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PROPAGATION OF THE WHITE SHRIMP, *PENAEUS SETIFERUS* (LINN.), IN CAPTIVITY

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In July, 1952 a research project was initiated at the Marineland Research Laboratory, Marineland, Florida to explore the possibilities of cultivating marine animals in ponds. The project was privately sponsored with the immediate objective of obtaining preliminary data on species suited to pond cultivation and appropriate management techniques to that end. Ultimately these data were to be used as the basis for a commercial enterprise on an expanded scale.

Initial experiments were conducted on the production of the striped mullet, *Mugil cephalus* (Linn.), in fertilized and unfertilized brackish water (Johnson, 1954a). The results of this work indicated that an intensive type of culture of a sea-food with an inherently higher market value than mullet would be necessary to support a commercial venture.

A rearing experiment in 1953 indicated that the production of the white shrimp, *Penaeus setiferus* (Linn.), in ponds had definite possibilities.

From the biological standpoint the continuance of such a program would depend primarily on a dependable source of small shrimp, or "seed-stock" for stocking the ponds. In certain estuaries of the Gulf Coast of the southern United States small shrimp are present seasonally in countless numbers. In those areas they could be collected from the nursery grounds in quantities sufficient to supply a commercial scale pond system.

This system of securing seed-stock is almost universally used in those world areas where brackish water pond culture is presently practiced. The pond culturist who uses this method is improving a natural resource immeasurably by promoting growth, reducing mortality due to predation, and simplifying harvest. However, he is still dependent on wild stocks and his aquiculture program is closely related to the natural fishery.

By contrast, if the pond-culturist were able to produce his own seed-stock from his own pond-reared adults he would, in effect, have created an entirely new resource. For, though the species were the same in both natural and pond waters, the fish farmer would control a self-perpetuating population in an entirely independent community. For this reason experiments on propagating the white shrimp in addition to those on rearing it were initiated as a major part of the overall experimental program.

The subsequent successful attempts at propagation were considered not only to have important implications for a well rounded pond-culture program, but purely scientific ones as well. A great deal is known of the life history of the white shrimp. However, much of this knowledge was gained through necessarily indirect methods due to the vast water areas involved. Although Pearson (1939) had described what he believed to be the metamorphic forms of *P. setiferus* from an extensive series of material obtained in plankton tows, they had never been observed *in toto* from known parentage.

It was not within the scope of this work to study the life-history of the white shrimp, or to describe its larvae and define their exact requirements except as a means to an end — the production of seed-stock for cultivation in ponds.

The authors do not wish to appear apologetic. However, they do wish to acknowledge the fact that from the standpoint of specifically furthering the understanding of the life history of the shrimp, their work could stand many refinements.

Special acknowledgement is due Mr. Nicholas S. Ludington of Philadelphia, Pennsylvania, whose private grant made this and allied research possible. Thanks are also due the management and staff of Marine Studios, whose facilities and cooperation contributed so greatly to their work. The authors also wish to thank Dr. Gordon Gunter for his critical analysis of the manuscript.

The senior author wishes to give full credit to Mr. Stanley (Bubs) Colee of St. Augustine, Florida, for his participation as project aid in 1954. Mr. Colee's interest, insight, and efforts were greatly appreciated and played no small part in the initial success of the propagation experiment.

Materials and Equipment

The general problems that were considered in designing the experimental propagation plant were divided into two major categories. The establishment of a controlled area in which the adults would find suitable conditions in which to spawn, and a rearing technique by which the hatchlings could be carried through the metamorphic stages.

Throughout the summer of 1953 a number of groups of sexually mature white shrimp were caught on the offshore fishing grounds and placed in ten-gallon aquariums and a wooden tank 12 x 4 x 2 feet at the laboratory. Within twenty-four hours all of the female shrimp in each case had shed their eggs. Heegaard (1953) had the same experience at Port Aransas in 1948. Heegaard referred to this as "spawning." We preferred to call it "aborting" as in all cases the eggs were infertile, and probably had been merely jettisoned by the shrimp due to unfavorable conditions. It was not known if the Marineland shrimp carried spermataphores, or, if so, by what means they were able to release infertile eggs. These experiments obviated the use of small tanks in securing viable eggs.

Penaeids are thought to be restricted to relatively deep offshore waters for their natural spawning grounds (Hudinaga 1935, 1942; Pearson *op. cit.;* Heegaard *op. cit.*). However, to the authors it seemed improbable that the trigger mechanism that precipitates successful spawning could be so intricate as to prevent spawning in smaller areas of lesser depths.

