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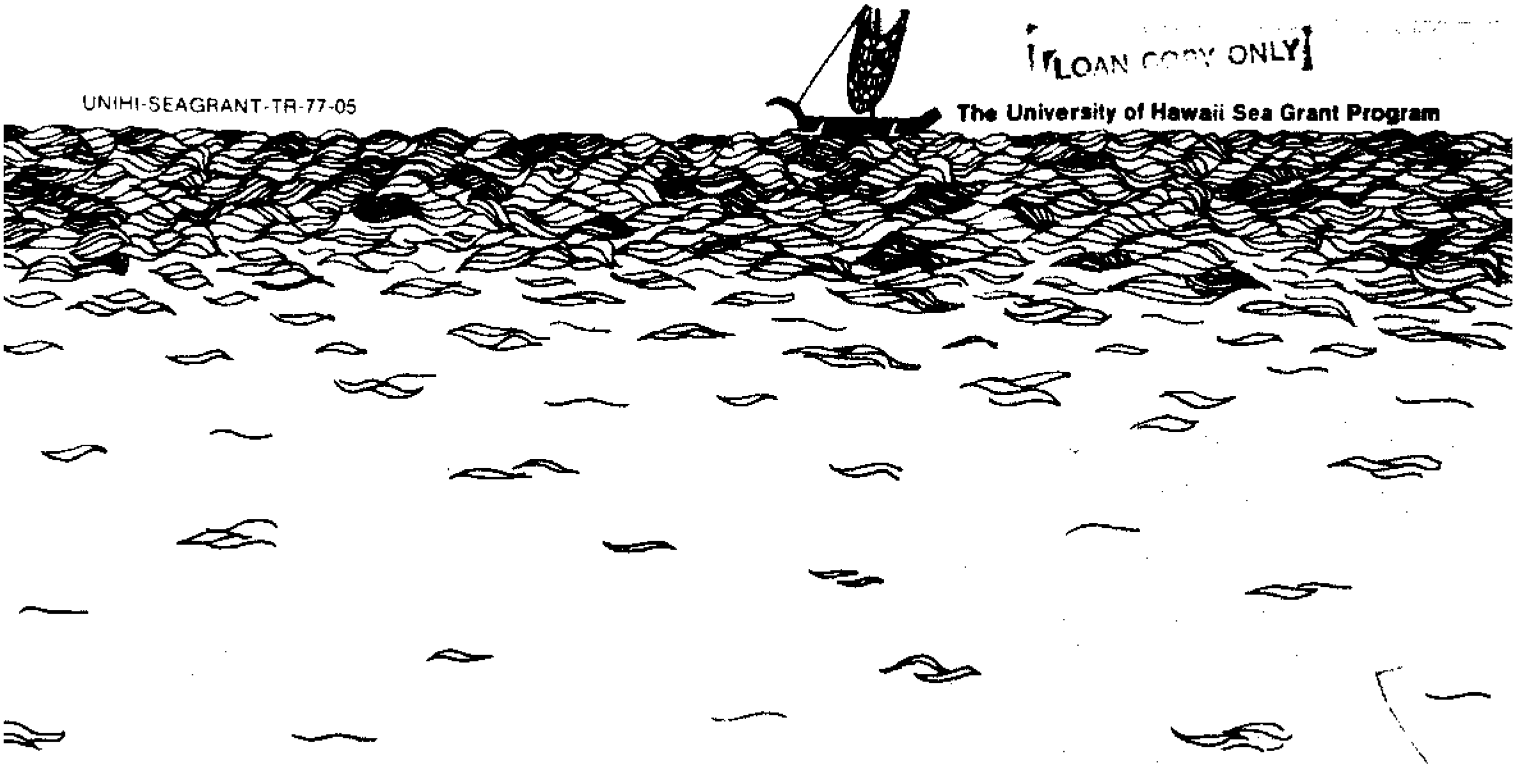

An Alternative Prawn Production Systems Design in Hawaii

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AN ALTERNATIVE PRAWN PRODUCTION SYSTEMS DESIGN IN HAWAII

by

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ABSTRACT

Freshwater prawn farming is a new and dynamic growth industry in Hawaii. Considerable progress has been made in hatching and rearing techniques since they were first introduced in 1965, yet there is still considerable room for improvement, especially for the grow-out system. The current "Anuenue" strategy is broken down to functional components and examined in detail through use of engineering economy methods. Areas with short-term potential for improvement are identified and an alternative approach utilizing a narrow canal pond design is recommended. There are various advantages of this alternative which result in a cost savings of 14.8 percent. The basic short-term improvement recommended is a pond design that permits mechanization of costly operations such as feeding, harvesting, and pond maintenance and the development of sophisticated management strategies aimed at increasing yields.

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INTRODUCTION

There are more than a dozen commercial prawn farmers with over 15 hectares (38 acres) of ponds in Hawaii today. These farmers practice multiple-stocking, selective-harvesting culture of *Macrobrachium rosenbergii* as opposed to the single-stocking, single-harvesting method practiced throughout Asia. Not only does the practice in Hawaii provide a more uniform product for the markets but, together with improved feeding and cultural practices, it yields between 3,000 and 3,500 kg/hectare/year (3,000 to 3,500 lb/acre/year) as opposed to the less than 1,000 kg/hectare/year yield generally obtained in Asia (Gibson, 1976).

However, with all the demonstrated success, there is still potential for improvement. This study is undertaken to explore the short-term possibilities of lowering production costs by increasing the physical efficiency of the production systems. An economic analysis of current production costs was undertaken in an attempt to separate each major task or operation. An evaluation was then made on alternatives and their costs. As a result, an alternative to the existing cultural practice is proposed.

Only engineering and management practices that can be developed within 1 to 3 years are included in the proposed alternative. However, these analyses obviously can also serve as a foundation from which more exhaustive production system analysis and improved management strategies can be developed.

The basic short-term improvement recommended is a pond design that permits mechanization of costly operations and the development of sophisticated management strategies. As such, this analysis concentrated on a direct comparison of construction and operating costs savings resulting from the recommended alternative production system. However, it is important to note that a true comparison can only be made on the basis of net profit or value of production minus cost of production. For the sake of simplicity, equal production levels are assumed for both systems in this analysis. Consequently, an inversely proportional relationship exists between net profit and cost of production, or one dollar saved in production cost results in one dollar more net profit. This approach permits an item by item comparison of costs.

However, there are several variations of the present management strategy which can substantially increase production with little or no effect on operating or production costs. The net effect is lower unit production costs or higher net profits.

Members of the University of Hawaii Sea Grant project, "Tropical Animal Aquaculture--Prawn Production and Management Systems Development," have long advocated the canal pond approach. In addition to its obvious advantages regarding mechanization, it offers flexibilities that will enable the canal pond system to adapt itself to future production management strategies such as nursery facilities, frequent size separation, and accelerated final fattening stage.

The economic analyses are kept exceedingly simple for three reasons.

1. The primary purpose of the analysis is to identify areas of improvement in current production practices.
2. Many of the costs are location specific and related to size of operation; therefore, detailed economic analysis must be prepared for each new venture and a generalized analysis at this time could be out-of-date before the manuscript is published.
3. A comprehensive system modeling of prawn production using mathematical programming techniques has begun as part of the long-term development of the "Tropical Animal Aquaculture--Prawn Production and Management Systems Development" project.

However, basic information required for related economic analysis has been included and the basis for cost estimations clearly stated so that they may be modified for specific conditions.

RECTANGULAR EARTHEN POND UNDER TRADITIONAL MANAGEMENT

Production Strategy

In Hawaii, prawns are reared in earthen ponds whose shape varies from nearly square to a length-to-width ratio exceeding 3 to 1. Sizes range from .2 to 1.4 hectares (.5 to 3.5 acres). Pond bottoms are usually sloped with depths varying from .75 m (2.5 ft) at the shallow end to 1.4 m (4.6 ft) at the deep end. Embankment slopes vary from 1.5:1 to 2.5:1, depending on soil type.

