Table 3. - Relative incorporation of ^{14}C from labeled dietary nutrients into shrimp muscle tissue

Labeled dietary ingredient	dpm ^{14}C per g dry tissue
Yeast protein	1835 ± 725
Yeast protein hydrolysate	680 ± 300
Tripalmitin	315 ± 110
Palmitic acid	770 ± 340
Starch	380 ± 225
Glucose	225 ± 140

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PINK SHRIMP FEEDING EXPERIMENTS WITH WHEAT BRAN[1]

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ABSTRACT

Other investigators have suggested that detritus enriched by the micro-organisms that degrade it is a major component of the natural diet of penaeid shrimp. This paper describes pink shrimp (Penaeus duorarum) feeding experiments in earthen ponds and concrete tanks, with wheat bran used to produce an artificial detritus food for the shrimp. Wheat bran and other foods are compared, and the effects of food type, feeding methods, and certain aspects of water quality on growth, survival and yield of pink shrimp are evaluated.

The artificial detritus method of feeding in the culture of shrimp is much simpler than the feeding of pelleted or other diets directly to shrimp, since the former does not depend upon monitoring of growth rates and population densities to determine feeding rates. Wheat bran is added to unaerated tanks or ponds at constant rates that do not cause oxygen depletion. We have added wheat bran to ponds at daily rates up to 35 kg per ha without causing obvious problems.

With wheat bran feeding, it seems possible to rear postlarval pink shrimp in ponds or tanks to about 4 g (live bait size) in 3 months and at stocking densities as high as 100,000 per ha, and with

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survival as high as 90%. Our investigations of the artificial detritus feeding method will continue with the goal of developing methods for producing food shrimp profitably.

INTRODUCTION

In the commercial culture of penaeid shrimp, considerable progress has been made toward development and improvement of methods for rearing large numbers of these animals from ova to the postlarval life stage (Tabb et al., 1972). There remain needs for: (1) development of methods to induce the females to mature in captivity to provide year-round control over the reproductive cycle and to allow selective breeding and hybridization, and for (2) development of methods to rear the shrimp from postlarvae to marketable size profitably. Both problems are receiving emphasis in shrimp culture research at the Rosenstiel School of Marine and Atmospheric Science, University of Miami, Florida. This paper deals with the second problem, that of developing methods to rear shrimp from postlarvae to marketable size at a profit. We have not yet attained this goal, but we believe the results contained herein show progress in that direction.

The pink shrimp (Penaeus duorarum) has been the subject of our investigations because it is among the three most important species of commercial shrimp of the United States and because it is readily available from south Florida waters. Anderson and Tabb (1971) suggested that a substantial reduction of costs might lead to a profitable shrimp culture. These costs include capital investment in land, hatchery and rearing facilities (e.g., ponds), and costs of labor, food, and acquisition of ova from gravid female shrimp collected on offshore spawning grounds.

Dall (1968) suggested that the large amount of unrecognizable material found in the gut of penaeid shrimps forms the main component of their diet and that the shrimp derive nourishment by browsing on the micro-organisms (bacteria, algae, and microfauna) which grow on the surface of the substrata. Heald (1971) showed that the red mangrove (Rhizophora mangle) is the dominant primary producer in the North River drainage system of Everglades National Park, Florida, an important nursery ground for pink shrimp. He observed that the degradation of mangrove leaves by micro-organisms tends to enrich this material as a food for detritus feeders, and Odum (1971) showed that pink shrimp consume this mangrove detritus. With these and similar other studies as a basis, it seemed that artificially produced detritus might be used as an inexpensive shrimp food, with possible additional savings in labor cost. For our initial tests of the artificial detritus feeding method, Tabb chose wheat bran (Table 1), because of his experience with its use in freshwater fish culture in ponds. We also have compared it with three other foods. It should be emphasized that the artificial detritus method of feeding in the culture of shrimp is much simpler than the feeding of shrimp with pellets. For the latter, the food is usually added at rates dependent upon the size and numbers of shrimp being fed. Such feeding necessitates continuous monitoring of population size and growth rates of the shrimp. With the artificial detritus feeding method, materials such as wheat bran are added to ponds at rates (usually constant) which will not cause oxygen depletion, and these rates are for the most part independent of size and numbers of shrimp. The substrates (e.g., wheat bran) are presumably enriched with microbial protein, etc., in the process of degradation, and this enriched material provides a source of nourishment for the shrimp.

FACILITIES

Tabb et al. (1969) described the University of Miami shrimp culture facilities near Biscayne Bay on property of the Florida Power and Light Company at Turkey Point, Florida (Figure 1). The seven ponds used in this study are above mean high water to facilitate draining. Surface areas of the bottoms of these ponds are about 0.08 ha (ponds 1-4), 0.16 ha (ponds 5 and 6), and 0.34 ha (pond 7). The bottom of each pond slopes from about 1.2 m on the shallow side to about 1.8 m on the opposite side near the drain. Levees are sloped sharply to discourage predation by wading waterfowl, etc., and they are sheathed on the inside with a rubberized material to reduce loss of water by seepage. Pond bottoms are sealed with a layer of oolitic marl about 10 cm deep. A band of coarse sand, about 8 cm deep and 1 m wide on top of the marl around the perimeter of the bottom, was added to each pond to attract shrimp to the sides to improve the efficiency of feeding, but its effectiveness is limited. The drain in each pond is 10 cm in diameter and is enclosed within a stack (Figure 1) with three sides of concrete and the fourth side formed from boards placed in slots. These removable boards are used to maintain or adjust water depth (Table 2). Water pumped into ponds was filtered through polyethylene bags with 345 μ bar mesh to reduce introduction of predators or competitors, or their ova. Despite this precaution such animals were sometimes introduced when a filter broke. We at times introduced anchovies (Anchoa), mojarras (Gerreidae), and seatrout (Cynoscion) into the ponds accidentally.

In addition to facilities described by Tabb et al. (1969), there are now 36 more concrete tanks at Turkey Point, and these were used in our experiments. These tanks are arrayed side by side from north to south near the laboratory (Figure 1). The bottom surface area of each tank was assumed to be 2 m^2 for our experiments, but the 95% confidence interval for the bottom surface area of the tanks was 1.94 $\pm$ 0.003 m^2. This relatively consistent but slight discrepancy was not considered to be of practical significance, and no adjustments were made in our calculations to correct for it. The 95% confidence interval for water depth, maintained in these tanks by overflow outlets, was 0.87 $\pm$ 0.007 m, but the total depth of each tank is about 1 m. Aeration from the bottom can be provided in each tank via two airlines, each fitted with a weighted airstone. Some of the tanks received less sunlight than others due to shading by the laboratory building near the end of the day. This shading effect was taken into consideration in the design of experiments (i.e., it was controlled by replication in a randomized block design).

SOURCE OF SHRIMP AND PREPARATION OF PONDS AND TANKS

All shrimp used in the experiments were pink shrimp reared at Turkey Point from ova obtained from gravid females collected from either the Tortugas or Sanibel spawning grounds of Florida.

Ponds were drained and dried prior to each experiment. Debris, primarily filamentous green algae mats left from previous experiments, was removed, and the bottom was tilled to a depth of about 2 cm to aerate it.

Concrete tanks were cleaned with high-pressure water spray after being scraped to remove sessile organisms such as oysters and barnacles.

FEEDING, STOCKING, AND SAMPLING

Food was broadcast by hand from pond levees and was introduced directly into tanks. Wheat foods (Table 1) were wetted with water after being weighed and before feeding to prevent them from floating. No adjustment in weight of food was made to compensate for differences in moisture content among the foods tested (Table 1). Foods were all kept in air-conditioned storage to limit moisture uptake and decomposition.

Direct counts were made to determine the number of shrimp to be stocked in tanks. When shrimp larger than postlarvae were stocked in tanks, checks were made on several days following stocking to remove any shrimp that died, and these were replaced with live ones of the same size. No attempt was made to confirm stocking densities when postlarvae were stocked in tanks because they could not be found in the tanks at such small size. Shrimp in tanks were not again handled until the experiment was terminated.

Numbers of postlarvae to be stocked in ponds were estimated volumetrically. The coefficient of variation (standard deviation x 100/average) for such pond stocking densities was estimated to be 16%. Thus, the average stocking densities used in our tables concerning pond experiments are somewhat imprecise, and such variation contributed to the total variation among ponds. Weekly samples, usually 25 to 50 shrimp, were removed from each pond and weighed to measure growth. Collections of small shrimp were made with dipnet, whereas larger shrimp were collected by seining. The shrimp in a sample were weighed together in a nylon mesh bag after excess moisture was removed centrifugally by swinging the bag containing the shrimp. When shrimp died during this sampling, some live ones were removed from all samples so

that the fraction of stocked shrimp removed in this manner was constant for all ponds. The remaining live shrimp were returned to the ponds. Such sampling mortality (including shrimp that died and others that were sacrificed) was less than 2% of the shrimp stocked. No adjustment was made in survival or yield values to correct for this sampling mortality.

HARVEST

Harvest of shrimp from tanks was accomplished by complete drainage, and direct counts and weighings of survivors were made. After the first experiment in Pond 7 in which attempts were made to harvest shrimp by seining and drainage during the day, the ponds were drained and flushed once or twice at night to harvest shrimp at the drain outlets (Table 3). We believe that harvest by drainage would have been much better with larger drains, and this should be considered in pond design. Volumetric and gravimetric methods were used to estimate the number of survivors, and samples were taken to estimate average weight per shrimp. Shrimp that remained in a pond after complete drainage were counted and added to the yield from drainage and flushing. Such sampling contributed further to the total variation in the data from ponds. All yields (kg per ha) represent shrimp with heads on.

