result, changes in production cost parameters have a similar effect on the cost of producing a five-year-old clam in either system (Figures 12 and 13). Stocking cost, which is the largest cost item, most greatly affects production costs for both systems.

Republic of Belau

The Micronesian Mariculture Demonstration Center (MMDC) in the Republic of Belau uses a land-based hatchery and a combined land-based and ocean-cage nursery system to produce 2-year-old *T. derasa*. The hatchery phase—about 5 months—produces clams measuring 1 cm. The nursery phase consists of seven months in land-based tanks, after which a clam measures 5 to 6 cm. After a 12-month growout in the ocean cage nursery, a 2-year-old clam measures about 10 to 12 cm (Figure 1). Details of that production system can be found in Heslinga, Watson and Isamu (1990).

This report assumes that about 200,000 1-year-old *T. derasa* are run through the hatchery and land-based nursery annually. Total capital costs amount to about $299,000, and annual operating costs come to $173,433 (see Table VII and Table VIII for detailed breakdowns). Producing a 1-year-old clam is estimated to cost about $0.82. The ocean cage nursery assumes a 75 percent survival rate with an annual production target of 150,000 clams. Capital costs and annual operating costs are detailed in Tables IX and X, respectively. The estimated total cost of producing 2-year-old clams is $1.41. The estimated costs of production are well below the farm-gate prices charged by MMDC for 1- and 2-year-old clams, which are $1.00 and $3.00 per clam, respectively.

The percentage breakdown of annual operating costs for the combined hatchery and land-based nursery phase (year one) and the ocean-cage nursery phase (year two) are shown in Figures 14 and 15, respectively. Wages and salaries, depreciation, and interest payments account for 78.6 percent of the combined hatchery and land-based nursery's total, annual operating costs. These items account for less than 23 percent of the ocean-cage nursery's total annual operating costs. The major expense for that system is stocking cost.

Figures 16 and 17 show the sensitivity of production cost to the changes in major expenses for the hatchery and land-based nursery phase (year one) and the ocean-cage nursery phase (year two). Production cost is most sensitive to relative changes in capital costs for the hatchery and land-based nursery and is most sensitive to relative changes in stocking cost for the ocean-cage nursery. If the survival rate in an ocean-cage nursery increased 10 percent, production costs would drop from $1.41 per clam to $1.28 per clam.

Kosrae, Federated States of Micronesia

The giant clam farm in Kosrae, operated by the Federated States of Micronesia's government, uses a culture system adapted from the MMDC. However, it is still experimental and is on a smaller scale than the operation in Belau. The combined hatchery and nursery operations are assumed to produce annually 100,000 2-year-old *T. derasa* with an average size of 5 to 10 cm. The hatchery phase lasts about 5 months. The clams are then transferred to land-based nursery tanks, where they are held for 3 months. Finally, the clams are planted in ocean nursery cages for 16 months (see Figure 1).

Total capital costs for this facility were about $183,000; operations cost $116,040 annually (see Tables XI and XII). The production cost for a 2-year-old clam is estimated at $1.23. Electricity and fertilizer are provided by the government; therefore, the production cost per clam would increase slightly if electricity and fertilizer costs are included.

Figure 18 shows a percentage breakdown of hatchery and nursery phase operating costs. Salaries and wages account for almost 60 percent of total costs. The remaining 40 percent comprises interest, depreciation, utilities/fuel, supplies, equipment maintenance and other costs. Production cost per clam is most sensitive to labor and capital costs (Figure 19). A 10 percent increase in labor and capital expenses would raise the cost per clam by $0.08 and $0.04, respectively.

American Samoa

American Samoa's giant clam culture facility—an adaptation of the MMDC system—uses a land-based hatchery and a combined land-based and ocean-cage nursery system to produce 2-year-old *T. derasa* (Figure 1). The hatchery and land-based nursery are located at the same site, while the ocean-cage nurseries are located in the villages of Ofu, Alofau, and Nuuuli.

The hatchery and land-based nursery operations have a production goal of 100,000 1-year-old *T. derasa* per year. The hatchery phase spans about 5 months, and the land-based nursery lasts about 7 months. A 1-year-old clam is about 6 cm in length. Currently, only a small number of 1-year-old clams are distributed to the three nurseries. The remainder are used for teaching, training, replacement and sales. Total capital costs and annual operating cost are estimated to be about $52,940 and $77,560, respectively (Tables XIII and XIV). Producing a 1-year-old clam costs about $0.76.

The ocean-cage nursery assumes a total of 3,050 clams stocked at all three nursery sites with a 60 percent survival rate. After 12 months in the ocean-cage nursery, the clams—now 2 years old—measure 13 cm. Tables XV and XVI show total capital costs and annual operating costs. The estimated production cost is $3.40 for a 2-year-old clam.

Figures 20 and 21 show the percentage breakdown of annual operating expenses of, respectively, the hatchery and land-based nursery phase and the ocean-cage nursery phase. In both phases, labor accounts for more than half of total costs. Labor costs form a substantially higher percentage of total costs than in the MMDC operation in Belau.

As expected, production cost is the most sensitive to labor costs in the hatchery and land-based nursery phase as well as in the ocean-cage nursery phase (Figures 22 and 23). A 10 percent increase in survival rates for the ocean-cage nursery operation would reduce the cost of production by $0.31 per clam.

Discussion

Comparing production costs between the different facilities was difficult because the time-table for calculating production costs varied for each facility (Table 1).

The system used in Kosrae is patterned after the MMDC system for culturing *T. derasa*;

hence its estimated production costs are very similar. In fact, producing a 2-year-old *T. derasa* costs an estimated $1.23 per clam in Kosrae.

Although the American Samoa facility uses a system adapted from the MMDC system, producing a 2-year-old *T. derasa* costs much more in American Samoa: $3.40 versus $1.41. The high labor costs associated with the training and teaching components of the American Samoa system raise production costs.

Cost and sales data for older clams are presented from only the Marshall Islands and the MMDC in Belau. Although not directly comparable, estimated production costs for 3- and 5-year-old *T. gigas* in the Marshall Islands appear to be below the MMDC's farmgate prices for *T. derasa.* The floating tank hatchery system in the Marshall Islands has lower production costs than a raceway hatchery system. However, whether the two systems will provide the same consistent production levels has not been demonstrated. The floating tank system may not provide production as consistent as that from the land-based raceway system. For the purpose of comparison, Tisdell *et al.* (1990) estimated that producing 1-year-old *T. gigas* in Australia cost between $0.32 and $1.57, depending on the size of operation. The higher estimated cost in Australia is expected because production costs—especially labor costs—are generally higher than those in developing nations such as the Republic of the Marshall Islands.

Giant clam culture production technology as currently practiced in the U.S.-affiliated Pacific islands apparently can be profitable. However, efforts to coordinate the giant clam supply from the entire Pacific region to the various demand centers may be necessary in order to ensure continued growth of this industry.

Economically Optimal Harvest Age for the Giant Clam *Tridacna derasa*

Much technical progress has been made in the culture of *Tridacna derasa* during the decade from 1983 to 1993. According to Tisdell (1986) and Heslinga and Fitt (1987), envisioning large-scale commercial farming in the Pacific by the end of the 1990s is not unrealistic. As Watson and Heslinga put it, "It is now possible to being quantitative assessment of the questions: What is the best time to harvest cultured specimens?" In their paper, they analyzed an optimal harvest schedule that would permit a clam farmer to maximize average annual production of biomass per unit area. This section extends their analysis to identification of the optimal harvest schedule (replacement cycle) to maximize economic returns.

Tisdell (1986) constructed a model to estimate the optimal duration for growout period to maximize the net present value of a batch of juvenile clams for a range of interest rates. Using growth estimates for *T. gigas* and mortality estimates for *T. derasa,* he estimated that the optimal growout period is 7 years, assuming that the meat—the only marketable product from the clam—can be sold for A$1.50 per kilogram and that the real interest rate is 10 percent. (Real interest rate is used to account for the effect of inflation and can be defined simply as the nominal interest rate less the expected inflation rate.) At this interest rate, the net present value of a juvenile clam is A$1.37. He concluded that clam farming can be quite profitable because the price of a juvenile was around $1,00 at the time of his analysis. It should be noted that his analysis incorporated no other cost. He also recognized that the analysis assumed that available space was not a major constraint on clam farming and suggested further work should be done to assess the optimal grow-out period if space was a constraint. However, he pointed out that a growout period of about 4 years would seem likely to be optimal.

Watson and Helsinga (1988) recognized that when space is a constraint, forest management techniques can be useful in controlling tridacnid clam resources. They used the basic principle of biological rotation of maximum biomass production and applied it to the size-at-age data for a cohort of *T. derasa* spawned at the Micronesia Mariculture Demonstration Center (MMDC) in 1979. These data, the most comprehensive set available for culture Tridacna, contain age-weight data for adductor muscle, other soft tissue and shell. Using the principle that maximum biomass production occurs at the age when average growth equals marginal growth, they found that the optimal harvest age for :

- adductor muscle is 6 years;
- other soft tissues is 6 years;
- shell is greater than 7 years.

This section uses Watson and Heslinga's (1988) data to determine the optimal length of a replacement cycle that will maximize economic returns.

Methods

Optimal Harvest Age for Maximum Biomass Production

The point of maximum biomass production occurs when average growth equals marginal growth (Avery 1975; Watson and Helsinga 1988). If a growth equation for each clam product can be estimated, then this equation can be used to determine marginal growth by taking the first time derivative of the growth equation.

Optimum Harvest Age for Maximum Economic Returns: The Faustmann Model

Maximizing biomass production does not usually maximize economic returns. With limited space, one generation of clams competes with a younger generation for the same area. By harvesting older clams whose marginal values are decreasing, space can be made available for younger clams, which grow faster and thereby yield a greater increase in value. This problem is similar to the optimal rotation problem in forest management as developed by Faustmann (1849). Clark (1976) and Bjorndal (1988) have demonstrated the use of Faustmann's model in fishery and aquaculture management, respectively. For the mathematical details of Faustmann's model as applied to giant clam culture, readers are referred to Leung *et al.* (1993).

Assumptions

To apply the Faustmann rule, assumptions must be made on survival, price of clam products, annual operating and juvenile cost. Munro (1988) estimated a constant survival rate of 0.9873 after one year of growth, using the same set of data analyzed in this section. The constant survival rate did not seem appropriate because clams' survival rates tend to increase with age. For this reason, the following survival rates were assumed:

Year of Growout	Survival Rate
1	90%
2	95%
3	97%
4	98%
5 to infinity	100%

Farm-gate prices were assumed to be US$0.60 per kilogram for shells, US$22.00 per kilogram for muscle (Heslinga and Watson 1985) and US$2.20 per kilogram for other meat (Kona Clam Co., Ltd., 1986).