Grass is generally planted on the perimeter of the pond for bank stabilization and also to provide shelter for young and molting prawns. In addition, the grass provides supplemental food for prawns.

Water is supplied continuously at rates varying from 140 to 233 liters/minute/hectare (15 to 25 gpm/acre). With evaporation and seepage, pond discharge rates are usually 50 to 150 liters/minute/hectare (5 to 16 gpm/acre).

A rich bloom of algae (.5 to 2 x 10^6 cells/ml) is maintained in each pond. Combined with aerobic nitrification, the algae utilize prawn metabolites, thereby cleansing the water. They also serve as the base of the food chain in the pond.

Juvenile prawns or postlarvae (PL's) approximately 1 cm in length are presently stocked at a rate of 10 to 20 animals per square meter of pond surface area (1 to 2 animals per square foot). Subsequent restockings are made each year in the summer or fall (Fujimura, 1974).

Approximately 7 months after the initial stocking, selective harvesting begins. A 4.4-cm (2-inch) mesh size seine net (measured stretched from knot to knot) with a bag attached to the trailing end is used to selectively harvest prawns greater than 11 cm (4.3 inches). A team of at least three workers enters the pond at one point and pulls the leading edge of the seine net around the perimeter of the pond. When the pond has been completely encircled and the leading edge of the net returned to the point of entry, the net is then pulled in. After the entire net is pulled in and only the bag remains, the prawns are scooped out of the bag, selected, and loaded by hand into transportation tanks. Undersized prawns are returned to the pond. During this process only 50 to 75 percent of the harvestable prawns are caught. The harvesting efficiency, or percentage of market-size prawns caught, depends on worker skill and the condition of the bottom of the pond. This relatively low harvesting efficiency is evidenced by the variance in the size of harvested animals. Prawn size typically varies from 11 cm (4.3 inches) to more than 18 cm (7.1 inches), the average size of the harvested animal being 12 to 14 cm (4.7 to 5.5 inches) (Gibson, 1976).

At present, there is no price differential given to larger-sized prawns. This situation will probably change as production increases and consumer preference becomes better defined.

Harvesting continues at a near constant rate with a slight decrease in yields during the winter period. This is presumably due to slower growth rates resulting from lower temperatures.

Typical yields vary from 3,000 to 3,500 kg/hectare/year with an average yield of 3,340 kg/hectare/year. Variance in yields can be attributed to several factors. Naturally, stocking density is important. Within the limits of 10 to 20 PL's/m^2, the higher the stocking densitites are, the higher the yields. Stocking in excess of 20 PL's/m^2 has resulted in prawn biomass exceeding the critical biomass (CB) level. When this occurs, a significant number of harvested animals exhibit missing appendages and show other signs of abuse (Gibson, 1976). Pond temperature, pond condition, water quality and flow rate, the amount of natural and artificial shelter, pond size and shape, harvesting frequency, and feed also affect yields.

Estimation of Construction and Operating Costs

Pond construction and operating costs were estimated in 1976 based on 5 years of actual production records of a small prawn farmer and interviews with several owners and managers, as well as interactions with equipment suppliers and earth-moving contractors.

Amortized pond construction costs

For the purpose of this study, pond life is assumed to be 10 years. Hence, construction costs are amortized over a 10-year period.

Calculations for pond construction cost are based on level ground with the volume of cut equal to the volume of fill for construction of embankments. This means that only the volume of soil necessary to fill or build embankments is cut or removed from what becomes the pond bottom. Cost is estimated for a .5 hectare pond which is 50 m long x 100 m wide x 1.25 m deep. The minimum total land required for a .5 hectare pond is .562 hectare or 112.4 percent of the actual emponded area. The additional land is necessary to allow for 4-m wide embankment crowns and access roads surrounding the pond. Only half of the road area surrounding each pond is attributed to the pond, for it is assumed a farm will be composed of many adjacent ponds. (See Appendix A for detailed excavation calculations.)

Total pond construction cost is then equal to excavation costs, including embankment compaction cost, and cost of discharge gate.

1. Excavation costs

   Area: .5 hectare

   Dimensions: 50 m long x 100 m wide x 1.25 m deep

   Volume of cut: 1,022 m^3

   First moment of cut: 19,273 m^4

   Excavation cost, $C_e = 19{,}273\ m^4 \times \$.10/m^4$

   $= \$1{,}927$

   Embankment compaction cost, $C_k = 1{,}022\ m^3 \times \$2/m^3$

   $= \$2{,}044$

2. Discharge gate cost

   Reinforced concrete volume = 3 m^3

   Cost of gate, $C_g = 3\ m^3 \times \$150/m^3$

   $= \$450$

Total pond construction cost, C, for a .5 hectare pond is then:

$$C = C_e + C_k + C_g$$

$$= \$4{,}421$$

Or, cost per hectare, P_c, is:

$$P_c = \$8{,}842$$

Based on the above calculations, amortization of construction costs per hectare per year is as follows:

Investment period: 10 years

Discount rate: 10 percent per annum

Type of discount: Uniform annual series of end-of-year payment

Salvage value: None

Amortized construction cost, C_c = P_c(A/P, .10, 10)/hectare/year

= \$8,842(.16275)/hectare/year

= \$1,439/hectare/year

Water delivery system

The water delivery system consists of a lateral pipe from the main line to the "head" of the pond. In addition, a portion of the main line from the well (or water source) to the pond site must be charged to the pond. Since the narrow side of the pond is 50 m, 75 m is attributed to each pond in order to allow for a portion of the main line to be charged to each pond.

Pipe length = 75 m/pond x 2 ponds/hectare = 150 m/hectare

Cost/meter = \$15/m (installed)

Piping cost, P_d = 150 m/hectare x \$15/m = \$2,250/hectare

Investment period: 10 years

Discount rate: 10 percent per annum

Type of discount: Uniform annual series of end-of-year payment

Salvage value: None

Water delivery system cost, C_d = P_d(A/P, .10, 10)/hectare/year

= \$2,250(.16275)/hectare/year

= \$366/hectare/year

Lease

The State Department of Land and Natural Resources currently leases unused state land for 6 percent of its market value or 3.5 percent of gross income derived from the land, whichever is greater (Mr. Ira Hutchison, 1976: personal communication). Good quality land zoned for diversified agriculture is currently selling for more than \$14,826 per hectare (\$6,000 per acre). Based on this figure, agriculture land lease would be \$890 per hectare per year.

The 5-year yield of the two ponds studied is approximately 3,340 kg/hectare/year. At an average wholesale price of \$7.15 per kilogram, the average gross income is \$23,881 per hectare of pond per year. Adjusting this figure for actual land utilization (1.124 hectare), the average gross income per hectare of land leased per year is \$21,246. Three and one-half percent of this value yields a lease value of \$744/hectare/year.

Due to the difficulty in assessing land value for aquaculture, the lease price will be based on a percentage of current value for agricultural land or \$890/hectare/year. Allowing for additional land for access roads (12.4 percent), the lease for one hectare of ponds would be \$1,000 per year.

Juveniles

The current cost for producing juveniles at the State Anuenue Fisheries Research Center is \$10/1,000 postlarvae. Using an animal stocking density of 20 PL's/m^2/year, the annual cost per hectare for juveniles is then:

$$C_j = 20 \text{ PL's/m}^2\text{/year} \times 10{,}000 \text{ m}^2\text{/hectare} \times \$10/1{,}000 \text{ PL's}$$

$$= \$2{,}000\text{/hectare/year}$$

Water

Water is fast becoming a limited resource. Private wells may require permits for use and may soon be metered by the counties and a charge for water assessed. Consequently, amortized well and pump costs in addition to pumping electricity alone may not reflect the total cost for water. On the other hand, city water rates of \$.35/1,000 gallons are excessively high.