OXYGEN, TEMPERATURE AND SALINITY

Oxygen, temperature, and salinity were usually monitored in tanks and ponds during each experiment (Figures 2 to 7). Water temperature near the bottom was measured electrometrically or with a mercury thermometer. Oxygen concentration of the water near the bottom was determined electrometrically. Salinity was measured with a refractometer. Only those oxygen and temperature measurements taken between 8:00 a.m. and 10:30 a.m. local time (usually E.S.T., but includes "daylight saving time") are presented, because these values exhibit considerable diel variation. Salinity values taken during daylight hours are presented.

EXPERIMENTS

Six experiments were conducted, three in ponds and three in the concrete tanks.

First Pond Experiment

The first pond experiment was conducted in the 0.34 ha pond (pond 7, Figure 1), and it produced the best growth rate observed in this study (Figure 2). The pond was stocked unsuccessfully with postlarvae on May 29, 1970, 23 days after it was filled with water. We believe the postlarvae were killed by a change in salinity from 32 ppt to 40 ppt in the transfer from tanks to the pond. No food was added to the pond prior to this stocking, but occasional feedings of wheat bran were made during June (Table 4), and a dense brown algae bloom developed and was maintained. By July, sampling showed that the stocking had failed, and feeding was not resumed until July 20 in preparation for restocking.

On July 29 the pond was restocked with postlarvae averaging 0.01 g. The approximate stocking density was 59,000 postlarvae per ha. The pond received 3,589 kg of wheat bran per ha, 41% of which was added prior to the second stocking on July 29. Though food was not added daily, and the feeding rate was increased during the study, the quantity of wheat bran averaged 21.2 kg per ha per day. A small amount of Oppenheimer pellets (about 1% of the total food) was also added to the pond from August 25 to September 8. The dense brown bloom lasted until September 12 at which time feeding was interrupted for several days to avoid oxygen depletion. By September 15 the bloom had changed to green or greenish-brown, and by November 10 the water had become gray, a condition we believe indicates overfeeding.

In addition to possible losses of shrimp through oxygen depletion, predation by waterfowl may have been a source of shrimp mortality. We also had difficulty with the harvest of shrimp (due to cold weather, etc.), and all the shrimp were not removed. Estimated survival was only 24%. Prior to the difficulties with harvest, survival may have been higher, but we have no accurate way of substantiating this. The shrimp grew to an average weight of 12.1 g in 117 days. Since survival was poor, the yield was only 171 kg per ha. Food conversion (weight of supplemental food/gain in shrimp biomass) was not estimated due to inaccuracies in survival and yield data.

We have not yet been able to duplicate the good growth (Figure 2) exhibited in this experiment, and we cannot be certain what produced it. Decreased density (due to mortality) may have enhanced growth. Large numbers of polychaetes were in the pond before the second stocking, and since these are eaten by shrimp they may have contributed to rapid growth. When growth began to slow in late September, comparatively few polychaetes could be found in bottom samples taken from the pond. During the period of good growth, water quality was good and the dense brown algae bloom prevented development of filamentous green algae mats. Attempts to compensate for slowed growth in the latter part of the experiment by increasing the feeding rate (Table 4) may have worsened conditions in the pond. This experiment is useful mainly in indicating that the introduction of wheat bran into a pond prior to and after stocking of shrimp can support rapid growth in the shrimp, whether they feed upon the wheat bran itself, or food organisms encouraged to grow by its presence, or both. This pre-feeding or pre-culturing technique is still under investigation.

First Tank Experiment

The first experiment in concrete tanks (Figure 3) tested the effects of food type (wheat bran, wheat shorts, Glencoe pellets, and Oppenheimer pellets), stocking density (15 vs 30 shrimp per m^2, or 150,000 and 300,000 per ha), and feeding schedule (once vs thrice per night) on survival, growth and yield of shrimp (Table 5). For this and the other experiments in concrete tanks, a factorial arrangement of treatments was used, with two replications of each treatment combination in a randomized block design. Only 32 of the concrete tanks were used in this experiment.

Shrimp were taken from ponds (other than pond 7) where they had been grown from postlarval size, and they were rather large, averaging 5.6 g. These shrimp were stocked in tanks on October 14, 1970 right after the tanks were filled with water filtered through polyethylene bags with 111μbar mesh. Significant differences in average initial weight per shrimp between the two stocking densities and between the two feeding schedules were accidentally built into the experiment, but the differences in average weight were 0.2 g or less (Table 6).

The once per night feeding was done at 9:00 p.m. local time, and the thrice per night feedings were at 9:00 p.m., midnight, and 3:00 a.m. The nightly feeding rate was 4.2 g of food per m^2 (42 kg per ha) for the lower stocking density and 8.3 g of food per m^2 (83 kg per ha) for the higher, or about 5% of the initial weight of the shrimp, and the same total quantities were fed per night under both feeding schedules (i.e., 1/3 of the nightly ration was fed at each of three feedings per night). Continuous aeration throughout the experiment was necessary to prevent oxygen depletion. Feeding was done at night because pink shrimp are more active at that time than during the day. The tanks were each covered with translucent green fiberglass (corrugated) to prevent dilution of salinities by rain, and no more water was added during the experiment. These covers transmit about 80% of incident light and about 60 to 80% of incident heat.

Shrimp were harvested on January 12, 1971, 90 days after stocking. Both food type (wheat vs pellets) and stocking density significantly influenced survival[3] (Table 7) and yield (Table 8), but only food type (wheat vs pellets) had a significant effect on average final weight per shrimp (Table 9). Feeding schedule had no demonstrable effect on survival, growth or yield. There were no significant differences between wheat bran and wheat shorts nor between Glencoe pellets and Oppenheimer pellets in survival,

[3]An angular transformation (arcsin $\sqrt{\text{percent survival}}$) of survival was conducted for all experiments to assure normality required for the analysis of variance. Average survival values (= untransformed average arcsin $\sqrt{\text{percent survival}}$) obtained by this method are slightly higher than values obtained by a direct averaging of percent survival data.

growth or yield. The wheat bran and wheat shorts did not promote growth and survival, thus there was a loss of biomass of shrimp fed these foods. However, there was no pre-culturing of the tanks with foods before shrimp were stocked in this experiment. The best average survival, 96.6%, was obtained with pellets at the lower stocking density (Table 7), and the best average yield, 173.3 g per m^2 (1,733 kg per ha), was obtained with pellets at the higher stocking density (Table 8), but this represents only a slight increase, 5.3 g per m^2 (53 kg per ha), in biomass. The best food conversion, about 25, was obtained with pellets at the lower stocking density.

Though this experiment was conducted during fall and winter when temperature drops (Figure 3) and growth usually slows, it does suggest that stocking densities lower than 15 per m^2 might have produced better results. There seems no need to feed more than once per night, if nightly feeding is employed. Oppenheimer pellets, designed specifically for shrimp, gave results not significantly different from those with Glencoe pellets, a trout fingerling food. In addition, the latter is a dryer and harder pellet and contains less protein than the Oppenheimer pellet (Table 1). For these reasons, Glencoe pellets probably have storage quality superior to that of Oppenheimer pellets. Two tanks, both for wheat shorts fed thrice per night, one at the lower stocking density and the other at the higher stocking density, exhibited total mortality (produced missing values in Tables 8 and 9). The fine particulate consistency of wheat shorts makes this food clump together when it is wetted, and these clumps tend to stick together in mats on the bottom. Thus, Glencoe pellets and wheat bran seem preferable to the other pelleted and wheat foods tested.

After the first experiments in pond 7 and concrete tanks, we decided to run experiments concurrently in ponds and tanks and to treat the two systems as similarly as possible. This was done to determine whether or not the results of experiments in tanks can be projected to represent ponds. We also abandoned attempts to feed shrimp at rates dependent on their size, and we began to base feeding rates upon the ability of tanks or ponds to maintain favorable oxygen levels under the chosen conditions of feeding.

Second Pond Experiment

The second experiment in ponds (0.08 ha and 0.16 ha) began with stocking of postlarvae averaging 0.01 g on May 18, 1971, 15 days after the ponds were filled (Figure 4). Pond 7 was similarly stocked to supply shrimp for the second experiment in tanks. Wheat bran was added to the ponds daily at the rate of 15.8 kg per ha from May 10 to 14 and at the rate of 34.6 kg per ha through August 22, except for 4 days (3 in June and 1 in July) when oxygen level was low in one pond. In this experiment, the effects of pond size (0.08 ha vs 0.16 ha) and stocking density (approximately 48,000 and 93,000 shrimp per ha) on survival, growth and yield of shrimp were tested (Table 10). The ponds received 3,400 kg of wheat bran per ha, only 5% of which was added prior to stocking.

Shrimp were harvested from ponds on August 20 to 25, 94-99 days after stocking. Pond size and stocking density had no significant effects on survival and growth. Survival averaged 86% and the average final weight per shrimp was 4.2 g. Pond size had no detectable effect on yield, but yield was significantly higher (when the effect of replications was combined with the experimental error term, thus increasing degrees of freedom for experimental error; Table 10) at the higher stocking density (Table 11). The best food conversion, about 7, was also obtained at the higher stocking density of 93,000 shrimp per ha. It is suspected that growth was inhibited to some extent by conditions of high salinity (Figure 4) resulting from a drought. Mats of filamentous green algae formed in the ponds early in the experiment. Many shrimp died when caught by these mats floating to the surface during the day. We did not remove this algae (as we have done in the past) so as not to remove materials that had potential of providing some productivity to the ponds.

Second Tank Experiment

The second experiment in concrete tanks (Figure 5) tested the effects of food type (wheat bran and Glencoe pellets), stocking density (4, 6, 8 and 10 shrimp per m^2, or 40,000, 60,000, 80,000 and 100,000 per ha), and water filtration mesh size (111 μ and 345 μ bar mesh filter bags) on survival, growth and yield of shrimp (Table 12). Only 32 tanks were used in this experiment. The shrimp used in this experiment were taken from pond 7 in which they had been stocked as postlarvae on May 18, 1971, and they averaged about 1.3 g (Table 13) when they were transferred to the tanks on June 23. A significant difference in average initial weight per shrimp between the two foods was accidentally built into the experiment, but the difference in average weight was only 0.1 g (Table 13). The tanks had been filled at the same time as the ponds, and they received wheat bran or Glencoe pellets on the same days (at daily rates of 1.2 g per m^2 during May 10 to 14, and 2.7 g per m^2 during May 15 to August 22) as in the second pond experiment. As was the case with the ponds, no food was added to tanks on 4 days (3 in June and 1 in July) during the experiment.

