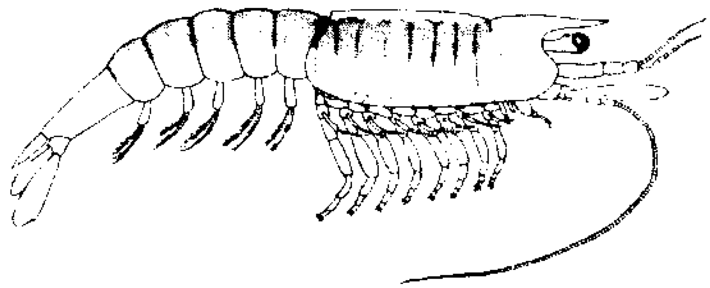
Culture of Pink Shrimp, *Penaeus duorarum* at the Turkey Point Experimental Mariculture Laboratory



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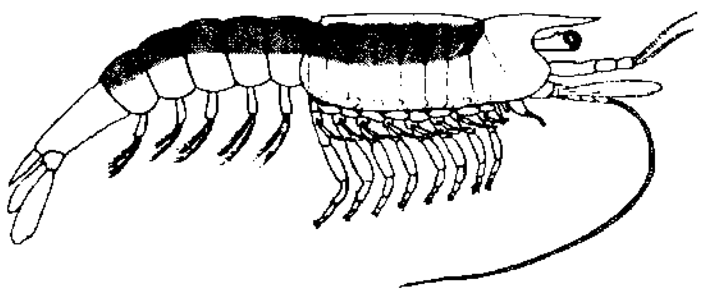

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ABSTRACT

A review and analysis of laboratory and pond studies on intensive culture of pink shrimp, *Penaeus duorarum*, at Turkey Point, Fla. since 1968 are presented. Data from over 45 production hatchery culture attempts and from 49 pond "grow-out" studies are analyzed to determine biological and economic feasibility of growing pink shrimp in Florida. Even though hatchery procedures have been optimized for the existing system, survival of shrimp from nauplii to postlarvae ranged from 0.5% to 55%. Biological failure, human error, and mechanical equipment failure were important factors in survival of larval shrimp; whereas low oxygen levels and low winter temperatures were related to survival of juvenile pink shrimp in ponds. Based on a time-motion and cost study of four production "runs", each producing 1 million postlarval shrimp a hatchery of the Turkey Point design could produce postlarval pink shrimp for $1.16 to $ 1.38 per 1,000. The greatest costs were labor for diatom production,capital investment, acquisition of gravid shrimp, and labor for harvest.

Growth of postlarval pink shrimp in ponds to a desirable market size required several months more than other species of shrimp and survival in over 22 percent of the ponds was less than 30 percent. Growth and individual size were greatly suppressed at postlarval stocking densities greater than 90,000/ha. Total biomass of market-sized shrimp produced in Turkey Point ponds in 100 to 160 days ranged from 400 to 580 kg/ha. Large standing crops, and therefore a greater biomass (1,722 kg/ha), were observed in "nursery-ponds" stocked with 1 million post larvae per ha. for 60 days. Poor water quality, low water temperature in the winter, and pond design problems contributed to the low yields in the ponds.

Major cost components in growing postlarvae to market-size were direct labor ($0.92/kg) and food ($0.71/kg). Estimated product/production cost (live weight) ranged from 1.63/kg to 1.92/kg whereas total market price which included capital investment and business overhead ranged from $2.95 to $3.24 per kg. Review of the biological data, facility design, and cost analysis indicate research areas which could substantially reduce the total market price of penaeid shrimp.

INTRODUCTION AND BACKGROUND

This presentation is a general summary of six years of research results that were accumulated at the University of Miami Turkey Point Experimental Mariculture facility located adjacent to Florida Power & Light Co. generating plant near Homestead, Fla. The combination hatchery and pond culture facility has been operated by faculty and staff of the University of Miami, Rosenstiel School of Marine and Atmospheric Science. Most of the planning, direction of research, and technical contributions resulted from the efforts of Rosenstiel School staff. We are particularly indebted to Drs. C.P. Idyll, D.C. Tabb, E.S. Iverson, W.T. Yang, C.W. Caillouet, E. Heald, and L. G. Anderson. The daily operation of the facility was the responsibility of numerous graduate students and research assistants with the able guidance of project managers Y. Herono, J.M. Heinen, and J.P. Norris.

Studies to determine the feasibility of culture of pink shrimp (Penaeus duorarum) at Turkey Point were made possible by the continuous and generous support from the Office of Sea Grant (NOAA). Initial construction costs, technical support, and early operation expenses were supported by the Florida Power & Light Co., the National Science Foundation Sea Grant Project Contract No. GH 000004 and GH 000100, Armour & Co., United Brands Co., Groton Associates, Ralston Purina, and Sea Farms of Key West. A description of the facility and details of some of the initial programs can be found in the University of Miami Sea Grant Information Leaflet No. 1 and the technical publication by Tabb et al., 1971.

Initial studies were to evaluate Japanese shrimp culture concepts Fujinaga, 1967; Hudinaga and Kittaka, 1967, reported during the mid-1960's and to determine if these techniques were applicable to the culture of penaeid shrimp in United States. The pink shrimp, *Penaeus duorarum*, was selected for study because it is one of the three most important species of commercial shrimp in the U. S. and is readily available in local south Florida waters. This approach complimented other mariculture investigations at the Galveston National Marine Fisheries Service Laboratory and in private industries that were using other species of shrimp. Within the first year, concepts for hatching and rearing penaeid postlarval shrimp were developed and incorporated into a hatchery operating maunal. This manual was released as University of Miami Sea Grant Special Bulletin No. 7, authored by Tabb et al. (1972). To date, only slight modifications have been made to the hatchery operating procedure contained in this manual and it serves as a reference for specific details on techniques for culture of penaeid shrimp reported in this study.

Operation of the saltwater pond facilities was somewhat more difficult and only recently has an effective management concept been developed. For the majority of the data reported in this review, pond operations were as described by Caillouet et al., 1972. A detailed description of the pond construction and water quality characteristics are also included in this publication.

The most important role of the Turkey Point facility has been to provide for a developing mariculture industry a prototype pilot operation for the culture of penaeid shrimp. The design of tanks and shrimp culture procedures have served as a basis for at least three existing commercial ventures (Sea Farms, Inc. of Key West, Ralston Purina of Crystal River, and Marifarms, Panama City). These organizations had a distinct technical and economic advantage through evaluation of design deficiencies at the Turkey Point facility enabling them to correct problem areas when they constructed their own facilities. The Turkey Point facility was, and still is, being carefully scrutinized for design deficiencies, biological problems and, most importantly, the economics involved in raising shrimp by this technique. One of the first reports of the economic potential of shrimp farming was prepared by Anderson and Tabb, 1970. More recent and detailed cost analyses have been prepared from data collected at the Turkey Point facility and furnished to private industry and granting agencies by Krantz, 1974.