It was thought, rather, that each shrimp at any one time lives in its own little circle of gloom and is unaware of the vast expanses which surround it. The fact that Hudinaga *(op. cit.)* had observed copulation and obtained viable eggs from *P. japonicus* in a concrete tank 18 x 18 x 1 meters substantiated this theory.

It did seem advisable, however, to have as large an enclosure as possible for a spawning tank. Size was compromised with available funds and a tank 70 x 30 x 4 feet was built at ground level. The bottom of the tank was a poured six-inch concrete slab. The sides were of concrete block filled with cement and adequately interlaced with reinforcing steel. The tank was equipped with a floor-drain and the bottom was covered with about four inches of fine coquina gravel to serve as a substrate.

To rear the larvae of *P. japonicus* Hudinaga *(op. cit.)* removed the eggs from the spawning tank and hatched them in glass jars. He used similar containers as nurseries.

Although this method was considered adequate for purely scientific studies it was thought to be too involved and costly to furnish seed-stock on a large scale. This assumption was correct, for Hudinaga later told the senior author in personal conversation that even the Japanese economy would not support it. The logical alternative then was to spawn the adults and rear the larvae in the same facility.

Methods

Other than furnishing water of the apparent quality of sea water to a supply of healthy, sexually mature shrimp, nothing was done to induce spawning.

In January, 1954, 175 large white shrimp were caught off-shore and held in a dirt pond ⅛-acre in size.

It was anticipated that in the event larval shrimp were obtained from these adults when they were transferred to the spawning tank the following spring, the facility would then become a nursery and would be managed as such.

Pearson *(op. cit.)* was unsuccessful in rearing nauplii of *P. setiferus* hatched from eggs in aquariums past the first zoea stage. He attributed this failure mainly to his inability to furnish microscopic food in quantities large enough to feed the larvae, yet small enough to prevent its entanglement in their plumose appendages. Entangled larvae precipitated to the bottom where they soon died. Hudinaga *(op. cit.)* and Herrick (1909) also considered this as one of the major problems in rearing decapod larvae.

Hudinaga further stated that the non-feeding nauplii, and the mysis and post-mysis stages were hardy and easily reared, the critical metamorphic stages being the zoea which are weak, have restricted habitat tolerances and must have an adequate, but not too heavy supply of microscopic food. It was planned to manage the nursery with these facts in mind.

During all of the experiments at Marineland, male shrimp were said to be "ripe" when the spermataphores were easily discernible as opaque whitish bodies. The females were considered to be ripe when the distended ovaries could be readily traced for the entire abdominal length by the "butterscotch" color of the mature eggs.

Breeding Experiment, 1954

Beginning March 1, 1954, periodic inspections were made of the brood-stock being held in the dirt ponds. Most of the males were obviously ripe by March 26, but only one female examined was in breeding condition on this date. However, ripe females were found more and more frequently from then on.

Size above a certain minimum seemed to have no bearing on time of maturity; individuals of uniform size were found to mature at random over the entire period to May 15, when the ponds were drained.

On March 8 the tank was filled with water pumped from a dirt pond that did not contain shrimp. On March 10 it was fertilized with five pounds of fish meal and 25 pounds of 7-9-0 inorganic fertilizer. This very heavy application of fertilizer was made erroneously by an assistant because of a displaced decimal point. It resulted in a heavy bloom of phytoplankton (mostly *Chlorella*) within a few days. Within a week the phytoplankton was supporting a tremendous population of copepods. Large numbers of barnacle, chaetognath, and crab larvae had also been pumped into the tank from the pond.

On March 15, twenty-two pairs of the adult ocean-caught shrimp were removed from the holding pond and placed in the brood tank. These animals were selected strictly on the basis of large size as none of the females were considered fully ripe at this time.

Plankton tows were made several times daily and the material examined microscopically. One month later on April 15, one (1) fourth nauplius of *P. setiferus* was found. Repeated plankton tows failed to produce more larvae. The specimen in hand was held in a syracuse dish in which it molted twice, reaching the first zoea stage within twenty-four hours. No attempt was made to rear the larva in the laboratory; it was killed and preserved on April 16.