Two-year-old juvenile clams were assumed to cost US$1.50 each if purchased (Including packing and shipping cost {MMDC 1989}) by a growout farm and US$0.53 per clam if produced on-site at the growout farm (unpublished data). Annual operating costs were adapted from unpublished data (Table 2). A 10 percent real interest rate was assumed.

To take into account the various possible farm configurations, four cases were analyzed.

In **Case 1**, clams were situated far from shore, so a boat and scuba diving gear were needed;

annual production costs included fuel, labor and depreciation; juvenile cost was assumed to be US$1.50 per clam.

In **Case 2**, clams were close to shore, so a boat and scuba diving gear were not needed; only labor costs were assumed to be incurred; juvenile costs was assumed to be US$1.50 per clam.

In **Case 3**, clams were situated far from shore, so a boat and scuba diving gear were needed; juvenile cost was assumed to be US$0.53 per clam.

In **Case 4**, clams were situated close to shore, so a boat and scuba gear were not necessary; only labor costs were incurred, and juvenile costs were assumed to be US$0.53 per clam.

The annual production costs for the four cases are presented in Table 3.

Results and Discussion

Estimated Growth Equations

Using the seven years of *T. derasa* growth data from Watson and Heslinga (1988), the growth equations given below were found to be most plausible for each commercially important product.

The estimated growth equations are generally very well fitted, as shown in Figure 24. The purpose of estimating these equations is to facilitate the calculations of the optimal replacement cycle, which will be discussed later.

Optimal Harvest Age for Maximum Biomass Production

Using the estimated growth equations for each clam product, the optimal harvest age for maximizing biomass production can be calculated by equating the average growth and marginal growth. The estimated optimal harvest age for

- the shell was 8.8 years;
- the muscle was 5.9 years;
- other meat was 7.0 years.

The results are slightly different from Watson and Heslinga's (1988) because estimated growth equations were used. They estimated the optimal harvest age for both muscle and other meat to be 6.0 years. The similarity between the results of these studies indicates that the estimated growth equations can approximate the actual growth process very well.

Optimal Harvest Age for Maximum Economic Returns

Table 4 shows the optimal harvest time for each individual clam product and some combinations of products in the four cases. This table also shows the changes of optimal harvesting time with clam product prices varying within 25 percent of the assumed prices. The optimal harvest time for shell, in terms of clam age, ranged from no production to 13.2 years. No muscle production should be carried out except when prices are higher, and no other meat production should be done except for the case in which the price is the highest and the production cost is the lowest. “No production” refers to the case in which net present value (NPV) is negative, indicating an unprofitable situation; hence the best decision is not to grow clams.

Table 4 also shows the optimal harvest time assuming (a) all the products could be sold, and (b) only the meat products could be sold. In (a), the optimal harvest time ranged from no production for situations in which prices were lowest and production cost was highest, to 10.7 years. In (b), it ranged from no production in situations in which product prices were low and production costs were high to 9.0 years.

Table 5 presents the corresponding net present values at optimal harvest time for each case. If only the shell was assumed to be saleable, the net present values were generally positive except in Case 1 and Case 3 with lower prices. If only muscle or other meat was saleable, the net present values were generally negative except in Case 4 with higher product prices. If all the products were saleable, all the net present values were positive except for Case 1 with lower product prices. If only meat could be sold, the net present values were positive only if the production costs were low and product prices. If all the products were saleable, all the net present values were positive except for Case 1 with lower product prices. If only meat could sold, the net present values were positive only if the production costs were low and product prices were high. The results indicated that if all the products could be sold, clam farming was generally economically feasible and the optimal harvest time, in terms of clam age, ranged from 7.0 to 10.7 years. If only meat was assumed to be saleable, clam farming could be profitable only when the product

Shell:	WS=9114.30 $[1-e^{-0.31\ (t-1.63)}]^3$ (6.05) (6.70)(8.64)	R^2=0.99	D-W = 2.81
Adductor Muscle:	WM = 95-78 $[1-e^{-0.69(t-2.16)}]^3$ (9.39) (4.02)(5.81)	R^2=0.97	D-W=2.82
Other Meat:	WO=831.26 $[1-e^{-0.49(t-2.05)}]^3$ (6.15) (3.71)(4.98)	R^2=0.99	D-W=2.86

Where:
WS is the Weight of Shell in grams;
WM is the Weight of Muscle in grams;
And WO is the Weight of Other Meat in grams;
T is age in years;
Numbers in parentheses are t-statistics;
D-W stands for the Durbin-Watson statistics;
A juvenile is approximately 2 years old; consequently, t=7 refers to the seventh year of age or the fifth year of growout;
The functional form employed in estimating the above equations is the von Bertalanffy (1938) growth function, which is commonly used in describing shellfish growth.

prices are high and production costs are low; optimal harvest time, in terms of clam age, ranged from 6.5 to 9.0 years. In general, the results indicated that as clam product price increases, the optimal harvest time decreased as expected. The optimal harvesting time decreased with decreasing costs as well. A sensitivity analysis (not given here) also shows that optimal harvesting time decreased with increasing survival rates and decreasing real interest rates.

One weakness of this study is the use of the estimated growth equation beyond the data for which the equation is estimated. However, the results are fairly plausible using the von Bertalanffy functional form. If longer growth data series become available in the future, this analysis can be updated.

Recently, clam producers started targeting two other strong potential markets for giant clams. These markets are the aquarium hobbyist and the food market for sushi. When more pricing information becomes available, these results could be extended to evaluate these products.

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Appendix A. Figures 1 through 24

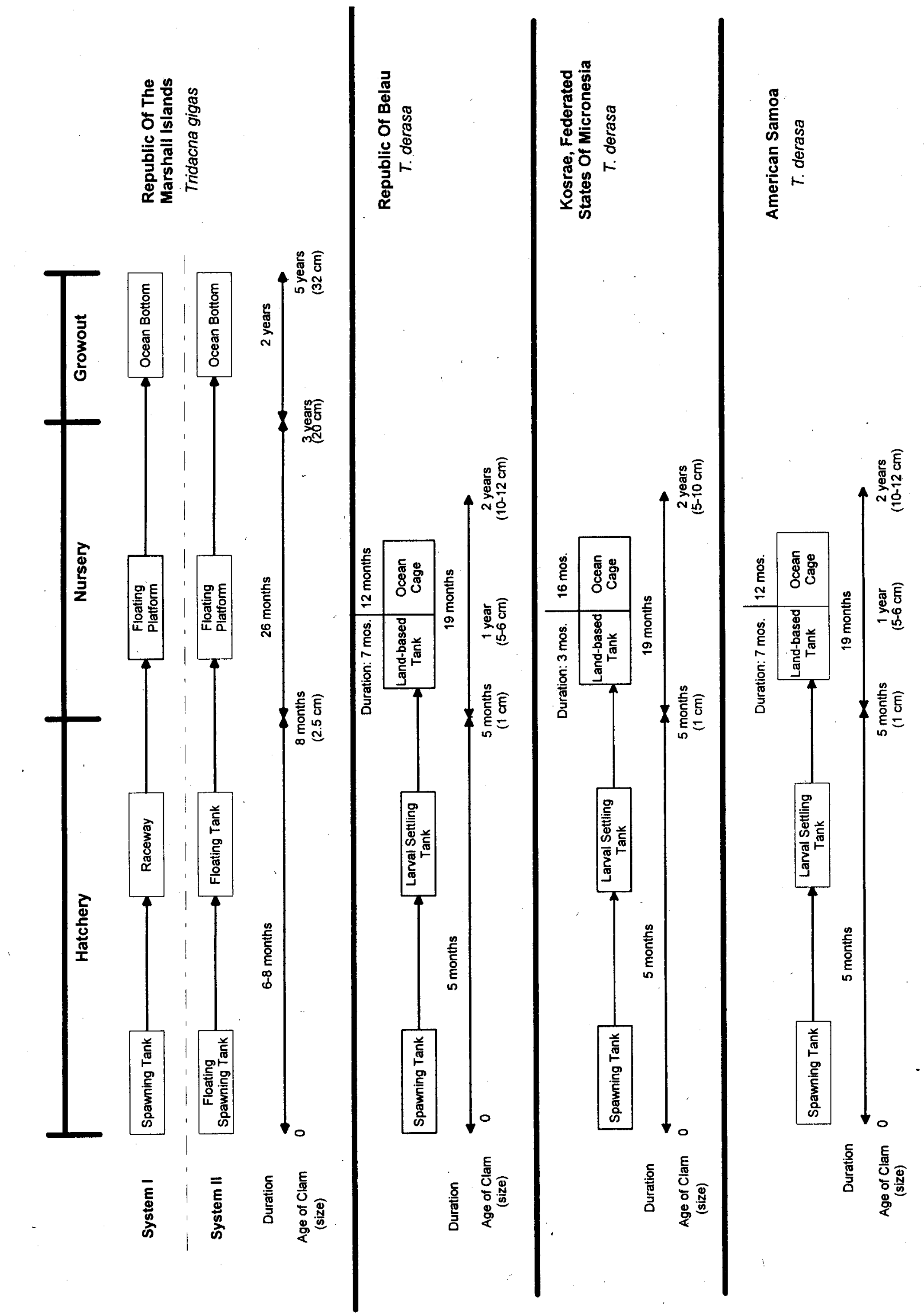

Figure 1.Giant Clam Production Systems

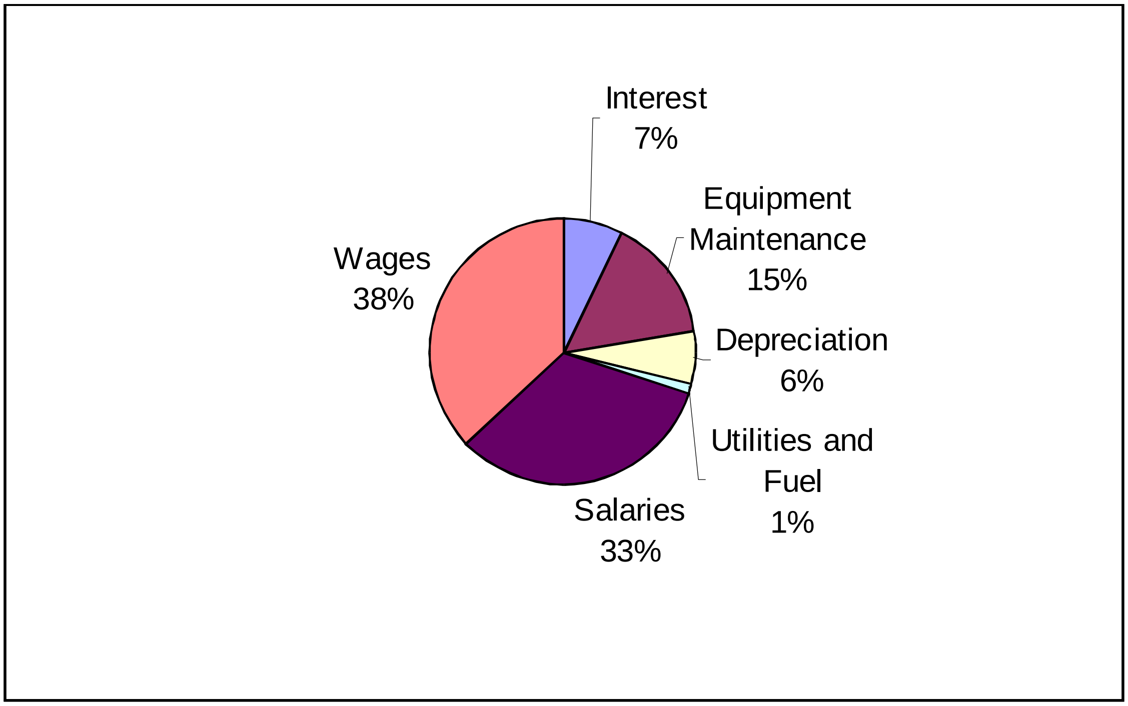

Figure 2. Annual Hatchery Operating Costs, Raceway System
Republic of the Marshall Islands

