POLYCULTURE OF PENAEID SHRIMP IN BRACKISH WATER PONDS RECEIVING POWER PLANT COOLING WATER

A Dissertation

by

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ABSTRACT

Polyculture of Penaeid Shrimp in Brackish Water Ponds Receiving Power Plant Cooling Water

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Penaeid white shrimp *Penaeus setiferus* and blue shrimp *P. stylirostris* and striped mullet *Mugil cephalus* were cultured in 0.1-ha earthen ponds receiving power plant effluent from the Houston Lighting and Power Company's Cedar Bayou Generating Station near Baytown, Texas during 1978 and 1979.

White shrimp were grown in polyculture with blue shrimp or striped mullet and in monoculture. No detrimental effect of either species on white shrimp was found. Blue shrimp yield was greater than that of white shrimp in the same ponds. Total pond yield was increased by polyculture.

An experiment was performed in which blue shrimp were stocked conventionally into ponds, or stocked in 3 temporally separated increments (staggered stocking study). A preliminary experiment was made in 1978, followed by a more expanded version in 1979. The staggered stocking method was found to increase pond yields compared to expected values from the control pond yields. No detrimental effect of staggered stocking on shrimp survival was found. Pond salinities were much lower in 1979 than in 1978, and lower growth, survival

and yield were experienced.

A distribution study performed in the staggered stocking study ponds revealed that blue shrimp in mixed size cultures tend to segregate by size, and that small shrimp show somewhat different distribution patterns and temporal activity patterns than large shrimp.

A related aquarium study indicated that the presence of large shrimp has an inhibitory effect on feeding activity of small shrimp, but that where food is not limited, no detrimental effect of large shrimp on small shrimp growth occurs.

All the organisms used also served as biological monitors of water quality. No dangerously high levels of heavy metals or pesticides were found in any of the cultured animals.

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volume of water than he would if only one species were cultured. This may also apply to more than one growth stage of the same species.

There is currently much interest in the U.S. in the use of waste heat from power plants for aquaculture, including shrimp culture. Heated water from power plant cooling operations may be used to increase the growth rate of cultured animals. Power plant effluents may also cause harm to organisms in the natural environments into which they flow, so animals cultured in effluent water may also serve as biological monitors of the water quality.

The major objectives of my study were the following:

1) To compare the growth, survival and yield of white shrimp (*Penaeus setiferus*) grown in monoculture and in polyculture with blue shrimp (*P. stylirostris*) or striped mullet (*Mugil cephalus*).

2) To compare the growth, survival and yield of blue shrimp grown in conventionally stocked ponds and in ponds stocked with three temporally separated increments of postlarvae.

3) To monitor the growth, survival and condition of white shrimp and striped mullet, two species native to Galveston Bay, cultured in the cooling water of a power plant.

4) To examine the population structure of shrimp in the ponds.

LITERATURE REVIEW AND STATEMENT OF PURPOSE

Thermal Effluents

Thermal effluents from power plants are a potential hazard for surrounding marine or aquatic life which may be exposed to lethally or stressfully high temperatures, supersaturation of gases, high concentrations of heavy metals from corrosion of condenser tubes and chemicals added to inhibit corrosion or fouling (de Sylva, 1969; Friedman, 1972; Becker and Thatcher, 1973; Jensen, 1974; Craddock, 1976). It is therefore important to monitor the quality of effluent water from power plants. This can be done by culturing marine or aquatic animals in power plant effluents and using them as biological monitors of water quality.

A potential benefit of waste heat from thermal effluents is its application to commercial aquaculture and mariculture (Yee, 1972a; 1972b). Heated water may be used to enhance growth rates, prolong growing seasons and overwinter broodstock animals. Thermal effluents have been used for penaeid shrimp culture on an experimental or pilot scale for some years, indicating that all of the above benefits may be applied to them (Parker et al., 1974; Conte, 1975; Chamberlain et al., 1980).

In my study I hoped to demontrate the benefits of thermal effluents in prolonging growing seasons and overwintering shrimp in ponds. My culture animals were also used as biological monitors of water quality.

Species Used

Penaeid shrimp, Penaeus setiferus and P. stylirostris

The white shrimp, Penaeus setiferus, occurs on the east coast of the U.S. and in the Gulf of Mexico. It is one of the 3 most important commercial species in the Gulf of Mexico. It is fished in bays and shallow offshore areas with mud and clay bottoms. It spawns from March to September, peaking in midsummer (Lindner and Cook, 1970). The blue shrimp, P. stylirostris occurs naturally from the northern Gulf of California in Mexico to northern Peru, and is an important commercial species throughout most of its range (Brusca, 1973). It is fished from very shallow water to about 12-14 fathoms. It is caught primarily during the day rather than at night, and is therefore presumably more active during the day. Spawning in Mexico occurs from March to early autumn, peaking in early summer (Chapa Saldana, 1959).

The general life cycle is similar for most cultured penaeid shrimp (Wickins, 1976). Mating and spawning occur at sea. In mating, the male attaches a spermatophore to the body of the female. She later emits up to one million eggs which are fertilized by sperm in the spermatophore as they leave her body. She may spawn many times in one season. The eggs are demersal but hatch within about one day into planktonic larvae. Larval stages include the nauplius (yolk-sac stage), protozoea and mysis, each with several substages. As postlarvae the shrimp enter estuaries and bay where they settle and take up a benthic life. Juvenile shrimp remain in the estuaries for sime months, but as they begin to mature, they migrate back out to the open sea where they complete there life cycle as adults. This description is true for both species treated here (Lindner and Cook, 1970; Chapa Saldana, 1959).

Penaeid shrimp in general are omnivorous scavengers or detritus feeders primarily feeding on small crustaceans, polychaetes, algae and detritus. They exhibit a fairly continuous browsing feeding behavior (Wickins, 1976).

In general shrimp can withstand a wide range of temperatures and salinities; rapid changes of these parameters may occur in an estuarine environment. It is important for the culturist to know what the critical levels of environmental factors are for the species cultured to avoid lethal or stressful levels. Huang (1983) found incipient upper lethal temperatures to be 38 to 40 C for P. stylirostris acclimated to 25 to 35 C. He found optimum salinity for growth and survival is 25 ppt, and that 5 ppt had a negative effect on growth, survival and ability to tolerate high temperatures. Postlarval blue shrimp acclimated to 29 C and 36 ppt have been found to withstand 15 C but die at 10 C (Gabriel Ojeda, Instituto Tecnologico y de Estudios Superiores de Monterrey, unpublished data). Hysmith and Colura (1976) found higher salinities increased survival of white shrimp in ponds at 7, 15 and 21 ppt. Resistance to extremes of temperature is generally reduced by exposure to stressful levels of salinity and vice versa (Wiesepape et al., 1972). Oxygen levels below 2 ppm are generally considered stressful to shrimp (Broom, 1971).

Striped mullet, Mugil cephalus

The striped mullet, Mugil cephalus, (also known as the grey mullet) is a panamic species occurring in all the world's oceans between latitudes 42 N and 42 S (De Silva, 1980). It is generally considered to be a catadromous speces, with breeding occurring at sea and the young migrating into low salinity bays and estuaries (Thomson, 1966) but it may complete its entire life cycle in exclusively marine or freshwater environments (Thomson, 1966; Johnson and McClendron, 1970). The species is tolerant to a wide range of temperatures (3-35 C) and salinities (0-38 ppt) (Sylvestor, 1974; Sylvestor et al., 1974). Salinity has little effect on growth rate of the striped mullet (De Silva and Perera, 1976).

The food habits of the striped mullet change with age; they feed on zooplankton as postlarvae, increasingly switch to phytoplankton up to about 40 mm in length, and are associated more with the bottom and a detritophagous life style as larger fish (De Silva, 1980). They may strain organic material from ingested substrates or they may graze on the microflora of diatoms and blue-green algae on the pond bottom (Thomson, 1966). They may continue to obtain some food from near the surface, especially during algal blooms (Odum, 1968).

The striped mullet is not considered a highly desirable food fish in the United States, except in isolated areas such as Hawaii and Florida, but the U.S. mullet fishery is the most productive in the world (Thomson, 1966). In other parts of the globe, the striped mullet is a sought-after species commanding a good price. It is cultured commercially in the Indo-Pacific region, Italy and Israel, often in polyculture with other species of fish and sometimes shrimp (Bardach et al., 1972; Prugenin et al., 1975; Korringa, 1976).

Spawning of striped mullet has been induced in captivity both in fresh (Yashouv, 1968) ans salt water (Shehadeh and Ellis, 1970), and techniques for larval culture have been worked out (Nash et al., 1974). However, since artificial spawning is not yet routine, fry are normally collected from the wild to stock culture ponds (Prugenin et al, 1975;Korringa, 1976; Bishara, 1978). Fry shortages due to overfishing are becoming a problem in Israeli mullet culture (Chervinski, personal communication).

Shrimp Mariculture

Historical Overview

Shrimp mariculture has become of increasing interest in the western hemisphere in recent years, but it is not a new idea. Shrimp have been cultured in Southeast Asia for at least five centuries (Bardach et al.,1972). In the traditional method of extensive culture, shrimp were recruited incidentally with tidal flow into fish ponds or rice fields.

More intensive methods of shrimp culture have been developed in Asia in the twentieth century. Singapore is credited with being the first country to initiate monoculture of shrimp (Bardach et al.,19 72) but most of the modern techniques were developed in Japan, which is the most advanced country in the world today in the field of shrimp mariculture (Bardach et al., 1972; Schafer, 1971).

Japanese shrimp culture techniques were introduced to the United States by Dr. Motosaku Fuginaga during the late 1950's and early 1960's (Hanson and Goodwin, 1977). Since then interest in shrimp culture has been growing steadily in the U.S. The most long-standing shrimp culture venture in the U.S. is Marifarms, Inc., near Panama City, Florida, which has been culturing shrimp in two 120-ha ponds since 1967. One of the most recent ventures is that of the Grace Company in conjunction with the University of Arizona Environmental Research Laboratory to develop a commercial shrimp farm in Hawaii using open-system raceways.

Although no commercial shrimp culture venture in the U.S. has yet reported a profit, the consistent high market price and demand for shrimp, coupled with continued efforts in shrimp culture research, ensure perennial optimism among workers in the field that economic success cannot be far away.

In other parts of the world, commercial shrimp culture remains important in Southeast Asia, Taiwan, the Philippines (Ling, 1972; Liu and Mancebo, 1983) and Japan (Shigueno, 1975). More recently it has become more important in other areas of the world, such as Australia (Anonymous, 1977) and Latin America, in particular Barizil (Anonymous, 1978; EEG-Pesagro-Rio, 1983), Costa Rica (Ministerio de Acuicultura y Ganaderia, Costa Rica, 1980), Ecuador (Barragan, 1977), Honduras (Direccion General de Recursos Naturales Renovables, de Honduras, 1979), and Peru (Instituto del Mar del Peru, 1979). World-wide, at least 34 species of marine shrimp have been cultured commercially or experimentally, including members of the genera _Artemesia_, _Metapenaeus_, _Penaeus_, _Trachypenaeus_, _Xiphopenaeus_ and _Hymenopenaeus_ (Wickins, 1976).

Seed Stock for Shrimp Mariculture

Seed stock from wild sources. In some extensive methods of shrimp culture, postlarval seed stock is collected in the wild for stocking in ponds (Ling, 1972). This method has obvious disadvantages; it is labor intensive and may result in overfishing and depletion of wild shrimp. Also, stocks are limited. A more efficient method is to fish gravid females (with mature ovary and attached spermatophore) from the wild, then spawn them in captivity and rear the larvae in the laboratory. The first laboratory spawning success was reported by Hudinaga (1942) in Japan. After years of development, this technique supplies seed stock to large-scale commercial operations in Japan. The method is so successful here because the Japanese market demands live shrimp. Gravid females are brought alive to the market place by ~~the~~ commercial fishermen, so their collection requires little effort by the shrimp culturist, other than transport from the market to the laboratory (Shigueno, 1975).