By April 26 no evidence of eggs could be seen in any of the female shrimp in the tank. The phytoplankton and micro-crustacean population was so dense at this time as to render the tank a murky brown. For this reason it was thought that if further spawnings had occurred, the resulting larvae had become entangled with suspended matter and died, or that they had been consumed by larger and more robust organisms. The tank was drained and allowed to sun-dry.

On May 13 the tank was refilled with clear salt-water pumped from the Intracoastal Waterway. The tank was immediately stocked with six pairs of the ocean-caught shrimp from the holding pond. The following day eleven pairs of freshly caught ocean shrimp were added. All of the individuals of both sexes were ripe.

A total of five pounds of 7-9-0 inorganic fertilizer was tied up in small parcels in cloth bags and suspended near the surface at intervals around the tank. It was hoped that the fertilizer would dissolve slowly but continuously and would be sustaining a light but continuing phytoplankton population by the time any shrimp larvae would be produced. This later proved to be the case.

No quantitative plankton studies were made in either experiment. However, visibility in the tank during the first experiment was less than six inches while in the one now under discussion, the floor of the tank could easily be seen in four feet of water.

No plankton tows were made until 8:00 a.m., May 17. At this time many fifth nauplius and first zoea stages of *P. setiferus* were found. In the afternoon of the same day two first nauplii were taken in the net, and the following day one embryonated egg was found. Hudinaga *(op. cit.)* and Pearson *(op. cit.)* reported rapid incubation of penaeid eggs and rapid ecdysis in the nauplius stages. In an experiment in 1955 the present writers found that *P. setiferus* larvae whose hatching time was known passed into the first zoea stage in less than forty-eight hours. Therefore, there are believed to have been at least three distinct spawns.

The fifth nauplius and first zoea stages found concurrently are considered as coming from one spawn. It does not necessarily follow that their parentage was the same. The first nauplii found the same day and the embryonated egg found the next are definitely from two later spawns.

The two more advanced broods survived the metamorphic stages. The last brood, identified by the embryonated egg, did not progress past the very early stages, if it hatched at all, as it was never identified in later samples.

The exact hatching time of the first brood is unknown. However, on the basis of the available knowledge of the length of time it takes penaeid larvae to pass through the nauplius stages, (Hudinaga; Pearson, *op. cit.*) May 15 was assumed to be the hatching date. The validity of this assumption was supported by observations in 1955 of the metamorphosis of *P. setiferus* larvae whose time of hatching was known.

The metamorphic pattern of the first brood as indicated by daily plankton tows was as follows:

Elapsed Time (Days)	Date	Time	Stage
0	May 15, 1954	—	Estimate eggs hatched
2	May 17, 1954	8:00 a.m.	1st zoea
3	May 18, 1954	8:00 a.m.	1st zoea
4	May 19, 1954	8:00 a.m.	2nd zoea
5	May 20, 1954	8:00 a.m.	2nd zoea
6	May 21, 1954	8:00 a.m.	3rd zoea
7	May 22, 1954	8:00 a.m.	1st mysis
8	May 23, 1954	8:00 a.m.	1st mysis
9	May 24, 1954	8:00 a.m.	1st mysis
10	May 25, 1954	8:00 a.m.	2nd mysis
11	May 26, 1954	8:00 a.m.	2nd mysis
12	May 27, 1954	8:00 a.m.	1st postlarva

The second surviving brood followed the same pattern, but remained exactly one day behind.

Feeding was begun on May 28 when all of the young shrimp had reached the first postlarval stage. Ground fresh fish and fish meal were added to the tank at the rate of 0.25 pound and 0.05 pound per day respectively. The bloom resulting from the suspended fertilizer was still apparent at this time. Feeding was continued at the same rate until the tank was drained.

The growth rate of the postlarval shrimp was phenomenal. The average sizes of the young shrimp sampled at weekly intervals prior to draining the tank and transferring them to a rearing pond were as follows:

May 28, 1954 (1st postlarvae)	4.5 mm
June 7, 1954	14.0 mm
June 14, 1954	39.0 mm
June 21, 1954	55.0 mm

The average increment for the twenty-four day period was 50.5 mm. The greatest increases recorded by Pearson *(op. cit.)* were 21 mm and 29 mm in a forty-three day period for two postlarvae held in a one-gallon aquarium. With any increase in population density, his growth increment suffered accordingly.

Periodic analyses of the tank water are tabulated in Table 1. The temperature of the surface six inches ranged from 78° F to 90° F. The minimum salinity recorded was 30.5 ‰. Salinity increased to 37.1 ‰ while the larvae were in the zoea stages, but was immediately reduced by diluting with fresh water and maintained between 32.7 ‰ and 34.7 ‰ for the duration of the metamorphic period.