Water had to be added to ponds about every 3 days to replace losses from evaporation and seepage, so we also added water to the tanks, but only about once a week. The fiberglass covers were removed from the tanks to make conditions of light and possible dilution by rain similar to those for ponds. Nylon netting was spread over the tanks to exclude predators. Aeration was supplied to all tanks between 5:00 p.m. and 8:30 a.m. hours local time each day, after the shrimp were introduced, to preclude oxygen depletion at night. None was supplied at other hours, because aeration produces a surface layer of foam that could reduce incident light. With regard to this nightly aeration, the tanks were treated differently from ponds. Less food per unit area was added to the tanks than to the ponds due to an error in calculation of the pond ration.

The 345 µ bar mesh filter bags were used to filter water introduced into ponds, and the 111 µ mesh filter bags were used to filter water used for the first experiment in tanks (Table 5). The larger mesh was expected to allow larger organisms (or their ova) to enter the tanks, and this could introduce predators, competitors, or supplemental food.

Shrimp were harvested on August 26, 64 days after stocking. Food type, stocking density and water filtration mesh size all had significant effects on growth (Table 14), but they did not influence survival which averaged 96.5%. The best growth (to 6.8 g) was obtained with Glencoe pellets at the two lowest stocking densities (4 and 6 shrimp per m^2), and in water filtered through 345 µ bar mesh. With only two exceptions, the shrimp grew better in water filtered through the larger mesh (Table 14), so whatever was introduced through the larger mesh (and excluded by the smaller) had a beneficial effect. There was obviously no benefit derived from greater filtration of the water with the smaller mesh, so the larger mesh was used in subsequent experiments. There was a linear decrease in average final weight per shrimp with increase in stocking density. (Table 14)

For wheat bran, the average final weight values (Table 14) compare closely with that, 4.2 g, obtained in the second pond experiment. Survival in the tanks was greater than that in the ponds. Food type and stocking density had significant effects on yield (Table 15), but water filtration mesh size did not. The best yield, 44.2 g per m^2 (442 kg per ha), was obtained with Glencoe pellets at a stocking density of 8 shrimp per m^2 (80,000 per ha). The highest yield with wheat bran, 36.4 g per m^2 (364 kg per ha), was also obtained at the highest stocking density (10 shrimp per m^2) and this was better than the yield, 318 kg per ha, obtained at a stocking density of 93,000 shrimp per ha in the second pond experiment (Table 11).

The best food conversion, about 8, was obtained with Glencoe pellets at a stocking density of 8 shrimp per m^2 (80,000 per ha). The best food conversion on wheat bran was 12 at the highest stocking density, 10 per m^2 (100,000 per ha). The tanks received a greater proportion, 41%, of the total food prior to shrimp stocking than did the ponds (5% of the total food), and the shrimp were stocked at a larger size than in the second pond experiment. This accounts in part for the better food conversion, about 7, for the second pond experiment. If we consider the period that these shrimp were in pond 7 prior to stocking in tanks, during which time wheat bran was being added to both the pond and the tanks, the overall food conversion for this tank experiment would be still poorer, but we do not think this is a valid way of expressing the result. In retrospect, the comparison between ponds and tanks would have been direct had we stocked the tanks and ponds at the same time. The longer period of preculturing of the tanks with wheat bran and the aeration at night did not result in sufficiently better growth and survival in tanks than those exhibited in the ponds. However, ponds have a residual productivity not present in cleaned concrete tanks.

Concurrently with this second experiment in tanks (Table 12), shrimp were stocked in two additional tanks at a density of 10 per m^2. Glencoe pellets were added to one tank and wheat bran to the other at rates similar to those for the other tanks. No aeration was provided to either of these two tanks, and all of the shrimp died in the tank into which pellets were introduced. Survival was high in the tank receiving wheat bran. Thus, aeration seems necessary for feeding of Glencoe pellets at a rate equivalent to 27.2 kg per ha per day, but not for feeding of wheat bran at a similar rate.

Third Pond Experiment

The third experiment in ponds (Figure 6) tested the effect of wheat bran feeding frequency (34.6 kg per ha every day, 34.6 kg per ha every 2 days, and 34.6 kg per ha every 3 days) with shrimp stocked at 52,000 per ha (Table 16). Half of the ponds (3, 4 and 6) were filled on September 21, 1971, and the other half (ponds 1, 2 and 5) were filled on October 4. On September 24, the first three ponds received 34.6 kg of wheat bran per ha, then on October 6 all six ponds received 174 kg of wheat bran per ha in preparation for stocking. Thereafter, the three feeding frequencies (Table 16) were employed, one for each pond in each replication. Table 17 summarizes feed quantities for this experiment. Shrimp averaging 0.04 g were stocked in all ponds on October 11. These shrimp had been held in a 20 m^3 larval rearing tank as postlarvae for 53 days, and they were stunted prior to use in this experiment.

The shrimp were harvested on December 2 to 3, 1971, 52 to 53 days after stocking. The experiment was terminated earlier than originally planned, because large numbers of waterfowl were preying on the shrimp.

There were no detectable effects of replications (filling dates) or feeding frequency on average final weight per shrimp, survival, or yield. The average final weight per shrimp was 4.0 g, average survival was 42%, and average yield was 89 kg per ha. Though the shrimp grew more rapidly in this experiment than in the second pond experiment, survival and yield were poorer. We can attribute the latter to heavy daily predation by about 30 mergansers, each of which could consume 100 or more shrimp per day, but we have no way of estimating the survival and yield prior to this predation. A food conversion estimate would not be meaningful for this reason. The only useful information from the third experiment in ponds is that on growth rate. Growth in this experiment was better than that in the second pond experiment, perhaps because of more favorable salinity. Use of stunted postlarvae for stocking had no obvious detrimental effect. Predation by waterfowl can be expected to be a problem in shrimp culture in ponds during fall and winter in south Florida.

Third Tank Experiment

The third experiment in concrete tanks (Figure 7) tested the effects of aeration (about 5 minutes of aeration each morning to prevent stratification, and continuous aeration overnight between 5:00 p.m. and 10:00 a.m. local time), stocking density (4, 8 and 16 shrimp per m^2, or 40,000, 80,000 and 160,000 per ha), and wheat bran feeding frequency (2.7 g per m^2 every day, 2.7 g per m^2 every 2 days, and 2.7 g per m^2 every 3 days) on survival, growth and yield of shrimp (Table 18). All 36 of the concrete tanks were used in this experiment. Tanks were uncovered except for nylon mesh used to prevent predation. The shrimp, averaging 0.04 g, were stocked on October 11, 1971 (same stocking date and source of shrimp as for the third pond experiment, Table 16). The tanks had been filled on October 4. On October 5 each tank received 2.7 g of wheat bran per m^2, and on October 6, 136 g of wheat bran per m^2 were added to each tank. Thereafter, food was added to tanks according to the three feeding frequencies (Table 18). On November 15 fresh water was added to all tanks to adjust salinity to values near those in the ponds (0.08 ha and 0.16 ha.)

Feeding was stopped after November 30 and the shrimp were harvested from the tanks on December 1, 51 days after stocking. Stocking density, feeding frequency and aeration all had significant effects (and significant interactions) on average final weight per shrimp (Table 19) and yield (Table 20), but only stocking density had a detectable effect on survival (Table 21). Stocking density and feeding frequency had significant curvilinear[4] components (Tables 19 and 20). The best growth (average final weight per shrimp, 2.7 g) was obtained at the lowest stocking density, 4 shrimp per m^2 (40,000 per ha) with daily feeding and brief daily aeration (Table 19). The best yield, 15.0 g per m^2 (150 kg per ha) was obtained at the highest stocking density, 16 shrimp per m^2 (160,000 per ha) with daily feeding and brief daily aeration (Table 20). Average survival was best at the lowest stocking density (Table 21), but it exceeded 96% at all stocking densities. Average final weight per shrimp decreased with increased stocking density (Table 19), and average yield

[4]The three stocking densities were purposefully chosen to represent a geometric series to expand the range of densities tested, but the orthogonal polynomial analysis (Tables 19 and 20) treated the three levels of the density factor as if they represented in arithemetic series. This in effect is a transformation of the density scale, and it should be taken into consideration in interpretation of the significant curvilinear components of the analysis of variance.

increased with increase in stocking density (Table 20). There were decreases in average final weight per shrimp and in yield with decrease in the frequency of feeding (and amount of food). Though less frequent feeding would reduce costs, especially when coupled with a decrease in the quantity of food, it would be at the sacrifice of growth and yield. However, food conversion was better, about 8, for the less frequent feedings (every 2 days and every 3 days) than for daily feeding (about 12). The most surprising result was that of poorer growth and yield under conditions of continuous overnight aeration. We expected aeration to improve growth and yield, but it did not. The agitation of water by aeration may have stimulated greater activity in the shrimp, thus wasting energy. Aeration may have increased oxidation of the food or kept the food suspended out of reach of the shrimp. It is also possible that the microbes that enrich the bran as a food for shrimp might be anaerobic. The expected advantages of aeration may be realized only at higher feeding rates and stocking densities that would otherwise cause oxygen depletion. The brief aeration in the morning was probably not essential in this experiment, since higher wheat bran feeding rates were used in the concurrent pond experiment without aeration and without oxygen depletion. These higher rates in ponds were accidental, due to an error in calculation.