In other areas, such as the Gulf of Mexico, shrimp are dead by the time they reach the market, so special trips need to be made by the culturist to obtain gravid females. This may be costly and success is not always certain. In addition it may be desirable to obtain seed stock for growout outside of the normal spawning season of the desired species. These considerations have led to much research in the field of induced maturation and spawning of shrimp under controlled conditions.

Laboratory maturation and spawning. Several penaeid species have matured and spawned viable eggs under laboratory conditions. These include *Penaeus monodon* (Santiago, 1977; Primavera, 1978; Aquacop, 1979; Beard and Wickins, 1980), *P. stylirostris* (Aquacop, 1979; Brown et al., 1980; Chamberlain and Lawrence, 1981), *P. vannamei* (Aquacop, 1979;

Chamberlain and Lawrence, 1981), *P. japonicus* (Aquacop, 1975; Laubier-Bonichon and Laubier, 1976), *P. mergiensis* (Aquacop, 1975; Beard et al., 1977), *P. aztecus*, *Metapenaeus ensis* (Aquacop, 1975) and *P. setiferus* (Lawrence et al., 1980). Among the techniques used to induce maturation and spawning are control of light intensity, photoperiod, temperature and food, unilatureal eyestalk ablation and artificial insemination.

Manipulation of environmental parameters should allow year-round maturation of shrimp in the laboratory. This has apparently been accomplished for blue shrimp (H.O. Pursyn, Hatchery Manager, Ralston Purina, Inc., Crystal River, Florida, personal communication), but as yet, no thoroughly reliable, routine source of postlarvae is available in the United States. Until such a source exists, shrimp culture cannot become economically viable in this country (Conte, 1978), therefore controlled reproduction of shrimp remains a high-priority research area in shrimp mariculture.

Although several successive laboratory generations of some species have been obtained (Aquacop, 1979), as yet no selective breeding experiments with penaeid shrimp have been reported.

Larval culture. Once fertilized eggs have been obtained, it is a relatively routine procedure to culture the shrimp to postlarvae suitable for stocking in grow-out systems. Larval shrimp culture was pioneered in Japan by Hudinaga (1942). After years of research, the Japanese technique of commercial larval culture is the following (Shigueno, 1975). Eggs are spawned, hatched, and the larvae cultured in natural sea water in the same large, aerated, concrete tank, 60-200 m^3 in capacity. Temperature is kept near optimum levels by heaters. After the eggs hatch, chemical fertilizers are added to the tanks to stimulate growth of diatoms, which the larvae feed on during the zoea and mysis stages. During the last larval stage brine shrimp (*Artemia salina*) nauplii are added to the tank; these are consumed by the postlarval shrimp. Six-day-old postlarvae (PL_6) are fed minced clam or formula feed. They are cultured until the PL_{20-30} stage, when harvesting occurs. Naupliar hatching rates are about 50%, and typical larval survival is 43.6% from nauplius to PL_1, and 47.7% from PL_1 to harvesting. Postlarval production is about 16,400 individuals per 1000 liters at the PL_1 stage, and 9,410 per 1000 liters at harvest.

Japanese methods of larval culture have been adapted and modified by workers at the National Marine Fisheries Service, Galveston, Texas (Mock and Murphy, 1970; Salser and Mock, 1974; Mock and Neal, 1974; Mock et al., 1980). The "Galveston technique" as described by Mock and Neal (1974) and Mock et al. (1980) involves much stricter control of environmental conditions than the Japanese technique. Gravid females are spawned in conical 400-L tanks equipped with airlift pumps. Viable eggs are transferred to round fiberglass 1,900-L rearing tanks where they are reared to postlarvae, as many as 500,000 per tank (about 250,00 per 1000 liters). Shrimp are fed pure cultures of fresh or frozen algae (Skeletonema or Tetraselmis) or active dry yeast during the zoea stage, and brine shrimp nauplii during the mysis and early postlarval stages. Hatchery water is treated with UV light to eliminate contaminating organisms. Temperature and salinity are controlled throughout the culture period, and survival from egg to postlarva is consistently 80% or higher. The Galveston technique thus gives superior results than the Japanese techniqe, and at a lower cost per postlarva produced (Mock and Neal, 1974).

An important problem in larval culture is the high cost and limited supply of brine shrimp eggs (Hanson and Goodwin, 1977). Current research efforts are attempting to find a suitable, less expensive substiture for brine shrimp nauplii, such as rotifers (Fontaine and Revera, 1980) or artificial diets (Teshima et al., 1983).

Grow-out Systems

Mariculture methods are classified on a gradual scale from extensive culture to intensive culture, with the degree of intensity referring to the degree of environmental control exercised by the culturist (Neal, 1973a). Culture in natural water bodies without supplementary feeding or fertilization would be classified as extensive; reaceway culture with a high degree of environmental control is intensive. Since there is no very clear-cut agreement on how to classify culture systems that fall between these extremes, for my review I will classify shrimp culture systems into 3 basic types: culture in natural water bodies, pond culture and raceway culture.

Culture in natural water bodies. It is sometimes difficult to decide when to call a production system a fishery and when to call it an extensive culture system. An example of this problem is shrimp production in lagoons on the Pacific coast of Mexico. Postlarval shrimp emigrate into the natural lagoons, and would normally migrate back out as juveniles, but their exit is prevented by the placement of screening devices called tapos over lagoon mouths. In addition, artificial artificial canals are dredged in the lagoons to facilitate postlarval entry and to concentrate the juveniles as they move toward the lagoon mouth. Juvenile shrimp are harvested commercially with castnets as they congregate in the canals and at the tapo. Yields from lagoons are about 100 kg/ha/yr of tails (Edwards, 1978).

A more intensive system is that employed by Marifarms, Inc. in Florida in the early 1970's. Postlarval shrimp were produced from hatcheries and stocked into progressively larger net enclosures as they grew, to be released finally into a 1000-ha embayment with tidal water exchange and a net at its mouth to prevent shrimp escape. Shrimp were fed supplementally, and harvested by trawling (Hanson and Goodwin, 1977). The system is no longer used because predation and net fouling problems caused economic losses. The company now uses only pond culture.

Pond culture systems. Culture of shrimp in ponds may also be by extensive methods, such as the traditional practices in the Indo-Pacific region. This method, like the Mexican lagoon system, takes advantage of the natural movement of shrimp postlarvae into shallow areas. Sluice gates allow the postlarvae to enter earthen ponds at high tide. They remain there without feeding or fertilization until they are harvested (Mistakidis, 1967; Bardach et al., 1972).

Pond culture offers much greater scope for environmental control than culture in natural water bodies, and many improvements have been made on the traditional culture system to increase yields. These include collection and stocking of additional fry, fertilization of ponds to increase primary productivity and ultimately shrimp food organisms, supplemental feeding, periodic drying of pond bottoms, control of pond soil pH by liming, poisoning of predators and competitors and control of water exchange (Association of Southeast Asian Nations, 1978). Typical yields from shrimp ponds in the Indo-Pacific region vary between 25-1600 kg/ha/yr, with the more intensively-managed ponds giving the highest yields (Bardach et al., 1972).

Shrimp pond mariculture in Japan is generally referred to as intensive (Bardach 1972; Schafer, 1971). Techniques include careful preparation and drying of pond bottoms, supplemental feeding of high-quality protein (Clams), 20-25% water exchange per day, pond aeration, and sometimes use of false bottoms to improve the quality of the sand the shrimp burrow in. All postlarvae are hatchery-reared. The national average commercial production is about 2,000 kg/ha/yr (Shigueno, 1975; Korringa, 1976).

Shrimp pond mariculture in the United States is still largely experimental. Pond sizes generally range from .1 to 8 ha, with the exception of two 120-ha "ponds" belonging to Marifarms, Inc. Commercial pilot operations stock usually between 60,000-180,000 shrimp per hectare, feed supplemenally at 5-15% of estimated shrimp body weight per day and achieve yields generally near 540-960 kg/ha of edible market-sized shrimp (Hanson and Goodwin, 1977). Marifarms average production is about 545 kg/ha/yr (McVey, 1980). Some maximum reported yields from experimental ponds are 2,331 kg/ha in 140 with Penaeus vannamei (Trimble, 1980), 1,715 kg/ha in 139 days with P. stylirostris, and 1,132 kg/ha in 142 days with P. setiferus (Parker, 1978).

Parker et al., (1974) describe a multiple cropping system utilizing 3 ponds of .05, .1 and .2 hectares. The system is designed for maximum space utilization. Postlarvae are stocked into the smallest pond, then moved successively through the larger ponds as they grow. By this means 3 separate crops can be moving through the system at any one time allowing more than one crop pre season to be harvested. They have acheived a marketable yield of 5,680 kg/ha for the whole system in one growing season. Predicted possible yields for such a system are as high as 31,360 kg/ha/yr, based on the assumptions of 7 crops per year, a 4,480 kg/ha/crop average yield and use of heated raceways for postlarval culture (Glude, 1977). However, this projection is overly optimistic; it assumes unlimited postlarval availability and high yields which have not proven to be consistently reproducible. Therefore such a scheme is not likely to be realized in the very near future.

Many factors affect growth and survival of shrimp in ponds. The species of shrimp stocked is of great importance. In pond studies, P. setiferus has been found more desirable for culture than the other 2 native species, P. aztecus and P. duorarum (Broom, 1968; More, 1970; Neal and Latapie, 1972; Parker and Holcomb, 1973), but has grown more slowly and produced less will than the exotic species P. vannamei and P. stylirostris (Dr. Jack Parker, Texas A&M University, personal communication). Growth rate generally decreases and yield increases with increasing stocking density if survivals are similar (Quarberg, 1974; Caillouet et al., 1974; Reitsema, 1975; Association of Southeast Asian Nations, 1978; Hardin, 1981). Survival generally increases if juvenile rather than postlarval shrimp are stocked (Hanson and Goodwin, 1977), predators are controlled (Parker et al., 1972) and shrimp are fed supplementally (Neal and Latapie, 1972). Survival is adversely affected by disease outbreaks (Johnson et al., 1973) and poor water quality such as low dissolved oxygen levels. Growth is enhanced by supplemental feeding (Broom, 1970; Reitsema, 1975; Hysmith and Colura, 1976; Fredieu, 1978; Rubright et al., 1981) and fertilization (Furness, 1978; Rubright et al., 1981). Larger ponds (.2 ha) have been found to give better shrimp growth than smaller ones (.1 ha) (Elam and Greene, 1974).

An important problem in pond culture is lack of predictability and consistency in shrimp survival. Survival of shrimp in ponds is extremely variable and the causes of high mortality are often undeterminable. This problem is a major block to making commercial shrimp pond mariculture economically feasible in the U.S. (Sparks, 1971; Neal, 1973b). It is extremely important to be able to accurately estimate the shrimp survival in ponds for feeding purposes. If survival is overestimated, overfeeding will result causing economic losses from wasted feed, and possibly water quality problems as uneaten food decomposes. Underestimations result in underfeeding and possibly depressed shrimp growth.

At present, there is no easy, reliable method for estimating standing shrimp populations in ponds (Hanson and Goodwin, 1977). Mark-recapture procedures give fairly accurate estimates of shrimp pond populations, but are too labor-intensive to be considered as a routine procedure in commercial culture (Baxter, 1972; Hutchins et al., 1980). Various types of gear have been used to estimate shrimp populations, but not with very consistent results. Quarberg (1974) and Reitsema (1975) both concluded that castnets give more accurate population estimates than either pushnets or seines, but their results were still quite variable. Hand-operated trawls do not give satisfactory estimates either (Hanson and Goodwin, 1977). Hutchins et al. (1980) developed a sampling procedure using a castnet that shows some promise, but the mean difference (in absolute value) of the predicted from the actual populations was 21.9%, with deviations of over 40% recorded. Population estimates are complicated by the patchiness of shrimp distribution in ponds, that may vary with wind direction, time of day and temperature (Furness and Aldrich, 1979; Chamberlain et al., 1980; Hutchins et al., 1980).