When the tank was drained (June 21) 1,024 small shrimp averaging 55.0 mm total length were recovered. Thirty of the original thirty-four brood animals were found to be alive.

The dirt pond that was used to hold the brood-stock had been used in fertilization experiments in 1953 (Johnson, 1954 a and b). The increased fertility carried over into 1954 and resulted in a dense plankton bloom. The pond was also contaminated with several species of fish including breeding populations of cyprinodonts.

Throughout the breeding experiments, daily plankton tows were made in the pond as well as the tank. No eggs or larvae were found in any of the material taken from the pond. Due to the consistency with which ripe shrimp spawned in the tank, it was unlikely that spawning did not also occur in the pond. Probably such eggs or larvae as were produced were eliminated through predation or "smothered" by the suspended micro-organisms. The latter was considered the more likely event in view of the poor results obtained with turbid tank water but with no contamination by fish.

Breeding Experiments, 1955

In 1954, four ⅛-acre dirt ponds were used in an experiment to approximate the pounds of shrimp that could be produced per acre per year in ponds, and the size to which individual shrimp could be grown at different rates of stocking.

Small shrimp with which to stock the ponds were taken from the tidal flats in the vicinity of Marineland. On June 21, 1954, the shrimp that were produced in the 1954 propagation experiment were stocked in one of the ponds with several thousand of these wild-caught shrimp. All of the shrimp were approximately the same size (400 per pound) at this time.

The brood-stock used in the 1955 breeding experiments were taken from this pond; if any of the tank-bred individuals were selected it was merely by chance for, of course, there was no way of identifying them. However, the brood-stock was certainly well conditioned to pond life. They had been grown from an approximate weight of 400 per pound to an average weight of 15.5 per pound in ponds. Detailed results of the rearing experiments are to be reported elsewhere.

The tank was flooded with water pumped from one of the ponds that did not contain adult shrimp, and immediately stocked with 59 female and 69 male white shrimp on April 22, 1955. All of these shrimp were ripe.

Well embryonated eggs were found in large numbers at 9:30 a.m., April 24. By 10:30 a.m. eggs held in syracuse dishes and observed with a stereoscopic microscope were hatching. Another plankton tow revealed that they were hatching in the tank as well.

At 11:00 a.m. fourth nauplii as well as first nauplii were taken in the net indicating a separate, earlier hatch.

At 3:30 p.m. the first and fourth nauplius stages plus newly spawned eggs were found. Subsequently the first two spawns could be distinguished by a difference in stages, but evidently none of the third spawn (3:30 eggs) hatched, as their nauplii were never found.

The metamorphic pattern of the brood observed hatching as indicated by daily plankton tows was as follows:

Elapsed Time (Days)	Date	Time	Stage
0	April 24, 1955	10:30 a.m.	Eggs hatching into 1st nauplius
0		9:00 p.m.	1st & 2nd nauplius
1	April 25, 1955	8:00 a.m.	2nd & 3rd nauplius
		12:30 p.m.	5th nauplius
2	April 26, 1955	8:00 a.m.	1st zoea
3	April 27, 1955	8:00 a.m.	1st zoea
4	April 28, 1955	8:00 a.m.	1st zoea

On April 28, live larvae could be found only with difficulty and in small numbers. They appeared to be very weak and were not feeding for no ingested material could be seen in their very transparent gut. The tank was heavily contaminated with copepods and chaetognath larvae. Therefore, the tank was drained and an attempt made to improve conditions for another brood.

A filter box three feet by eight feet was built by walling off an area in one corner of the tank with concrete blocks. The sides of the filter were made level with the sides of the tank, and one-half-inch end spaces were left between the blocks in the two lower courses. Successive six-inch layers of river gravel, coquina gravel, and mason's sand in that order from the bottom were used as filter material. A thinner layer of river gravel covered the sand to break the force of the inflowing water.

When the tank was refilled from the same pond as before the filter was found to be effective in eliminating micro-crustaceans and minute larvae.

The tank was immediately stocked with eighteen pairs of ripe adult white shrimp on May 5, 1955.

On May 6 plankton tows produced no eggs or larvae. On May 7 many fourth nauplius larvae were found.