Growth was not as good in the third experiment in tanks (Table 19) as it was in the third pond experiment (Figure 6). Heavier feeding was done in ponds. There was only brief preculturing of the tanks with wheat bran before shrimp were introduced. This pre-culturing seems important to shrimp growth and yield in tanks (see second experiment in tanks, Tables 14 and 15), but we have not shown it to be essential for ponds, perhaps because of the compensating effect of residual productivity in ponds. The question may arise as to whether or not pink shrimp would grow equally well in ponds without supplemental food in the form of wheat bran, since we could not detect significant differences in growth obtained with three different feeding frequencies in ponds. Failure to detect significant differences in pond experiments is partly a result of inherently large variation among ponds. Our tank experiment, which provides a more sensitive test of this effect, clearly shows that growth and yield are poorer as the interval between feedings increases (and as the amount of food decreases).

LABOR ESTIMATES

Crude estimates of the man-hours required for these experiments are presented in Tables 22 and 23, for those interested in making an economic analysis of the wheat bran method of shrimp culture. Many of these man-hours would not be included in a commercial operation.

SUMMARY AND CONCLUSIONS

A brief summary of experiments (three in ponds and three in tanks) is given in Table 24. Though these experiments were purposefully designed to be of relatively short duration so that more experiments could be conducted per unit time, the results are still indicative of the various conditions which might enhance growth, survival and yield of pink shrimp in a commercial shrimp farming operation. Pelleted foods (Glencoe and Oppenheimer) gave better results than wheat foods (bran and shorts), but pellets may not be sufficiently better to compensate for their greater cost (Table 1). One feeding per day (or night) seems sufficient, but daily (or nightly) feeding may be necessary for good growth and yield, especially when only wheat bran is used. However, food conversion is better with feeding frequencies of every 2 days, and every 3 days (also less food, proportionately).

The practice of using water filtered through 345 μ bar mesh filters seems to be a good one. It apparently allows some enrichment of tanks and ponds, while preventing major problems with predators, competitors or both. Aeration of ponds does not seem necessary when wheat bran is fed at daily rates up to 35 kg per ha. In one experiment in tanks, continuous aeration at night produced slower growth and lower yields than brief aeration in the morning. Aeration may be necessary at higher rates of wheat bran feeding; i.e., at levels that would otherwise cause oxygen depletion. We have added wheat bran to ponds at daily rates up to 35 kg per ha without causing obvious problems. Within a range of stocking densities from 40,000 to 160,000 shrimp per ha, there seems to be a decrease in growth rate and an increase in yield with increase in stocking density.

We have had some success with harvesting pink shrimp from ponds by draining and flushing at night. On several occasions we harvested over 90% (by number) of the shrimp with one draining and one flushing. With drains larger than 10 cm diameter, we would expect even greater success in the harvest of shrimp by drainage.

We had problems with floating mats of green filamentous algae in the second and third pond experiments. Besides causing mortality by entrapping shrimp, these mats hampered harvest of the shrimp. The dense bloom in the first pond experiment apparently prevented development of such mats. High salinities may also encourage development of these mats.

While our goal is the development of methods to raise penaeid shrimp to sizes marketable as food at a profit, we believe that the results of experiments described in this paper are more immediately applicable to commercial production of live bait shrimp. With wheat bran feeding, it seems likely that pink shrimp could be reared dependably in ponds or tanks from postlarvae to bait sizes (about 4 g) in 3 months and at stocking densities as high as 100,000 per ha, with survival as high as 90%.

The artificial detritus feeding method (using wheat bran and other inexpensive substrates) deserves further investigation as a means for reducing costs of food and labor in the culture of shrimp to sizes marketable as food.

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Drs. Eric Heald and J. L. Runnels reviewed the manuscript.

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Table 1. - Proximate analysis (percent based on wet weight) and cost[a] of wheat bran, wheat shorts, Glencoe pellets and Oppenheimer pellets

	Wheat bran	Wheat shorts	Glencoe pellets[b]	Oppenheimer pellets[c]
Protein	14.5	16.0	40.4	54.8
Fat	3.5	3.5	7.3	8.1
Fiber	11.0	7.0	4.8	-
Soluble carbohydrate (by difference)	52.5	56.5	31.5	-
Ash	4.0	3.5	7.7	11.7
Moisture	14.5	13.5	8.3	17.4
Cost per kg[d]	$ 0.08	$ 0.08	$ 0.22	$ 0.26

[a]Delivered (rail/truck). Approximations provided by dealers. All values subject to change.

[b]Enriched trout fingerling pellets, 2.4 mm; information provided by Glencoe Mills, Inc., Glencoe, Minnesota.

[c]Experimental diet developed for shrimp by Dr. Carl H. Oppenheimer at Florida State University, Tallahassee, Florida (see Subrahmanyam and Oppenheimer, 1970).

[d]In lots exceeding 10 metric tons, except for Oppenheimer pellets in which cost is based upon 45.4 kg lots, since the latter is not available commercially.

Table 2. - Average depth of water[a] in ponds at Turkey Point, Florida

Pond	Average depth, m
1	0.77
2	0.77
3	0.90
4	0.80
5	1.01
6	0.84
7	0.86

[a]Average depths during experiments were at times slightly shallower due to seepage and evaporation, but seawater was added at intervals to restore that lost.

Table 3. - Percent of total number of shrimp harvested from ponds by drainage and flushing, August and December 1971

Pond	Drainage and first flushing		Second flushing		Remaining in drained pond	
	Aug. %	Dec. %	Aug. %	Dec. %	Aug. %	Dec. %
1	27	63	29	5	44	32
2	91	96	4	2	5	2
3	99	81			1	19
4	41	73	14	4	45	23
5	79	98	3		18	2
6	92	98			8	2

Table 4. - Feeding summary for the first experiment in the 0.34 ha pond, July 29[a] to November 23, 1970

Inclusive dates[b]	No. of days of feeding	Total kg fed per ha: Wheat bran	Total kg fed per ha: Oppenheimer pellets	Average kg of wheat bran per ha per day[c]
June 8 - 24	8	166	0	9.8
June 25 - July 19	0	0	0	0.0
July 20 - Sept. 29	46	1,380	38	19.2
Sept. 30 - Oct. 20	18	780	0	37.1
Oct. 21 - Nov. 17	17	1,260	0	45.0
Nov. 18 - 23	0	0	0	0.0
Total	89	3,589	38	21.2

[a]Date of second stocking. The first stocking on May 29 failed.

[b]Includes the period preceeding the second stocking.

[c]Calculation includes days on which there was no feeding.

Table 5. - Sources of variation tested in the analysis of variance of data from the first experiment in concrete tanks, October 14, 1970[a] to January 12, 1971

Source of variation	Degrees of freedom
Replications	1
Food type, F	
Wheat vs pellets	1
Bran vs shorts	1
Glencoe vs Oppenheimer	1
Stocking density, D	
15 vs 30 shrimp per m^2	1
Feeding schedule, S	
Once vs thrice per night	1
F X D interactions	
Wheat vs pellets	1
Bran vs shorts	1
Glencoe vs Oppenheimer	1
F X S interactions	
Wheat vs pellets	1
Bran vs shorts	1
Glencoe vs Oppenheimer	1
D X S interaction	1
F X D X S interactions	
Wheat vs pellets	1
Bran vs shorts	1
Glencoe vs Oppenheimer	1
Experimental error	15
Total	31

[a]Date of stocking

Table 6. - Accidental significant[a] variation in average initial weight per shrimp with a summary of significant sources of variation for the first experiment in concrete tanks, October 14, 1970[b] to January 12, 1971

A. Average initial weight per shrimp (g) by stocking density and feeding schedule

Feeding schedule	Stocking density, No. of shrimp per m^2 15	30
Once per night	5.7	5.5
Thrice per night	5.6	5.5

B. Significant sources of variation

Source of variation	Sum of squares	Relative contribution to the total sum of squares percent	F
Stocking density	0.128	27	15.51
Feeding schedule	0.072	15	8.65

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

Table 7. - Average percent survival with a summary of significant[a] sources of variation for the first experiment in concrete tanks, October 14, 1970[b] to January 12, 1971

A. Average percent survival (= untransformed average arcsin $\sqrt{\text{percent survival}}$) by stocking density and food type

Food type	Stocking density, No. of shrimp per m^2 15	30
Wheat (bran and shorts)	93.7	35.9
Pellets (Glencoe and Oppenheimer)	96.6	83.0

B. Significant sources of variation (for transformed data)[c]

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Stocking density	5,497	28	13.57
Food type (wheat vs pellets)	2,154	11	5.32

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

[c]Two values were zero, one in each replication. Both zero survival values were for wheat shorts fed thrice per night, one at the lower stocking density and the other at the higher stocking density. No substitutions were made for these zero values.

Table 8. - Average yield with a summary of significant[a] sources of variation for the first experiment in concrete tanks, October 14, 1970[b] to January 12, 1971

A. Average yield (g per m^2) by food type and stocking density

Food type	Stocking density, No. of shrimp per m^2: 15	30
Wheat (bran and shorts)	78.9	69.6
Pellets (Glencoe and Oppenheimer)	99.8	173.3

B. Significant sources of variation[c]

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Food type (wheat vs pellets)	31,063	29	13.75
Food type (wheat vs pellets) X stocking density interaction	13,766	13	6.09

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

[c]Two values were zero, one in each replication. Both zero yield values were for wheat shorts fed thrice per night, one at the lower stocking density and the other at the higher stocking density. No substitutions were made for these zero values.

Table 9. - Average final weight per shrimp with one significant[a] source of variation for the first experiment in concrete tanks, October 14, 1970[b] to January 12, 1971

A. Average final weight per shrimp (g) by food type

Wheat (Bran and Shorts)	Pellets (Glencoe and Oppenheimer)
5.7	7.4

B. Significant source of variation[c]

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Food type (wheat vs pellets)	21.54	56	49.11

[a]At the 95 percent level of confidence. The listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

[c]The degrees of freedom for experimental error were reduced by two prior to the significance test because two missing values were estimated, one in each replication. Both missing values were for wheat shorts fed thrice per night, one at the lower stocking density and the other at the higher stocking density.