This presentation is an overview of all the hatchery and pond culture studies with emphasis on the commercial production potential of pink shrimp in south Florida. Hopefully, it will delineate some new biological, economic, engineering, and mass production problems, as well as indicate some new research needs in shrimp mariculture.

TURKEY POINT HATCHERY OPERATION

Procedures for culture of shrimp larvae are essentially those used by Fujinaga (1969) except two sizes of tanks (2 cu meters indoor and

20 cu meters outdoor) were used. Gravid female shrimp were captured from local waters and spawned in the tanks of filtered, aged sea water (30 ppt and 23^{o} to $28^{o}C$). Spent female shrimp were removed and larval development continued in the same tank. Diatoms (Phaeodactylum tricornutum, Skeletonema costatum, and/or Cyclotella) which were cultured to high density in separate tanks were introduced at the fifth naupliar stage and were maintained at about 5×10^{4} cells/ml through the third mysis stage. Artemia nauplii were introduced during early mysis stages. Minced squid and chopped fish were provided to postlarval stages. Postlarvae were held in culture tanks until 12 to 15 mm in length. Aeration and daily changes of water were necessary to maintain water quality.

After initial studies of techniques for raising pink shrimp had shown promise of success, other species of shrimp (Peneaus aztecus, P. californiensis, and P. setiferus) were brought to the Turkey Point facility and evaluated for their adaptability to the procedures, techniques, and equipment design. Only minor modifications were needed to adjust the procedures contained in Special Bulletin No. 7 to the requirements of the new species. Table 1, which summarizes the sequence of development of larval stages of some of the penaeid shrimp studied at the Turkey Point facility, demonstrates that each species had a characteristic time for larval stage development. However, the development time for any species was variable and reflected any abnormal event in culture procedure, tank environment, or feeding regime. Differences in development occurred within a given species when animals were raised at different temperatures. Compare on Table 1 the

Table 1. Range of duration in hours of larval stages of penaeid shrimp cultured at the Turkey Point facility.

Species (Temp.)	Hours in NAUPLUS	Hours in ZOEA	Hours in MYSIS	Total Hours
P. duorarum (27-28 C)	37-50	100-167	58-118	195-335
P. duorarum (23-23 C)	63-68	112-189	79-93	254-350
P. aztecus (26-28 C)	83-91	143-234	137-226	363-551
P. aztecus (27-28 C)	51-57	146-217	116-145	313-459
P. setiferus (27-28 C)	11-13	71-147	96-125	178-285

development of *Penaeus duorarum* at 27^{o} to $28^{o}C$ vs. the same species 23^{o} to $25^{o}C$. Larvae of *P. duorarum* developed more rapidly than larvae of *P. aztecus*. Both of these species developed slower than the larvae of white shrimp, *P. setiferus.* Data in this table were based on development during a minimum of five production runs, where more than a half-million postlarvae were produced in each run.

Once the larval penaeid shrimp reached postlarval stage, it was advantageous to hold them in culture tanks or in a closely controlled environment until they reached stage five postlarvae. Our experience suggests that this is the earliest stage that pink shrimp can be transferred to a pond environment and be expected to exhibit reasonable survival. The duration from first stage to fifth stage postlarvae again depends upon the species, diet, and environmental temperature. *Penaeus duorarum* grown at 27^{o}-$28^{o}C$, requires approximately 10-14 days; grown at 23^{o}-$25^{o}C$, 14-24 days; *Penaeus aztecus* cultured at $28^{o}C$, 14-20 days; *Penaeus setiferus* at $28^{o}C$, 8 days; *Penaeus californiensis* at $28^{o}C$, 7 days; and *Penaeus occidentalis* at $28^{o}C$, 8-10 days.

Not all of the attempts to culture large quantities of penaeid shrimp were successful. Some of the reasons for operational problems and high mortality are listed in Table 2. These data represent hatchery "runs" where more than 500,000 (penaeid shrimp) nauplii were obtained for spawning females. In the light successful hatchery runs using pink shrimp, survival of nauplii to postlarvae ranged from 5.5% to 55% with a mean survival of 22%. Biological failure, an important reason for poor success in raising white shrimp, included failure of eggs to hatch

Table 2. Turkey Point shrimp hatchery operation efficiency

Species	Total Runs	Successful Runs	Biological Failure	Disease	Human Error	Equipment Failure	Biological Problem & Human Error
P. duorarum	21	8	2	2	3	2	4
P. aztecus	2	0	2	0	-	-	-
White Shrimp	15	5	8	1	1	-	-

due to female immaturity, mechanical injury to the females and eggs, egg abortion due to stress during shipment of females, or an environmental factor which prevented the eggs from hatching. This category also includes failure of the larval stages to develop normally. There were several instances where apparently healthy larvae failed to undergo metamorphosis into the next stage and eventually died.

Disease problems were caused by ectoparasites (protozoa and filamentous bacteria) attached to the gills and external surfaces of the larvae. This problem was created by the inefficient water filtration and failure of technicians to clean debris from the culture tank bottom. The debris served as substrate for the proliferation of the ectoparasites which then attached to the larval shrimp and killed them during metamorphosis.

Human error or incorrect judgment on the part of technicians was responsible for several losses. Most attempts to correct a biological problem were not conducive to the survival of the larval shrimp. Losses due to human error strongly suggest that the operation of a shrimp hatchery is not a foolproof manufacturing process but is a learned skill supported by a good understanding of biological processes and a significant amount of experience. Inexperienced technicians that had participated in a minimum of five production runs could be trusted to operate without direct supervision.

Equipment failures were mechanical problems in air supply and temperature control equipment. Failures of these life support systems always occurred during periods of maximum operating output and suggested mechanical design problems. Due to the short time in which destructive environmental changes can occur, all mechanical systems must have standby systems or be easily repaired by unskilled craftsmen (i.e., biologists). Maintenance of air supply and temperature control equipment was very high since none of the equipment at Turkey Point was designed to operate in a humid, salt air environment. Equipment at this facility reached only 30% of manufacturers' life expectancy. There is a definite need for new materials and salt-resistant equipment, as well as component and system engineering to solve the problems of mechanical inefficiency in mariculture systems.