The metamorphic pattern of this brood as indicated by daily plankton tows was as follows:

Elapsed Time (Days)	Date	Time	Stage
0	May 6, 1955	—	Estimate eggs hatched
1	May 7, 1955	8:30 a.m.	4th nauplius
2	May 8, 1955	8:30 a.m.	5th nauplius; 1st zoea
3	May 9, 1955	8:30 a.m.	1st zoea
4	May 10, 1955	8:30 a.m.	1st and 2nd zoea
5	May 11, 1955	8:30 a.m.	1st, 2nd, & 3rd zoea
6	May 12, 1955	8:30 a.m.	1st mysis
7	May 13, 1955	8:30 a.m.	1st & 2nd mysis
8	May 14, 1955	8:30 a.m.	2nd mysis
9	May 15, 1955	8:30 a.m.	2nd mysis
10	May 16, 1955	8:30 a.m.	2nd mysis; 1st postlarva

The water had not been fertilized and remained clear until the larvae entered the first feeding stage. To make food immediately available at this time, water was pumped in from a dirt pond that had a heavy bloom of rotifers and minute planktonic algae. The water was not filtered, which proved to be a serious error as several hundred killifish were introduced at the same time.

During the entire metamorphic period, larvae in each stage were much more abundant than in any prior experiment. Larvae from this brood were obviously the most active and hardy yet produced, especially in the zoea stages. They also became postlarvae two days quicker than those reared in 1954. This alone was considered substantial evidence that conditions were much more favorable for their welfare than in the preceding experiments.

TABLE 1.
WATER ANALYSIS OF THE SHRIMP BROOD TANK, 1954

Date	Salinity, ‰	pH	O_2 ppm	CO_2, ppm
March 8	31.5	—	—	—
March 10	31.5	8.1	—	—
March 11	31.5	8.1	—	—
March 15	31.8	8.4	12.5	0.0
March 22	31.5	8.6	8.5	0.0
March 23	—	8.6	9.9	0.0
March 26	31.2	8.9	13.8	0.0
April 1	32.3	9.1	9.0	0.0
April 5	33.7	9.0	6.3	0.0
April 12	33.6	8.5	8.6	0.0
May 17	37.1	—	—	—
May 18	35.5	—	—	—
May 19 a.m.	35.7	—	—	—
May 19 p.m.	34.7	—	—	—
May 20	32.7	—	—	—
May 21 a.m.	33.2	—	—	—
May 21 p.m.	33.4	8.4	—	—
May 22	33.5	8.3	—	—
May 24	34.0	8.3	—	—
May 25	34.0	8.5	7.6	0.0
May 26	34.0	8.8	—	—
May 27	34.1	8.7	—	—
May 28	34.1	8.7	—	0.0
May 31	30.5	8.6	—	—
June 1	33.2	8.5	10.3	0.0
June 4	32.3	8.1	9.7	0.0
June 7	32.8	—	—	0.0
June 14	32.3	8.6	10.2	0.0

The small differences in water chemistry (Tables 1 & 2) in this experiment and the successful 1954 experiment were not considered significant. As the accumulated data included no other exact habitat criteria, the specific factor causing the improvement was not definitely known. However, suspended material in relatively small quantities during the nauplius stages, and a light, but adequate and continuous supply of microscopic food during the feeding stages, would seem to be closely related to the successful rearing of white shrimp larvae in confinement. Any other theories such as pond-conditioned parentage, etc., would be highly speculative.

TABLE 2.
WATER ANALYSIS OF THE SHRIMP BROOD TANK, 1955

Date	Salinity, $^0/_{00}$	pH	O_2 ppm	CO_2, ppm
May 5	37.0	8.1	6.5	0.0
May 6	33.3	8.1	6.2	0.0
May 7	33.1	8.1	7.2	0.0
May 9	33.5	8.3	7.6	0.0
May 12	34.3	—	—	0.0
May 13	34.9	8.4	—	0.0
May 16	34.7	8.6	—	0.0
May 19	34.5	8.7	6.5	0.0
May 23	34.0	8.3	—	0.0
May 24	34.8	8.6	7.2	0.0
May 26	35.7	—	—	—
May 27	35.4	8.3	7.5	0.0
May 30	36.1	—	—	—
May 31	36.7	8.3	7.2	0.0
June 1	34.6	—	—	—
June 2	34.6	8.3	6.6	0.0

On May 23, feeding was begun at the rate of 1.0 pounds of ground fish per day and continued until the tank was drained.