For agricultural usage in Hawaii, a realistic charge may be taken from the rates of the Waimanalo Irrigation District on Oahu. The current charge is \$.02/1,000 liters (\$.08/1,000 gallons) plus an additional flat rate assessment of \$6.18/hectare/month (\$2.50/acre/month).

The current recommendation is approximately 190 liters/minute/hectare (20 gpm/acre) on a 24-hour basis (Fujimura, 1974). Therefore, the annual water requirements, W, are:

$$W = 190 \text{ liters/minute/hectare} \times 1{,}440 \text{ minutes/day} \times 365 \text{ days/year}$$

$$= 9.99 \times 10^7 \text{ liters/hectare/year } (1.05 \times 10^7 \text{ gallons/acre/year})$$

The cost of water, C_w, per hectare per year is then:

$$C_w = 9.99 \times 10^7 \text{ liters/hectare/year} \times \$.02/1{,}000 \text{ liters}$$

$$+ \$6.18\text{/hectare/month} \times 12 \text{ months/year}$$

$$= \$2{,}072\text{/hectare/year}$$

Miscellaneous equipment

This includes all equipment and expendable supplies associated with seine net harvesting, post-harvest handling, and processing. Actual records of a small prawn farmer were averaged over the period from August 1970 to December 1975 and scaled up to the estimated number of ponds the equipment could handle.

Typical farming equipment includes:

1. Seine net and bag: 4.4-cm mesh size net 2 m x 100 m + bag
2. Holding tanks
3. Transportation tanks
4. Scale
5. Hand nets
6. Floating nets
7. Wet suits
8. Aeration equipment
9. Portable pump
10. Spray equipment
11. Mowing equipment
12. Processing equipment
13. Miscellaneous equipment
14. Pickup truck
15. Garden tractor

A three-man crew can harvest approximately three .5 hectare ponds per day. Assuming harvesting is done on a biweekly basis, a harvesting crew can then harvest 15 hectares during the 2-week cycle. To do this, the equipment cost, including replacement items, when amortized on the basis of 10-year life, 10 percent interest, and no salvage value, is $3,650 per 15 hectares, or $243/hectare/year.

Gas, oil, and maintenance

Gas, oil, and maintenance for a pickup truck and other equipment fall under operating expenses. The 4-year adjusted average of one farmer is $166/hectare/year.

Feed

Prawn farmers currently use a ratio of 90 percent broiler starter to 10 percent shrimp meal. The cost of broiler starter is \$.31/kg (\$.14/lb) and the cost of shrimp meal is \$.55/kg (\$.25/lb). The current average conversion ratio is 3.3:1. For a yield of 3,340 kg/hectare/year, 11,022 kg/hectare/year of feed are needed. The cost of feed, C_f, is then:

$$C_f = 11{,}022 \text{ kg/hectare/year } [.90(\$.31/\text{kg}) + .10(\$.55/\text{kg})]$$

$$= \$3{,}681/\text{hectare/year}$$

Security

The cost of security is based upon the cost of the average amount of feed it takes to feed a guard dog per hectare per year. This cost is estimated at \$200. Thus, the cost of security, C_s, is \$200/hectare/year.

Insurance

The cost of insurance, C_i, for liability and crop protection is assessed at \$500/hectare/year.

Major pond repair

It is anticipated that canal embankments and access roads will require major repair at 5-year intervals. The cost of such repair is estimated at \$1,500/hectare/5 years. The present value of such a repair cost per hectare per year is:

$$C_r = \$1{,}500(A/F,\ .10,\ 5)/\text{hectare/year}$$

$$= \$1{,}500(.2638)/\text{hectare/year}$$

$$= \$396/\text{hectare/year}$$

Routine pond maintenance

Pond maintenance is separated into four major categories. The 4-year average time expended by a local farmer is used. The cost of labor is estimated at \$4 per man-hour.

1. Mowing

$$C_a = 68 \text{ man-hours/hectare/year} \times \$4/\text{man-hour}$$

$$= \$272/\text{hectare/year}$$

2. Weed spraying

$$C_b = 89 \text{ man-hours/hectare/year} \times \$4/\text{man-hour}$$

$$= \$356/\text{hectare/year}$$

3. Silt pumping every 3 years

P_c = 63 man-hours/hectare/3 years x \$4/man-hour

= \$252/hectare/3 years

Adjusting this for annual cost gives:

C_c = \$252(A/P, .10, 3)/hectare/year

= \$252(.40210)/hectare/year

= \$101/hectare/year

4. Miscellaneous maintenance

C_d = 87 man-hours/hectare/year x \$4/man-hour

= \$348/hectare/year

Thus, routine pond maintenance costs, $C_m = C_a + C_b + C_c + C_d$

= \$1,077/hectare/year

Feeding

Feeding is done once a day. At present, feed is loaded onto the bed of a pickup truck and as one man drives along the side of a pond, another man shovels the feed. The estimated cost per hectare per year based on a labor cost of \$4/man-hour is:

C_f = .5 man-hour/day/pond x 2 ponds/hectare x 365 days x \$4/man-hour

= \$1,460/hectare/year

Harvesting

Typically, it takes a three-men crew 2.5 hours to harvest a .5 hectare pond using a seine net. Harvesting every other week, and using a labor cost of \$4/man-hour, the cost per hectare per year is:

C_h = 3 men x 2.5 hours/pond/harvest x 2 ponds/hectare

x 26 harvests/year x \$4/man-hour

= \$1,560/hectare/year

Processing

Post-harvest handling and processing of prawns vary among farmers. Some transport live prawns to wholesalers in aerated tanks. Others ice the prawns immediately after harvesting. Still others blanch prawns and then cool them with ice. The shelf life is about 2 to 3 days for ice-cooled prawns and about 6 to 7 days for blanched and ice-cooled prawns.

The cost of processing is taken as the labor involved in blanching prawns. This amounts to approximately one-half hour of work for two men per harvest at $4/man-hour or:

$$C_p = 2 \text{ man-hours}/.5 \text{ hectare/harvest} \times 26 \text{ harvests/year} \times \$4/\text{man-hour}$$

$$= \$208/\text{hectare/year}$$

Administrative overhead

Administrative costs include a portion of the working manager's salary, bookkeeping, maintaining marketing contact, and security. Costs range with size of farm but will be taken as $15,000/15 hectares/year, or $1,000/hectare/year.

Total estimated construction and operating costs for rectangular earthen ponds are shown in Table 1.

TABLE 1. TYPICAL ANNUAL COSTS FOR RECTANGULAR EARTHEN PONDS

Cost item	Percentage of total cost	Cost per hectare (dollars)	Cost per acre (dollars)
Amortized pond construction costs	8.3	1,439	583
Water delivery system	2.1	366	148
Lease	5.7	1,000	405
Juveniles	11.5	2,000	809
Water	11.9	2,072	839
Miscellaneous equipment	1.4	243	98
Gas, oil, and maintenance	1.0	166	67
Feed	21.2	3,681	1,490
Security	1.2	200	81
Insurance	2.9	500	202
Major pond repair	2.3	396	160
Routine pond maintenance	6.2	1,077	436
Feeding	8.4	1,460	591
Harvesting	9.0	1,560	631
Processing	1.2	208	84
Administrative overhead	5.7	1,000	405
TOTAL	100.0	17,368	7,029

ANALYSIS OF FEASIBLE ALTERNATIVES

Out of the 14 expenditure categories, feed, feeding labor, water, harvesting, and amortized pond construction cost account for 58.8 percent of cost in traditional earthen pond production. These five categories are examined below for possible improvements that will introduce cost savings.