During 1973-1974, eight successful production scale runs of the Turkey Point hatchery yielded an average of 1.1 million postlarvae per run. These runs were conducted close together to simulate operation of a commercial venture. As a result of loading the hatchery system to its maximum capacity, several design deficiencies were found. The capacity of the laboratory to sustain adequate production of diatoms was at first a limiting factor. Due to the long generation time and variation growth during mass culture of the diatoms and phytoplankton used at Turkey Point, only four of the 16 outdoor 20,000-liter culture tanks could be used. Therefore, only 1.5 million postlarval shrimp could be produced per month from a facility with a potential of about six million postlarval shrimp. The ratio of volume of diatom production to larval rearing tank volume was close to five units of food culture volume to one unit of larval rearing tank volume.

Many facility operational problems and reasons for human error were related to larval culture tank design. The 20,000-liter tanks are 2 meters wide, 5 meters long, and 2.1 meters deep. Indoor culture tanks and most smaller culture tanks at Turkey Point are of this same depth to width proportion. This ratio tank depth to total volume interferes with proper visual examination of the tank bottom for debris, makes observation of larval shrimp very difficult, and interferes with cleaning of the tanks during operational runs. Water flow characteristics in these tanks prohibits uniform blending and dilution of waste products when old culture water is exchanged with fresh, filtered sea water. The outdoor concrete larval culture tanks are not enclosed (photo in Special Bulletin No. 7) and control of environmental fluctuations is impossible. Larval shrimp culture cannot be conducted in the outdoor tanks between 1 December and 1 April which is the most desirable period for U. S. mariculturists to produce an early spring shrimp crop. Many of these design deficiencies were noted by other U. S. mariculture firms who corrected these problems in their facility construction.

During 1973-74 hatchery operations, manpower expended for various tasks in the hatchery was closely monitored similar to any industrial time-motion study. Observations on manpower expenditures for four production runs are reflected in Table 3. Each production run lasted 28-30 days and yielded over 750,000 fifth stage postlarvae. Only 71.8 man-hours were expended in a 30 day period, yet harvest operations alone required a minimum of two people. Obviously, two technicians must staff the facility, yet they are not utilized fully in the culture of postlarval shrimp. At Turkey Point and other commercial shrimp hatcheries, these technicians also participate in facility maintenance, in record preparation, and in operation of the shrimp grow-out facility. Diatom or phytoplankton culture required the greatest expenditure of labor which could be reduced by tank design and new construction materials. Note that the operational feeding techniques outlined in Special Bulletin No. 7 required very little expenditure of labor. However, this manpower must be available seven days a week each morning and evening.

Data in Table 3 could be expressed as direct labor as part of the estimated cost for producing postlarvae (Table 4). Support overhead (plant maintenance, accounting, station management) reflect only a minimum of daily operational needs of the production facility. Capital invested in the physical plant and equipment is the most costly production component, yet it is often overlooked by biologists and businessmen who discuss mariculture costs. Current estimates for construction of a hatchery of the Turkey Point design in south Florida would exceed $75,000. Interest rates of only 8.5% for a 15 year amortization period are included in the estimate of capital investiment.

Procurement of gravid female shrimp has been a very expensive component of shrimp mariculture in the United States. Recently several Gulf Coast fishermen have equipped their shrimp boats with proper holding facilities and can furnish very healthy shrimp at dockside. During natural spawning periods, *P. duorarum* and *P. aztecus* can be obtained, transported to Turkey Point, and a high percentage (60-90%) spawned at a maximum cost of $20 per spawning female. Our experience with white shrimp has not been as good. In several instances when gravid females were difficult to find and then lost their spermatophore during handling, the livestock procurement costs exceeded $300 per spawning female and over $1 per healthy postlarval shrimp!

Table 3. Manpower expenditure for production of one million postlarval shrimp at Turkey Point hatchery duration 28-30 days

	Man Hours
Diatom Production	29.6
Culture Tank Cleaning	10
Culture Tank Prep. & Hatch	8
Diatom Feeding	5.2
Artemia Feeding	1
Shrimp Population Checks	4
Water Exchange	2
Harvest	12
TOTAL	71.8

Labor at $3.00/hr. = $215.00

Table 4. Hypothetical cost (U. S. dollars) of producing postlarval shrimp based on Turkey Point hatchery operation concept

		Cost/1000	
A.	Direct labor	0.22	
B.	Support overhead (100%)	0.22	
C.	Capital Investment	0.52	
D.	Procure females	0.20	
	Total cost: independent farm (A+B+C+D)		1.16
E.	Profit (100% of direct labor)	0.22	
	Total cost: larval culture facility (+E)		1.38
F.	Shipping costs - Direct labor	0.03	
	Air freight (US)	0.44	
	Air freight (foreign)	1.30	
	Total cost: Shipped in US (+F)		1.82
	Total cost: Shipped to foreign (+G)		2.68

Based on the data in Tables 3 and 4, an independent shrimp farm with its own hatchery of Turkey Point design could produce its own postlarval shrimp at about $1.16/1,000. To envision the production cost of postlarvae for a mariculture venture which just raises postlarvae and then ships them to other pond grow-out facilities, a profit of 100% of direct labor is added (Item E, Table 4). The figure of $1.38/1,000 postlarvae is 19% higher than an operation growing its own postlarvae. This is a very low estimate since costs of business overhead, financial growth, or shipping charges are not included. From our experience at Turkey Point, about 25 man-hours are required to package and transport one million postlarvae to the Miami airport. Air fare for the 35-pound shipping boxes containing 20,000 postlarval shrimp was about $.25 per pound in the U. S. and $.75 per pound for international shipment. Transportation costs alone destroy the economic viability of a postlarval production hatchery which ships its product to other sites by air.

The advantages of a postlarval hatchery at a grow-out site are numerous and obvious. In addition to an assured supply of postlarvae at a given date, control of production costs, and increased larval-postlarval survival in ponds, the integrated farm will save from 10% to 60% on the cost of livestock (postlarval shrimp) for its operation. Costs of shipping postlarval shrimp to foreign countries are prohibitive and could be 150% to 200% of the real postlarvae production cost. Production of postlarvae (livestock) can be a significant cost component (livestock cost in Table 7) of the shrimp harvested for market. In the theoretical data developed in this study, livestock cost was about 20% of the product cost.

POND CULTURE OF POSTLARVAL SHRIMP TO A COMMERCIALLY VALUABLE SIZE

The second major objective of the Turkey Point studies was to evaluate the growth and production of penaeid shrimp in saltwater ponds in south Florida. The seven above-ground ponds were constructed in coral rubble which necessitated lining the ponds with butyl rubber and marl substrate. Construction details and specific techniques for operation and management of the ponds may be found in publications by Caillouet _et al._, 1972; Caillouet _et al._, 1973; and Norris, 1974. The unsloped bottoms, small drain size, and inadequate water flow into the ponds have created conditions peculiar to Turkey Point. Whether or not data collected in the ponds is applicable to ponds in other regions or ponds of another design is unknown. Additionally, the statistical analysis of the data and conclusions developed in this report should always be treated as a range of results under circumstances not fully understood or described in this report. However, many of the guidelines for pond culture of shrimp in the U. S. and Caribbean were developed from the early studies at Tureky Point.