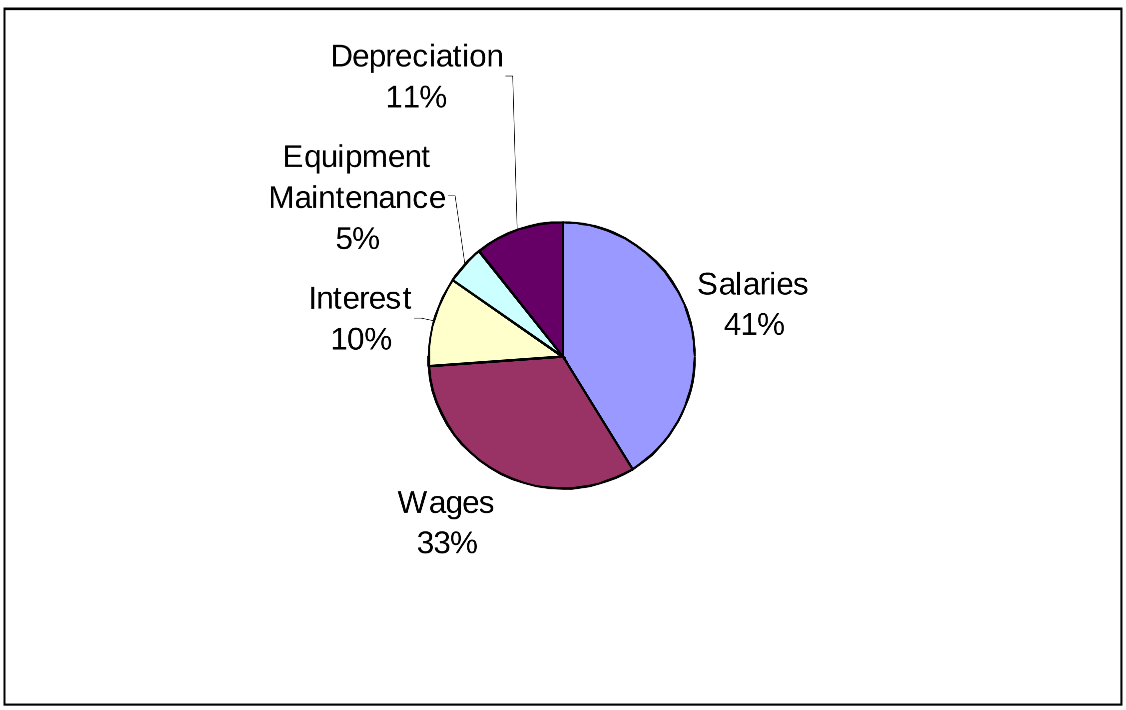

Figure 3. Annual Hatchery Operating Costs, Floating Tank System
Republic of the Marshall Islands

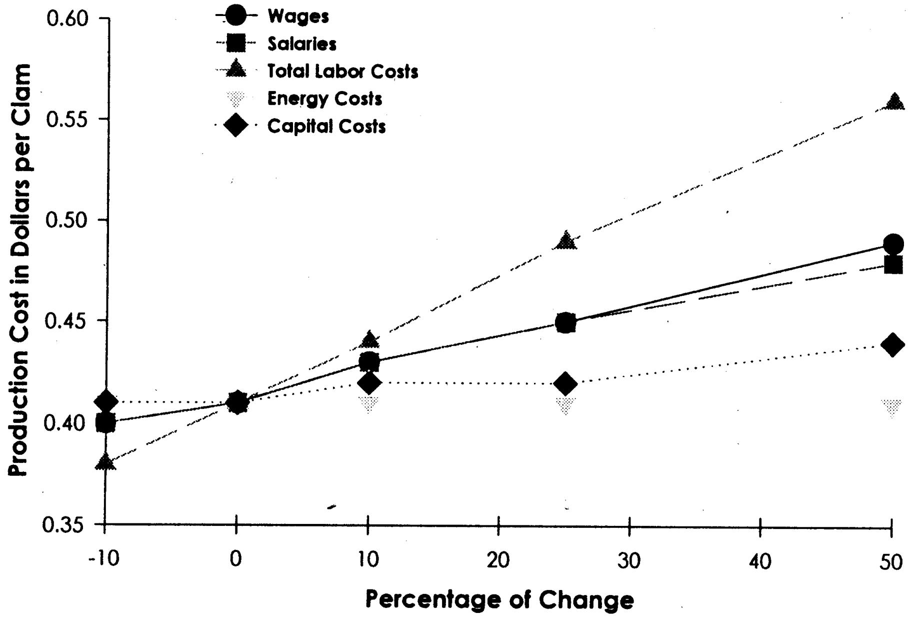

Figure 4.

Sensitivity of Production Cost to Changes in Labor Costs, Energy Costs, and Capital Costs, Raceway Hatchery Operations, Republic of the Marshall Islands

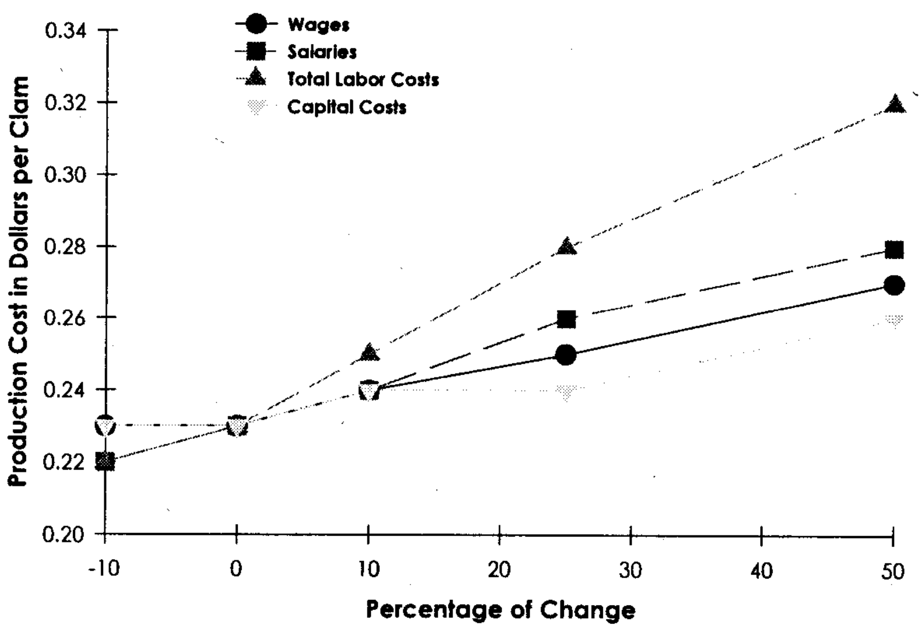

Figure 5.

Sensitivity of Production Cost to Changes in Labor Costs and Capital Costs, Floating Tank Hatchery Operations, Republic of the Marshall Islands

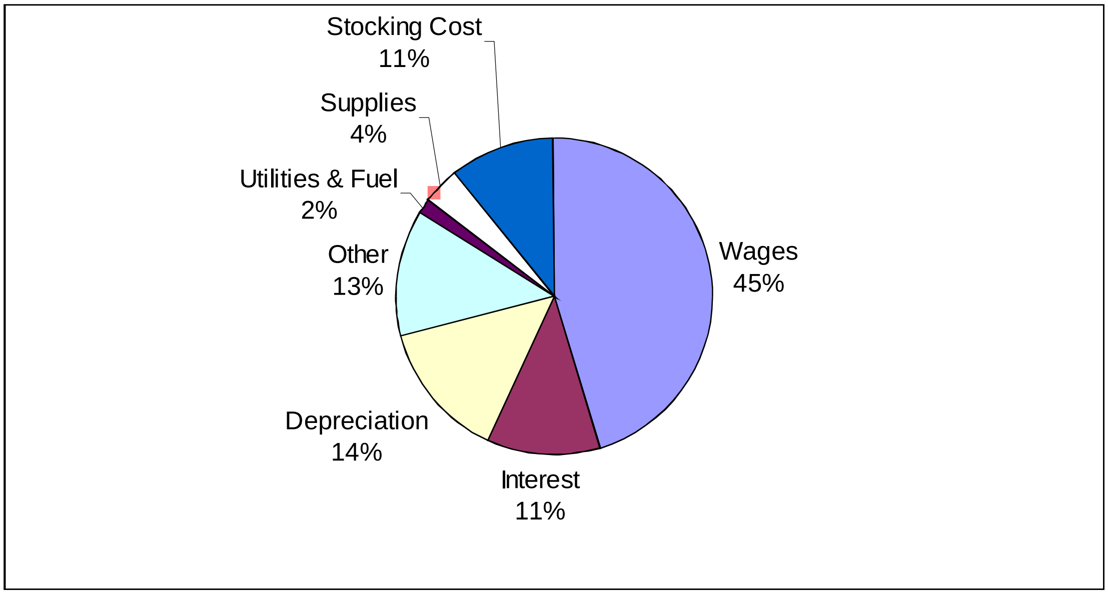

Figure 6. Annual Nursery Operating Costs, Raceway Hatchery System
Republic of the Marshall Islands