Feed

Feed accounts for 21.2 percent of total estimated production costs under current production management practices. Feed utilization efficiency may be improved by feeding the prawns more than once a day, by improving uniformity in feed distribution, and by developing a better feed formula. The development of a better feed will probably take more than 2 to 3 years of extensive research.

Feeding Labor

Feeding labor accounts for 8.4 percent of total estimated production costs under current production management practices. The development of mechanical feeding equipment can reduce the feeding labor requirement. The two-man crew can be reduced to one, and the speed at which the ponds can be serviced greatly increased. To achieve an acceptable level of uniform feed distribution and still keep the cost of the equipment within reason, the maximum throw of the feeder should be limited. The width of the rectangular pond may have to be reduced in order to facilitate the development and operation of mechanical feeders.

Water

The current recommended water requirement is approximately 190 liters/minute/hectare (20 gpm/acre). Since the average evaporation loss in Hawaii is about 52.1 liters/minute/hectare and the seepage loss from a reasonably well-maintained pond should be in the neighborhood of 24.3 liters/minute/hectare, only 76.4 liters/minute/hectare is required, on the average, to meet evaporation and seepage losses. Therefore, a reduction in water demand of up to 60 percent is possible.

This possible reduction can be important in two ways. First, it will allow prawn production under considerably more severe water resources constraints. Second, it might produce cost savings. In order to reduce the water requirement, alternative means of increasing the oxygen supply to the pond water and other water quality maintenance practices will have to be introduced.

Two areas should be investigated: first, an efficient means of supplying oxygen to pond water and second, an integrated aquaculture/agriculture production system. The idea of an integrated aquaculture/agriculture production system is not new. The basic difficulty is in the proper matching of the intensiveness of the subsystems. The prawn production system produces waste material on a more or less constant basis; hence, the agriculture production system must produce waste materials on the same basis. Additionally, the labor requirements for the two subsystems must be suitably matched. The integration of these subsystems will require extensive interdisciplinary research and cannot be expected to be completed in a few years.

Another possible way of reducing water cost and increasing the production potential of prawns in coastal regions is to utilize brackish water in place of fresh water. Sandifer et al. (1976), Deece (1976), and Forrester and Wickens (1972) indicated that comparable prawn growth rates can be achieved in brackish water of up to 18 ppt. Coastal regions in Hawaii have a shallow brackish water lens that can be exploited by shallow wells. Applied exploratory research in this area should be given maximum encouragement.

Harvesting

For maximum production, prawns reaching a predetermined size should be removed from the pond. Large prawns require a disporportionately large space and there are reasons to suspect that the food conversion ratio of prawns may decrease after they have reached a certain size. These biological phenomena have brought about the belief that development in production strategies will lead to the establishment of separate management strategies and even different physical facilities for prawns of different sizes and ages. The present harvesting procedure often leaves oversized prawns unharvested and therefore must be improved.

Harvesting is basically a separation process. Among the many separation processes, the mechanical process (seine net harvesting) has proven to be successful, but needs to be improved to increase its harvesting efficiency and to reduce its labor requirement.

Tests conducted in the University of Hawaii Aquacultural Engineering Laboratory with Sea Grant support have proven that separation of prawns by sizes requires little labor. The tests were conducted in 1976 in a 6.1 m long x 1.5 m wide x .4 m deep (20 ft x 5 ft x 1.5 ft) laboratory model pond using a slow moving net attached to a rigid frame. The tests were not completed at the time this report was being prepared; however, enough evidence had been gathered to establish the feasibility of mechanical harvesting or separation of prawns.

To reduce equipment cost, the width of the harvester that straddles the production pond must be limited. As indicated earlier, narrow canal ponds are preferred to the rectangular ponds currently in use.

The development of separation equipment will not only reduce harvesting cost, but will also lead to the general ability to separate prawns of different sizes with relative ease and little cost. In the long run, this will facilitate the development of sophisticated production management strategies.

Amortized Pond Construction Cost

Given identical topographical and soil conditions, pond excavation costs can be considered to roughly correspond to the volume of cut required and the distances the cuts must be moved. In other words, assuming the volume of cut is equal to the volume of fill or the amount of earth removed is equal to the amount required to build embankments, then the excavation cost can be estimated by calculating the first moment of the required cut.

As shown in Appendix A, the excavation cost for a narrow canal pond can be somewhat less than for rectangular ponds. For a wetted area of .5 hectare at a 1.25 m depth, the first moment of the cut for a 50 m x 100 m rectangular pond is 19,273 m^4, while only 6,755 m^4 for a 10 m x 500 m canal pond.

The possible advantages of a canal pond in harvesting and feeding have already been discussed. Another advantage is that it is much easier to remove waste material from a narrow canal pond. This advantage may be important in the development of an integrated aquaculture/agriculture production system. It may also contribute to the ability to maintain more uniformly higher water quality in the pond, which in turn may lead to a higher growth rate of the prawn.

Looking into the future, because the canal pond can be easily partitioned, it will have the flexibility for sophisticated management strategies which may require varied animal densities within a pond where prawns at various ages or sizes are reared.

EARTHEN CANAL POND

Production Strategy

By incorporating the above recommendations, the costs and benefits of a canal pond versus a rectangular pond can be examined.

A geometric shape which lends itself to mechanized selective harvesting is a long, narrow pond or canal. A typical canal pond might be 10 m in width and approximately 500 m in length with a sloping bottom from .75 to 1.25 m deep. Since harvesting would be mechanized, only narrow, 1.25-m embankment crowns would be necessary. Four-meter access roads would run normal to the canals at the top and bottom. The minimum land area needed for a .5 hectare canal would be .567 hectare or 113.4 percent of the canal (see Appendix A). This is 1 percent more land than that required for a rectangular pond. As mentioned earlier, only one-half of the embankment crown is attributed to each pond for it is assumed that a farm will be composed of many adjacent ponds.

The canal lends itself to mechanized selective harvesting or size separation since a lightweight prime mover could span the 10 m width. The prime mover could also assist in pond maintenance and silt removal.

Estimation of Construction and Operating Costs

In order to provide a direct comparison of total costs between the existing practice and a canal pond operation with mechanization, the feeding and harvesting oeprations include labor cost, amortization cost of each machine, and machine operating costs.

Amortized pond construction costs

Pond life is assumed to be 10 years; hence, construction costs are amortized over a 10-year period.

Total canal construction cost is equal to excavation costs, including embankment compaction cost, and cost of discharge gate.

1. Excavation costs

   Area: .5 hectare

   Dimensions: 10 m long x 500 m wide x 1.25 m deep

   Volume of cut: 1.231 m^3

   First moment of cut: 6,756 m^4

   Cost of excavation, C_e = 6,756 m^4 x \$.10/m^4

   = \$676

   Cost of embankment compaction, C_k = 1,231 m^3 x \$2/m^3

   = \$2,462

2. Discharge gate cost

   Reinforced concrete volume = 3 m^3

   Cost of gate, C_g = 3 m x \$150/m^3

   = \$450

Total canal construction cost, C, for a .5 hectare pond is then:

$C = C_e + C_k + C_g$

= \$3,588

Or, cost per hectare, P_c, is:

P_c = \$7,176

Based on the above calculations, amortization of construction costs per hectare per year is as follows:

Amortized construction cost, $C_c = P_c(A/P, .10, 10)$/hectare/year

= \$7,176(.16275)/hectare/year

= \$1,168/hectare/year

Water delivery system

The cost of the water delivery system, C_d, is assumed to be the same as for a rectangular pond, \$366/hectare/year.