Raceway culture. A further intensification of shrimp culture methods in recent years has been the development of man-made raceways for grow-out. Open-system raceways (i.e. those using once-through water flow) have been used experimentally for shrimp culture for several years in Mexico as a joint project of the Universities of Arizona and Sonora. Shrimp are stocked at high densities in nursery systems (500-600/m^2) and later in grow-out systems (170/m^2) to reach a final weight of about 21 g in a total of 7 months from the postlarval stage. Almost all their nutrition comes from formulated diets. Repeated yields of over 2.5 kg/m^2 (25,000 kg/ha) have been achieved in this system (Salser et al., 1978; Perez Alvidrez, 1978). A recent maximum yield of 7.9 kg/m^2 of P. vannamei with a food conversion ratio of 2 has been recorded from such a system in Hawaii (Dr. Neal Hicks, University of Arizona Environmental Research Laboratory, personal communication). A closed-system raceway (involving recycling of water) has been developed and used to produce bait-sized shrimp on as experimental scale (Mock et al., 1977).

Raceway culture offers certain advantages over the more extensive pond culture techniques. There is greatly increased visibility and accessability of shrimp in raceways making monitoring of survival, growth and well-being far easier. Other advantages include elimination of predation problems, greater ease of disease treatment and harvesting, and the opportunity to manipulate environmental parameters such as temperature, salinity and flow rate to optimum conditions for shrimp growth, thus maximizing stocking densities and yields. Furthermore, closed systems offer the possibility of removing shrimp entirely from coastal areas to any desired location (Hanson and Goodwin, 1977; Salser et al., 1978).

Raceway culture has disadvantages as well when compared to pond culture. High shrimp densities contribute to cannibalism and exacerbate disease problems, a nutritionally complete diet must be fed considerably raising feed costs, and very high water quality must be maintained. Capital required, operating costs and the level of technical skill required are greater in raceways than in ponds (Perez Alvidrez, 1978; Salser et al., 1978).

Open-system raceways have given good production, but diseases and cannibalism still remain problems causing variation in survival (Perez Alvidrez, 1978). Closed system raceways pesent a variety of technical problems in waste removal and maintainance of high water quality. More basic research is required to determine the most efficient methods of recycling water (Kennedy, 1980). However, in spite of remaining problems, some investors beleive shrimp mariculture in both open and closed raceways is now economically feasible. The Grace Company is planning a commercial farm in Hawaii using open-system raceways. Aquabiotics, Inc. hoped to culture marine shrimp in closed system raceways in Illinois, with a target production of

55,000 kg/week (McVey, 1980). The company has since gone out of business, but its failure was apparently due to administative rather than technical problems (Dr. Robert Brick, Oceanic Intitute of Hawaii, formerly with Aquabionics, Inc., personal communication).

Culture in laboratory aquaria

Culture of shrimp in laboratory aquaria is the most intensive culture system type. The culturist has nearly complete control of the environment of shrimp in laboratory tanks. Such systems are not applicable to commercial grow-out of shrimp, but have commercial applications in the maturation, spawning and larval rearing of shrimp. Also, laboratory tanks are vital to shrimp mariculture because they are the media of basic research. Nutrition, behavior, environmental tolerances and disease studies all require the use of laboratory aquaria. The lack of a sufficient data base from such research certainly contributes to the unpredictability of shrimp in pond culture. Intensified efforts in basic research areas are required before shrimp mariculture becomes a commercial reality in the United States.

Shrimp Nutrition

Knowledge of shrimp nutrition can be divided into 2 basic areas: 1) Pure nutrition, or knowledge of the quantitative and qualitative requirements of amino acids, fatty acids, sterols, vitamins, carbohydrates and minerals, and 2) Practical nutrition or knowledge of compounds sufficient to provide the essential requirements.

Some, but not all of the nutritional requirements of shrimp are understood. Eleven amino acids are known to be essential to shrimp. They are methionine, valine, phenilalanine, isoleucine, threonine, tryptophan, histidine, arginine, lysine, leucine and tyrosine (Cowey and Forster 1971; Shewbart et al., 1973). The quantitative requirements of each amino acid have not yet been determined, but it is suggested that that a balanced diet should contain the same proportion of amino acids as that of shrimp tissue (Deshimaru and Kuroki, 1975; Colvin, 1976; Colvin and Brand, 1977). Shrimp, like most commercially important aquatic organisms, require higher amounts of protein than commercially produced land animals such as poultry, cattle and swine (New, 1976). In pure nutritional studies 50% protein diets have given the best growth (Kanazawa et al., 1970) while in practical diets 30-36% seems to be the best range (New, 1976). Since shrimp require methionine, lysine and arginine, amino acids found only in small quantities from plants sources, it is necessary to include animal protein in well-balanced shrimp diets. Casein has been the major protein source in purified diets (Kanazawa et al., 1970; 1977a) while fish meal, squid meal and tuna meal are the most widely used sources for practical diets (Zein-Eldin and Corliss, 1976; Brand and Colvin, 1977; Fenucci and Zein-Eldin, 1980). In general, it is felt that about 10% of the protein should be of animal origin.

Few details about shrimp lipid requirements are known. They require fatty acids of the omega-3 family (linolenic acid) rather than the omega-6 (linoleic) family required by land animals and humans (Kanazawa et al., 1977a; 1977b). They also require long chain unsaturated fatty acids because their ability to elongate fatty acids is poor (Kanazawa et al, 1979). Sources of such fatty acids are oils derived from marine animals, such as herring oil, cod liver oil and squid oil. Practical diets usually contain 4-8% oil to fulfill the fatty acid requirements of shrimp. Higher proportions of oil make feeds difficult to prepare and tend to cause rancidity from fatty acid oxidation (New, 1976). One essential lipid for shrimp is cholesterol, and should be added as 1% of the diet (Kanazawa, 1971).

Little is known about carbohydrate requirements of shrimp. Glucose adversely affects shrimp growth while sucrose at levels up to 40% of the diet increases growth (Deshimaru and Yone, 1978; Abdel-Rahman et al., 1979; Pascual et al., 1983). Andrews et al. (1972) found that P. setiferus grew better on diets with 30% starch than on diets without starch. Much more work needs to be done in this area.

Several vitamins have been found to be essential to shrimp, but it is difficult to determine the quantitative levels required because the effects of vitamin deficiencies in shrimp are not well-known, and the time required for shrimp to present pathological symptoms is too long (New, 1976).

Some commercial feeds are available for shrimp pond culture. Although they do not provide all shrimp nutritional requirements (Farmanfarmian, 1979) at least one, Purina Marine Ration 25, does enhance shrimp growth in ponds. Fredieu (1978) found a significant difference in weight gain between unfed shrimp and shrimp fed the Purina ration. Hardin (1981) found this ration to give superior shrimp growth than another commercial shrimp feed (969..R, Central Soya Co.). Rubright et al. (1981) found enhanced growth of shrimp fed this ration, but even greater growth in ponds that were fertilized as well as fed. This indicates that natural pond production is an important part of pond shrimp diets even in supplementally fed ponds.

Several diets that give good growth in intensive culture systems have been described (Shigueno, 1975; Goswani and Goswani, 1979; Fenucci and Zein-Eldin, 1980). Feeds for commercial culture in intensive systems need to satisfy all the nutritional requirements of shrimp at low cost and with little waste. Much information on such diets is proprietary and not available to the public. The University of Arizona Environmental Research Laboratory presently uses a diet of approximately 34% protein supplemented with free amino acids, the major protein sources being fish meal, squid meal, soybean meal and wheat flour (Kevin Fitzsimmons, University of Arizona Environmental Research Laboratory, personal communication).

Diseases and parasites

Shrimp are subject to attack by a wide variety of diseases and parasites. In culture, crowding and other stress factors may allow agents normally present in low numbers to flourish, causing severe mortalities in the cultured populations. Several good reviews of shrimp diseases and parasites are available (Lightner, 1975; 1977; Johnson, 1978).

Lightner (1977) describes the following 14 disease conditions that are actual or potential problems in shrimp mariculture:

1) Virus disease of larvae caused by Baculovirus penaei.

2) Bacterial septicemia caused by Vibrio and possibly Aeromonas and Pseudomonas, attacking stressed or wounded shrimp, or those weakened by another disease.

3) Chitinoclastic bacterial disease caused by Beneckea, Vibrio and Pseudomonas, which eat away parts of the exoskeleton allowing secondary invasion by other pathogens.

4) Filamentous bacterial disease caused by Leucothrix and possibly other filamentous bacteria ar blue-green algae. Death is by asphyxiation when shrimp gills are heavily infested.

5) Larval mycosis caused by the fungus Lagenidium callinectes.

6) Fungus disease by Fusarium solani. The fumgus attacks and grows on damaged tissues creating lesions that may allow entry of other pathogens such a Vibrio.

7) Milk or cotton desease caused by the microsporidians Nosema nelsoni, Pleistophora sp. and Thelohania duorara.

8) Invasion of reproductive organs by the microsporidian Thelohania penaei which sterilizes, weakens or kills shrimp.

9) Ciliate disease caused by Zoothamnium penaei and Epistylus sp., which grow on gills and appendages, interfering with respiration.

10) Black gill disease, cause unknown. The gills turn dark, atrophy, and may be destroyed.

11) "Black death" disease, caused by ascorbic acid deficiency.

12) Blisters, cause unknown. Fluid-containing blisters, usually on the carapace, have been associated with "black death" and fungus disease.

13) Cramped tails, cause unknown, where shrimp tails cannot be straightened.

14) Spontaneous muscle necrosis, caused by stress from overcrowding and sudden environmental changes.

Gas bubble disease may also occur in shrimp as a result of supersaturation of nitrogen in the water (Lightner et al., 1974) or of oxygen supersaturation caused by algae blooms (Supplee and Lightner, 1976). Recently described viral diseases have caused catastrophic losses of raceway cultured shrimp in Hawaii. The only method available for control is complete eradication of affected populations and sterilization of facilities (Lightner et al., 1972; Lightner et al., 1973).

Most of the reported epizootic enfections of the disease conditions described by Lightner (1977) have been in very intensive culture situations such as laboratory tanks and raceways. However, it may well be that disease problems are as important in ponds, the difference being that shrimp in raceways can be seen and their health readily assessed, while they are rarely seen in normally turbid ponds. Sindermann (1971) points out that the often high, unpredictable mortalities observed in ponds may easily be due to disease organisms that are certainly present in ponds, but rarely observed at epizootic levels. He feels that the importance of disease in shrimp culture is severely underrated. Even where disease does not cause marked mortality, it may cuase significant monetary losses. For example, "cotton shrimp" are unacceptable to shrimp processors (Johnson, 1978) and incidence of the condition has reached 15-16% in some pond cultures (Lightner, 1977).

At present, disease control lies mainly in prevention by maintaining good water quality and avoiding overcrowding. Identification of causative agents and development of treatments and controls for recognized diseases remains an important area of research (Hanson and Goodwin, 1977).

Possible disease prevention by immunization is a topic of interest to at least one major researcher. Shrimp have been shown to exhibit a non-specific immunologic response to exposure to *Vibrio* under controlled conditions (Lewis, 1973). Lewis (personal communication) is confident that a method of immunizing shrimp by osmotic infiltration such as is used for cultured salmon and trout can be developed. He feels this may significantly reduce mortality in grow-out ponds. In a pond study, production of *P. setiferus* and *P. stylirostris* was 10-15% greater for shrimp exposed to *Vibrio alginolyticus* bacterins before stocking compared to controls (Lewis and Lawrence, 1983).

Polyculture

Bardach et al. (1972) define polyculture as the culture of different species or age groups in the same habitat. A pond is a 3-dimensional habitat that provides several distinct niches. Stickney (1978) describes a typical culture pond as composed of three basic zones: 1) the fairly flat bottom, or benthic zone, where benthic invertebrates predominate, 2) the shallow water above the sloping pond banks, or macrophyte zone, where rooted plants most often occur, and 3) the open water above the pond bottom, the pelagic zone, where phyto- and zooplankton are most abundant. A single species cultured in a pond may not utilize all the available space and potential food organisms. Therefore, total production of cultured animals from a pond can often be increased by polyculture of different species or age groups that eat the natural food in the different areas.