Table 10. - Sources of variation tested in the analysis of variance of data from the second experiment in ponds, May 18[a] to August 25, 1971

A. Including tests of the effect of pond size

Source of variation	Degrees of freedom
Replications	
0.08 vs 0.16 ha ponds	1
Between 2 replications of 0.08 ha ponds	1
Stocking density	1
Experimental error (Replication x stocking density interaction)	2
Total	5

B. Excluding tests of the effect of pond size (replication differences included in experimental error)

Source of variation	Degrees of freedom
Stocking density	1
Experimental error	4
Total	5

[a]Date of stocking.

Table 11. - Average yield with one significant[a] source of variation for the second experiment in ponds, May 18[b] to August 25, 1971

A. Average yield (kg per ha) by stocking density

Approximate stocking density, No. of shrimp per ha	
48,000	93,000
180	318

B. Significant source of variation

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Stocking density	28,292	78	13.84

[a]At the 95 percent level of confidence. Stocking density has one degree of freedom.

[b]Date of stocking.

Table 12. - Sources of variation tested in the analysis of variance of data from the second experiment in concrete tanks, June 23[a] to August 26, 1971

Source of variation	Degrees of freedom
Replications	1
Food type, F	
Wheat bran vs Glencoe pellets	1
Stocking density, D	
(4, 6, 8 and 10 shrimp per m^2)	
D_{Linear}	1
$D_{Quadratic}$	1
D_{Cubic}	1
Water filtration mesh size, M	
111 μ vs 345 μ bar mesh	1
F X D interactions	
F X D_{Linear}	1
F X $D_{Quadratic}$	1
F X D_{Cubic}	1
F X M interaction	1
M X D interactions	
M X D_{Linear}	1
M X $D_{Quadratic}$	1
M X D_{Cubic}	1
F X M X D interactions	
F X M X D_{Linear}	1
F X M X $D_{Quadratic}$	1
F X M X D_{Cubic}	1
Experimental error	15
Total	31

[a]Date of stocking.

Table 13. - Accidental significant[a] variation in average initial weight per shrimp with one significant source of variation for the second experiment in concrete tanks, June 23[b] to August 26, 1971

A. Average initial weight per shrimp (g) by food type

Wheat bran	Glencoe pellets
1.3	1.2

B. Significant source of variation

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Food type (wheat bran vs Glencoe pellets)	0.082	11	5.03

[a]At the 95 percent level of confidence. The listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

Table 14. - Average final weight per shrimp with a summary of significant[a] sources of variation for the second experiment in concrete tanks, June 23[b] to August 26, 1971

A. Average final weight per shrimp (g) by food type, stocking density and water filtration mesh[c] size

Food type	Mesh size, μ	Stocking density, No. of shrimp per m^2 4	6	8	10
Wheat bran	111	4.6	3.9	4.1	3.5
	345	4.8	4.9	4.0	3.9
Glencoe pellets	111	6.6	4.9	5.4	5.4
	345	6.8	6.8	6.6	4.0

B. Significant sources of variation

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Food type (wheat bran vs Glencoe pellets)	20.74	44	44.87
Stocking density (Linear)	7.98	17	17.27
Water filtration mesh size X stocking density (Quadratic) interaction	2.70	6	5.84
Food type X water filtration mesh size X stocking density (Quadratic) interaction	2.12	4	4.59

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

[c]Bar mesh.

Table 15. - Average yield with a summary of significant[a] sources of variation for the second experiment in concrete tanks, June 23[b] to August 26, 1971

A. Average yield (g per m^2) by stocking density and food type

Food type	Stocking density, No. of shrimp per m^2 4	6	8	10
Wheat bran	17.5	25.2	30.7	36.4
Glencoe pellets	24.5	32.7	44.2	38.7

B. Significant sources of variation

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Stocking density (Linear)	1,355	37	24.96
Food type (wheat bran vs Glencoe pellets)	460	12	8.48

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

Table 16. - Sources of variation tested in the analysis of variance of data from the third experiment in ponds, October 11[a] to December 3, 1971

A. Including test of the effect of replications (filling dates)

Source of variation	Degrees of freedom
Replications (filling on September 21 vs filling on October 4)	1
Feeding frequency, F (34.6 kg per ha every day, 34.6 kg per ha every 2 days, and 34.6 kg per ha every 3 days)	
F_{Linear}	1
$F_{Quadratic}$	1
Experimental error (replication X feeding frequency interaction	2
Total	5

B. Excluding test of the effect of replications (replication effect included in experimental error)

Source of variation	Degrees of freedom
Feeding frequency, F	
F_{Linear}	1
$F_{Quadratic}$	1
Experimental error	4
Total	6

[a]Date of stocking.

Table 17. - Feeding summary for the third experiment in 0.08 and 0.16 ha ponds, October 11[a] to December 3, 1971

	Total kg of wheat bran fed per ha		
	Fed every day	Fed every 2 days	Fed every 3 days
Ponds filled on September 21	2,118	1,145	833
Ponds filled on October 4	2,082	1,110	798

[a]Date of stocking.

Table 18. - Sources of variation tested in the analysis of variance of data from the third experiment in concrete tanks, October 11[a] to December 1, 1971

Source of variation	Degrees of freedom
Replications	1
Aeration, A (brief in morning vs continuous at night)	1
Stocking density, D (4, 8 and 16 shrimp per m^2)	
D_{Linear}	1
$D_{Quadratic}$	1
Feeding frequency, F (2.7 g per m^2 every day, 2.7 g per m^2 every 2 days, 2.7 g per m^2 every 3 days; wheat bran only)	
F_{Linear}	1
$F_{Quadratic}$	1
A X D interactions	
A X D_{Linear}	1
A X $D_{Quadratic}$	1
A X F interactions	
A X F_{Linear}	1
A X $F_{Quadratic}$	1
F X D interactions	
F_{Linear} X D_{Linear}	1
F_{Linear} X $D_{Quadratic}$	1
$F_{Quadratic}$ X D_{Linear}	1
$F_{Quadratic}$ X $D_{Quadratic}$	1
A X F X D interactions	
A X F_{Linear} X D_{Linear}	1
A X F_{Linear} X $D_{Quadratic}$	1
A X $F_{Quadratic}$ X D_{Linear}	1
A X $F_{Quadratic}$ X $D_{Quadratic}$	1
Experimental error	17
Total	35

[a]Date of stocking

Table 19. - Average final weight per shrimp with a summary of significant[a] sources of variation for the third experiment in concrete tanks, October 11[b] to December 1, 1971

A. Average final weight per shrimp (g) by stocking density, feeding frequency and aeration

Aeration	Feeding frequency[b]	Stocking density, No. of shrimp per m^2		
		4	8	16
Brief, in morning	Every day	2.7	1.5	1.0
	Every 2 days	1.7	1.1	0.8
	Every 3 days	1.7	0.9	0.6
Continuous, overnight	Every day	2.2	1.2	0.7
	Every 2 days	1.2	0.7	0.6
	Every 3 days	1.0	1.0	0.5

B. Significant sources of variation

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Stocking density (Linear)	6.775	54	277.86
Stocking density (Quadratic)	0.180	1	7.39
Feeding frequency (Linear)	2.057	16	84.35
Feeding frequency (Quadratic)	0.543	4	22.28
Aeration	0.873	7	35.82
Feeding frequency (Linear) x stocking density (Linear interaction	0.665	5	27.29
Feeding frequency (Linear) x stocking density (Quadratic) interaction	0.138	1	5.68
Feeding frequency (Quadratic) x stocking density (Linear) interaction	0.220	2	9.04
Aeration x stocking density (Linear) interaction	0.237	2	9.74

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

Table 20. - Average yield with a summary of significant[a] sources of variation for the third experiment in concrete tanks, October 11[b] to December 1, 1971

A. Average yield (g per m^2) by feeding frequency, stocking density and aeration

Aeration	Feeding frequency[b]	Stocking density, No. of shrimp per m^2		
		4	8	16
Brief, in morning	Every day	10.8	11.9	15.0
	Every 2 days	6.9	8.2	11.4
	Every 3 days	6.4	6.5	9.2
Continuous, overnight	Every day	8.8	9.3	10.6
	Every 2 days	4.7	4.9	9.0
	Every 3 days	4.0	7.4	8.2

B. Significant sources of variation

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Feeding frequency (Linear)	102.87	36	135.86
Feeding frequency (Quadratic)	18.10	6	23.87
Stocking density (Linear)	79.95	28	105.45
Stocking density (Quadratic)	3.88	1	5.11
Aeration	42.14	15	55.58
Aeration x feeding frequency (Linear) interaction	7.33	3	9.67
Aeration x feeding frequency (Linear) x stocking density (Linear) interaction	3.48	1	4.59

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

Table 21. - Average percent survival with a summary of significant[a] sources of variation for the third experiment in concrete tanks, October 11[b] to December 1, 1971

A. Average percent survival (= untransformed average arcsin $\sqrt{\text{percent survival}}$) by stocking density

Stocking density, No. of shrimp per m^2		
4	8	16
99.9	96.5	97.8

B. Significant sources of variation (for transformed data)

Source of variation	Sum of squares	Relative contribution to the total sum of squares, percent	F
Stocking density (Linear)	275.1	11	4.69
Stocking density (Quadratic)	261.6	10	4.46

[a]At the 95 percent level of confidence. Each listed source of variation represents a significant orthogonal comparison among treatment combinations and has one degree of freedom.

[b]Date of stocking.