Lease

The annual cost of leasing land is computed in the same manner as for a rectangular pond. Assuming an average annual yield of 3,340 kg/hectare/year and a wholesale price of \$7.15/kg, the gross sales per hectare of pond per year is \$23,881. Adjusting this figure for the actual land used (1.134 hectares), the average gross revenue per hectare per year is \$21,059. Thus, 3.5 percent of gross revenue is \$737/hectare/year. Again, basing lease as 6 percent of current value of agricultural land and adjusting for actual land use (1.134 hectares), C_l = \$1,009/hectare/year.

Juveniles

The current cost of producing juveniles at the State Anuenue Fisheries Research Center is \$10/1,000 PL's. Using the same stocking density of 20 PL's/m^2/year, the annual cost per hectare for juveniles, C_j, is then:

C_j = 20 PL's/m^2/year x 10,000 m^2/hectare x \$10/1,000 PL's

= \$2,000/hectare/year

Water

The cost of water, C_w, is assumed to be the same as for a rectangular pond, \$2,072/hectare/year.

Miscellaneous equipment

The cost of miscellaneous handling and processing equipment, C_e, is estimated at \$200/hectare/year. This is \$43/hectare/year less than the cost of miscellaneous equipment for a rectangular pond. The difference is attributed to the fact that seine nets are no longer needed; harvesting is assumed to be mechanized.

Gas, oil, and maintenance

The cost of gas, oil, and maintenance, C_g, for pickup trucks and other equipment, excluding the harvesting machine, is assumed to be the same as for a rectangular pond, \$166/hectare/year.

Fuel, oil, and maintenance costs for the feeder and harvester are included in the feeding and harvesting costs.

Feed

Feed cost is assumed to be the same as for a rectangular earthen pond or \$.334/kg of feed consisting of 90 percent broiler starter and 10 percent shrimp meal. The same feed consersion ratio of 3.3:1 is also used. The cost of feed, C_f, at a production level of 3,340 kg/hectare/year is then:

$$C_f = 3{,}340 \text{ kg/hectare/year} \times 3.3 \text{ lb/lb} \times \$.334\text{/kg}$$

$$= \$3{,}681\text{/hectare/year}$$

Security

The cost of security is based upon the cost of the average amount of feed it takes to feed a guard dog per hectare per year. This cost is estimated at \$200. Thus, the cost of security, C_s, is \$200/hectare/year.

Insurance

Liability and crop protection insurance, C_i, is assessed at \$500/hectare/year.

Major pond repair

It is anticipated that canal embankments and access roads will require major repair at 5-year intervals. The cost of repair, C_r, is estimated at \$1,500/hectare/5 years. The present value of such a repair cost is:

$$C_r = \$1{,}500(A/F, .10, 5)\text{/hectare/year}$$

$$= \$1{,}500(.2638)\text{/hectare/year}$$

$$= \$396\text{/hectare/year}$$

Routine pond maintenance

Pond maintenance is divided into four major categories as in the case of rectangular ponds. The same figures apply.

Mowing labor	= \$ 272/hectare/year
Weed spraying	= \$ 356/hectare/year
Silt pumping	= \$ 101/hectare year
Miscellaneous maintenance	= \$ 348/hectare/year
Routine pond maintenance, C_m	= \$1,077/hectare/year

The canal pond can be partitioned into sections to facilitate maintenance. Water requirements can be greatly reduced in a well-maintained pond because of reduced seepage.

Feeding

Feeding would be accomplished by one man operating a garden tractor pulling a bin-fed feeding device. Each pass between two canals would distribute feed simultaneously to both canals. The cost of this operation is estimated as follows:

1. Garden tractor

   The discounted capital investment of the tractor has been included in the cost of miscellaneous handling and processing equipment. No direct charge is assessed to feeding since the tractor is primarily used for routine maintenance and is used for less than 10 minutes/hectare/day for feeding. Likewise, all gas, oil, and maintenance costs for the tractor have already been included.

2. Feeder and bin

   Initial cost: $1,200

   Expected life: 5 years

   Salvage value: None

   Discount rate: 10 percent per annum

   Number of hectares: 15 (30 canals)

   Operating speed: 4 kph

   Feeder bin cost = 1/15 hectares x $1,200 (A/F, .10, 5)/year

   = $80 (.2638)/hectare/year

   = $21/hectare/year

3. Feeder maintenance

   Assessment rate: $10 per 100 hours of use

   Time per hectare: 1/8 hour/hectare/day

   Feeder maintenance cost = $10/100 hours x 1/8 hour/hectare/day

   x 365 days/year

   = $5/hectare/year

4. Feeding labor

Wage rate: \$4/man-hour

Distance traveled: 500 m + 10 percent per two .5 hectare ponds

Operating speed: 4 kph

Feeding cost = .55 km/hectare/day x 1 man-hour/4 km x \$4/man-hour

x 365 days/year

= \$201/hectare/year

Total feeding cost, C_f, is then:

C_f = \$21/hectare/year + \$5/hectare/year + \$201/hectare/year

= \$227/hectare/year

Harvesting

With mechanized harvesting, one man would operate the harvester. At a travel speed of .5 kph, it would take one hour to travel the length of the pond. When the end is reached, another man would remove the harvested prawns and load them into transportation tanks. Each harvester could harvest 4 ponds (2 hectares) per day or 40 ponds (20 hectares) in a 2-week cycle.

1. Labor

Cost per harvest = [1 man-hour/pond harvest + (2 x .5 man-hour/

pond harvest)] x \$4/man-hour

= \$8/pond harvest

At a harvesting interval of 2 weeks, the annual harvesting labor cost per hectare is:

Cost of labor = \$8/pond harvest x 2 ponds/hectare

x 26 harvests/year

= \$416/hectare/year

2. Machine cost

Estimated weight: 1,800 pounds

Manufacture cost per pound: \$3.50

Estimated equipment cost, P_2: \$6,300

Amortization period: 5 years

Discount rate: 10 percent per annum

Type of discount: Uniform annual series of end-of-year payment

Salvage value: None

Number of hectares: 20

Annual machine cost, C_2 = P_2(A/P, .10, 5)/20 hectares/year

= \$6,300(.2638)/20 hectares/year

= \$1,662/20 hectares/year

The cost of machine, C_m, per hectare per year is then:

C_m = \$1,662 x 1/20 hectares/year

= \$83/hectare/year

3. Fuel and oil

Consumption rate: .5 pound/hp/hour

Horsepower required: 7.5 hp

Fuel costs: \$.40/gallon

Cost of fuel and oil = .5 pound/hp/hour x 1 gallon/6.5 pounds x 7.5 hp x 1.5 hours/harvest x 26 harvests/pond/year x 2 ponds/hectare x \$.40/gallon

= \$18/hectare/year

4. Maintenance

Assessed rate: \$25/100 hours

Maintenance cost = 1.5 hours/harvest x 26 harvests/pond/year x 2 ponds/hectare x \$25/100 hours

= \$20/hectare/year

The total cost is then:

$$C_h = \$416/\text{hectare}/\text{year} + \$83/\text{hectare}/\text{year} + \$18/\text{hectare}/\text{year}$$

$$+ \$20/\text{hectare}/\text{year}$$

$$= \$537/\text{hectare}/\text{year}$$

Processing

The labor cost of blanching prawns is taken as processing cost, C_p, and is the same as for a rectangular pond, $208/hectare/year.

Administrative overhead

Administrative costs, C_a, include a portion of a working manager's salary, bookkeeping, maintaining market contact, etc. Costs of administration vary with size of farm, but will be taken as $15,000/15 hectares/year, or $1,000/hectare/year.

Total estimated construction and operating costs for canal ponds are shown in Table 2.