It is often stated that successful polycultre is that which stocks non-competetive species together (Stickney, 1978). However, it is important to make a distinction here between scramble competition (use of the same resource, such as food) and interference competition (inhibition of one species performance directly by the other). There is some evidence that scramble competition can be a positive influence in polyculture systems. Black drum (Pogonias cromis) grown in ponds with striped mullet have been found to grow faster than black drum in monoculture ponds (Branch, 1978; Rossberg, 1979). This is apparently due to the actively feeding mullet inducing the

the black drum to consume more food. Also, in tanks, black drum tend to occupy the bottom of the tank in the presence of striped mullet and the upper water column when cultured alone (Gibbard, 1979). Perhaps black drum consume more natural benthic food in pond polyculture with mullet than they do in monoculture. Werner and Hall (1976;1977) have examined competition and nich shifts in two sunfishes, the green sunfish (*Lepomis cyanellus*) and the bluegill (*L. macrochirus*). When each species is stocked alone in ponds, both prefer the food organisms associated with the attached pond vegetation, but when they are stocked together, the bluegill exhibits a niche shift and utilizes smaller prey in the pelagic zone of the pond.

Penaeid shrimp live and feed primarily on the pond bottom, so they are good candidates for polyculture with fish that feed on plankton or macrophytes. Polyculture of penaeid shrimp with the milkfish (Chanos chanos), a macro-algae feeder, is common in Taiwan, the Philippines, Indonesia, Vietnam and Malaysia. The shrimp species used are Penaeus monodon, P. indicus, P. semisiculatus, P. merguiensis, Metapenaeus monoceros, M. joyneri and M. affinis (Ling, 1972; Blanco, 1972). Postlarval shrimp may be stocked purposely in fish ponds or they may enter naturally with tidal flows, but the shrimp crop in thses systems is secondary to the fish crop. For example, in Taiwan, in extensive milkfish pond culture, a crop of about 1,900 kg/ha/yr of fish can be expected. An additional 175-280 kg/ha/yr of P. monodon can be produced in polyculture with milkfish (Chen, 1972).

In India it has been found that polyculture of milkfish, mullet (M. cephalus and others) and shrimp (P. monodon or P. indicus) in unfed ponds is more profitable than monoculture of either milkfish or prawns (Dwivedi and Reddi, 1977). The shrimp in this system account for no more than 13% of the total pond production reported but they bring a price 7-8 times higher than that of the fish, so they are very important economically in this polyculture scheme.

The freshwater prawn, Macrobrachium, occupies essentially the same niche in freshwater ponds that penaeid shrimp occupy in salt water ones. In Texas, Macrobrachium rosenbergii has been grown successfully in polyculture with the primarily herbivorous cichlid, Tilapia aurea. Polyculture increases the total pond production without decreasing the yield of the more valuable prawns (Brick and Stickney, 1979; Rouse et al., 1980).

In some cases polyculture of shirmp or prawns with carnivorous fish is successful. Huner et al. (1980) reported that polyculture of *M. rosenbergii* with channel catfish (*Ictalurus punctatus*) fry did not affect prawn production while allowing more efficient use of pond space. The small size of the fish accounts for their lack of predation on the prawns, which were allowed over a month's growth before the catfish were stocked with them. Trimble (1980) showed that polyculture of Florida pompano (*Trachinotus carolinus*) with blue shrimp could be more profitable than monoculture of either species, even though growth and survival of both were reduced somewhat in polyculture. The economic success of the system is due to the increase in total pond production. Earlier experiments on stocking techniques (Tatum and Trimble, 1978) developed the best method to keep shrimp mortality from pompano predation to a minimum.

There are some other reports of shrimp/fish polyculture. They did not have monoculture controls to assess interspecific competition, but they may indicate potentially successful combinations of shrimp and fish species. Gundermann and Popper (1977) concluded that polyculture combinations of P. monodon, *P. merguiensis* ~~and~~ or *P. japonicus* with three fish species (milkfish, *Tilapia mossambica* ~~and~~ or *Siganus vermiculatus*) were all successful. Silva et al. (1977) reported on polyculture of mullet (*Mugil incilis*) with *Macrobrachium acanthurus*. It may be feasible to grow brown shrimp (*Penaeus aztecus*) at low densities with carnivorous black drum or Florida pompano (Rossberg, 1979).

(Polyculture continued, mixed-size polyculture)

Polyculture of more than one size or age group of the same species may be based on changing food or habitat preferences with age, or merely on maximum space utilization in the pond at all times. In the culture of milkfish in the Indo-Pacific region, fish may be stocked and harvested by 4 basic methods: 1) one size in culture, with one harvest per year, 2) one size at a time in culture, but with several complete harvests per year, 3) 2 sizes in continuous culture with several selective harvests per year, and 4) several sizes in culture, one stocked every 1-2 months, with several selective harvests per year. Method 4) gives yearly pond yields several times greater than method 1) (Ling, 1972). Apparently the small as well as the large milkfish utilize the same food source, benthic algae. But the greater efficiency is attained because the pond can be maintained constantly near its carrying capacity of fish biomass. In single-size culture, much algae goes to waste in the early growth stages of the fish, so pond carrying capacity is not not finally reached until the fish are harvested (Tang, 1972).

In Israel, farmers used to grow 2 sizes of common carp (*Cyprinus carpio*) together, fingerlings and fish fattening for market, in an effort to more efficiently utilize culture ponds (Palewsky and Sarig, 1954; Yashouv, 1966). However, Yashouv (1969) showed that there was significant intraspecific competition between the 2 groups, greater than that between carp and other species of fish. As a result, mixed size culture of carp was discontinued and replaced entirely by multi-species polyculture in Israel (Reich, 1975).

Freshwater prawns are routinely cultured commercially in mixed sizes in Hawaii. Postlarvae are stocked once or twice per year, and larger prawns are selectively harvested every few weeks by seining. Culture is year-round, and ponds are not normally completely emptied. This method gives average pond yields of over 3,000 kg/ha/yr (Hanson and Goodwin, 1977).

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Statement of Purpose

I hoped by my studies to contribute to the body of knowledge related to shrimp mariculture, primarily in the area of polyculture. Since there is so much interest in shrimp/fish polyculture in some parts of the world, I hoped to demonstrate whether striped mullet had a detrimental effect on white shrimp in polyculture. I also hoped to show whether polyculture of white shrimp and blue shrimp, a combination not reported in the literature, might be more profitable than white shrimp alone. I attempted to show whether culture of mixed sizes of shrimp might improve pond yields. This is known to occur in some fish species and in the fresh water prawn, but has not been studied in penaeid shrimp. In supplementary studies, I attempted to add to the understanding of shrimp movements in ponds, which might give clues to better estimations of populations. By conducting a controlled laboratory experiment I tried to contribute to basic knowledge about shrimp biology and behavior.

DESCRIPTION OF THE STUDY SITE

The Power Plant

The study site was the Houston Lighting & Power Company's Cedar Bayou electric generating station near Baytown, Texas. There are three 750-MW units in the power plant, whose cooling requires up to 253.4 X 10^3 m^3/hr (66.94 X 10^6 gal/hr) of water. The plant draws water for its cooling operation from two sources; it draws fresh water from Cedar Bayou and saline water from Tabbs Bay in the upper Galveston Bay system via Cedar Bayou and a dredged intake canal (Fig. 1). The heated effluent water flows through a 9.8-km discharge canal and a 1053-ha cooling lake before being discharged into Trinity Bay, an estuary that is fringed by considerably less industrial and urban development than the intake area. The power plant adds some pollutants to the discharge water in the form of heavy metals leached from conduit walls by the salt water and chlorine used to control fouling organisms in the cooling apparatus. This system has caused fears of environmental damage to Trinity Bay by addition to it of water that is more polluted, more saline, and warmer than the bay (Carter, 1970).

The Ponds

About 200 m from the origin of the discharge canal are 25 0.1-ha earthen ponds arranged in a single row (Fig. 2). They are approximately 82.3 m long, 12.2 m wide and vary in depth from about .5 to 1.5 m in a gradual slope from one end to the other. Heated water from the discharge canal enters the ponds at the shallow end, either by gravity flow or by means of a 75-hp pump, through individually regulated 10.2-cm diameter PVC pipes. After flowing through the ponds, water leaves them at the deep ends by way of adjustable, 20.3-cm diameter PVC standpipes.

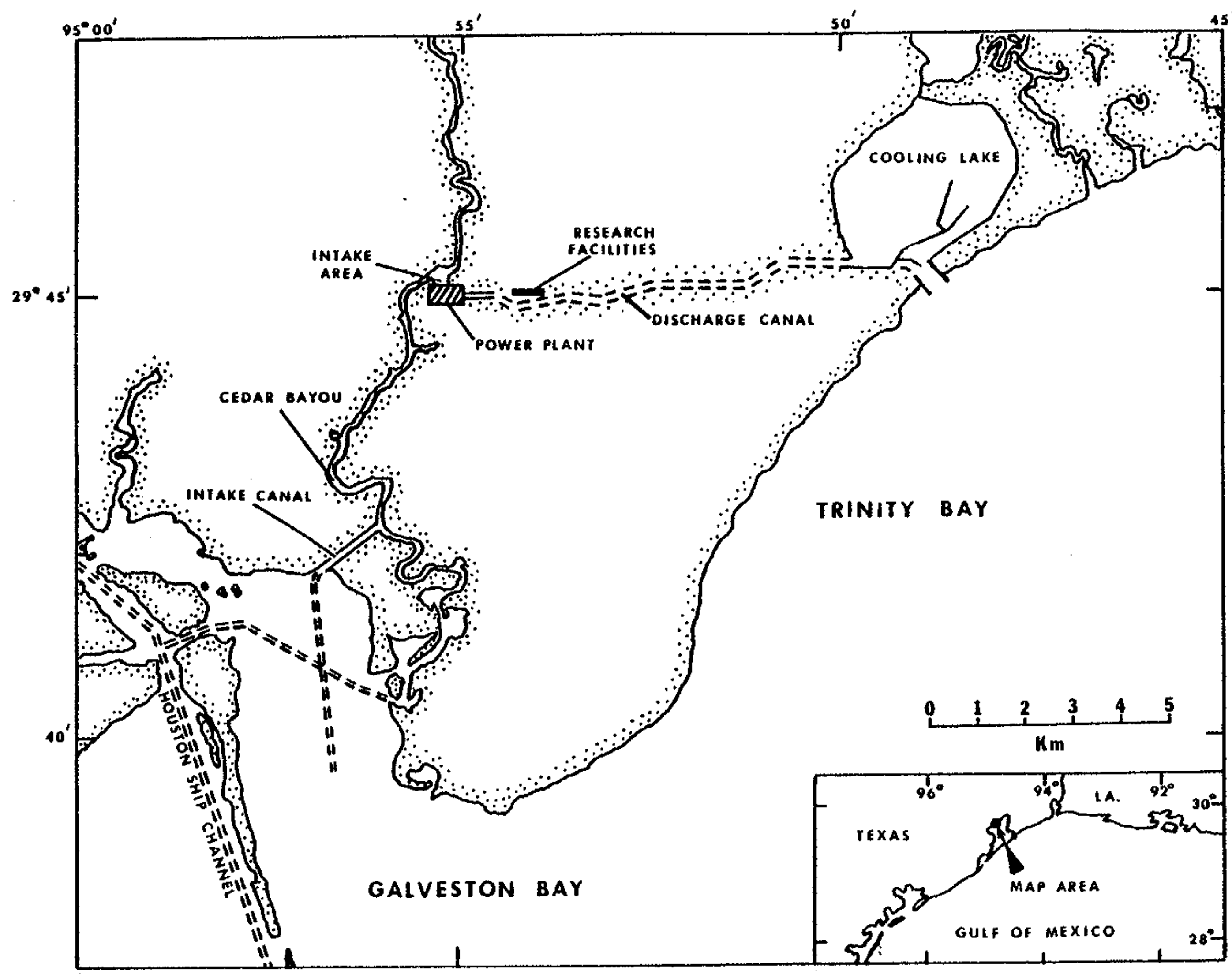

Figure 1. Map of the Cedar Bayou area.