Some of the early attempts to raise shrimp at Turkey Point used chopped squid and trash fish as food. However, many technical problems were encountered with the frozen, chopped squid-fish diet. Labor to prepare and feed the diet was five times higher than when pelleted food was used. Severe water quality problems were encountered, especially with chopped fish. Food conversion efficiency of the "natural" product diet was far inferior to other diets used at Turkey Point (Table 5). Acceptable food conversion ratios have been obtained with wheat bran and commercially available catfish pellets. Caillouet *et al*., 1972, showed the economic advantages of wheat bran to raise bait-size shrimp.

Table 5. Food conversion efficiency of *Penaeus duorarum* in ponds with greater than 30% survival.

Diet	N	Nursery Stage Mean	Nursery Stage Range	N	Growout Stage Mean	Growout Stage Range
Squid-Fish	6	2.3	1.0-4.2	5	3.4	1.3-5.8
Wheat Bran	18	3.0	0.7-9.3	2	1.5	1.3-1.7
Oppenheimer Pellet	2	4.9	4.7-5.0	-	-	-
Catfish Pellet	7	0.8	0.4-1.5	2	1.5	1.5

Analyses of growth, survival and final standing crop suggested that data on food conversion should be separated into nursery stage and grow-out stage. Nursery-stage shrimp were postlarvae less than 0.1 gram when stocked, and grown to greater than 2-gram mean size. "Grow-out stage" were data collected on shrimp that were stocked at an average size greater than 0.1 gram. While only moderate levels of production were obtained (400 to 600 kg/ha/crop), data in Table 5 indicate that shrimp *can* be raised on commercially available dry diets with economically attractive food conversion efficiency. Attempts to obtain greater densities from the ponds at Turkey Point resulted in water quality problems, reduced shrimp size, and occasionally complete loss of shrimp in the pond. Therefore, food conversion data were only for ponds with greater than 30% survival.

Economic viability of a shrimp mariculture facility is greatly dependent upon the total biomass harvested from a given-size pond, as well as the individual shrimp size and the length of time required to reach this acceptable size.

A large number of variables (temperature, light, diet, water quality, feeding rate, etc.) affect the growth of shrimp in ponds. Incorporation of all these variables on one figure to represent growth of shrimp is impossible. Initial stocking density and size of the shrimp at stocking are two of the most important factors which influence productivity of a pond and the size of shrimp at harvest. Figure 1 represents the biomass (in kilogram per hectare) produced by 36 ponds that were stocked with postlarvae of P. duorarum weighing 0.005 to 0.09 grams each. Directly below the figure is Figure 2, aligned to show the mean size of individual shrimp in the same population at time of harvest. The greatest production of marketable shrimp (650 kg/ha) occurred after 4.5 months of growth. The two higher production values (at two months) occurred in nursery ponds with extremely high stocking density and the ponds produced only 1.5 to 2 grams shrimp (Figure 2). In general, growth of pink shrimp in Turkey Point ponds was very slow reaching five grams in three months and a minimum acceptable market size of 12 grams after six months. However, whenever pink shrimp were left in the ponds for more than five months, we observed very low survival due to water quality problems during summer months or cold temperature shock in the winter.

In seven instances, ponds were stocked with juvenile pink shrimp weighing more than 0.1 grams each. Figures 3 and 4 are paired similar to Figures 1 and 2, to show very low production and slow individual growth of juvenile pink shrimp. Weekly measurements of pink shrimp in low-density tank culture experiments at Turkey Point confirmed this poor growth rate. Comparable studies in Turkey Point ponds using P. setiferus and P. occidentalis showed that these species can reach 5 grams in 90 days and 12 grams in 120 days. These growth rates are similar to the growth of Penaeus vannamii in Texas ponds (Parker, 1974). A limited number of pond culture studies with P. aztecus indicate that this species grows faster than P. duorarum but slower than most white shrimp species. Growth rate of animals and size of individuals, especially shrimp, is dependent upon density. Maximum production from a pond necessitates that enough individual livestock are placed in the pond to use the available space and food as efficiently as possible.

Therefore, data in Figures 1,2,3, and 4 must be considered in terms of initial stocking density. Data in Figures 5 and 6 suggest that stocking postlarvae at densities less than 150,000/ha failed to efficiently use the potential productivity of the pond but stocking densities greater than 90,000/ha may have suppressed growth if shrimp remained in the ponds more than 60 days. Our studies of growth during the first 60 days in the pond showed reduced growth only at densities of 1,000,000/ha.

The only acceptable market-sized pink shrimp produced at Turkey Point occurred when postlarvae were stocked at a very low density and only 150 and 300 kg/ha biomass was produced by the pond. When ponds were stocked with juvenile shrimp, we observed less effect of stocking density on the size of individual shrimp and pond production at time of harvest (Figures 7 and 8). However, the limited number of observations on juvenile shrimp in this study may have masked the effect of density on growth.

All data collected on growth and production of pink shrimp in Turkey Point ponds were severely influenced by mortality. Throughout the six years of study, very high and even complete mortality was observed in ponds of pink shrimp, especially during Florida "winter" conditions. Most of the "winter-kills" were related to rapid changes in pond water temperatures from 15^{o}C to 18^{o}C to as low as 6^{o}C in a 24-hour period. During those periods of low temperature, subtropical phytoplankton were killed and water quality was altered especially by the high B.O.D. from decay of dead plants and aquatic animals. Dramatic losses or poor survival also occurred during the summer months, but less frequently. All of the summer losses were preceded by prolonged periods of low dissolved oxygen levels (0.3-0.5 ppm at 0800 hours). Details of this phenomenon were reported by Krantz and Iversen, 1974.