The tank water had a total salt content of 37.0 $^0/_{00}$ when the brood-stock was introduced. This was immediately lowered by dilution and maintained between 33.1 $^0/_{00}$ and 34.9 $^0/_{00}$ throughout the metamorphic period. Temperature records during this period were inadvertently destroyed. However, the range is known to have been much the same as that for the May, 1954, experiment. Periodic analyses of the tank water are tabulated in Table 2.

The tank was drained June 13, 1955, and only 103 small shrimp were recovered. Evidently the killifish had consumed the rest of the brood, which had seemed much heavier at least to the postlarval stage than any previous brood. All of the brood-stock (36) were found alive and in good condition.

The young shrimp averaged 53.4 mm total length; the average growth increment for the twenty-eight day period beginning May 16 was 48.9 mm.

The pond in which the brood-stock was held was contaminated by fish and sustained a heavy plankton bloom throughout the period. Daily plankton tows were made in the pond, but no eggs or larvae of *P. setiferus* were taken.

THE EGGS AND LARVAE

Both newly spawned eggs, and eggs containing fully developed nauplius larvae were observed under a compound microscope. The purplish-blue color of the egg membrane described by Pearson *(op. cit.)* was easily seen when the margins were illuminated with a relatively soft light transmitted through a substage condenser.

The color of the yolk was considered to be a yellow-brown in newly spawned eggs, but could possibly be said to have a greenish tinge if viewed with strong transmitted light. The egg just prior to hatching was completely filled with the dark brown embryo. The embryo seemed to break out of the shell by expanding its appendages, and several minutes elapsed before it became active.

To date no minute examinations of the larvae have been made. The nomenclature for the various larval stages used in this paper is that of Pearson *(op. cit.)*. It can not be stated definitely that Pearson was correct as to species in his description of the larvae of penaeid shrimp. However, each of the stages, and only those stages described by him as being *P. setiferus* were easily recognized with a stereoscopic microscope under 36X magnification. The distinctive differences in each of the larval forms with the exception of the second and third nauplii would in all probability not appear without actual ecdysis. These facts should lend added significance to Pearson's work.

Salinity and the Rate of Growth of *Penaeus setiferus*

Although much remains unknown concerning the life history of the white shrimp, the ecological pattern for each life stage (larval, juvenile, and adult) is recognized but not fully understood.

Generally, it is this: (1) the adults spawn at sea in water of normal sea-water salinity; (2) while passing through a number of larval stages many of the young shrimp are carried toward the inlets to bays by shoreward currents; those that are not, apparently perish; (3) by the time they enter the inland waters the young shrimp are postlarvae or pre-adults and tend to migrate toward shallow, marginal waters; these waters are generally waters of low salinity due to river discharge and local land drainage; (4) as the small shrimp increase in size they tend to migrate back to the deeper open waters of higher salinity, and finally to the sea, where they in turn spawn when about one year old.

These movements may be explained theoretically in terms of stimulus to migration. The three more obvious theories are:

(a) The postlarval and small adult shrimp seek low salinities; the larger adults seek high salinities *per se*.

(b) The postlarval and juvenile shrimp seek the marginal waters because of high concentrations of plankton and organic detritus on which they feed. Low salinities are merely coincident in these areas.

(c) The migratory pattern is atavistic in origin, and is not controlled directly in individual shrimp by any one stimulus. It has, however, inadvertently enabled the shrimp to evolve into a highly successful species.

Gunter and Hildebrand (Hildebrand and Gunter, 1953; Gunter and Hildebrand, 1954) found a strong statistical correlation between the white shrimp catch for a given year and total rainfall for that and the two preceding years in Texas. Although they recognized that rainfall could affect the production of white shrimp by enriching the estuarine waters with nutrients washed from the land or by some more complicated ecological relationship, they were inclined to accept salinity as the "probable effective factor."

In briefly outlining the life history of the white shrimp, these writers (Gunter and Hildebrand, 1954) made the concluding statement: "This type of life history is necessary for the white shrimp and those postlarvae that fail to enter inside waters perish." This is probably true as most workers are agreed upon it. However, since it appeared in the introduction to a paper purporting to show an inverse relationship between shrimp production and estuarine salinities, it could imply that postlarvae that fail to enter inside waters succumb to high salinity. For this reason it is emphasized here that at Marineland the postlarvae were reared in water with a total salt content roughly equal to that of the open sea.