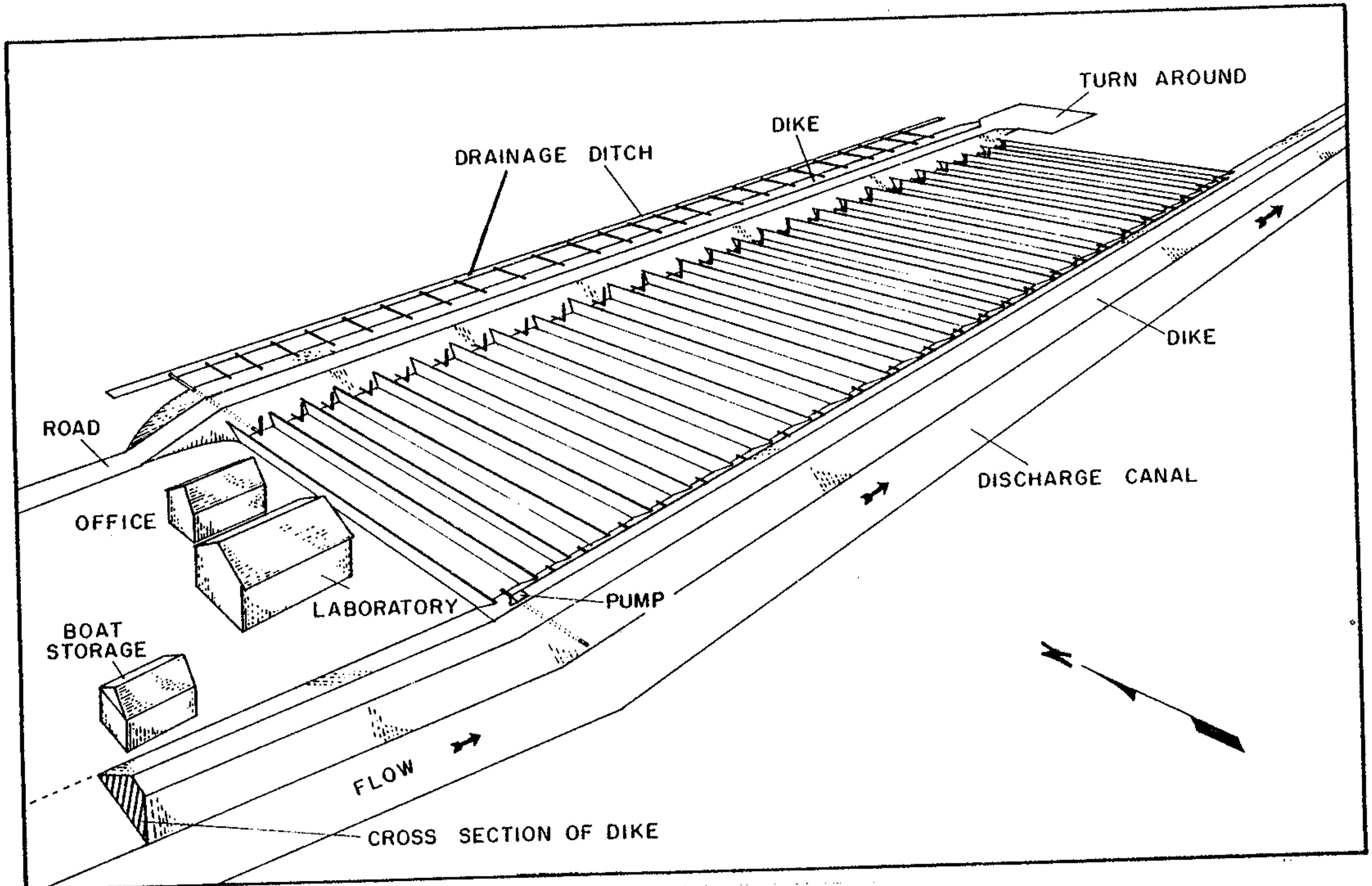

Figure 2. Diagram showing location of the 25 research ponds relative to the discharge canal. Pond 1 is nearest the laboratory.

THE EXPERIMENTS

General Methods and Data Analysis

General Pond Techniques

All ponds were drained and allowed to dry for at least one week before stocking, except where otherwise noted. They were refilled a few days before shrimp were introduced. The ponds received a variable flow of water from the power plant discharge canal; the incoming water was filtered through double thickness nylon bags of 800-μm mesh size to keep out potential competitors and predators. Outlet pipes were screened with suitable mesh sizes to prevent escape of shrimp from the ponds.

Shrimp postlarvae were held from 1 to 4 days in 190-L aerated plexiglass tanks in a greenhouse laboratory and gradually accustomed to pond temperatures and salinities before stocking. While in the tanks they were fed brine shrimp (*Artemia* spp.) nauplii. The postlarvae were caught on hand-sized pieces of fiberglass window screen, counted, and placed in aerated plastic buckets containing pond water in which they were transported to the ponds.

At the time of stocking each batch of postlarvae, a random sample of 100 was measured individually to the nearest 0.5 mm total length, from the tip of the rostrum to the tip of the telson. Sampling for growth in the ponds was done by catching shrimp with a 6.1-m bag seine (6.3-mm bag mesh size) or a 1.22-m radius monofilament line castnet (1.5-cm stretch mesh). The shrimp were individually measured to the nearest millimeter total length, then blotted dry on a paper towel and weighed to the nearest 0.1 g in 1978 and to the nearest 0.01 g in 1979 on either a Mettler P 160N top-pan model balance or a Mettler P T200 digital balance (Mettler instrument Corporation, Hightstown, New Jersey). The shrimp were returned alive to the ponds after sampling. Sample sizes varied with the experiment.

Shrimp were fed Purina Experimental Ration 25 (25% protein, Appendix Table A1) approximately 6 days per week. During the first month after stocking, the feed was ground in a food grinder, mixed with a small amount of water, and applied to the ponds at the rate of 1.360 kg/10,000 shrimp stocked/day. Thereafter, the normal, extruded flake feed was given at an estimated rate of 10% shrimp body weight per day. Survival for feeding purposes was assumed to be 68%.

In 1978, all ponds were fertilized once per week with 4.5 kg of urea until September 1. The practice was discontinued after this date when low dissolved oxygen levels, apparently associated with heavy algae blooms, caused mortalities in 2 ponds.

Harvesting was effected by draining the ponds; shrimp were caught in nylon harvest bags attached to the ends of the drainpipes. Any shrimp remaining in the ponds after draining were picked up by hand. Survival was determined by counting all the shrimp from each pond, and adding the number that had died during sampling or were removed from the pond for other reasons.

Hydrological data were taken near the surface and bottom of each pond with a Hydrolab Model 6D 12.2 Portable Surveyor Unit (Hydrolab Corporation, Austin, Texas) approximately 6 times per week, usually just after 0800 hrs. Readings were temperature to the nearest 0.5 C, dissolved oxygen to the nearest 0.1 ppm, conductivity to the nearest 0.1 mmhos/cm and pH to the nearest 0.1 unit. No pH readings were taken in 1979 due to equipment failures.

Data Analysis

Conductivity values over 20 mmhos/cm were converted to salinity (ppt) by use of a graph provided by the Hydrolab Corporation (Appendix Figure B1). Values less than 20 mmhos/cm were converted by the following equation:

$$\text{Salinity} = -0.2277 + 0.586818\ \text{Conductivity}$$

$$R = 0.9994,\ n = 21,\ P < .0001$$

Shrimp condition coeffiecients (K) were calculated by the following formula, derived by Lagler (1956) and modified by Wheeler (1967):

$$K = \frac{W(10^6)}{L^3}$$

where W = weight (g) and L = length (mm). K is used as a relative measure of plumpness or general well-being of shrimp. The mean length and weight of each sample was used in the formula to calculate the mean condition value. The corresponding formula for fish is:

$$K = \frac{W(10^5)}{L^3}$$

where L = standard length (mm).

Food conversion ratios (FCR) were calculated by the following formula:

$$FCR = \frac{\text{weight of food fed (g)}}{\text{weight gain of shrimp (g) X \# of shrimp harvested}}$$

Pond yields (kg/ha) were calculated by the formula:

$$\text{Yield} = \text{total } wt_f - \text{total } wt_i \text{ X } 10$$

where total wt_f and total wt_i are the mean final and initial weights of the animals multiplied by the number recovered or stocked, respectively.

The formula for instantaeous growth rate (g/g/day or mm/mm/day) is:

$$\frac{\log(wt_f/wt_i)}{\text{\# days}} \text{ or } \frac{\log(lgt_f/lgt_i)}{\text{\# days}}$$

where wt_f, wt_i, lgt_f and lgt_i are the final and initial weights and lengths respectively of the shrimp and # days refers to the number of days in the sample period.

A Hewlett Packard 9830 mini computer was used for basic statistics and to produce plots of the data. The Texas A&M University Amdahl 570 computer was used for analysis of variance, analysis of covariance, regression analysis, Duncan's New Multiple Range tests and other complicated procedures.

Polyculture of White Shrimp With Blue Shrimp or Striped Mullet

Introduction

While multi-species polyculture involving penaeid shrimp is important in other parts of the world, little work on penaeid shrimp polyculture has been done in the United States. The study I performed was designed to answer the following questions:

1) Does polyculture with striped mullet influence white shrimp survival and yield?

2) Does polyculture with blue shrimp influence white shrimp survival and yield?

3) How do growth, survival and yield between white shrimp, an indigenous species, and blue shrimp, an exotic species, compare when the two are grown under identical pond conditions?

4) Can total pond yield be increased by polyculture of white shrimp with blue shrimp or striped mullet?

Materials and Methods

In this experiment white shrimp were cultured alone, with blue shrimp or with striped mullet in 6 ponds, with 2 replicate ponds for each treatment. On July 24, 4 ponds (6,7,21 and 23) were stocked with 4100 white shrimp post-larvae each, and 2 ponds (4 and 22) were each stocked with 1945 white shrimp and 2155 blue shrimp postlarvae for a total stocking density of 4100 shrimp per pond. Mean length of the postlarvae was 5.5 mm for white shrimp and 7.9 mm for blue shrimp. This stocking scheme utilized all the shrimp postlarvae available. A 1:1 ratio of blue to white shrimp in the mixed species polyculture ponds was intended but the actual number of white shrimp present was considerably lower than the hatchery estimate, and there were not enough white shrimp to complete the stocking scheme.

Ponds 7 and 23 were each later stocked with 135 striped mullet collected from Trinity Bay (mean weight 12.3 g). Because of difficulty encountered in collecting sufficient numbers of mullet, they were stocked on 4 separate dates from August 8 to August 29, but the same number was stocked in each pond every time (Table 1). Because of the scarcity of mullet, and limited ponds available, there were no striped mullet monoculture ponds in the study. All fish were weighed to the nearest 0.1 g and measured to the nearest millimeter (standard length and total length) before stocking. They were not sampled again until harvest, when they were drained into the catch bag with the shrimp, counted, weighed to the nearest gram and measured to the nearest millimeter.

Table 1. Numbers stocked and stocking dates for white shrimp, blue shrimp and striped mullet in the mixed species polyculture experiment.