Survival of shrimp in 49 Turkey Point ponds is expressed as a frequency distribution in Table 6. Data are separated as to when the ponds contained shrimp. Ponds in winter condition refers to those which

Table 6. Survival frequency of populations of *Penaeus duorarum* in Turkey Point ponds for 1968-1974

% Survival	Total Number	Winter*	Summer
0 - 9	7	6	1
10 - 19	1	0	1
20 - 29	2	0	2
30 - 39	1	1	0
40 - 49	9	7	2
50 - 59	6	1	5
60 - 69	2	0	2
70 - 79	7	1	6
80 - 89	8	2	6
90 - 99	6	1	5
TOTAL	49	19	30

* 20 November to 15 March

contained shrimp from 20 November to 15 March. Commercially acceptable survival - something greater than 65% - occurred more frequently in the summer (63% of the time) than in the winter (21%). Median survival of shrimp in the pond was 41% in the winter and 72% in the summer. However, if pond management techniques (water exchange, fertilization, stocking density) and feeding regime were such as to not overload the oxygen producing capacity of the pond, survival of shrimp in the summer can usually exceed 72%.

OPERATIONAL CONCEPTS

From the data in Figures 1-8, an operational concept has been developed recently for Turkey Point ponds with their peculiar characteristics of pond design, water quality, soil type, climatic regime, and for a given shrimp species. For pink shrimp (*P. duorarum*), postlarvae or nursery-reared shrimp are stocked at 90,000/ha and are kept in the pond for 90-100 days, when they will reach either bait-shrimp size or a minimum size of 12 grams for human consumption. If wheat bran is the diet for postlarval shrimp, daily feeding rate must be lower than 27 kg/ha/day or severe water quality problems occur. If dry, pelleted foods are used, this diet is fed at 5% body weight per day as determined by weekly samples of shrimp size and an assumed survival of 100%. Improved feeding efficiencies have recently been obtained (1:1 for postlarvae to two grams and 1.5:1 for post larvae to 8 grams) by use of a curve-linear growth curve and a daily feeding rate changing from 3% body weight for small shrimp to 6% body weight in larger shrimp. Attempts to raise _P. duorarum_ from postlarvae to an acceptable size for human consumption have required seven to eight months of growth. If populations of pink shrimp of any size are subjected to south Florida winter conditions, a high level of mortality and reduced yield can be expected. Unfortunately, the time period for the growth of pink shrimp to acceptable market size, and the lethal winter water temperatures would limit a commercial shrimp farm to less than two crops of shrimp per pond per year. The maximum standing crop (650 kg/ha) observed in these ponds would limit production to less than 1300 kg/ha/year. This is approximately 10 to 50% of the weight of land-based agricultural crops produced in this area of south Florida.

ECONOMICS OF PRODUCING MARKETABLE SHRIMP

One of the primary contributions of the Turkey Point facility has been to develop estimates of the cost of a commercial shrimp mariculture operation. Anderson and Tabb (1970) utilized some data from the early years of operation of the facility to develop cost estimates of farming bait shrimp in Florida. They assumed many values to develop their cost estimates such as: labor, pond construction cost, hatchery construction costs, acquisition cost of gravid female shrimp, and used low estimates of productivity from the hatchery production regime and grow-out ponds. Since this time, more realistic data have been acquired and we have utilized them to develop a theoretical cost of producing penaeid shrimp with the Turkey Point operational concept during the fall of 1974. One variation from the observed facts is an assumption that

2,000 kg of shrimp per hectare per crop could be produced in the Turkey Point ponds. This would necessitate a change of shrimp species from Penaeus duorarum to P. vannamii or P. setiferus and a modification in the operational concept to provide aeration of the pond water. A detailed estimate of the hatchery operation costs to produce postlarvae was developed earlier (Table 4). These costs are shown on Table 7 as a livestock cost of \$.08 - \$.13 per pound (\$1.8 - \$.29/kg). A range of costs is given since there are variations in monthly hatchery output and there must be some consideration given to disasters which affect sustained monthly output. Direct labor costs on Table 7 were developed from labor required to manage the Turkey Point pond grow-out system in south Florida. Two men are the minimum work crew that could be utilized and each man should manage a surface acreage capable of producing 50,000 pounds (22,680 kg) of product (live weight) per year of employment. This would be about 25 acres (11 hectares). Considering the loss of labor involved in raising shrimp to such things as vacation, sick leave and maintenance of the pond facility, it is necessary to add the cost of \$.42 a pound (\$.93/kg) to the production of the shrimp. This direct labor cost (\$10,000 per man a year) is greater than that used by Anderson and Tabb (1970); however, it reflects the type of labor needed to properly manage ponds of the Turkey Point design in the south Florida environment. Labor cost could be reduced by as much as 50-75% through the utilization of properly designed ponds in other locations in the United States, Caribbean, or South America. Food costs were calculated from a 2:1 food conversion ratio of dry food to shrimp flesh and a

Table 7. Theoretical cost of producing penaeid shrimp. Based on Turkey Point operational concept with pond yields of 2,000 kg/ha per crop. Costs are in United States dollars (live weight)

Item	Cost (per pound)		Cost (per kilogram)	
Livestock (Table 4)	.08 - .13		.18 - .29	
Labor (direct)	.42		.93	
Food	.24 - .32		.53 - .71	
PRODUCT COST		.74 - .87		1.64 - 1.93
Overhead	.23		.50	
Capital investiment	.05		.11	
Contingency	.10		.22	
Profit (± 15%)	.12		.26	
R & D or Growth	.10		.22	
MARKET PRICE		1.34 - 1.47		2.95 - 3.25

Miami market value of $.12 - $.16 per pound ($.26 - $.58/kg) for bulk delivered fish foods. This figure is considerably lower than July 1974 prices for marine rations and especially prepared shrimp diets in bags. However, it is contemplated that a large production operation would utilize custom blended food and negotiate a delivery contract at about the rates used in this calculation. Three major components, the live-stock, the labor for raising and harvesting the crop, and the food for growing the shrimp constitued the product cost as shown as a sub-total of $.74 - $.87 per pound ($1.64 - $1.93/kg) of live weight.

Below the product cost on Table 7 are several costs that often escape the attention of research biologists, but are extremely important to businessmen or investors interested in mariculture. An overhead figure must be included to cover the cost of a secretary, legal fees, accountant fees, and corporate business operation. Most U. S. small business overhead ranges from 55% to 150% of direct labor. The low range of overhead was used since it is more frequently found in agriculture and food processing industries. Capital investment is calculated on a 15 year amortization of the cost of buying land and constructing shallow ponds in south Florida. This figure includes 8½ percent interest on the investment and is prorated on the theoretical output of the ponds. All of the above figures are based on the experience of developing performers during the 1972-74 period and approximately the same values used by conservative venture capital groups considering shrimp mariculture in the United States.