TABLE 2. TYPICAL ANNUAL COSTS FOR EARTHEN CANAL PONDS

Cost Item	Percentage of total cost	Cost per hectare (dollars)	Cost per acre (dollars)
Amortized pond construction costs	7.9	1,168	473
Water delivery system	2.5	366	148
Lease	6.8	1,009	408
Juveniles	13.5	2,000	809
Water	14.0	2,072	839
Miscellaneous equipment	1.3	200	81
Gas, oil, and maintenance	1.1	166	67
Feed	24.9	3,681	1,490
Security	1.3	200	81
Insurance	3.4	500	202
Major pond repair	2.7	396	160
Routine pond maintenance	7.3	1,077	436
Feeding	1.5	227	92
Harvesting	3.6	537	217
Processing	1.4	208	84
Administrative overhead	6.8	1,000	405
TOTAL	100.0	14,807	5,992

SUMMARY AND RECOMMENDATIONS

The existing practices and a particular set of feasible alternatives have been presented. A comparison of estimated annual costs for rectangular versus canal ponds is presented in Table 3. The total overall savings of 14.8 percent is attributed to costs of pond construction (1.6 percent), feeding (7.1 percent), harvesting (5.9 percent), and miscellaneous equipment (.2 percent). These comparisons represent possible savings potentials.

TABLE 3. A COMPARISON OF TYPICAL ESTIMATED ANNUAL COSTS PER HECTARE FOR RECTANGULAR EARTHEN PONDS VERSUS EARTHEN CANAL PONDS

Cost Item	Rectangular Pond (dollars)	Earthen Canal Pond (dollars)
Amortized pond construction costs	1,439	1,168
Water delivery system	366	366
Lease	1,000	1,009
Juveniles	2,000	2,000
Water	2,072	2,072
Miscellaneous equipment	243	200
Gas, oil, and maintenance	166	166
Feed	3,681	3,681
Security	200	200
Insurance	500	500
Major pond repair	396	396
Routine pond maintenance	1,077	1,077
Feeding	1,460	227
Harvesting	1,560	537
Processing	208	208
Administrative overhead	1,000	1,000
TOTAL	17,368	14,807

The foregoing described, in some detail, both the present rectangular pond and a viable alternative, the earthen canal pond. Although of primary interest was the inseparable problem of pond design to facilitate economical mechanized harvesting and other operations, three other areas of significant savings are possible as shown in Table 3. The total possible savings of 14.8 percent were determined from engineering economy methods. Outside the realm of engineering, there is a need for nutritional research for more effective and less expensive feeds, since feed costs represent over 25 percent of the total production cost.

Water constitutes 15 percent of total cost. It seems reasonable to assume that this figure could be substantially reduced through the use of shallow-well brackish water and/or a reduction of flow rates with supplemental mechanical aeration and silt removal. Integration of a prawn farm with other terrestrial and/or aquatic food production systems would further reduce the cost of water by sharing the purchasing and/or pumping costs with the other systems.

By maintaining biomass at its maximum sustainable level, several variations of the "Anuenue" strategy may have a substantial effect on yields. Four alternatives are presented as follows:

1. More frequent restocking of postlarvae
2. Separate nursery facilities to produce older animals for stocking, thereby reducing the effect of early mortality on management uncertainty and greatly increasing production efficiency
3. Varying pond size to maintain constant biomass (pendulum culture)
4. Monosex culture

As previously mentioned, ponds are currently restocked on an annual basis. As a consequence, prawn biomass exhibits a cyclic pattern as seen in Appendix B. If constant biomass could be achieved, an increase in yield of 16 percent could be realized.

One method of achieving a more constant biomass is more frequent restockings. However, care must be taken not to exceed the critical biomass level of any given pond. Using the prawn population model developed by Gibson (1976), Steinke (1976) developed a computer-simulation model for prawn populations in an earthen pond in Hawaii. Basically, it allows for the implementation of various restocking schemes and calculated prawn biomass for any time, t. The grid method was used to determine the restocking strategy which would maximize yields. The practical optimum was determined and is shown in Appendix C.

Simulation outputs are not actual field experimentations. However, they are useful as a management tool. Using the simple computer model, a variety of restocking strategies have been tested. The one selected, the 60-day restocking interval and 10 PL's/m^2/year combination, yielded a steady biomass of 2,600 kg/hectare which is slightly under the critical biomass level of 2,700 kg/hectare (Gibson, 1976).

Based on the above, it is felt that the current average yield of 3,340 kg/hectare/year achieved by small owner-operated prawn farms can be surpassed by using a restocking strategy similar to that suggested by the simulation result. The resulting increase in yields is estimated at about 15 percent.

Gibson (1976) reviewed available data and suggested that the mortality function of prawn can be described by a negative exponential function with respect to time, which means the majority of mortality occurs long before harvesting. There are two directions toward which searches for other restocking strategies can be directed. Nursery ponds, or nursery sections in production ponds, can be established to allow different feed and stocking densities for postlarvae. Recent research by Willis et al. (1976) indicated the feasibility of nursery operation in prawn production where postlarvae are first cultured in a high density environment to produce stronger stocking material for the grow-out operation. An average conversion ratio of 1.31:1 for a 2-month nursery operation can be achieved by feeding Purina Trout Chow (40 percent protein) to the prawn. Growth during this 2-month nursery operation is comparable with that of a 4-month average growth in the pond. The possible advantages of having one or more intermediary steps before a prawn enters into the final production pond should be investigated because it may contribute significantly towards increasing yields on a per hectare per year basis without requiring genetic improvement (Wang et al., 1975).

Stocking grow-out ponds with older, say 2 to 4 month old animals, may serve several purposes. Obviously, the effect of early mortality will be reduced, but more importantly, higher efficiency in pond utilization can be achieved. Nursery ponds can be stocked at numerical densities far in excess of normal grow-out ponds, provided there is adequate shelter. In addition, the growth rate can be increased with higher temperatures, a procedure not economically feasible in larger ponds and, as previously mentioned, feed conversion ratios far in excess of those currently achieved.

Canal pendulum culture also shows great promise. Maximum yield per unit area can be achieved when biomass density is maintained at its highest sustainable level. As successive harvests reduce biomass, its density in a canal may be kept constant by a movable partition stretched across the canal. When the partition is moved, a new stocking can be placed on the opposite side. Thus, as space is reduced for the initial population, it is increased for the younger, growing population. When the partition has moved the entire length of the canal and all of the initially stocked animals are harvested, the partition is again moved, this time in the opposite direction (like a pendulum), and the process repeats itself.

This strategy has several advantages: (1) separate stockings are isolated, eliminating any differential size mortality; (2) the average harvest area is reduced; (3) the younger population is not disturbed until sufficient numbers reach harvestable size.

Monosex culture studies have shown considerably higher survival rates in males in a crowded environment (Gibson, 1976; Wang et al., 1975). If increased revenue from higher survival rates more than offsets the costs of sexing, monosex culture may prove advantageous.

The preceding comments, although reasonable, are nonetheless rational speculations. Most remain to be proven. Preliminary investigations show them to be feasible and profitable; however, it is essential that a prototype be constructed and operated to verify this model and provide a working situation that can be used for the improvement of aquaculture production systems.

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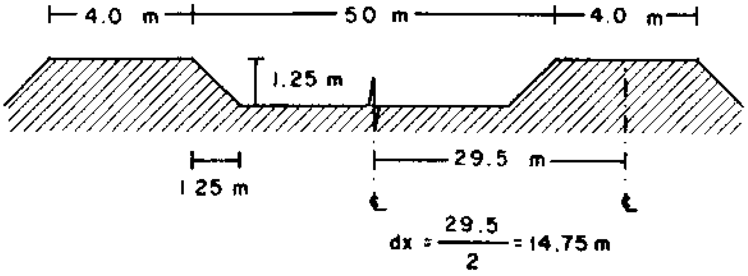
APPENDICES

Appendix A. Excavation Calculations

The following calculations are based on the average end area method where level ground is assumed and volume of cut is equal to volume of fill.