Pond	Species	Date	# Stocked
4	white shrimp	7-24-78	1945
	blue shrimp	7-24-78	2155
	combined		4100
22	white shrimp	7-24-78	1945
	blue shrimp	7-24-78	2155
	combined		4100
6	white shrimp	7-24-78	4100
21	white shrimp	7-24-78	4100
7	white shrimp	7-24-78	4100
	striped mullet	8-09-78	62
	"	8-11-78	30
	"	8-12-78	30
	"	8-29-78	13
	mullet total		135
23	white shrimp	7-24-78	4100
	striped mullet	8-09-78	62
	"	8-11-78	30
	"	8-12-78	30
	"	8-29-78	13
	mullet total		135

Yield of mullet at harvest was calculated using the following formula:

$$\text{Yield} = \sum_{j=1}^{4} \left((wt_f - wt_{ij})(\#\ \text{stocked}_j) \right)$$

where wt_f is the final mean weight for all the fish in the pond, and wt_{ij} and # stocked_j are the initial mean weight and the number stocked for each stocking increment j.

Sampling of shrimp in the ponds commenced one month after stocking and was repeated approximately every 2 weeks thereafter. Sample sizes were 30 shrimp per species per pond. The ponds were harvested on October 21-23, or 89-91 days after stocking, when random samples of 100 shrimp per species per pond were taken for measurement.

White and blue shrimp used in this experiment were obtained courtesy of Dr. Jack Parker, Texas A&M University. The white shrimp postlarvae had been spawned from wild gravid females fished off the Texas coast. The blue shrimp postlarvae were spawned from wild gravid females fished off the coast of Panama.

Since the ratio of white to blue shrimp in the white shrimp/blue shrimp polyculture ponds was not exactly 1:1 as it would have been in the ideal stocking strategy, I also calculated adjusted yields for each species for the two polyculture ponds. The actual stocking ratio of white to blue shrimp in those ponds was .949:1.051. By dividing the actual yield by the proportion of the ideal density that was actually stocked I calculated the yields that would have been expected from each species under identical conditions of growth and survival if the stocking ratio had been 1:1. Where indicated, statistical comparisons were made twice, first using the actual yields, then substituting the adjusted yields to see if the latter would change the observed trends or levels of significance.

Results and Discussion

Hydrological data are presented in Appendix Figures B2-B10. Temperatures during the experiment ranged from 20.5 to 36.0 C near the surface and from 20.5 to 33.0 C near the bottom of the ponds. Pond salinities ranged from 9.7 to 18.2 ppt near the surface and from 9.7 to 18.2 ppt near the bottom. In general, pond temperatures decreased throughout the experiment. Temperatures and salinities were similar in all the ponds and were generally within an acceptable range for good shrimp growth and survival.

Values of pH fluctuated widely during the experimental period (Appendix figures B8-B10). The ranges recorded for near surface and near bottom were 6.9-9.7 and 7.0-9.8, respectively. Dissolved oxygen levels also varied greatly throughout the experiments. The recorded range was 1.2-18.7 ppm near the surface and 0.7-15.2 ppm near the bottom of the ponds. Near bottom levels fell below 2 ppm on several occasions (once each in ponds 4, 21 and 22, and 3 times each in ponds 6 and 7). Levels this low are generally considered stressful to shrimp, but mortalities were associated with low dissolved oxygen on only one occasion. On September 1, near bottom levels were 0.7 ppm in ponds 7 and 21. Eighty-four dead shrimp were collected from the edges of pond 7, and 2 were seen in pond 21.

Survival at harvest was much lower for pond 7 than for the other ponds (Table 2). I felt that this was probably due to low oxygen death rather than an effect of the experimental treatment, so data from that pond were not included in comparisons of survival and yield among the treatments. Since this left only one replicate for the white shrimp/striped mullet polyculture treatment, that treatment was not compared statistically with the others, but the values were used as indicators of trends.

A strong linear relationship was apparent between mean shrimp weight at harvest and percent survival (Figure 3). Regression analysis showed a correlation coefficient of -.97 (P=.006). Since growth so obviously depends on survival, I did no comparisons of shrimp growth among the treatments, but looked rather at survival and yield as the best indicators of shrimp performance. Growth curves for length and weight show generally similar patterns, although some ponds showed faster rates of growth than others (Appendix Figures C1-C8).

There was no significant difference in white shrimp survival between white shrimp/blue shrimp polyculture and the white shrimp monoculture control compared by Students t test (P>.25) (Table 2). Survival in the white shrimp/striped mullet polyculture pond was higher than in the monoculture control, so certainly no detrimental effect of mullet or blue shrimp on white shrimp survival is indicated. Blue shrimp showed a lower survival rate than did white shrimp, both when compared to white shrimp survival for all 5 ponds (P<.05) and when compared only to those grown in polyculture with the blues (P<.06).

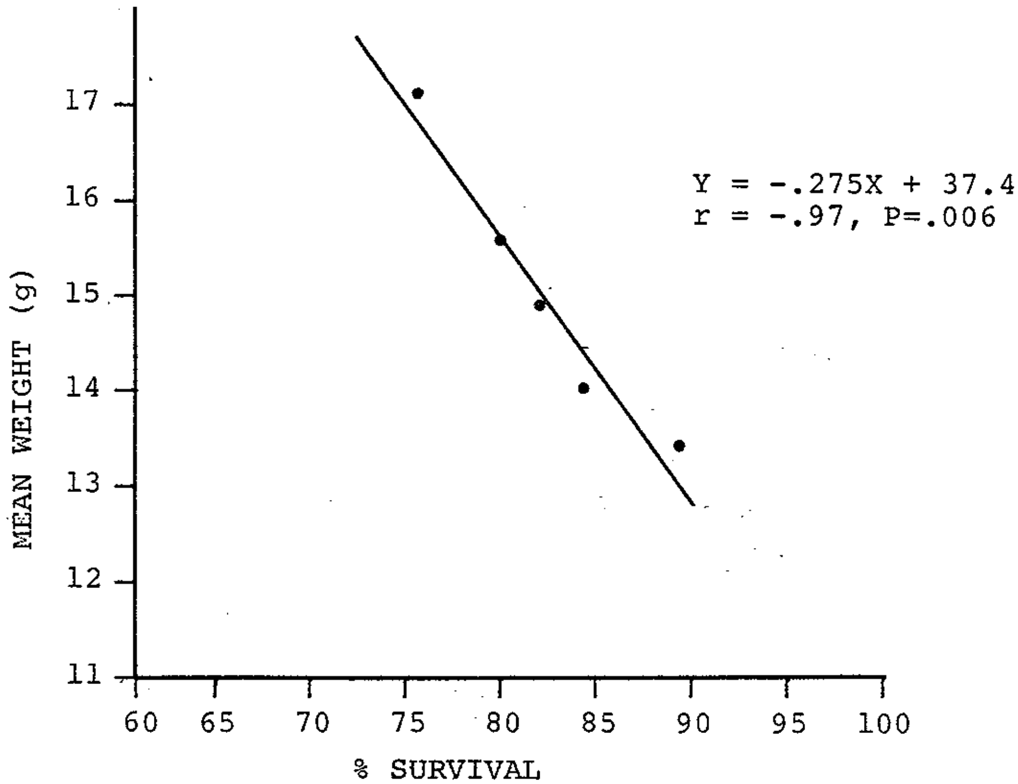

Figure 3 . Relationship between final mean weight and percent survival of white shrimp in the polyculture experiment. Stocking density was 4100 shrimp/0.1 ha pond.

The mean yield of P. setiferus in polyculture with P. stylirostris was compared to one-half the mean yield from the monoculture controls, showing no significant differece ($P < .17$). However, the yield of blue shrimp was significantly greater than that of white shrimp in the same ponds ($P<.005$). (Use of the adjusted yields would not change either the trend seen or the level of significance). Mean yield of white shrimp was only 70% that of blue shrimp, even though survival was better. This was due to the greater final weight of blue shrimp achieved (Table 2). These results indicate that blue shrimp would perform better in general than white shrimp at this facility, but since there was no blue shrimp monoculture control this cannot be stated with any certainty. I know of no studies directly comparing pond performance of blue and white shrimp, but in general blue shrimp are considered to be a more desirable culture species in the Gulf area. Trimble (1980) reported yields of blue shrimp that surpassed yields acieved in previous years with indigenous species, including white shrimp, at the same culture facility in Louisiana. Likewise Parker et al. (1974) achieved yields of blue shrimp higher than those previously recorded for white shrimp at the same Texas facility (Parker and Holcomb, 1973).

When total pond yields are compared, the benefits of polyculture become obvious (Table 3). Mean pond yield (total biomass of cultured organisms) was increased significantly ($P < .04$) from 502 kg/ha in white shrimp monoculture to 586 kg/ha in white shrimp/blue shrimp polyculture. (Again, use of the adjusted yields would not change either the trend seen or the level of significance). Thus it can be stated with confidence that a combination of blue and white shrimp is more desirable than white shrimp alone for culture at this facility. It is not clear whether this is due to any benefit from polyculture or simply due to the greater production of blue shrimp. Certainly there is no indication that the white shrimp received any benefit from the polyculture situation. However, there is some incidental data that suggest

Table 3. Total pond yields (combined yields of cultured organisms) for white shrimp in monoculture, white shrimp and blue shrimp in polyculture, and white shrimp and striped mullet in polyculture.

Treatment	Pond	Total pond yield (kg/ha)	Adjusted Total pond yield (kg/ha)
White shrimp	6	524	
monoculture	21	480	
"	mean	502 a	
white shrimp/	4	587	583
blue shrimp	22	585	581
polyculture	mean	586 b	582 b
white shrimp/ mullet polyculture	23*	634	

*Not compared statistically to other treatments. Means bearing different letters are significantly different (P<.04) compared by Students t test.

blue shrimp may benefit from polyculture with white shrimp. It It was discovered that about 2% of the shrimp in the white shrimp ponds were actually blue shrimp (apparently some accidental mixing occurred in the hatchery). At harvest, these animals were much larger than those in the blue shrimp/white shrimp polyculture ponds (mean weights were 41.83, 31.28, 28.58 and 30.77 g for ponds 6,7,21 and 23, respectively). This indicates that the density of blue shrimp present in a pond has more effect on blue shrimp growth than the density of blue shrimp plus white shrimp. In the only other study I have seen in the literature on polyculture of blue shrimp with another shrimp species, final weight of blue shrimp was found to increase as the density of *P. vannamei* increased and the density of P. stylirostris decreased (Chamberlain et al., 1981). Pond yields in that study, however, were not increased by polyculture, primarily because of uniformly low survival of the blue shrimp. It certainly seems worthwhile to examine further the possible benefits of blue shrimp polyculture with other shrimp species.

The highest total pond yield (634 kg/ha) was achieved in the white shrimp/striped mullet polyculture pond. However, it must be noted that the mullet harvested were not of marketable size. At least it can be stated that mullet had no detrimental effect on survival or yield of white shrimp. It does not look as though polyculture of shrimp and mullet will be very successful in a semi-intensive system such as this one, where ponds are completely harvested every 3-4 months. The problem of how to keep the mullet in the pond for a longer growing period while getting the shrimp out seems prohibitive. However, mullet are cultured with penaeid shrimp in more extensive systems in other parts of the world. A system that utilizes a partial harvesting technique could benefit by addition of mullet, since they apparently do not adversely affect shrimp performance and utilize space that would otherwise be wasted. It would be particularly appropriate to culture mullet with mixed size cultures of shrimp using a selective harvest system without draining to remove only the largest shrimp.

Staggered Stocking Pond Experiments

Introduction

I have stated that successful polyculture is based on the concept of efficient niche utilization within one habitat, a concept which may apply to more than one growth stage of the same species. Fredieu (1978) suggested that such a situation occurred in a pond containing pink shrimp (Penaeus duorarum) when 2 increments of post-larval shrimp stocked 10 days apart (because of an inadequate first shipment from the hatchery) exhibited a bi-modal size distribution at harvest with modes greater than or almost equal to the single mode from a pond stocked all at once. This suggested that shrimp of different sizes in the same pond may utilize resources more efficiently than shrimp of one size. The experiment I performed was designed to test that idea. Specifically, the objective was to assess the effect of a staggered stocking method on shrimp survival and yield compared to conventional stocking methods.

Materials and Methods

Two sets of experiments on mixed size culture of blue shrimp were done; a preliminary one during the late summer and fall of 1978 and a more expanded version in the spring and summer of 1979. Sampling for growth in these experiments was always done with a bag seine.