Nevertheless, the correlation between rainfall and shrimp catch in Texas was well defined. If low salinity as a function of rainfall was the effective factor in high catch years, it could have been effective in either of two ways: by increasing the growth rate of the smaller individuals or by having some sort of survival value for the same group. That is, pounds catch would be up because either larger or more shrimp were available than in drier years. Actually, the former probably would not occur without the latter because a fast growing juvenile population would leave the nursery grounds more quickly than a slower growing one and thus make more rapid recruitment possible.

If the salinity *per se* theory were true it would have important implications for the pond culture of shrimp as arrangements could be made to regulate salinity for maximum growth. Therefore, preliminary to relocating and expanding the pond culture project it was considered desirable to know if a large supply of fresh, as well as salt water should be a major consideration in selecting a site.

Ten, ten-gallon aquariums were stocked with five small white shrimp each. The shrimp were carefully weighed before being placed in the tanks and again weekly for two weeks. The small shrimp in each tank were fed fresh fish at the rate of 10% of their initial body weight per day. Invariably all of the food was eaten.

Five of the tanks contained water with a salinity of 34.0 $^0/_{00}$; the other five contained water with a salinity of 18.5 $^0/_{00}$. This salinity differential (almost 50% based on the higher concentration) certainly should have shown any growth differential due to the amount of dissolved salts. The results are tabulated in Table 3.

The shrimp at the higher salinity grew faster and converted their food more efficiently than those at the lower salinity. It should also be mentioned that the phenomenal growth tabulated in the sections "Shrimp Propagation, 1954; 1955" occurred in water with a salinity equal to or exceeding that of sea-water.

TABLE 3.
A COMPARISON OF THE GROWTH RATE OF WHITE SHRIMP AT DIFFERENT SALINITIES
AUGUST 16 TO AUGUST 30, 1954
Salinity = 18.5 $^0/_{00}$

Tank No.		Initial Weight, Gms.	Terminal Weight, Gms.	Total Gain, Gms.	Percent Gain	Total Food Consumed, Gms.	Conversion Ratio
1	1st week	—	—	—	—	—	—
	2nd week	8.8	8.4	0.4	0.0	5.4	0.00
2	1st week	6.6	7.4	0.8	12.1	4.2	5.25 : 1
	2nd week	11.3	11.6	0.3	2.6	6.6	20.00 : 1
3	1st week	10.5	11.5	1.0	9.5	6.0	6.00 : 1
	2nd week	—	—	—	—	—	—
4	1st week	7.9	8.8	0.9	11.4	4.8	5.33 : 1
	2nd week	—	—	—	—	—	—
5	1st week	4.4	5.0	0.6	13.7	2.4	4.00 : 1
	2nd week	5.0	5.2	0.2	4.0	3.0	15.00 : 1
Salinity = 34.0 $^0/_{00}$							
6	1st week	10.3	12.0	1.7	16.5	6.0	3.53 : 1
	2nd week	12.0	12.1	0.1	0.8	7.2	72.00 : 1
7	1st week	10.8	11.9	1.1	10.2	6.2	6.00 : 1
	2nd week	11.9	12.0	0.1	0.8	7.2	72.00 : 1
8	1st week	—	—	—	—	—	—
	2nd week	7.4	7.5	0.1	1.3	4.2	42.00 : 1
9	1st week	8.2	9.2	1.0	12.2	4.8	4.80 : 1
	2nd week	9.2	10.3	0.5	5.4	5.4	10.80 : 1
10	1st week	3.4	4.2	0.9	26.5	1.8	2.00 : 1
	2nd week	4.2	4.5	0.3	0.7	2.4	8.00 : 1

For reasons unknown the rate of growth of the shrimp in all tanks was insignificant during the second week. Therefore the totals for only the first week's growth for the two treatments are compared below.

Salinity	Int. Wt. Gms.	Terminal Wt. Gms.	Gain Gms.	Percent Gain	Food Consumed	Conversion Ratio
34.0 $^0/_{00}$	32.7	37.3	4.6	14.1	19.2	4.09 : 1
18.5 $^0/_{00}$	29.4	32.7	3.3	11.2	17.4	5.27 : 1

Although this work was not sufficient to reflect the detailed effect of salinity on rate of growth, it did give the project personnel some confidence in selecting a site for a commercial pond system by indicating that, except beyond wide limits, salinity is not a critical factor in the rearing of shrimp. It must be remembered, however, that small white shrimp generally grow up in salinities below 18.0 $^0/_{00}$. These experiments did not encompass this lower range and further tests will be necessary before more definite conclusions can be drawn.