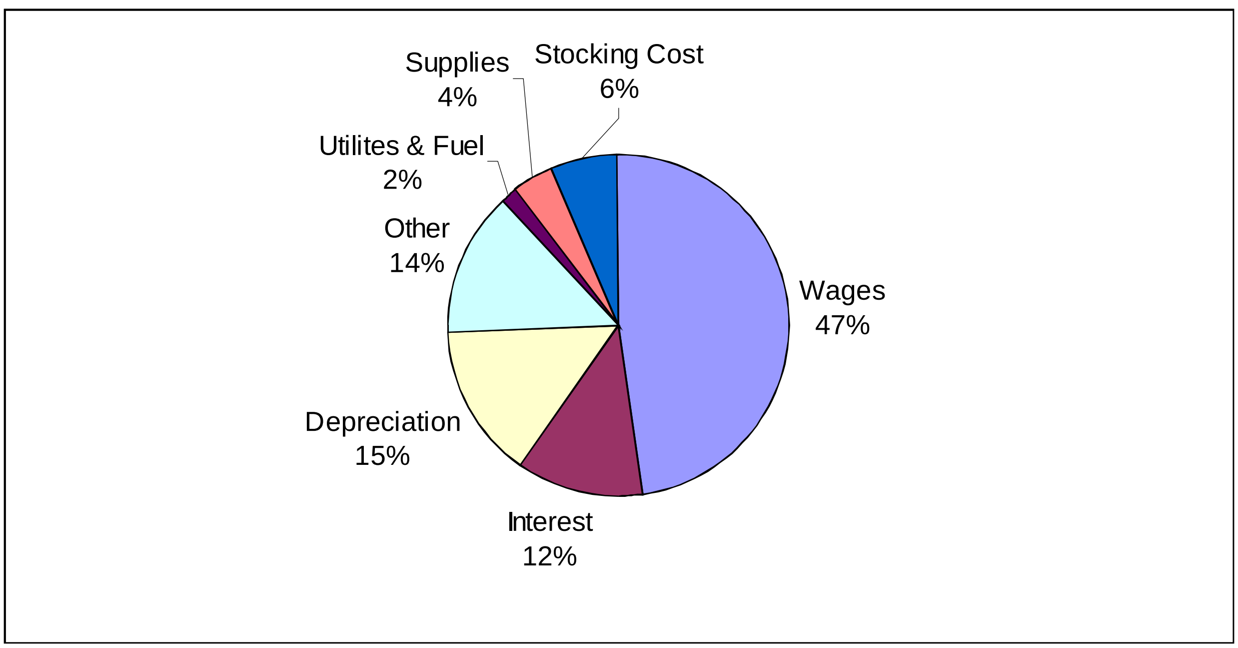

Figure 7. Annual Nursery Operating Costs, Floating tank Hatchery System
Republic of the Marshall Islands

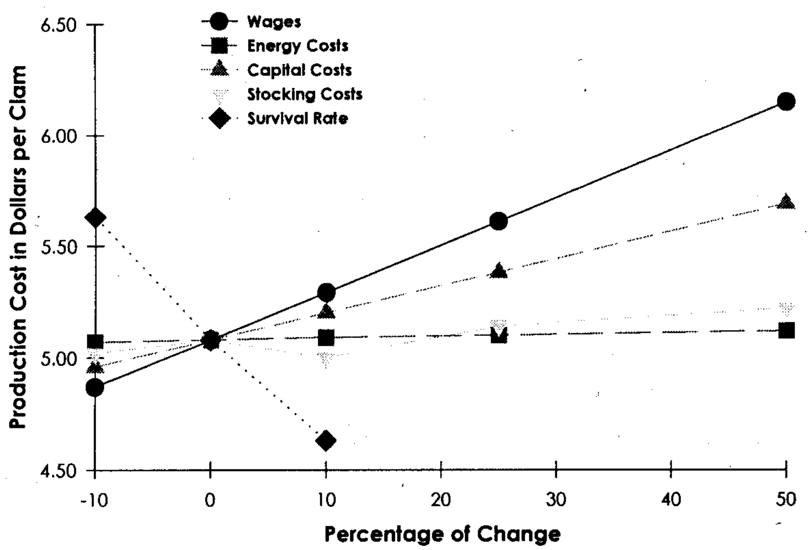

Figure 8.

Sensitivity of Production Cost to Changes in Wages, Energy Costs, Capital Costs Stocking Cost and Survival Rate for the Nursery Phase, Raceway Hatchery System, Republic of the Marshall Islands

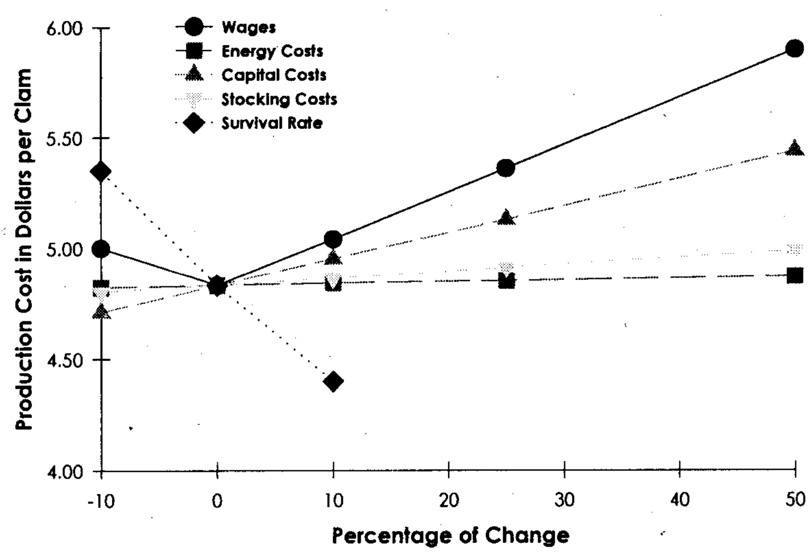

Figure 9.

Sensitivity of Production Cost to Changes in Wages, Energy Costs, Capital Costs, Stocking Cost and Survival Rate for the Nursery Phase, Floating Tank Hatchery System, Republic of the Marshall Islands

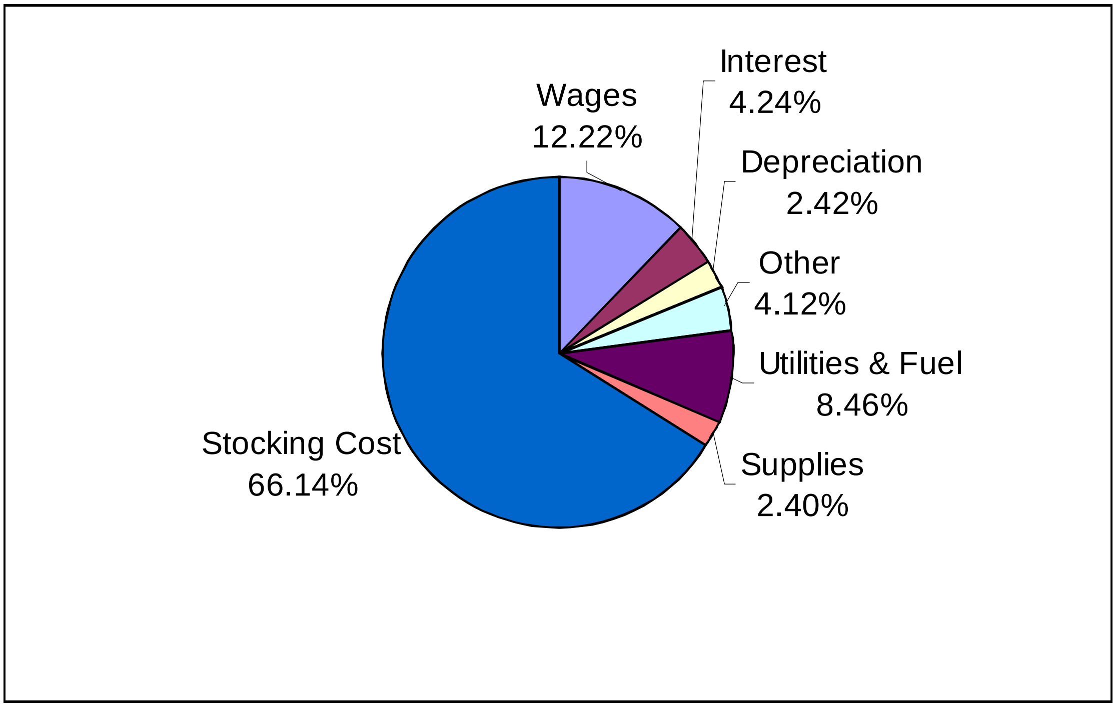

Figure 10. Annual Growout Operating Costs, Raceway Hatchery System, Republic of the Marshall Islands

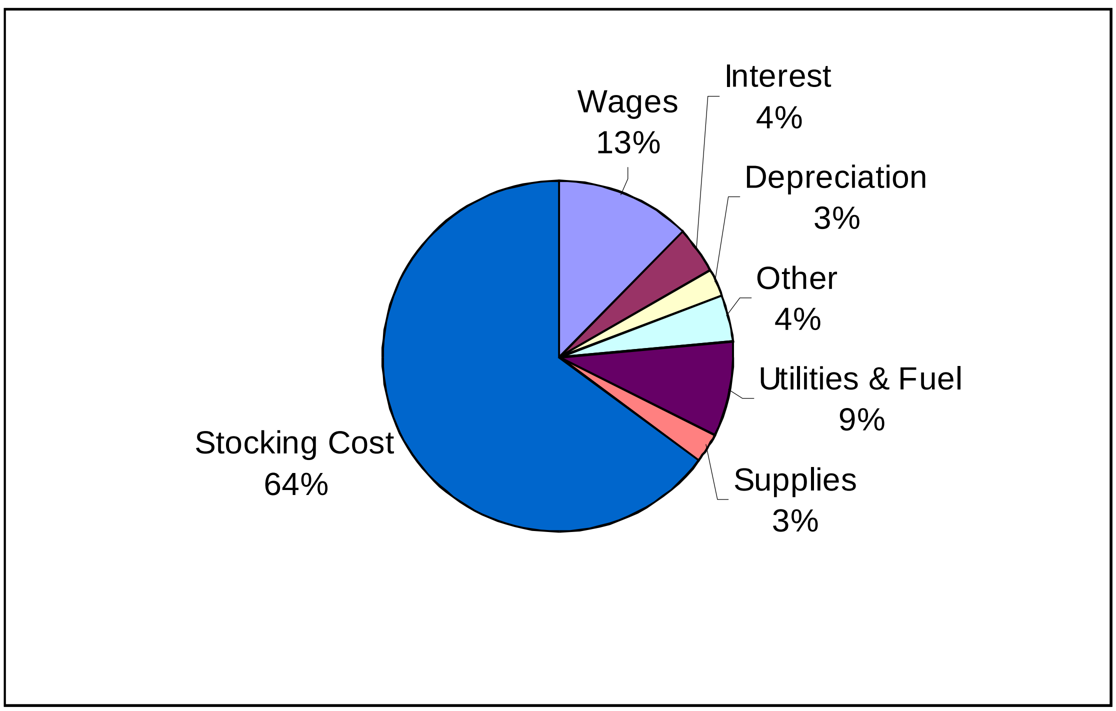

Figure 11. Annual Growout Operating Costs, Floating Tank Hatchery System, Republic of the Marshall Islands