1978 Experiment

I used 3 separate shrimp stocks (stocks I, II and III). A total of 4 ponds was stocked during the experiment. On August 19, 1978, shrimp postlarvae (stock I), mean length 7.9 mm, obtained courtesy of Dr. Jack Parker, Texas A&M University, were stocked into 4 ponds. Two control ponds received 10,000 shrimp each. Each of 2 other ponds (staggered stocked ponds) were stocked with 3,333 shrimp. The latter 2 ponds received 2 subsequent increments of 3,333 stock II shrimp, mean length 7.3 mm, and 3,334 stock III shrimp, mean length 6.2 mm, purchased from Ralston Purina, Inc., Crystal River, Florida, on September 6 and September 26 , respectively. The stocking schedule appears in Table 4.

Table 4. Pond stocking schedule during the 1978 staggered stocking experiment.

		Number of shrimp stocked/0.1 ha			
		Date stocked			
Pond	Treatment	Stock I 8-19-78	Stock II 9-6-78	Stock III 9-26-78	Total
2	Control	10,000			10,000
5	Control	10,000			10,000
3	Staggered	3,333	3,333	3,334	10,000
24	Staggered	3,333	3,333	3,334	10,000

Initial sample sizes after one month were 30 shrimp from each control pond and 60 from each staggered stocked pond. Sample sizes were increased throughout the experiment to 100 from all ponds. At harvest, 300 shrimp from each pond were sampled.

One of the staggered stocked ponds (24) was harvested on October 23, when adequate water flow and therefore good growth temperatures could no longer be maintained in that pond. The harvest was separated and counted by size class, and a random sample of 100 shrimp from each class weighed and measured. The size divisions, estimated from the sample taken 5 days earlier, were <80 mm, 80-115 mm, and >115 mm. On October 20 the other staggered stocked pond (3) and one control pond (5) were partially harvested by seining with a 5-cm stretch mesh seine. One thousand fifty-five shrimp larger than 110 mm were taken from pond 3 and 1,543 larger than 100 mm from pond 5. The partial harvest was done in an attempt to see if the smaller shrimp left in the pond would increase their growth rate after a substantial number of larger shrimp were removed. Since replication had already been lost with the loss of pond 24, I felt it was worth the effort to look for indications or trends that might be developed in future research.

All the ponds were completely harvested on November 28. Size classes could not be separated, so a final random sample of 300 shrimp was taken from each pond.

1979 Experiment

Again, I used 3 separate shrimp stocks (stocks I, II and III), all purchased from Ralston Purina (Table 5). A total of 11 ponds was stocked during this experiment. On April 28, 1979, postlarval shrimp (stock I, mean length 9.3 mm) were stocked into 6 ponds. Three control ponds (control I) received 7,800 shrimp each. Three other ponds (staggered stocked ponds) were each stocked with 2,600 shrimp. On May 24 a second batch of postlarvae (stock II, mean length 6.7 mm) was stocked; 7,800 into each of 3 new control ponds (control II) and a second increment of 2,600 into each of the same 3 staggered stocked ponds. There were not enough shrimp in stock III (mean length 9.1 mm) for a third stocking at these rates, so only 2 new control ponds (control III) received 2,435 postlarvae each, and only 2 of the staggered stocked ponds each received a third increment of 2,435 on June 18.

Table 5. Pond stocking schedule during the 1979 staggered stocking experiment.

		Number of shrimp stocked/0.1 ha			
		Date stocked			
Pond	Treatment	Stock I 4-28-79	Stock II 5-24-79	Stock III 6-18-79	Total
3	Control I	7,800			7,800
8	Control I	7,800			7,800
14	Control I	7,800			7,800
2	Control II		7,800		7,800
12	Control II		7,800		7,800
13	Control II		7,800		7,800
4	Control III			2,435	2,435
7	Control III			2,435	2,435
5	Staggered	2,600	2,600	2,435	7,635
9	Staggered	2,600	2,600	2,435	7,635
15	Staggered	2,600	2,600		5,200

Shrimp postlarvae arrived at temperatures and salinities of 23 to 24 C and 0.9 to 2 ppt, respectively. They were held in water that was gradually adjusted to pond temperatures and salinities over a period of 2 to 4 days before stocking.

Sampling for growth began 19 days after stock I was introduced and was repeated every 2 weeks thereafter. Samples of approximately 150 were taken from each pond. The ponds were drained and harvested on August 10-12 when random samples of 300 were taken for measurement and weighing.

To assess the effect of staggered stocking on pond production I compared the yields harvested from the staggered stocked ponds to expected yields calculated using the mean values from the control ponds. This was done only for the 2 ponds that were stocked with all 3 increments of shrimp. the staggered stocked ponds received one-third the number of stock I and stock II shrimp as did control I and II ponds and received the same number of stock III shrimp as did control III ponds. Therefore the expected yield (Y_E) from staggered stocking was calculated by the formula:

$$Y_E = 1/3(Y_I) + 1/3(Y_{II}) + Y_{III}$$

where Y_{I-III} are the mean yields for control ponds I, II and III.

Similarly, expected survival (S_E) was calculated for the staggered stock ponds. S_E is an average of the control pond mean survivals, weighted according to the number of shrimp from stocks I, II and III put into each staggered stocked pond. The formula was:

$$S_E = \frac{N_I S_I + N_{II} S_{II} + N_{III} S_{III}}{N_{total}}$$

where N_{I-III} are the respective numbers of shrimp from stocks I-III that were put into the staggered stocked ponds, S_{I-III} are the mean survivals from control ponds I-III, and N_{total} is the total number of shrimp stocked into each staggered stocked pond.

An attempt was made to identify the separate shrimp stocks within each staggered stocked pond by analyzing the length-frequency data at harvest according to the method described by MacDonald and Pitcher (1979). This portion of the data analysis was supervised by Dr. James Matis, Department of Statistics, Texas A&M University.

A quantitative test for relative pond bottom softness was made on August 9, 1979, using the method described by Furness (1979). A 1.5-kg brick was dropped from a height of 15 cm onto one end of a 1.8-m, 5 cm X 5 cm post whose other end was resting on the pond bottom. Penetration of the post into the substrate was measured to the nearest 0.1 cm. This was done 4 times each in the deep, middle and shallow sectors of each pond.

Results and Discussion

1978 Experiment

Hydrological data are presented in Appendix figures B11-B16. Temperatures in the 1978 experiment in general decreased throughout the experiment. They ranged from 14.5 to 35.0 C near the surface and from 20.5 to 33.5 C near the bottom. They were similar among the ponds until mid-October, when pond 24 began to be consistently lower than the other ponds due to insufficient water flow (Figure B14). Salinities ranged from 3.6 to 18.0 ppt near the surface and from 5.3 to 17.7 ppt near the bottom. The lowest values occurred immediately before harvest; generally salinities were above 10 ppt. Dissolved oxygen ranged from 2.4 to 20.0 ppm near the surface and from 1.9 to 18.0 ppm near the bottom. The only recorded level below 2 ppm was on one occasion in pond 24. No mortalities were seen associated with low dissolved oxygen. Levels of pH varied widely, from 7.3 to 10.4 both near the surface and the bottom. Values above 10 were recorded on one day only (Figures B15 and B16) and may have been due to faulty equipment.

By the end of the preliminary 1978 experiment all replication of treatments had been lost, therefore no statistical comparisons of treatments could be made. However, some interesting indications are found in the data.

Stock I shrimp in the 2 staggered stocked ponds grew faster than in the control ponds. Sixty days after initial stocking the control pond shrimp show length-frequency distributions with modes at about 112 mm (pond 2) and 116 mm (pond 5), while the staggered stocked ponds had modes at 131 mm (pond 3) and 140 mm (pond 24) (Figure 4). This may be due to the initially lower stocking density in the staggered stocked ponds allowing stock I shrimp to grow at a faster rate than in the more crowded conrol ponds.

Survival was lower in the staggered stocked ponds than in the control ponds; 28.7% and 33.3% vs 51.3% and 51.5%, respectively (Table 6). Also, assuming my size class divisions were appropriate, it was possible to get survival estimates for the different stocks from the harvest data from staggered stocked pond 24. They were: stock I 38%, stock II 35% and stock III 25%. In crustacean culture cannibalism is a potential problem. In a culture of mixed size classes, the smaller shrimp could experience a higher mortality due to cannibalism by the larger animals. The above survival statistics indicate that this may have happened in my experiment, but since there were no stock II or stock III control ponds (due to lack of ponds) I could not be sure whether this decreasing survival was caused by the staggered stocking method, or whether it was due to inherent differences in the shrimp stocks. These considerations influenced the design of the better-controlled 1979 experiment.

The partial harvest of staggered stocked pond 3 appears to have been quite efficient. The group that was harvested, shrimp larger than 110 mm on October 20, was clearly from

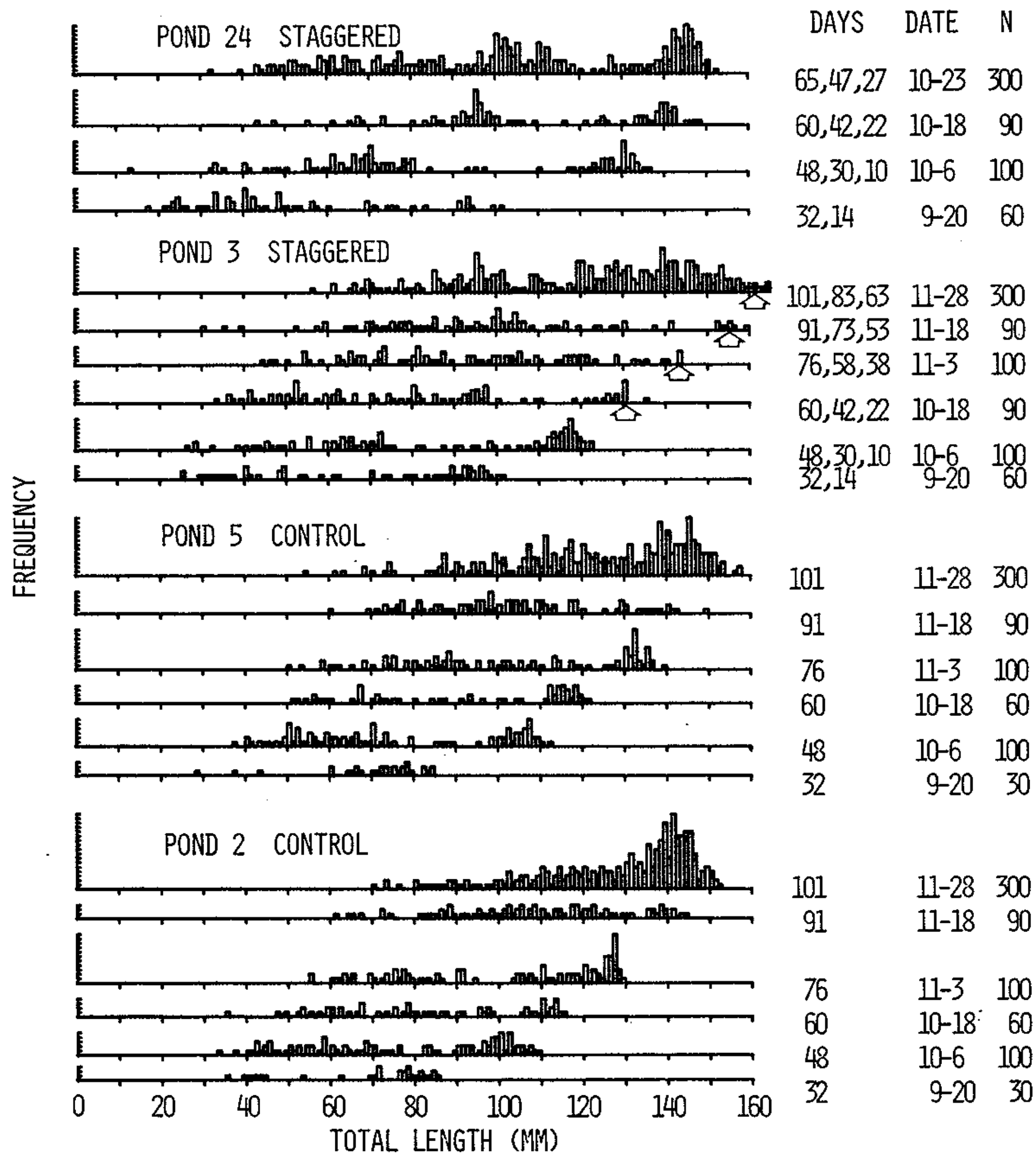

Figure 4. Length-frequency distributions of blue shrimp throughout the 1978 staggered stocking experiment. Treatment, number of days in culture at time of sample, date of sample and number sampled (N) are indicated.