General Discussion

Sexually mature white shrimp spawned readily in the concrete tank at Marineland. In the experiments in which the brood-stock was obviously mature when it was placed in the tank, spawning took place within forty-eight hours. It would be interesting to know if normal spawning would have occurred in the holding ponds within the same period, or if the removal of the brood-stock to "new" water precipitated spawning. Although both male and female shrimp were stocked in the tank, it is probable that copulation had taken place in the holding ponds and viable eggs would have been produced without the inclusion of the males. Neither an optimum number of brood-stock to use nor a minimum size tank in which they would spawn is known.

It was clearly pointed out in the introductory portion of this paper that the work outlined herein was directed primarily towards developing a practical shrimp-hatchery operation; an attempt was made throughout to present the material from that standpoint. It therefore appears needless to recapitulate this material in summary. However, there are certain moot questions concerning the life history of the white shrimp that may be clarified to some extent by information gained from the captive adults and larvae. Only those data concerned with questions subject to speculation are summarized and in some instances briefly expounded.

The larvae of *P. setiferus* go through probably five, but certainly four nauplius, three zoea, and two mysis stages before becoming postlarvae. By gross examination these larvae and the eggs of the white shrimp seem to have been accurately described by Pearson *(op. cit.)*.

The duration of the metamorphic period is not fixed, but depends to some extent on local conditions of food and habitat. The brood reared in 1954 required twelve days to become postlarvae; the one in 1955 only ten.

The postlarvae of *P. setiferus* did not perish, but thrived at salinities approximately equal to that of offshore waters.

Captive postlarvae grew at the rate of 2.1 mm a day for twenty-four days in 1954, and 1.7 mm a day for twenty-eight days in 1955. Very rapid growth was first observed in juvenile white shrimp by Viosca (1920) and later estimated for wild populations at 1.0 mm a day by Gunter (1950) and 1.2 mm a day by Williams (1955). The theoretical maximum growth rate of any species is usually modified by available food; the tank reared postlarvae are believed to have been full-fed and to have approached this maximum rate. Hudinaga *(op. cit.)* obtained daily growth increments below 1.0 mm in a four month period in 1940 with tank-reared *P. japonicus*.

White shrimp stocked in ponds at an approximate weight of 1.1 gm in July, 1954, spawned in April, 1955, at an average weight of 29.3 gm. There is little doubt that wild shrimp hatched one summer spawn the following summer at an age of one year or less.

The adult shrimp used in the experiments remained in excellent condition for over thirty days after spawning; they were killed when the tank was drained at the termination of each experiment. It is not known if adult shrimp survive from one spawning season to the next; however, it can be said that they do not die immediately as a result of spawning.

Gunter and Burkenroad in editing the work of Heegaard *(op. cit.)* remarked that all females that had been examined to date whose ovaries showed evidences of prior spawnings also showed some degree of reripening. It was therefore not certain if *P. setiferus* had ever been seen within the first few days after spawning. The ovaries were removed from two female white shrimp exactly five days after they had spawned in the brood tank. Sections of these ovaries examined by Mr. Albert Stenger, histologist at New York University, were found to contain large numbers of both degenerating and developing ova. It is likely that wild females whose ovaries contain egg remnants and ova in the early stages of development have spawned within the last few days.

Embryonated eggs and a number of each of the larval forms of *P. setiferus* recovered from the brood tank in 1954 and 1955 were preserved. These specimens and mounts of the ovarian sections of the recently spawned females are on file at the Fisheries Building, Alabama Polytechnic Institute, Auburn, Alabama, where they are undergoing more critical examination by Dr. John S. Dendy.

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ABSTRACT

In 1954 and 1955, sexually mature white shrimp, *Penaeus setiferus* (Linn.), that had been reared or held in dirt ponds, spawned viable eggs when placed in a concrete tank filled with salt water. The resulting larvae were reared through the metamorphic stages and to a pre-adult length of approximately 50.0 mm in the same facility.

The metamorphic forms could be identified by the descriptions of Pearson (1939); no additional stages were observed. The metamorphic period lasted twelve and ten days in the two years respectively. Upon becoming postlarvae the young shrimp grew at a daily rate of 2.1 mm in 1954 and 1.7 mm in 1955.

Observations on the captive larvae, juvenile, and adult shrimp are discussed where appropriate to a better understanding of the life history of *P. setiferus*.