Contingency is simply a figure of safety to reimburse the investor for failures involved in shrimp mariculture. If an economist were to use the frequency of pond survival shown on Table 6, this figure should be roughly 33% of the total product cost. However, 10% is used since it is the opinion of the investigator that any viable mariculture operation would have a better record than the Turkey Point facility. Profit is shown at about 15% which is the lowest acceptable level of investment for corporate business in the Unites States as of this time. Research and development for growth of the corporate structure is a figure which some businessmen desire to place in their product market value. This provides them a small investment based on the incremental cost of their product so their industry can expand, establish new markets, and develop into a larger corporation. This expansion and development increases corporate net worth and will provide a greater dividend to stockholders who have invested in the corporation. A research and development cost of 15% of product cost is a minimum figure. Adding these "business costs" to the product cost would develop a market value or market price of the shrimp raised in south Florida to $1.34 to $1.47 a pound ($2.95 - $3.25/kg) for whole animals.

At times during 1973, this price could have been competitive with dockside shrimp prices, but in 1974 there has been a depressed shrimp market, and frequently shrimp prices are as low as $.55 - $.60 a pound ($1.21 - $1.32/kg) dockside. Under current conditions, estimated market prices of pond-raised shrimp are prohibitive and would dampen the enthusiasm of any investor and most of the astute mariculturists.

Table 7 should focus the interest of researchers on areas where techniques to improve efficiency and procedures are needed to reduce costs. Direct labor involved in managing ponds and harvesting animals is one of the most expensive components. These costs could greatly be reduced by mechanization and by plant design for increased operating efficiency.

Food costs used in Table 7 can hardly be justified to raise shrimp considering current market values and price trends. However, a highly acceptable food conversion efficiency of 2:1 was utilized. It is therefore evident that research should be aimed at producing lower cost shrimp foods, not necessarily more nutritious or those that produce better conversions. In fact, earlier in this report it was demonstrated that food conversion efficiencies of 1.5:1 were obtained by feeding shrimp commercially available catfish pellets. However, catfish pellets are currently selling at $.16 a pound ($.58/kg) in the Miami area. If some of the expensive components could be removed, a diet could probably be developed for about $.07 a pound ($.15/kg) which would be in the price range of wheat bran. It has been shown by earlier investigators (Caillouet et al.) and in this report that wheat bran was a suitable diet for the growth of shrimp during the early life stages and did provide relatively efficient conversion.

Reduced livestock costs through improvement of hatchery techniques has been the objective of studies at Turkey Point since 1968. This cost can be improved and reduced by about 50% by the redesigning of the existing hatchery along the lines used by other commercial ventures. Untested improvements could further reduce this by another 50% if funds were available to build a hatchery to test the design improvements and costs. Direct labor involved in managing ponds and harvesting animals is one of the most expensive components. These costs could greatly be reduced by mechanization and by plant design for increased operating efficiency.

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It is conceivable that with a reduction of 50% on livestock costs, 50% on labor and 50% on food costs, shrimp could be raised for as low as \$.14 a pound (\$.31/kg) product cost in the United States. Overhead capital investment, contingency, profit, and research and development costs are items of commercial interest and would be adjusted for any individual corporation. However, these costs will remain approximately as shown on Table 7. If the product cost of raising shrimp could be reduced to \$.14 (\$.31/kg), there would be a better balance between product cost and corporate operating cost. Pond-raised shrimp could be produced at market price of \$.90 a pound (\$1.98/kg) which would be highly competitive with the dockside prices of shrimp during the last ten years in the United States.

One of the functions of an academic institution being involved in pilot production or a research and development program, is to define areas which need greater research effort. Throughout this report, an attempt has been made to show other investigators where research effort is needed. Delineation of the most critical problem and estimates of the theoretical cost of producing shrimp (Table 7) should assist commercial companies in evaluating the attributes of penaeid shrimp as a mariculture candidate.

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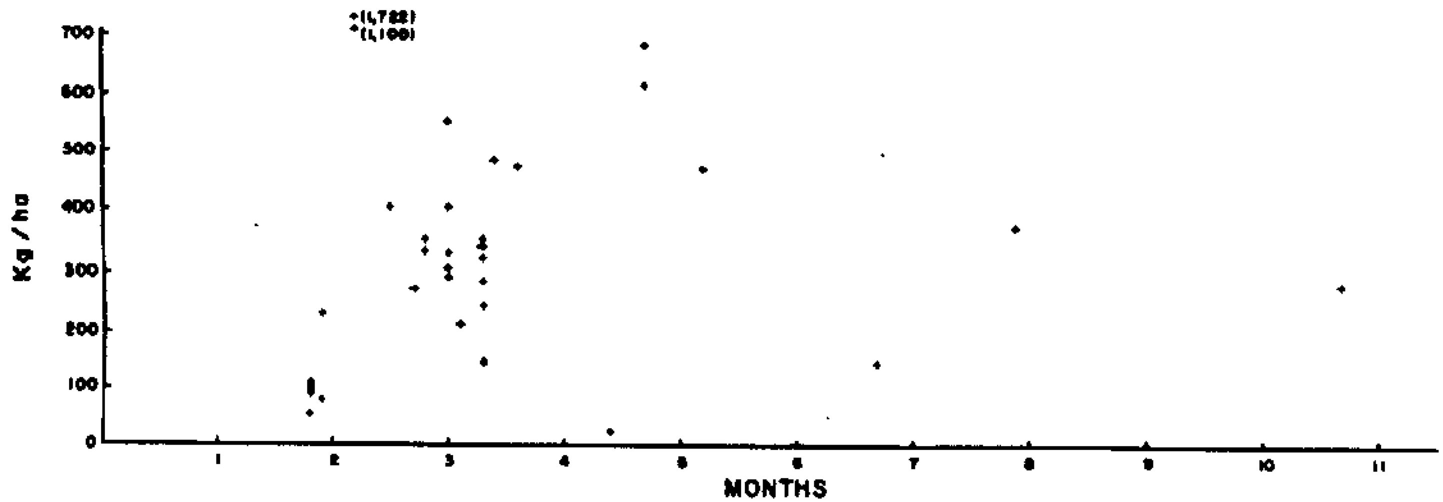

Figure 1. Biomass in kilogram per hectare produced by Penaeus duorarum stocked as postlarvae (0.005 to 0.09 gram) and grown in Turkey Point ponds.