1. Rectangular earthen pond

Wetted area: .5 hectare
Total area: .562 hectare
Total area as a percentage of wetted area: 112.4 percent
Dimensions: 50 m long x 100 m wide x 1.25 m deep



a. Cut for X-section:

$$C_X(45 + 2C_X) = [1.25 - C_X][4 + (2.5 - 2C_X)]$$
$$45C_X + 2C_X^2 = 8.13 - 2.5C_X - 6.5C_X + 2C_X^2$$
$$54C_X = 8.13$$
$$C_X = .1505 \text{ m}$$

b. End area for X-section:

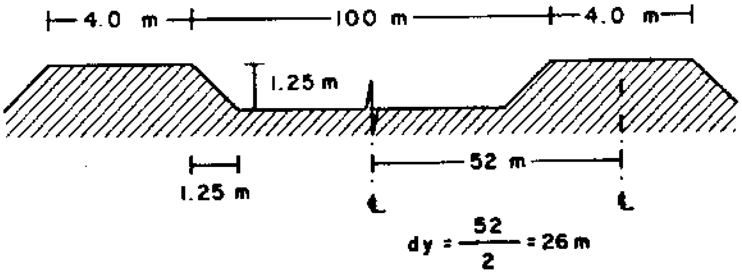
$$A_X = C_X(45 + 2C_X)$$
$$A_X = 6.81 \text{ m}^2$$

c. Volume for X-section:

$$V_X = 95(A_X)$$
$$= 647.5 \text{ m}^3$$

d. First moment for X-section:

$$M_X = V_X d_X$$
$$= (647.5 \text{ m}^3)(14.75 \text{ m})$$
$$= 9{,}551.1 \text{ m}^4$$



e. Cut for Y-section:

$$C_y(95 + 2C_y) = [1.25 + (.151 - C_y)][4 + (2.5 - 2C_y)]$$

$$95C_y + 2C_y^2 = 9.11 - 2.802C_y - 6.5C_y + 2C_y^2$$

$$104.3C_y = 9.11$$

$$C_y = .08731 \text{ m}$$

f. End area for Y-section:

$$A_y = C_y(95 + 2C_y)$$

$$= 8.31 \text{ m}^2$$

g. Volume for Y-section:

$$V_y = 45A_y$$

$$= 373.93 \text{ m}^3$$

h. First moment for Y-section:

$$M_y = V_y d_y$$

$$= (373.93)(26)$$

$$= 9,722.23 \text{ m}^4$$

i. Total volume

$$V = V_x + V_y$$

$$= 1,021.46 \text{ m}^3$$

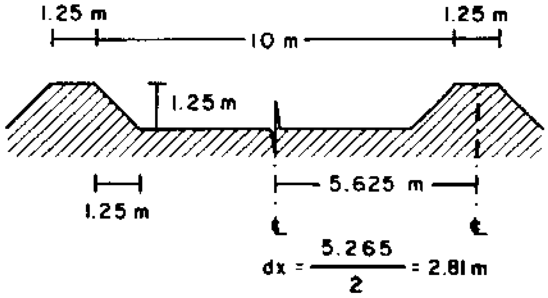
j. Total moment

$$M = V_x d_x + V_y d_y$$

$$= 19,273.3 \text{ m}^4$$

2. Canal pond

Wetted area: .5 hectare
Total area: .567 hectare
Total area as a percentage of wetted area: 113.4 percent
Dimensions: 10 m long x 500 m wide x 1.25 m deep



a. Cut for X-section:

$$C_x(5 + 2C_x) = \left[1.25 - C_x\right]\left[1.25 + (2.5 - 2C_x)\right]$$

$$5C_x + 2C_x^2 = 4.69 - 2.5C_x - 3.75C_x + 2C_x^2$$

$$11.25C_x = 4.69$$

$$C_x = .417 \text{ m}$$

b. End area for X-section:

$$A_x = C_x(5 + 2C_x)$$

$$= 2.433 \text{ m}^2$$

c. Volume for X-section:

$$V_x = 495A_x$$

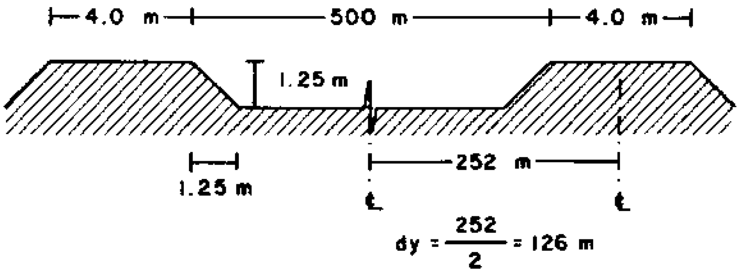
$$= 1{,}204.23 \text{ m}^3$$

d. First moment for X-section:

$$M_x = V_x d_x$$

$$= (1{,}204.23 \text{ m}^3)(2.81 \text{ m})$$

$$= 3{,}383.87 \text{ m}^4$$



e. Cut for y section

$$Cy(495 + 2Cy) = (1.25 - .417 - Cy)(4 + 2.5 - 2Cy)$$

$$495Cy + 2Cy^2 = (.83 - Cy)(6.5 - 2Cy)$$

$$495Cy + 2Cy^2 = 5.41 - 1.66Cy - 6.5Cy + 2Cy^2$$

$$503.16Cy = 5.44$$

$$Cy = .0108 \text{ m}$$

f. End area for y section

$$Ay = Cy(495 + 2Cy)$$

$$= 5.35 \text{ m}^2$$

g. Volume for y section

$$Vy = 5Ay$$

$$= 26.76 \text{ m}^3$$

h. First moment for y section

$$M_y = V_y d_y$$

$$= 3{,}371.62 \text{ m}^4$$

i. Total volume

$$V = V_x + V_y$$

$$= 1{,}231 \text{ m}^3$$

j. Total first moment

$$M = V_x d_x + V_y d_y$$

$$= 6{,}755.5 \text{ m}^4$$

Appendix B. Calculation of Potential Increase in Yields Through Multiple Restockings

Figure B1 represents the typical cyclic pattern resulting from single annual restocking. Critical biomass, CB, is the maximum sustainable biomass level possible for that particular pond. The shaded area, A_1, represents the maximum potential gain if biomass were kept constant at level CB throughout. The area below, A_2, represents the yield during the one year period from day 555 through day 920 (areas were determined with a planimeter). The potential gain in terms of percentage of current yields is a ratio of the two areas or:

$$\begin{aligned} \text{Percentage gain} &= A_1/A_2 \times 100 \\ &= 12.9 \text{ cm}^2/79.35 \text{ cm}^2 \times 100 \\ &= 16 \text{ percent} \end{aligned}$$