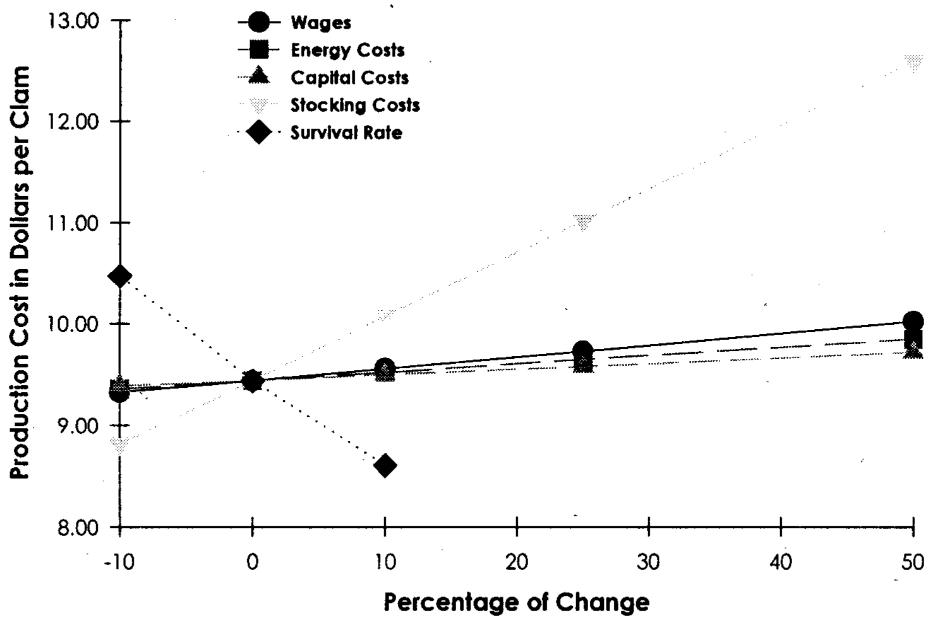

Figure 12. Sensitivity of Production Cost to Changes in Wages, Energy Costs, Capital Costs, Stocking Cost and Survival Rate for Growout Operations, Raceway Hatchery System, Republic of the Marshall Islands

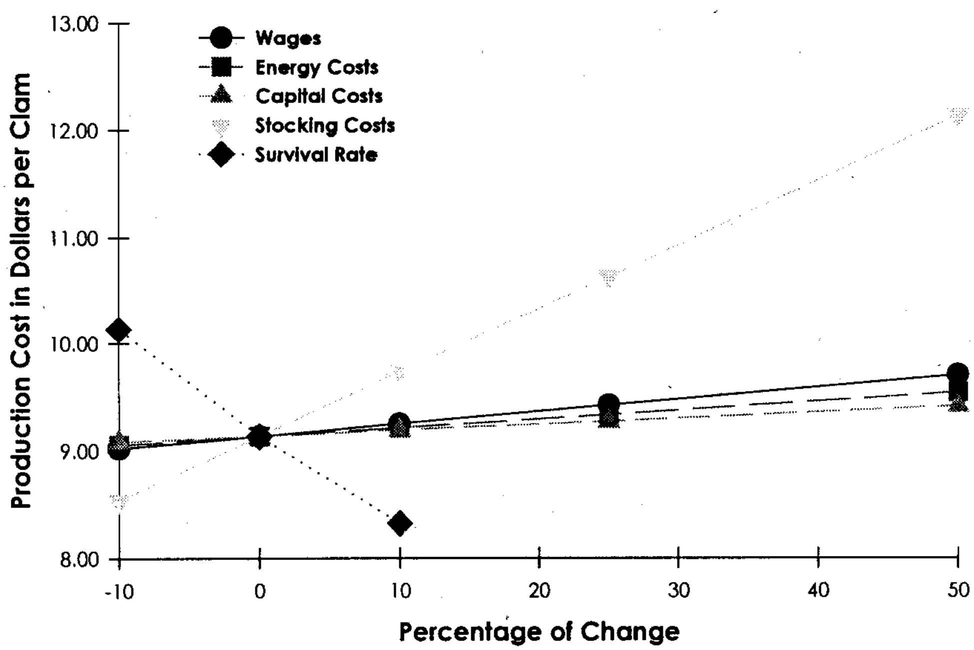

Figure 13. Sensitivity of Production Cost to Changes in Wages, Energy Costs, Capital Costs, Stocking Cost and Survival Rate for Growout Operations, Floating Tank Hatchery System, Republic of the Marshall Islands

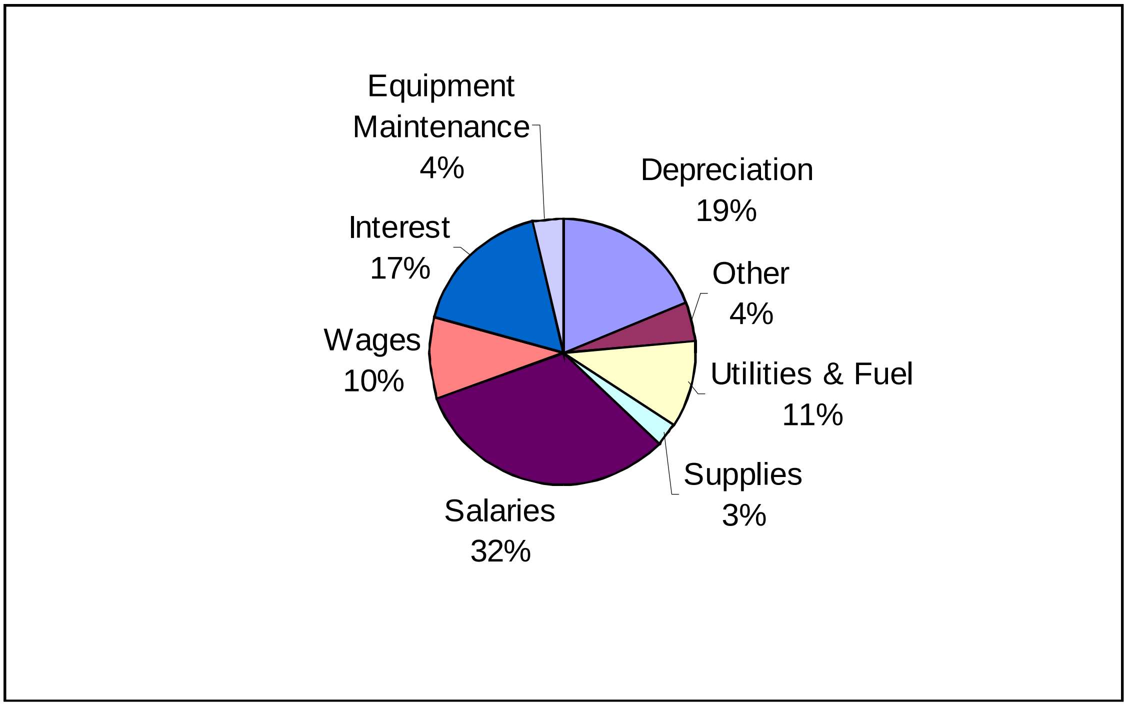

Figure 14. Annual Operating Costs of Combined Hatchery and Land-based Nursery Phase, Republic of Belau