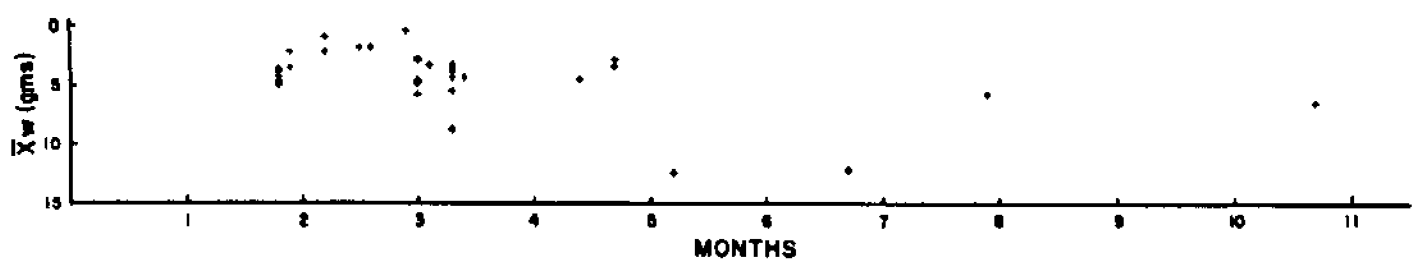

Figure 2. Mean weight of Penaeus duorarum postlarvae at time of harvest. Size at stocking was 0.005 to 0.09 grams.

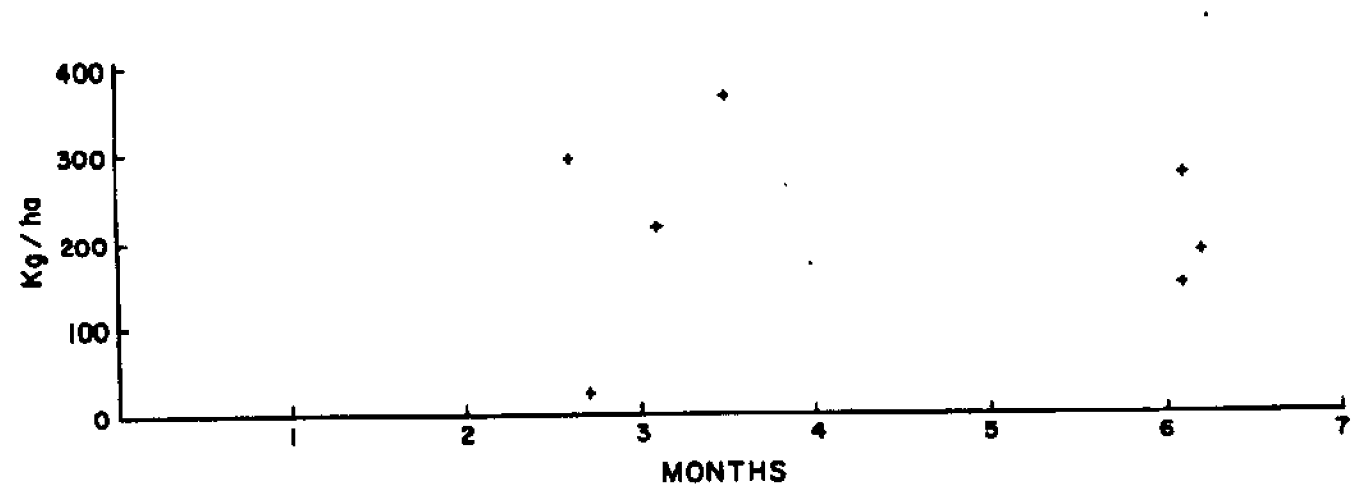

Figure 3. Biomass in kilograms per hectare produced by *Penaeus duorarum* stocked as nursery-reared juveniles (0.1 to 2 grams) and grown in *Turkey Point* ponds.

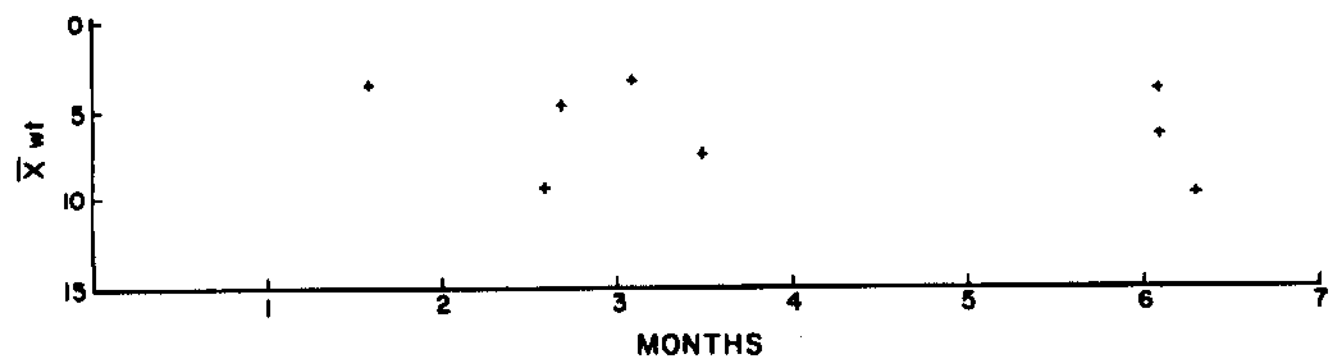

Figure 4. *Penaeus duorarum* nursery-reared juveniles at time of harvest. Size at stocking was about 0.1 gram.

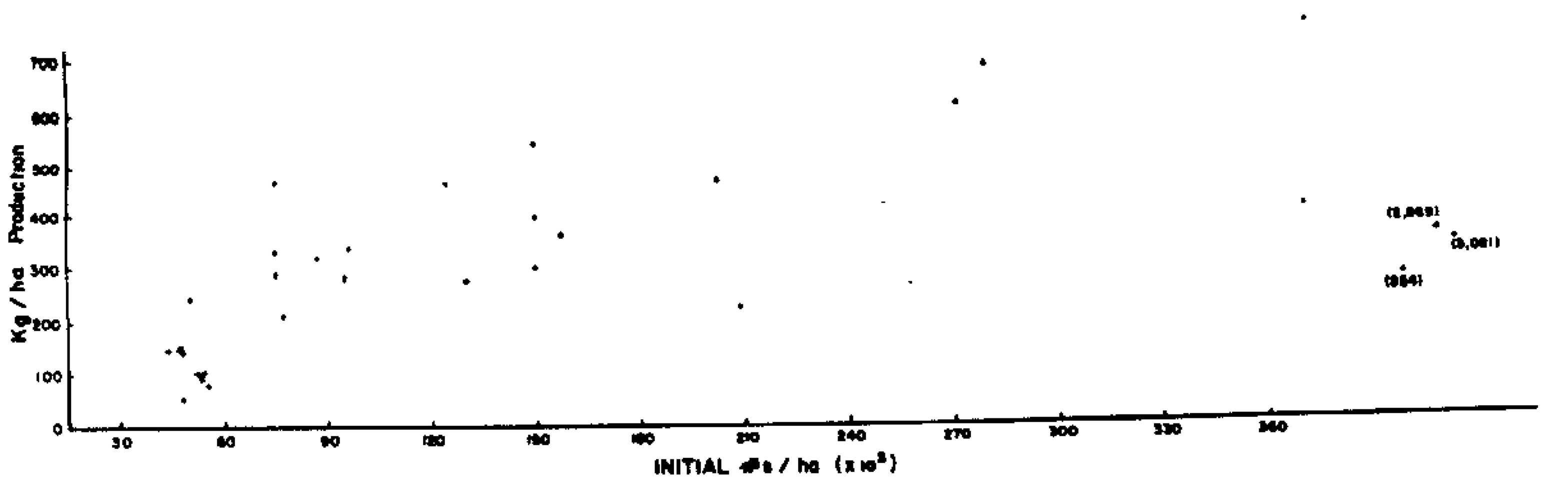

Figure 5. Production in Turkey Point ponds as influenced by initial stocking density of postlarval <u>P. duorarum</u>.