Table 22. - Estimates of man-hours required for a single experiment in 36 concrete tanks

Activity	Man-hours
Scraping and spray cleaning of tanks	23
Installation of water filter bags	4
Filling tanks and cleaning filter bags	5
Stocking (including replacement of dead shrimp the next day)	10
Monitoring oxygen, temperature and salinity	1 per day
Food weighing and feeding (once daily)	1 per day
Replacement of water lost by evaporation	2 per month
Harvest and weighing of shrimp	10

Table 23. - Estimates of man-hours per pond required for a single experiment in ponds

Activity	Man-hours per ha
Removal of debris	99
Tilling bottom	10
Installation of water level control boards in drainage stack	1
Pond repairs and installation of water filter bag	1
Filling pond and cleaning filter bags	1
Stocking (including volumetric estimation of numbers of shrimp)	1
Monitoring oxygen, temperature and salinity	2 per month
Food weighing and feeding (once daily)	1 per day
Harvest and weighing of shrimp	12
Miscellaneous	1 per month

Table 24. - Summary of best results (growth and yield of pink shrimp) from each of six experiments (three in ponds and three in tanks) with wheat bran feeding

	First experiments		Second experiments			Third experiments		
	Pond 7	Tanks	Ponds 1-6	Tanks		Ponds 1-6	Tanks	
Duration, days	117	90	99	64		53	51	
Season	Summer-fall	Fall-winter	Spring-summer	Summer		Fall-winter	Fall-winter	
Average initial weight per shrimp, g	0.01	5.6	0.01	1.3		0.04	0.04	
Average final weight per shrimp, g	12.1	5.7	4.2	4.9	3.5	4.0	2.7	1.0
Stocking density, number of shrimp per ha	$59x10^3$	$150x10^3$	$93x10^3$	$60x10^3$	$100x10^3$	$52x10^3$	$40x10^3$	$160x10^3$
Yield, kg per ha	171	789	318	252	364	89	108	150

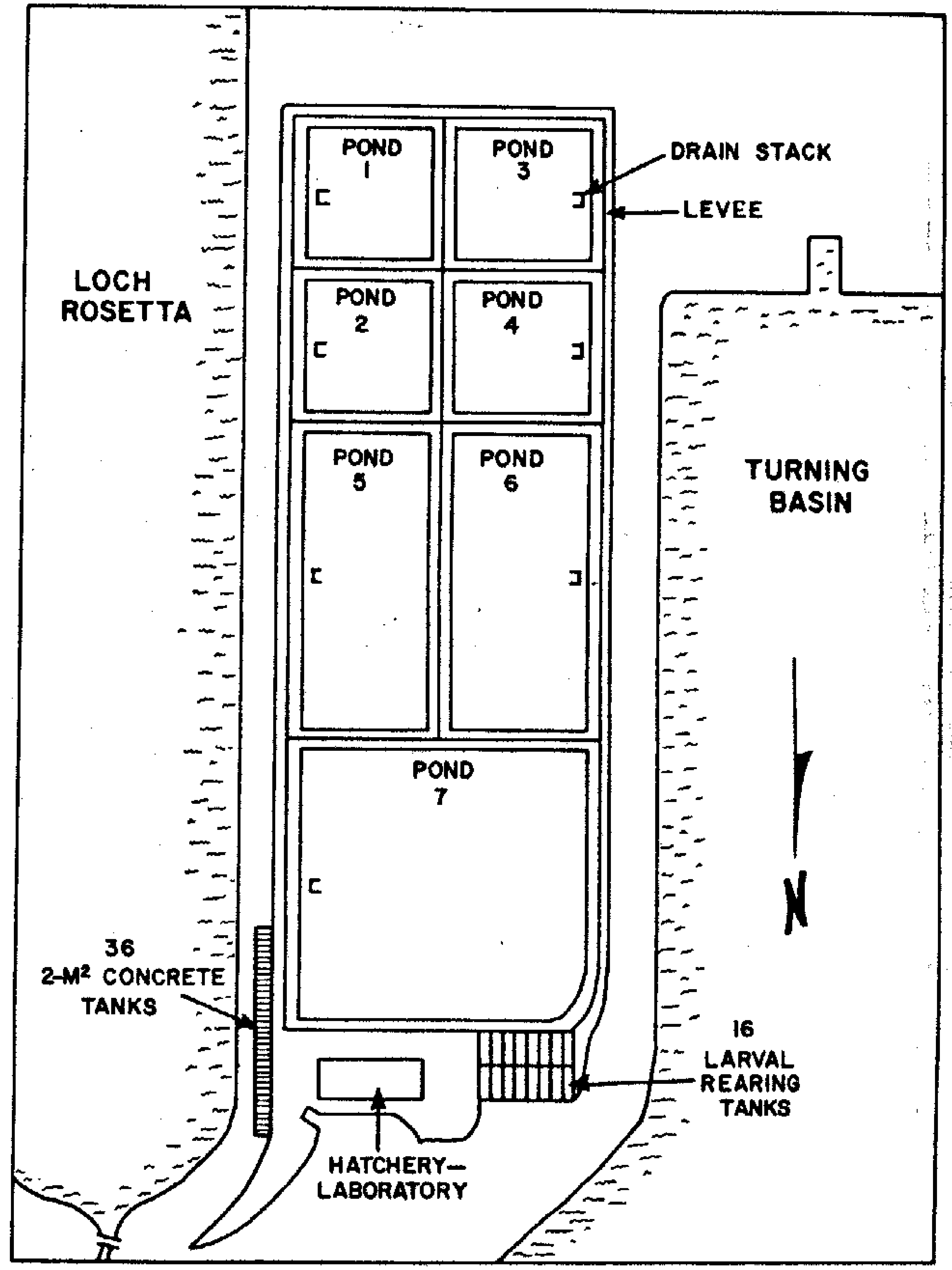

Figure 1. Diagram of shrimp culture research facilities at Turkey Point, Florida. Ponds 1-4 are about 0.08 ha, ponds 5-6 are about 0.16 ha, and pond 7 is about 0.34 ha. Each of the 36 concrete tanks is about 2 m^2 in bottom surface area.

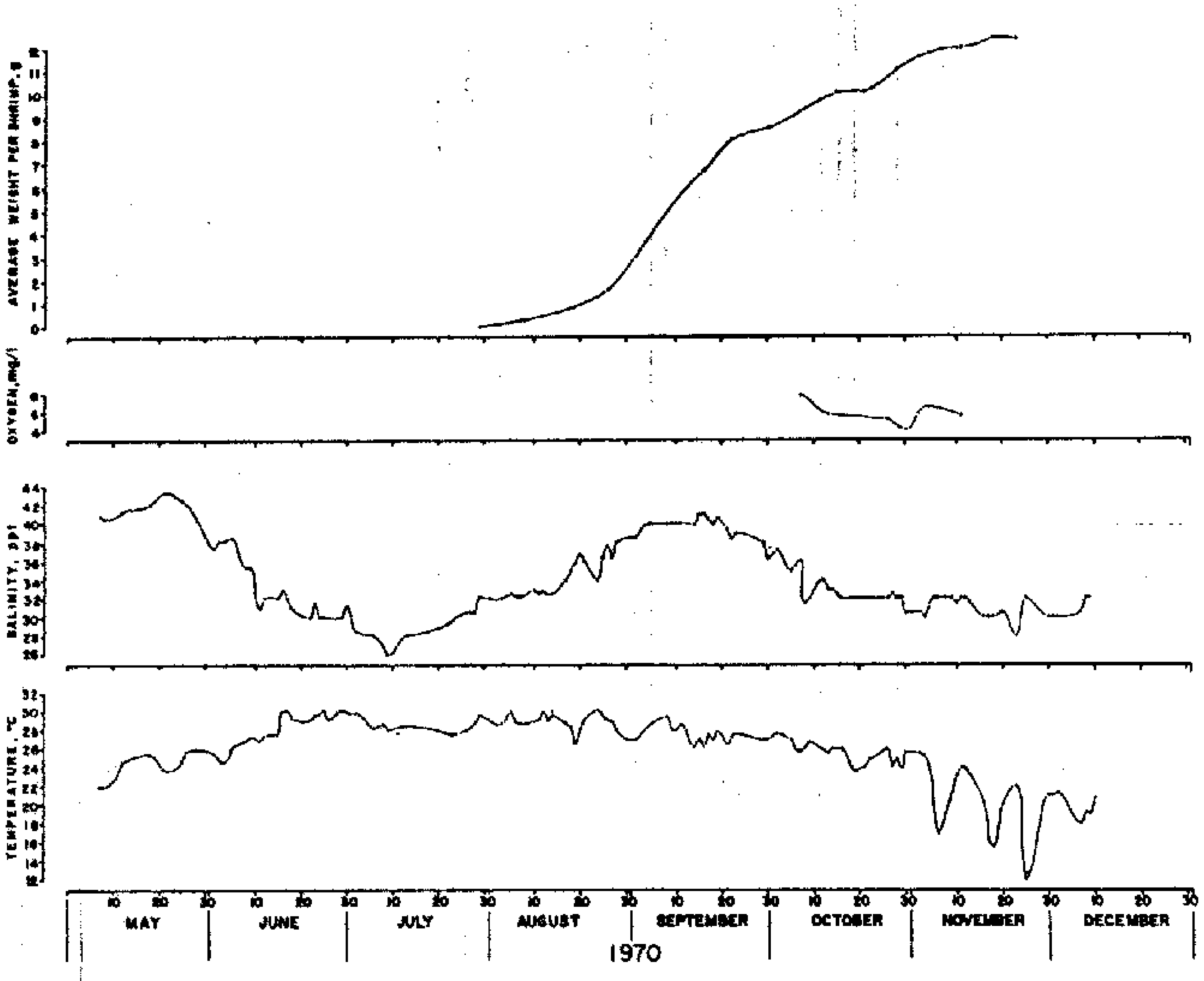

Figure 2. Average weight per shrimp, oxygen, temperature and salinity during the first experiment in the 0.34 ha pond. Few oxygen measurements were made and these were taken during periods of heavy feeding when oxygen depletion might have occurred.