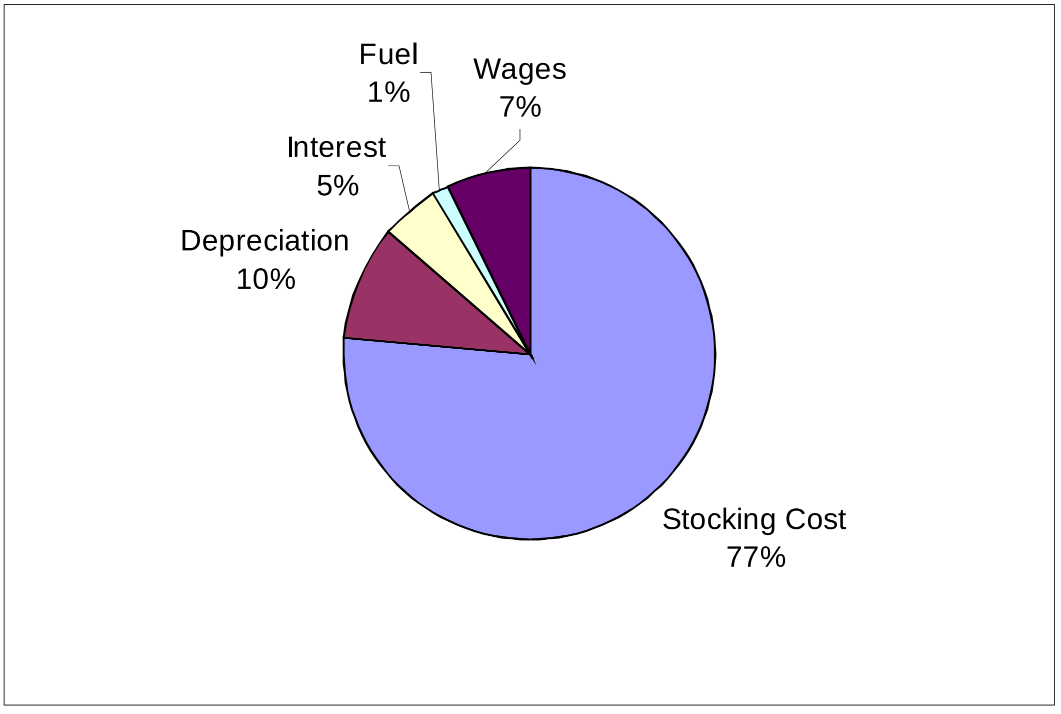

Figure 15. Annual Nursery Operating Costs Republic of Belau

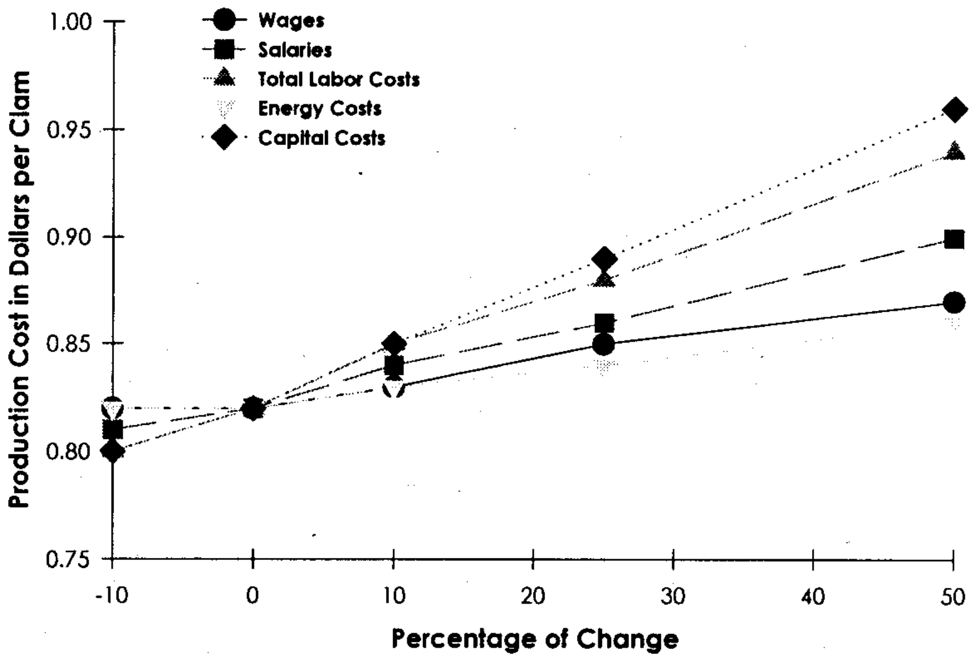

Figure 16. Sensitivity of Production Cost to Changes in Labor Costs, Energy Costs and Capital Costs for Combined Hatchery and Land-based Nursery Phase, Republic of Belau

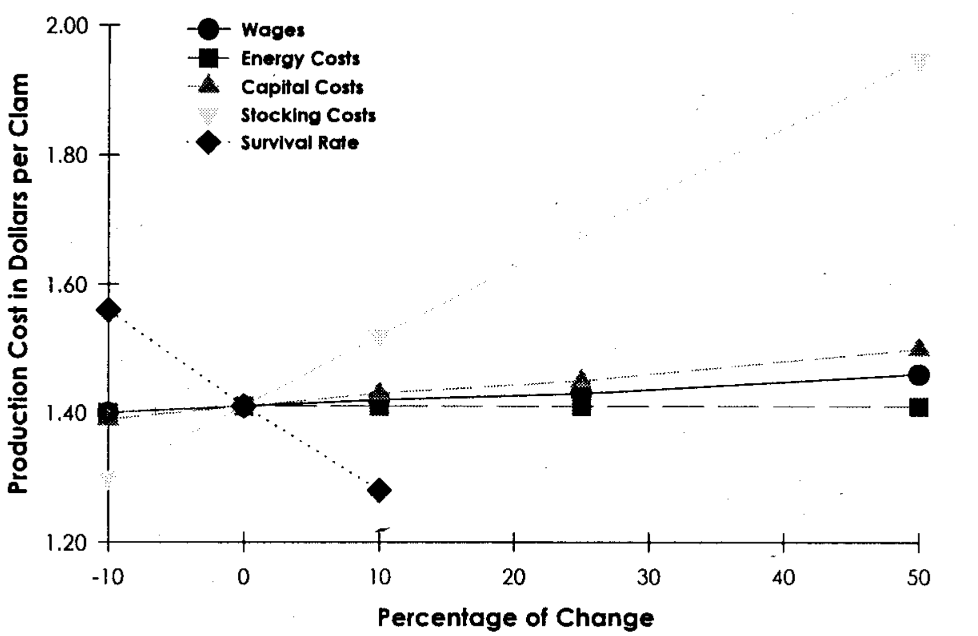

Figure 17. Sensitivity of Production Cost to Changes in Wages, Energy Costs, Capital Costs, Stocking Cost and Survival Rate for Ocean-cage Nursery Phase, Republic of Belau

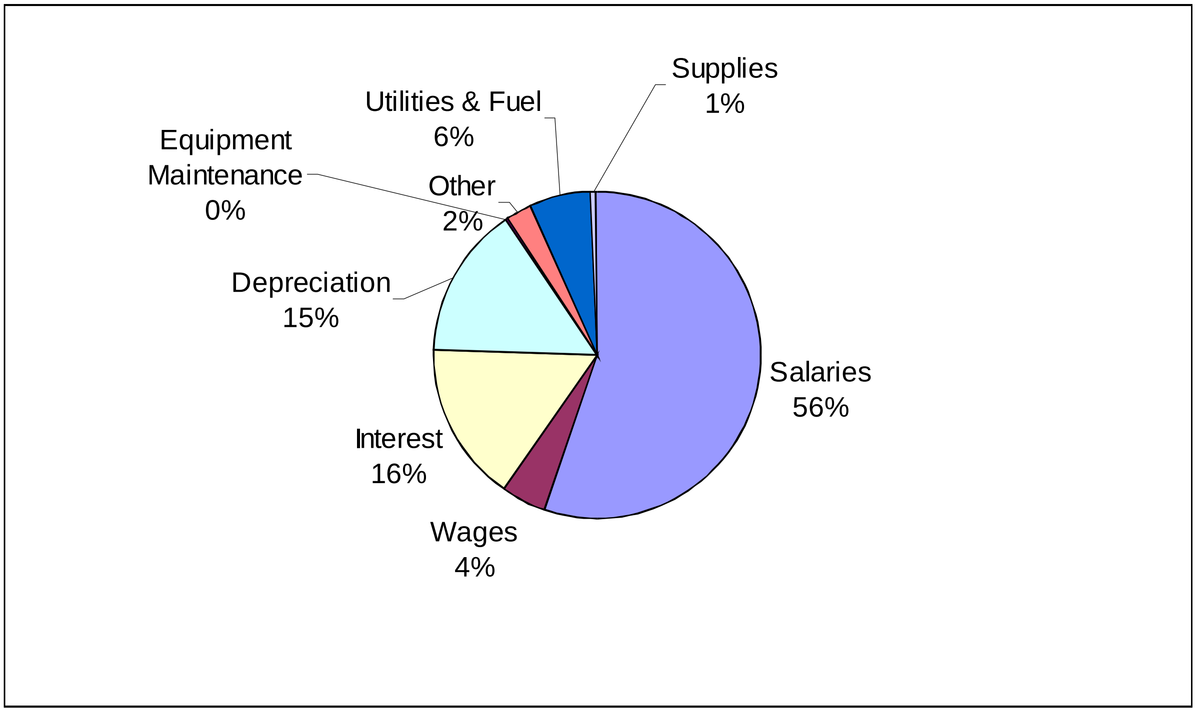

Figure 18. Annual Hatchery and Nursery Operating Costs, FSM National Aquaculture Center, Kosrae, Federated States of Micronesia

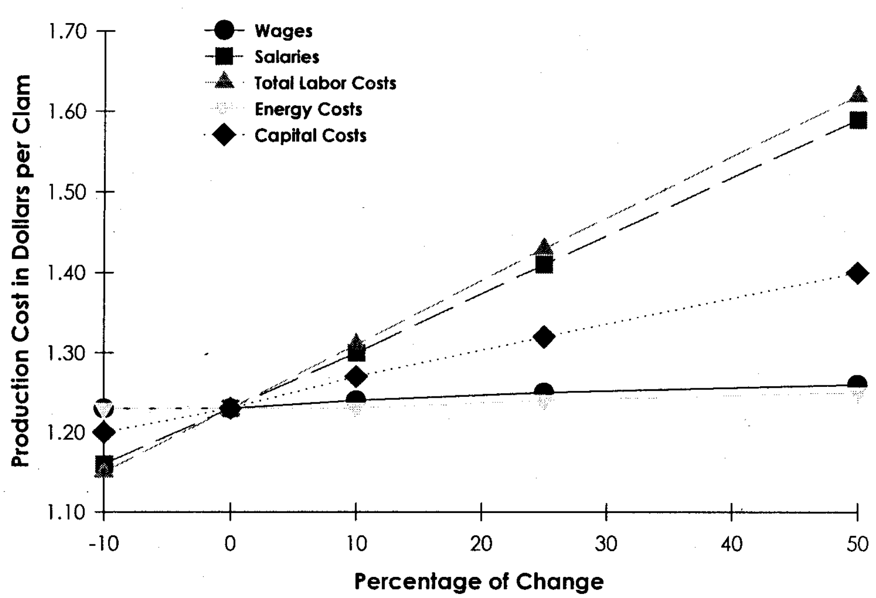

Figure 19. Sensitivity of Production Cost per Clam to Changes in Labor Costs, Energy Costs, and Capital Costs for Hatchery and Nursery Operations, FSM National Aquaculture Center, Kosrae, Federated States of Micronesia

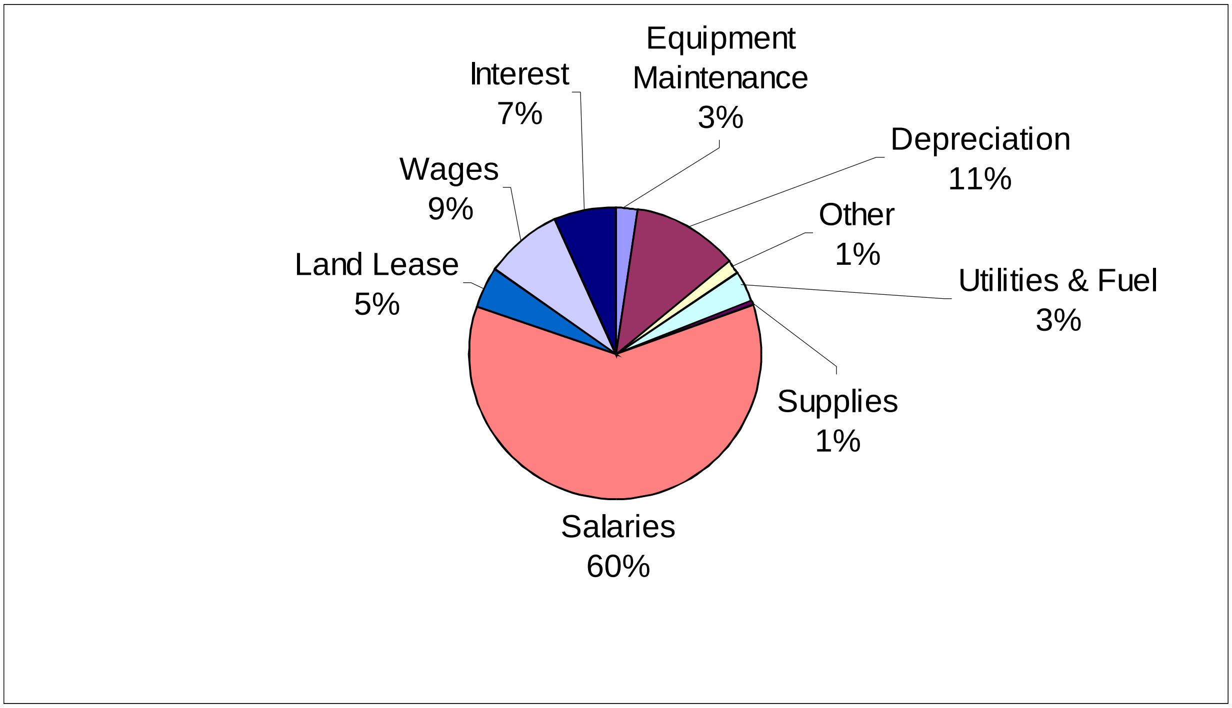

Figure 20. Annual Operating Costs of Hatchery and Land-based Nursery Phase, American Samoa