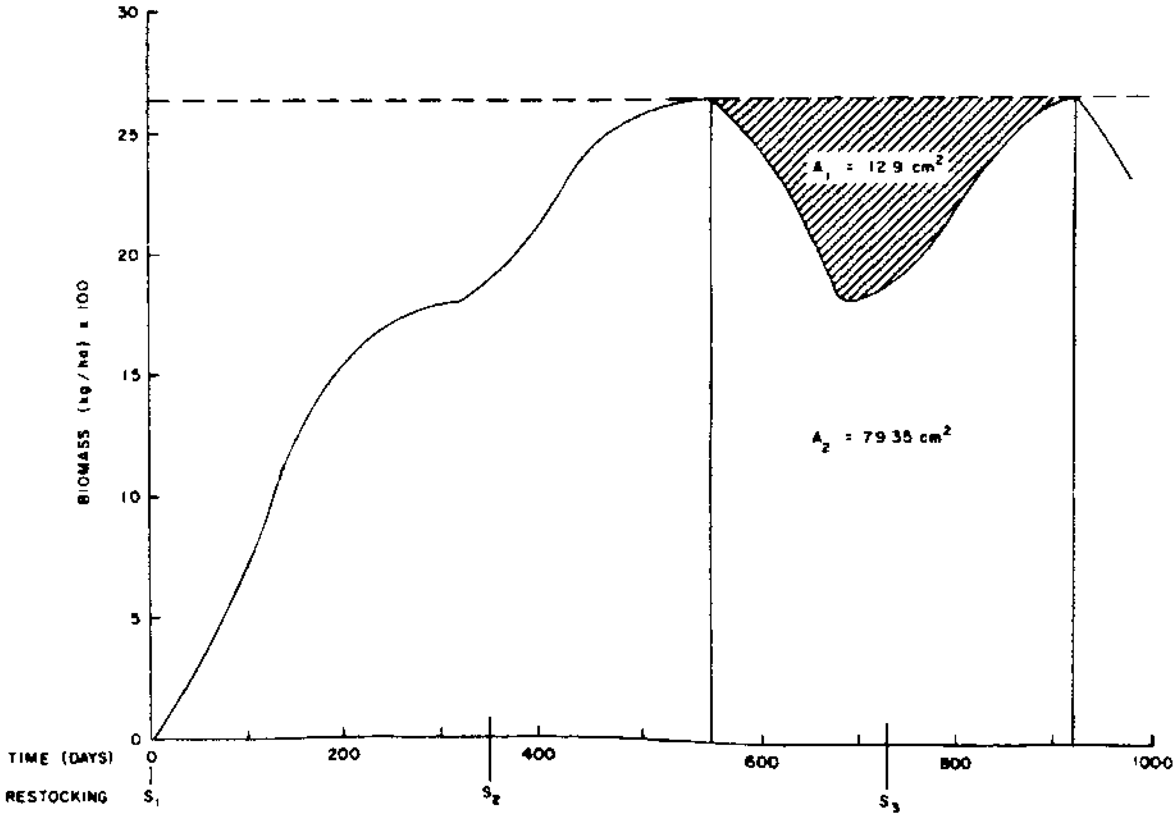


Figure B1. Biomass in Ota's pond 1 from initial stocking, S_1, in August 1970 through two annual restockings, S_2 and S_3

Appendix C. Simulation Model

Developing the survival function for first population

$$N_t = \sum_{i=1}^{2} \left\{ .5\ N_o\ e^{-.0006047 \left[t_1 + (t - t_1)\ e^{m_i\ (D_o - 9.44)} \right]} \right\} (t > t_1)$$

$$i = \begin{cases} 1 & \text{males} \\ 2 & \text{females} \end{cases}$$

$N_o = 10{,}000 \cdot D_o$

t_1 = date cannibalism becomes evident

D_o = total stocking per square meter per year

$t > t_1$

Survival function for subsequent populations

$$N_t = \sum_{i=1}^{2} \left[.5\ N_o\ e^{-.0006047(t - t_i)\ e^{m_i\ (D_o - 9.44)}} \right] \qquad (t > t_1)$$

Harvest function for all populations

$$H_{tj} = 36.1447\ D_o^{\ .52699} \langle t - 200 \rangle \qquad (t > 200)$$

H_{tj} = total number of prawns harvested from each hectare from the jth population

Population function

$N_{Rj} = (N_{tj} - H_j)$ for each population $j = 1, 2, \ldots, n$

N_R = number of prawns remaining from the jth population

Biomass for each population

$$BM_j = W_{tj}(N_{tj} - H_j)$$

$$= W_{tj} \cdot N_{Rj}$$

Total biomass at any time

$$BM_{TOT} = \sum_{i=1}^{m} W_{tj} \cdot N_{R_j} \text{ for } j = 1, 2, \ldots, n \text{ populations}$$

BM_{TOT} in kg/hectare

The application of these equations in the simulation model yields a visual plot of prawn biomass vs time. By varying stocking density and interval, the optimum combination was found to be 10 juveniles/m^2/year with a stocking interval of 60 days as shown in Figure C1.

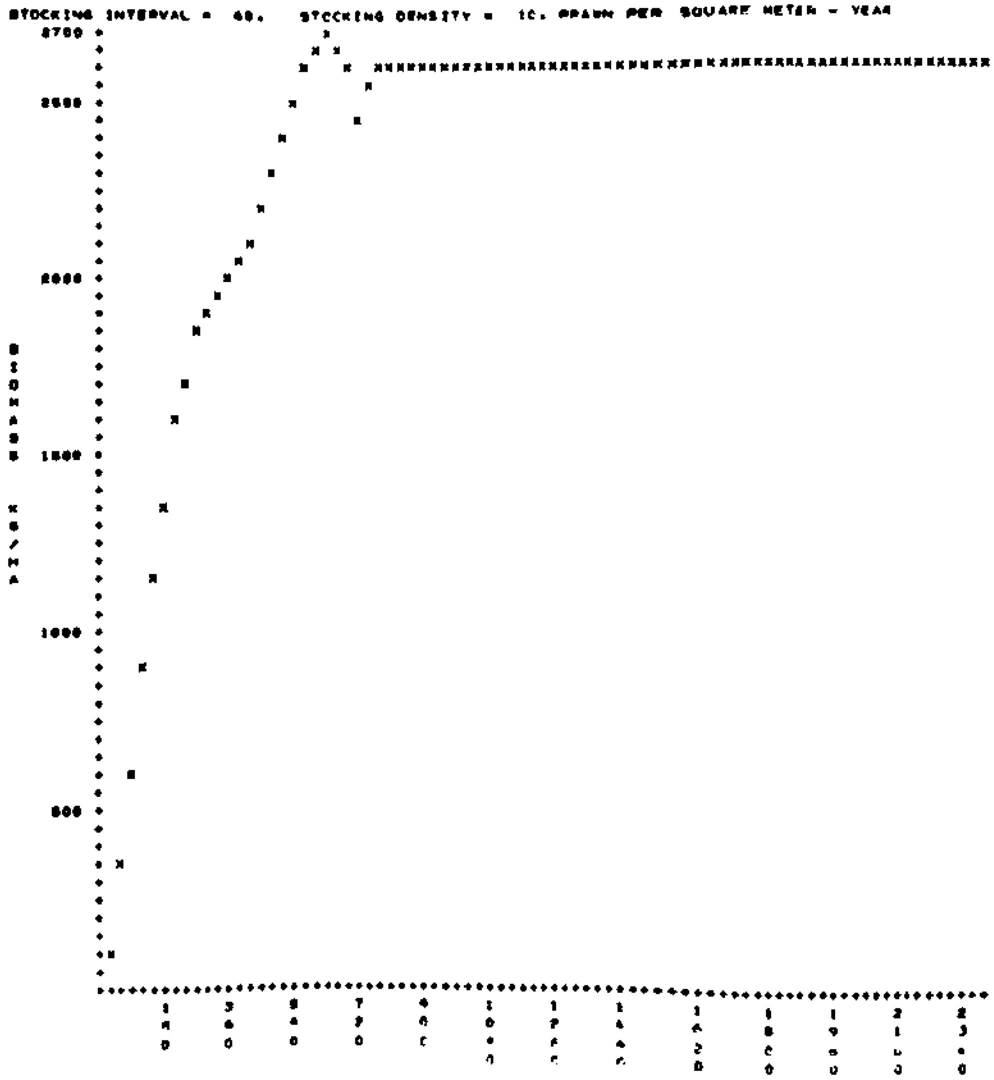


Figure C1. Prawn biomass vs time under optimum restocking strategy