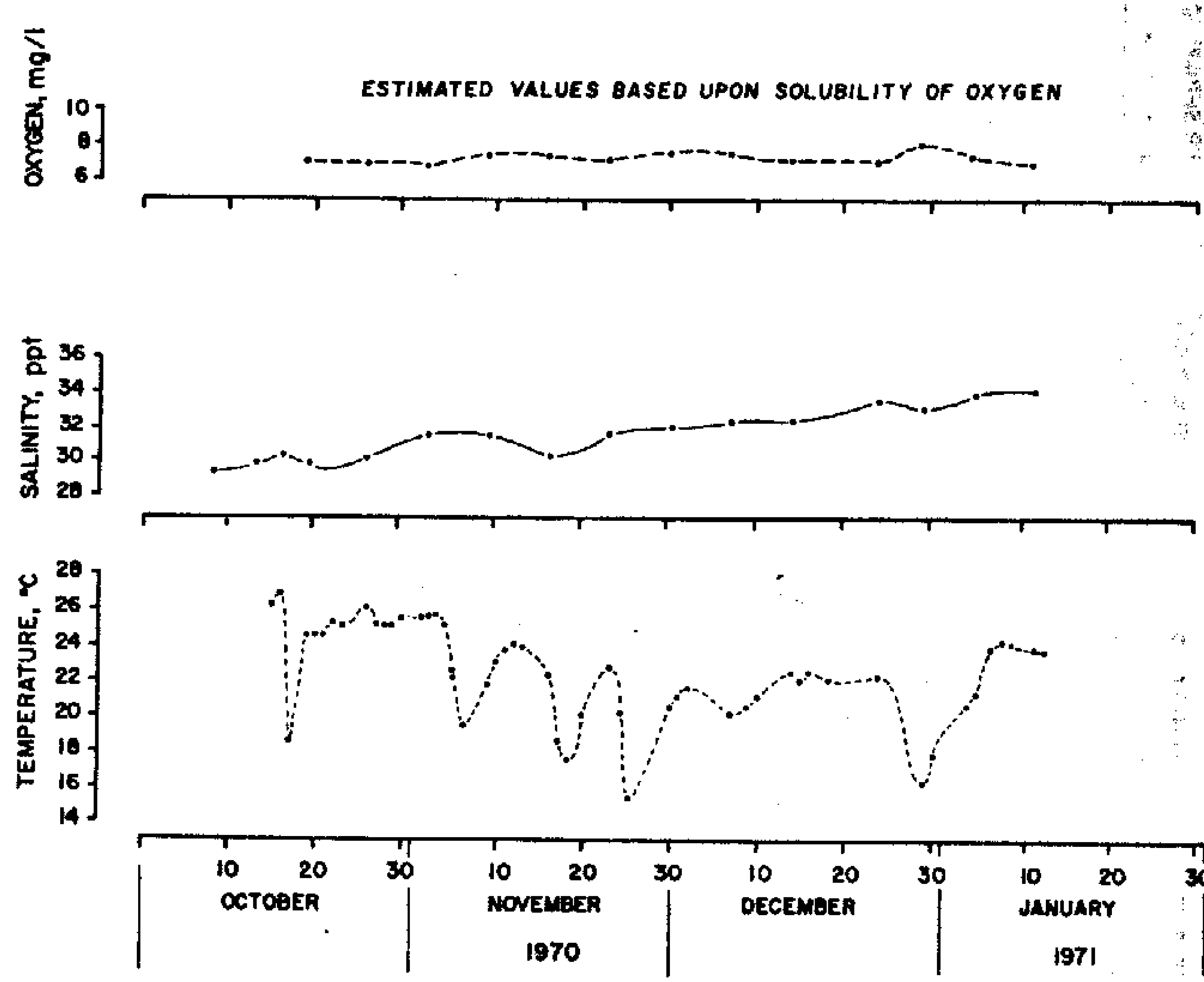

Figure 3. Oxygen, temperature and salinity during the first experiment in concrete tanks. Values are averages for 32 tanks. The tanks were aerated continuously, so no oxygen measurements were made. Oxygen values presented were calculated based upon oxygen solubility.

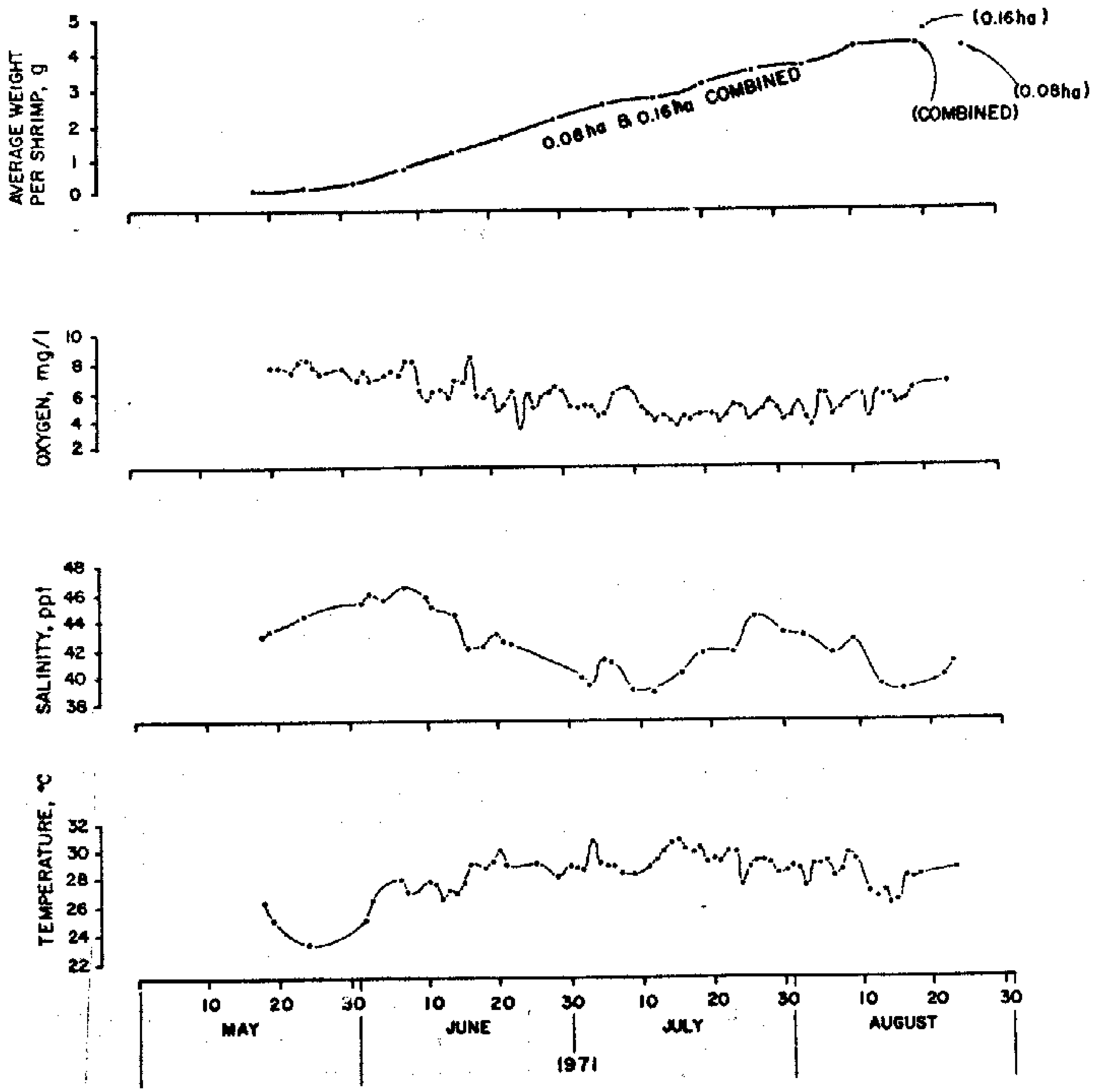

Figure 4. Average weight per shrimp, oxygen, temperature and salinity during the second experiment in 0.08 and 0.16 ha ponds. Values are averages for six ponds.