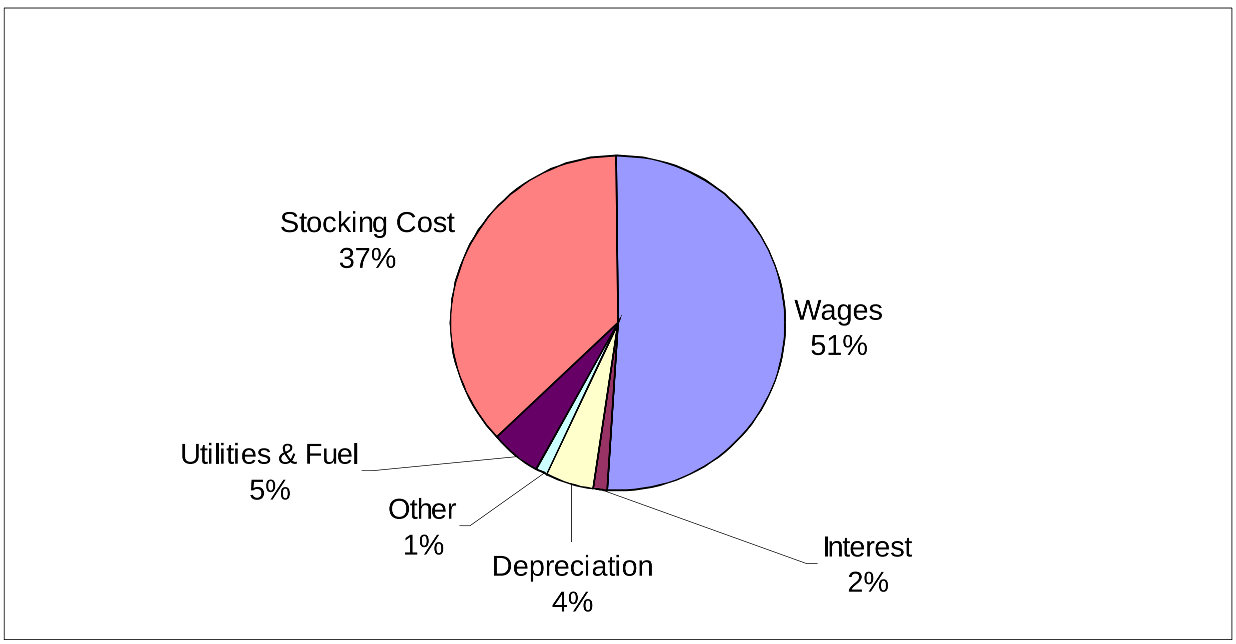

Figure 21. Annual Operating Costs of Ocean-cage Nursery Culture Phase, American Samoa

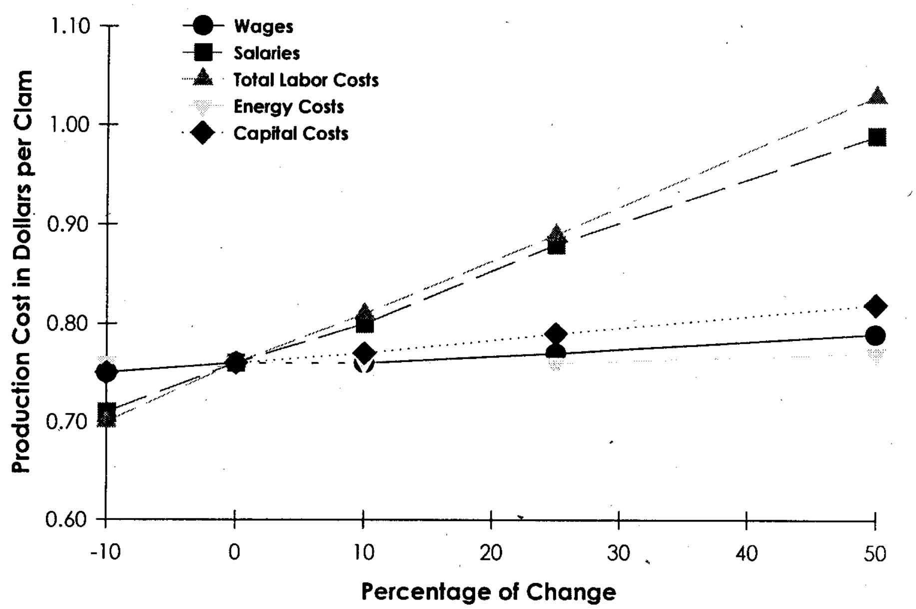

Figure 22. Sensitivity of Production Cost Per Clam to Changes in Labor Costs, Energy Costs and Capital Costs for Hatchery and Nursery Phase, American Samoa

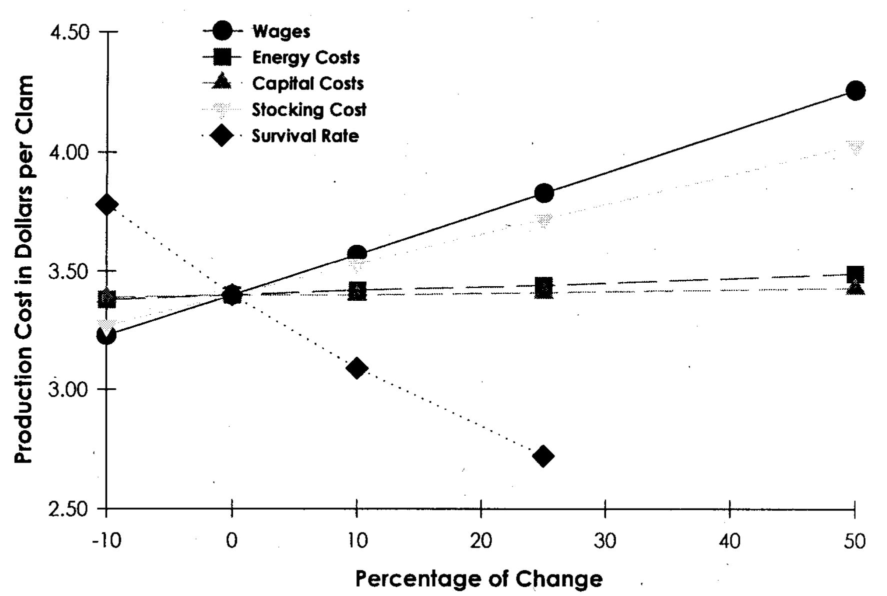

Figure 23. Sensitivity of Production Cost per Clam to Changes in Wages, Energy Costs, Capital Costs, Stocking Cost and Survival Rates for an Ocean-cage Nursery Phase, American Samoa

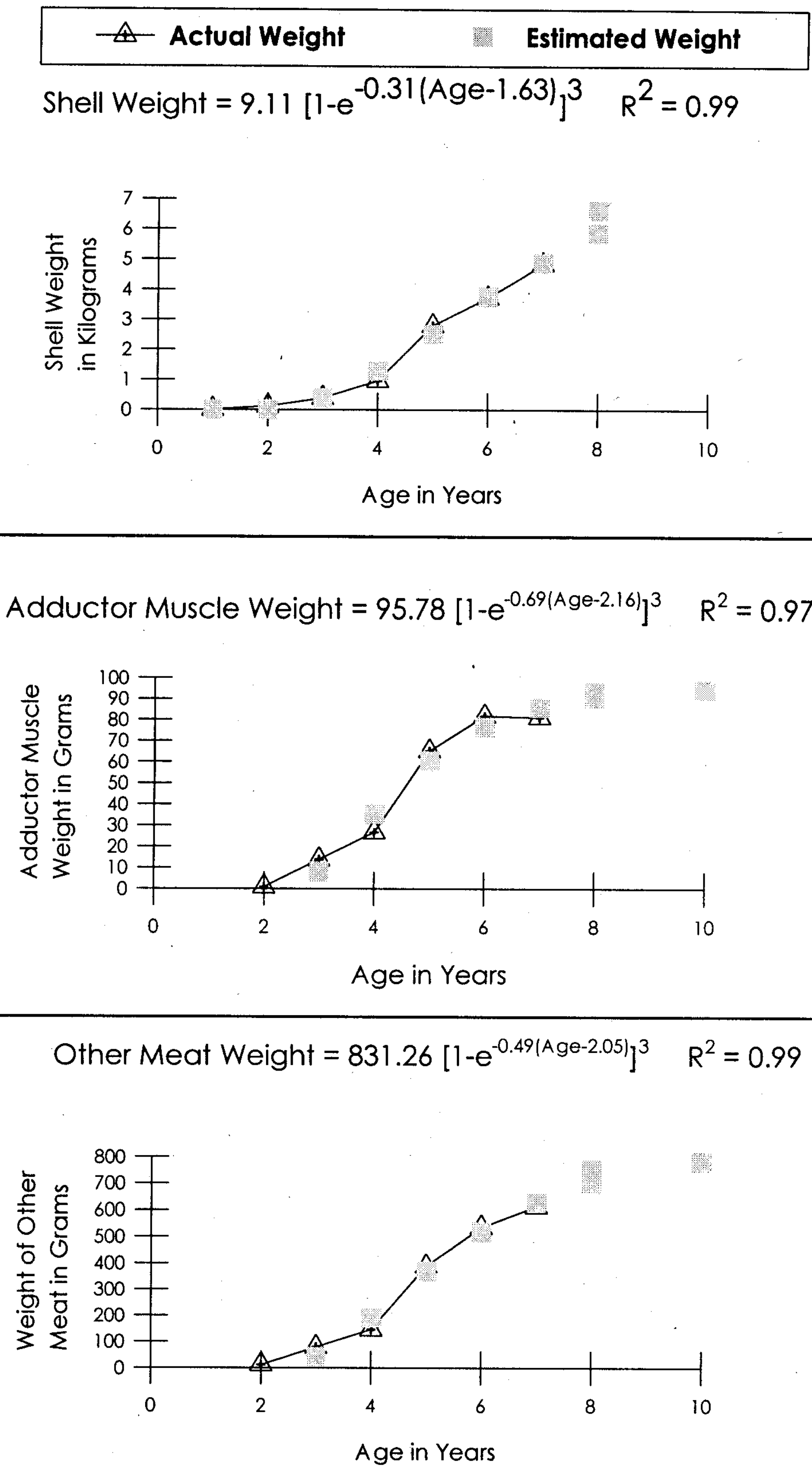

Figure 24. Average Shell Weight, Adductor Muscle Weight and Weight of Other Meat and Estimated Growth Equations