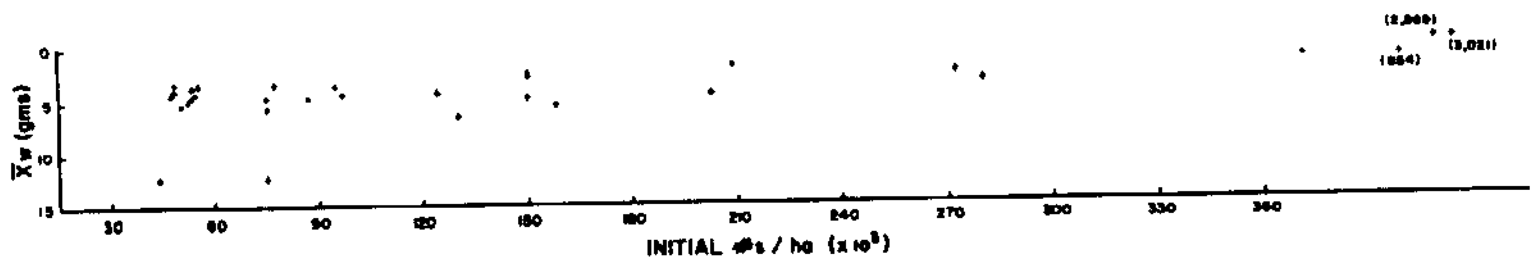

Figure 6. Influence of initial stocking density on final mean weight of <u>Penaeus duorarum</u> postlarvae grown in Turkey Point ponds. Size at stocking = 0.005 to 0.09 grams.

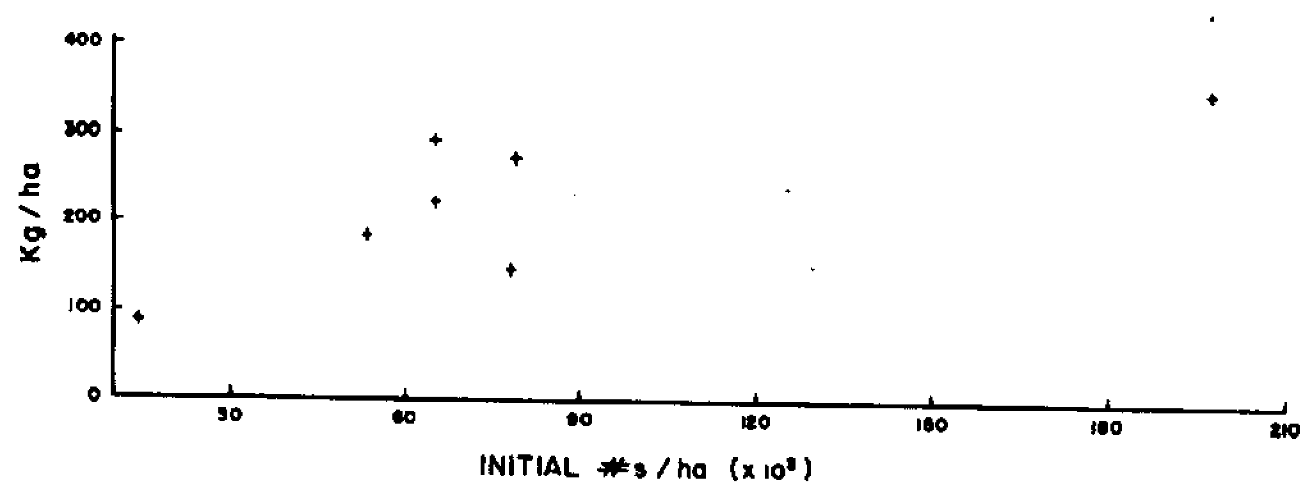

Figure 7. Production in Turkey Point ponds as influenced by initial stocking density of juvenile <u>P. duorarum</u>.

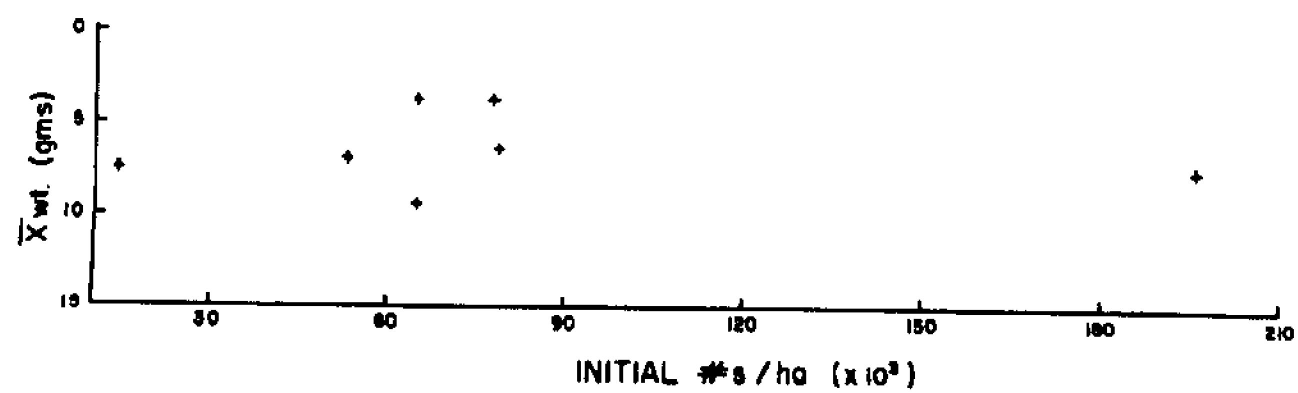

Figure 8. Influence of initial stocking density on final mean weight of <u>Penaeus duorarum</u> *nursery-*reared juveniles grown in Turkey Point ponds. *Size at stocking about 0.1 grams.*