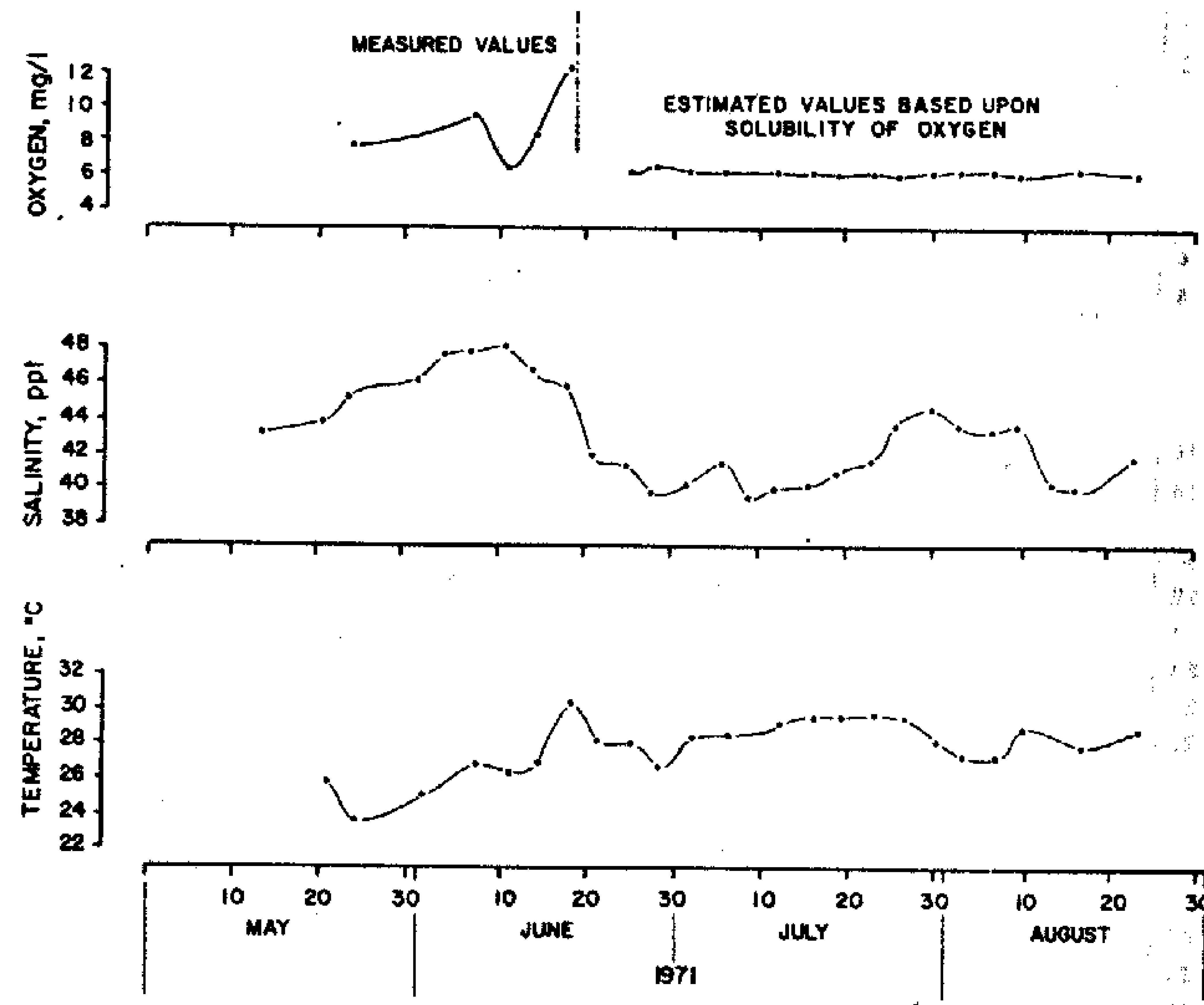

Figure 5. Oxygen, temperature and salinity during the second experiment in concrete tanks. Values are averages for 32 tanks.

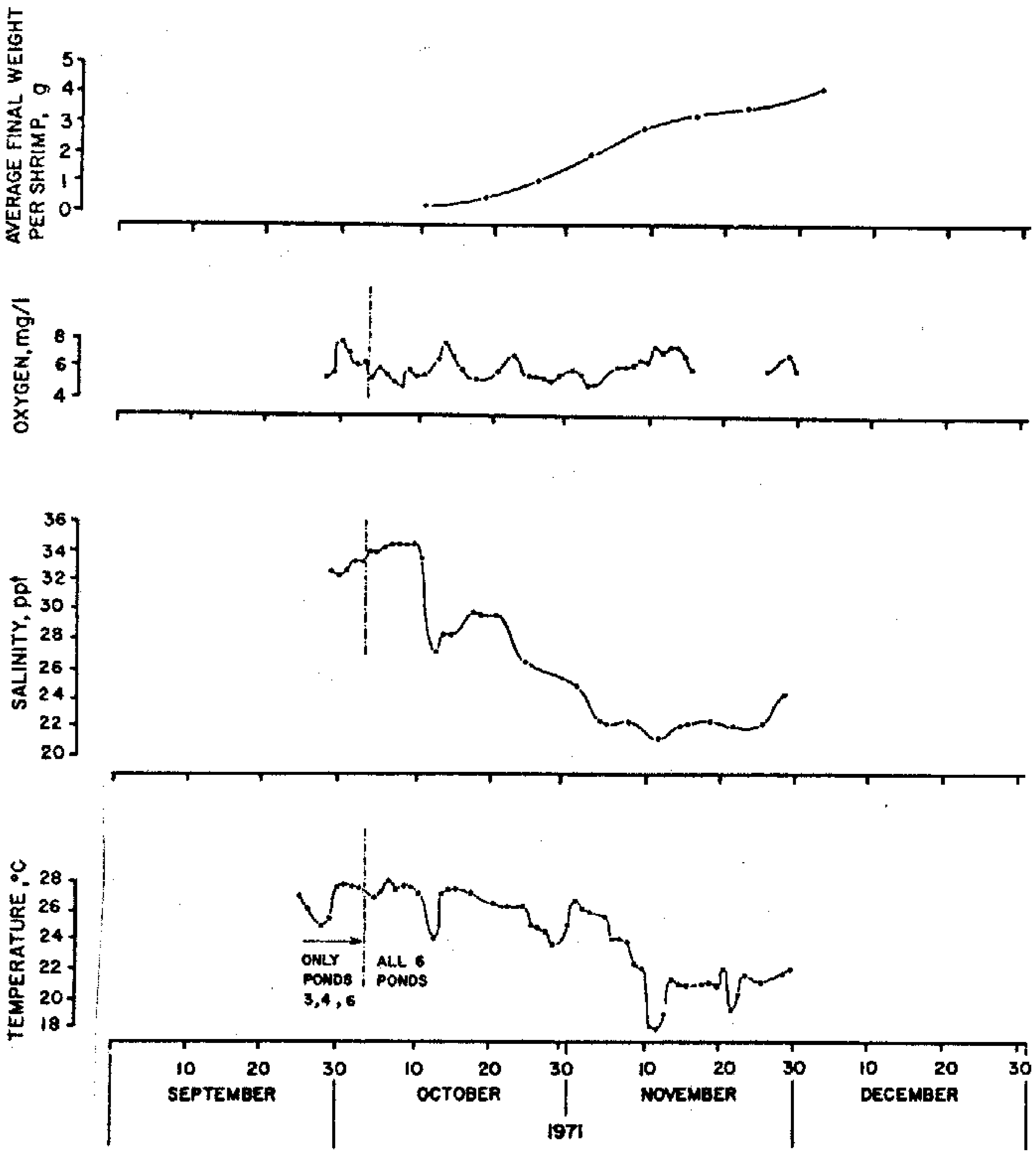

Figure 6. Average weight per shrimp, oxygen, temperature and salinity during the third experiment in 0.08 and 0.16 ha ponds. Values are averages for six ponds after October 3.

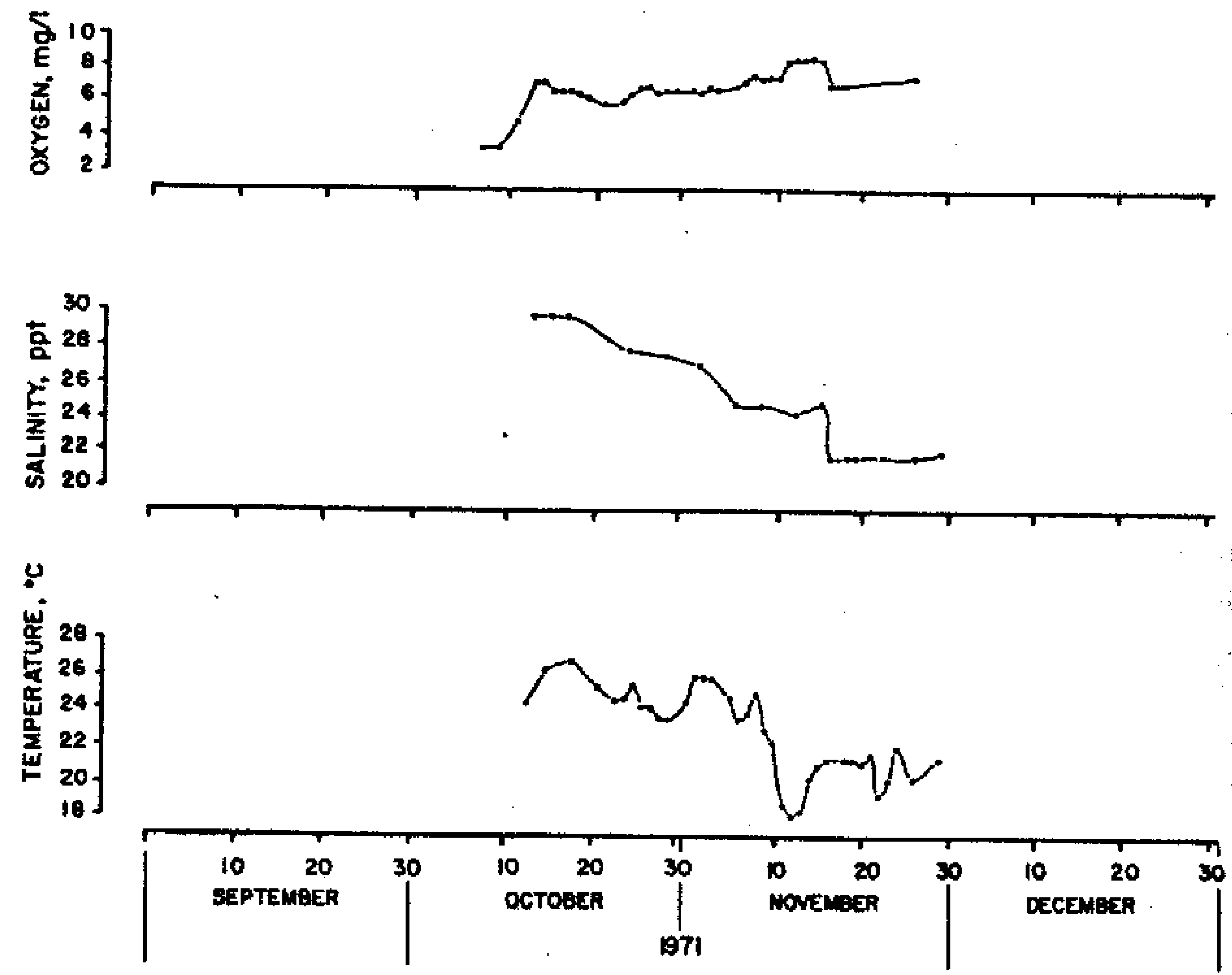

Figure 7. Oxygen, temperature and salinity during the third experiment in concrete tanks. Values are averages for 36 tanks.