Appendix B. Tables

Table 1. Comparative Costs of Producing Giant Clams in the U.S.-Affiliated Pacific Islands					
Site	**Age of Clam**				
	8 Months	**1 Year**	**2 Years**	**3 years**	**5 Years**
Marshall Islands					
Raceways in hatchery phase	$0.41			$5.08	$9.44
Floating tanks in hatchery phase	$0.23			$4.83	$9.13
Belau		$0.82	$1.41		
Kosrae, FSM			$1.23		
American Samoa		$0.76	$3.40		
1991 Farmgate Price, MMDC Belau,		$1.00	$3.00	$9.00	$50.00

Table 2. Annual Operating Cost (Unpublished Data)			
Item	**Year in Growout**		
	1	**2**	**3**
Fuel (per clam)	$0.64	$0.36	$0.01
Number of trips	104	52	2
Cost per trip	10	10	10
Number of trays	60	60	60
Number of clams per tray	27	24	22
Labor (per clam)	$0.64	$0.33	$0.01
Depreciation (per clam)	$0.16	$0.16	$0.10
Total (per clam)	**$1.44**	**$0.88**	**$0.13**
Costs are given in U.S. dollars.			

Table 3. Annual Production Costs Under Different Farm Configurations				
Year in Growout	**Case 1**	**Case 2**	**Case 3**	**Case 4**
1	$2.94	$2.14	$1.97	$1.17
2	$0.88	$0.36	$0.88	$0.36
3	$0.13	$0.01	$0.13	$0.01
Costs are given in U.S. dollars per clam.				

Table 4. Optimal Harvest Time in Years Under Different Farm Configurations

Saleable Product	Price in US Dollars	Case 1	Case 2	Case 3	Case 4
Shell only	$0.45 **$0.60** $0.75	NO NO 13.0	13.2 10.9 9.9	NO 12.3 10.6	9.9 9.0 8.5
Muscle only	$16.50 **$22.00** $27.50	NO NO NO	NO NO NO	NO NO NO	NO NO 10.5
Other meat only	$1.65 **$2.20** $2.75	NO NO NO	NO NO NO	NO NO NO	NO NO 10.5
All products Shell Muscle Other Meat	$0.45 $16.50 $1.65	NO	9.7	10.7	8.0
Shell Muscle Other Meat	**$0.60** **$22.00** **$2.20**	10.7	8.5	9.0	7.3
Shell Muscle Other Meat	$0.75 $27.50 $2.75	9.3	7.9	8.2	7.0
Meat only Muscle Other Meat	$16.50 $1.65	NO	NO	NO	7.8
Muscle Other Meat	**$22.00** **$2.20**	NO	9.0	NO	7.0
Muscle Other Meat	$27.50 $2.75	NO	7.8	8.3	6.5

Case 1--Clams were situated far from shore, and juvenile cost was US$1.50/clam;
Case 2--Clams were situated close to shore, and juvenile cost was US$1.50/clam;
Case 3--Clams were situated far from shore, and juvenile cost was US$1.50/clam;
Case 4--Clams were situated close to shore, and juvenile cost was US$0.53/clam.

The numbers in bold are the assumed prices, and the numbers above and below are 25 percent of the assumed prices.

Note: NO indicates that "no production" is the best choice because the cost of production is higher than the revenue.

Table 5. Net Present Values at Optimal Harvest Time Under Different Farm Configurations

Saleable Product	Product Price	Case 1	Case 2	Case 3	Case 4
Shell only	$0.45	N	0.16	N	0.47
	$0.65	N	0.48	0.02	0.82
	$0.75	0.03	0.82	0.38	1.17
Muscle only	$16.50	N	N	N	N
	$22.00	N	N	N	0.04
	$27.50	N	N	N	0.24
Other meat only	$1.65	N	N	N	N
	$2.20	N	N	N	N
	$2.75	N	N	N	0.07
All products Shell Muscle Other meat	 $0.45 $16.50 $1.65	N	0.60	0.14	0.97
Shell Muscle Other meat	**$0.60** **$22.00** **$2.20**	0.30	1.13	0.69	1.50
Shell Muscle Other meat	$0.75 $27.50 $2.75	0.84	1.66	1.24	2.01
Meat only Muscle Other meat	$16.50 $1.65	N	N	N	0.32
Muscle Other meat	**$22.00** **$2.20**	N	0.23	N	0.66
Muscle Other meat	$27.50 $2.75	N	0.56	0.13	1.00

Prices are in U.S. dollars per kilogram.

Case 1--Clams are situated far from shore; juvenile cost was US$1.50/clam.
Case 2--Clams are situated close to shore; juvenile cost was US$1.50/clam.
Case 3--Clams are situated far from shore; juvenile cost was US$0.53/clam.
Case 4--Clams are situated close to shore; juvenile cost was US$0.53/clam.

The numbers in bold are the assumed prices, and the numbers above and below are 25 percent of the assumed prices.

Note: N indicates that the net present value is negative.

Table Ia. Hatchery Capital Costs, Raceway System Republic of the Marshall Islands					
Item	**Number of Units**	**Cost per Unit**	**Total Cost**	**Useful Life**	**Annual Depreciation**
Spawning tank	1	$2,000.00	$2,000	20 years	$100
Solar panels	1	$3,000.00	$3,000	20 years	$150
Battery	1	$500.00	$500	5 years	$100
Battery charger	1	$150.00	$150	3 years	$50
Generator	1	$600.00	$600	3 years	$200
Raceways	2	$1,500.00	$3,000	20 years	$150
Trays	64	$1.25	$80	10 years	$8
Diesel pump (backup)	1	$2,000.00	$2,000	10 years	$200
Solar pump systems	2	$500.00	$1,000	10 years	$100
Total			**$12,330**		**$1,058**

Table Ib. Hatchery Capital Costs, Floating Tank System Republic of the Marshall Islands					
Item	**Number of Units**	**Cost per Unit**	**Total Cost**	**Useful Life**	**Annual Depreciation**
Floating spawning tank	1	$3,500.00	$3,500	10 years	$350.00
Solar panels	3	$300.00	$900	20 years	$45.00
Batteries	3	$200.00	$600	5 years	$120.00
Floating settlement tanks	2	$2,500.00	$5,000	10 years	$500.00
Trays	108	$1.25	$135	10 years	$13.50
TOTAL			**$10,135**		**$1,028.50**

Table IIa. Hatchery Annual Operating Costs, Raceway System Republic of the Marshall Islands		
Item	**Cost**	**Percentage of Total**
Salaries Manager Technician	 $3,600.00 $2,000.00	 21.3% 11.8%
Wages	$6,240.00	37.0%
Overhaul of diesel pump	$500.00	3.0%
Diesel fuel	$150.00	0.9%
Repairs and maintenance	$2,000.00	11.8%
Solar pump replacement	$100.00	0.6%
Interest	$1,233.00	7.3%
Depreciation	$1,058.00	6.3%
TOTAL	**$16,881.00**	

Table IIb. Hatchery Annual Operating Costs, Floating Tank System Republic of the Marshall Islands		
Item	**Cost**	**Percentage of Total**
Salaries Manager Technician	 $2,000.00 $2,000.00	 20.5% 20.5%
Wages	$3,210.00	32.9%
Repairs and Maintenance	$500.00	5.1%
Interest	$1,014.00	10.4%
Depreciation	$1,029.00	10.6%
TOTAL	**$9,753.00**	

Table III. Nursery Capital Costs, Republic of the Marshall Islands					
Item	**No. of Units**	**Cost per Unit**	**Total Cost**	**Useful Life**	**Annual Depreciation**
Tray Platform	15	$120.00	$1,800.00	5 years	$360.00
Trays	135	$1.25	$169.00	5 years	$34.00
Boat	1	$3,000.00	$3,000.00	20 year	$150.00
TOTAL			**$4,969.00**		

Table Iva. Nursery Annual Operating Costs, Raceway Hatchery System Republic of the Marshall Islands		
Item	**Cost**	**Percentage of Total**
Wages *($1.50/hour)*		
Tray separation *(Once/month, 30 minutes/tray)*	$1,215	31.42
Diving *(Once/month, 10 minutes/tray)*	$405	10.47
Harvesting *(cleaning, 5 minutes/clam; diving, 5 minutes/tray)*	$117	3.03
Miscellaneous	$500	12.93
Dive gear	$150	3.88
Fuel *($5/trip)*	$60	1.55
Stocking cost *($0.41/clam)*	$410	10.60
Interest	$466	12.05
Depreciation	$544	14.07
TOTAL	**$3,867**	

Table IVb. Nursery Annual Operating Costs, Floating Tank Hatchery System Republic of the Marshall Islands		
Item	**Cost**	**Percentage of Total**
Wages *($1.50/hour)*		
Tray separation *(Once/month, 30 minutes/tray)*	$1,215	31.42
Diving *(Once/month, 10 minutes/tray)*	$405	10.47
Harvesting *(cleaning, 5 minutes/clam; diving, 5 minutes/tray)*	$117	3.03
Miscellaneous	$500	12.93
Dive gear	$150	3.88
Fuel *($5/trip)*	$60	1.55
Stocking cost *($0.23/clam)*	$230	10.60
Interest	$466	12.05
Depreciation	$544	14.07
TOTAL	**$3,687**	

Table V. Growout Capital Costs, Republic of the Marshall Islands					
Item	**No. of Units**	**Cost per Unit**	**Total Cost**	**Useful Life**	**Annual Depreciation**
Boat	1	$3,000	$3,000	20 years	$150
Total			**$3,000**		**$150**

Table Via. Growout Annual Operating Costs, Raceway Hatchery System Republic of the Marshall Islands		
Item	**Cost**	**Percentage of Total**
Wages @ $1.50 per hour		
Diving *(Checking clams twice/week, 4 hours/trip)*	$624	10.12
Harvesting *(cleaning, 5 minutes/clam; diving, 2 minutes/clam)*	$126	2.04
Miscellaneous	$250	4.06
Dive gear	$150	2.43
Fuel ($5/trip; 2 trips/week)	$520	8.43
Stocking cost ($5.08/clam)	$4,064	65.92
Interest	$281	4.56
Depreciation	$150	2.43
TOTAL	**$6,165**	