Table 6. Summary of harvest data from the 1978 staggered stocking experiment.

Pond	Treatment	# Days stocking-harvest	Partial harvest: Mean wt. (g) ± S.D.	Partial harvest: # recovered	Final harvest: Mean wt. (g) ± S.D.	Final harvest: # recovered	Total survival %	F.C.R.	Yield (kg/ha)
2	Control	101			16.24±5.26	5126	51.3	3.15	832.5
5	Control	101	11.21 ± .22	1543	15.24±6.31	3610	51.5	3.05	729.7
3	Staggered	101,83,63	15.01±2.00	1055	16.70±13.4	1818	28.7	4.64	462.0
24	Staggered	65,47,27			11.81	3331	33.3	2.98	393.3

stock I whose distribution had a mode of 130 mm at that time (Figure 4). Arrows on the histogram indicate the approximate position of this group after the partial harvesting was done. At the final harvest, this group makes only a very small proportion of the whole. The largest mode at harvest apparently represents primarily stock II shrimp, which as a group are now as large as stock I shrimp in the control ponds. Thus it appears feasible that if staggered stocking is found to be worthwhile, it might be combined with staggered harvesting to most efficiently utilize a pond. A continual harvesting method is currently in use in _Macrobrachium_ culture in Hawaii, although stocking is done only once or twice a year (Malecha et al. 1981).

There is no evidence from the histograms that stock II shrimp increased their rate of growth after the removal of the larger shrimp from pond 3. There was a very large spread of sizes at harvest in the control ponds as well as the staggered stocked ponds, making it difficult to pick out differences in performance among the separate stocks. A sudden apparent increase in growth rate between the last sample and harvest occurred in all ponds except pond 24 (Appendix table C3, Appendix Figures C9-C12). This is probably an artifact due to a disproportionate number of small shrimp being caught by the sampling gear.

1979 Experiment

Hydrological data for 1979 are presented in Appendix

Figures B17-B27. Temperature range in the ponds was from 20.0-33.0 C near both surface and bottom. In general temperatures increased during the experiment. Dissolved oxygen ranges were 1.9-19.8 ppm near the surface and 1.1-18.0 ppm near the bottom. Levels fell below 2 ppm once in pond 9 (staggered stocked pond) and once in pond 13 (control II pond), but no mortalities were seen associated with these levels. Salinities ranged from 1.0 to 7.0 ppt both near the surface and bottom. They were near 2 ppt during much of the experimental period.

Again, a very large spread of shrimp sizes at harvest occurred in all the ponds (Figures 5-7). This phenomenon, representing a significant proportion of small or stunted shrimp, is not uncommon in populations of blue shrimp spawned from parents that were themselves spawned and matured under laboratory conditions (Dr. Neil Hicks, University of Arizona Environmental Research Laboratory, personal communication). All the blue shrimp used in the staggered stocking experiments, were from such populations produced in Florida. In contrast, the blue shrimp used in the polyculture experiment had a much narrower size range at harvest (Figure 8). These shrimp had been produced from gravid females captured in the wild in Panama.

It was not possible to distinguish the 3 stocks in the staggered stocked ponds by analysis of the length-frequency data. There was too much scatter in the data and overlap of individual sizes in the stocks.

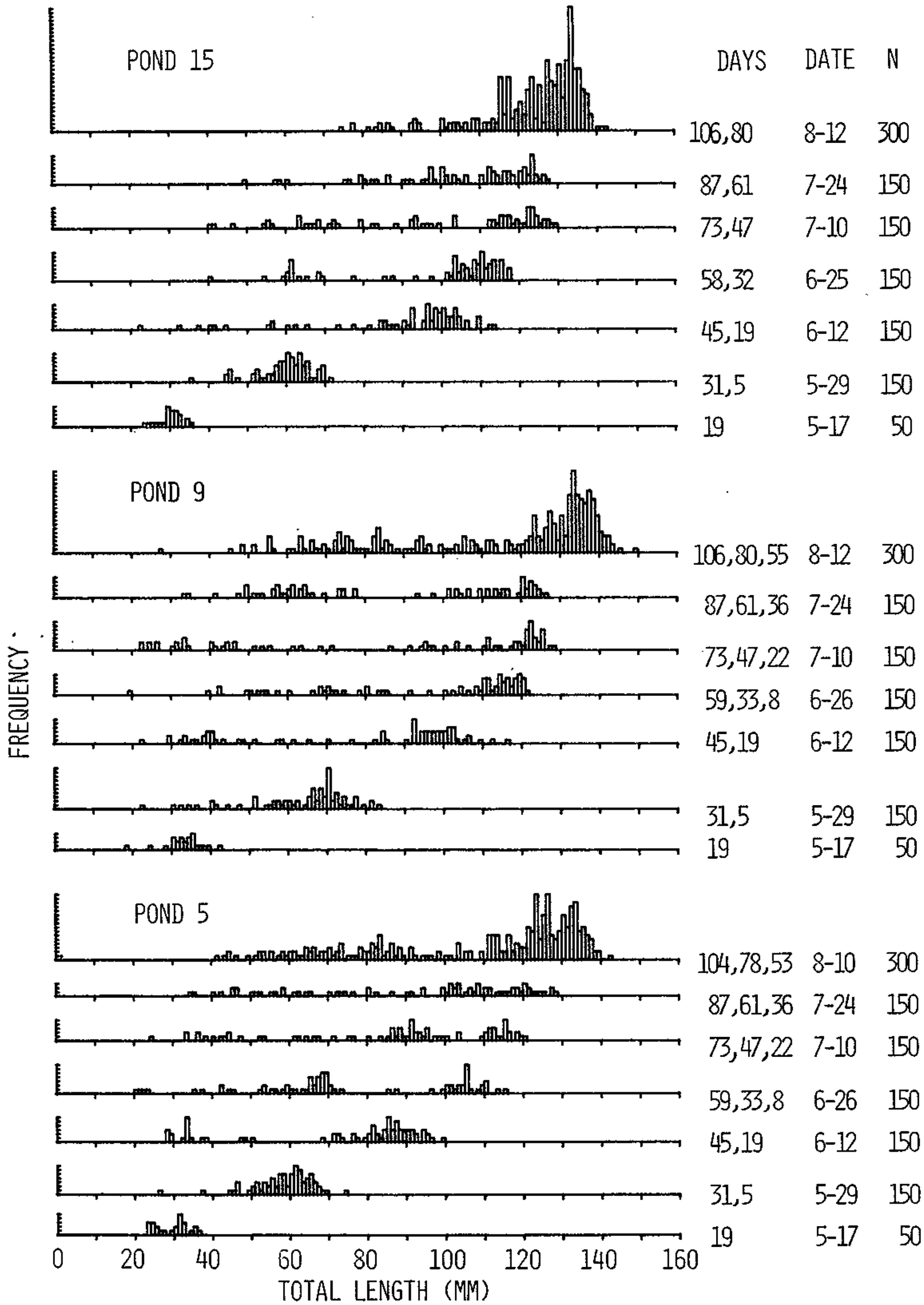

Figure 5. Length-frequency distributions of blue shrimp in the staggered stocked ponds throughout the 1979 staggered stocking experiment. Number of days in culture at time of sample, date and number sampled (N) are indicated.

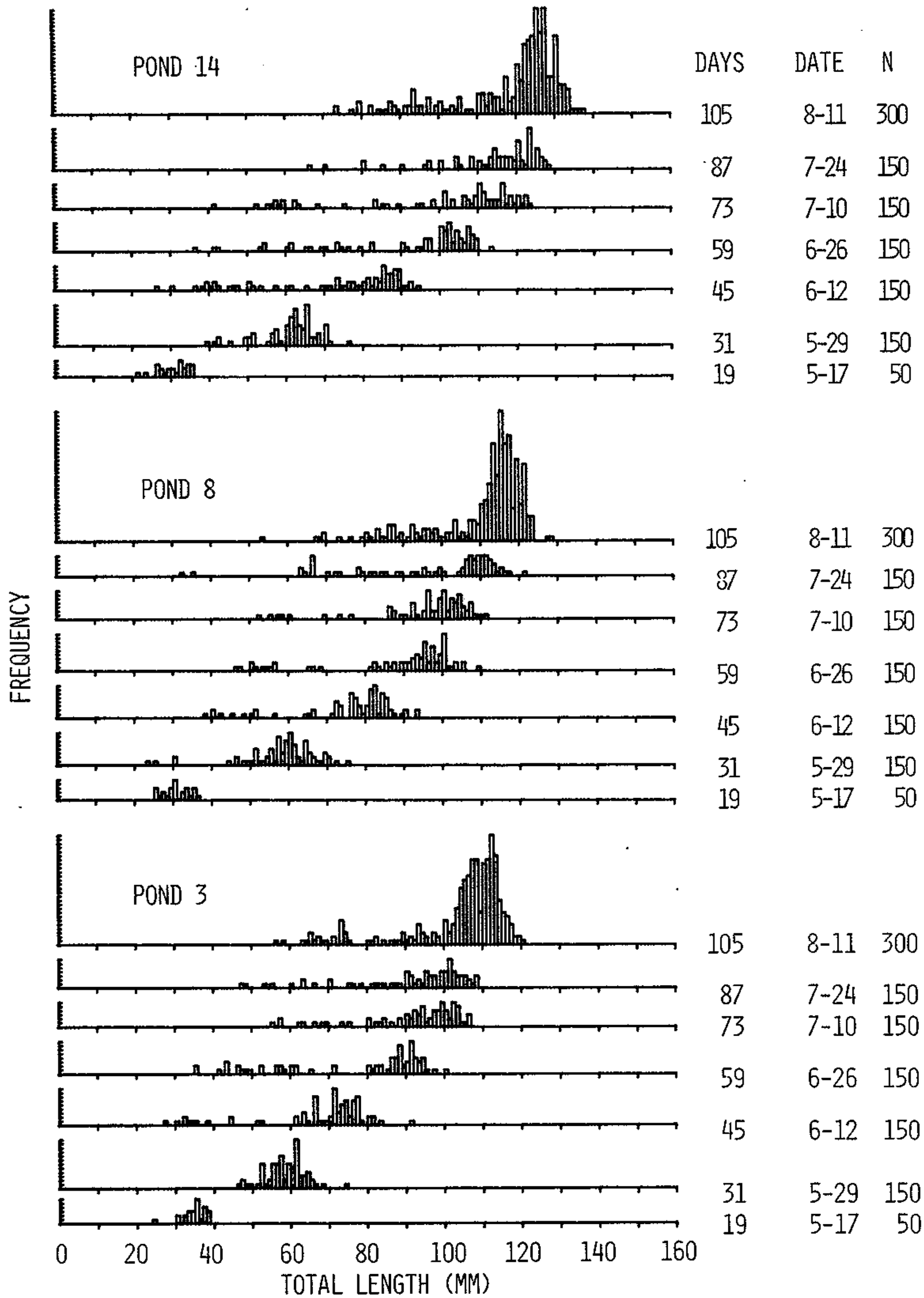

Figure 6. Length-frequency distributions of blue shrimp in in the control I ponds throughout the 1979 staggered stocking experiment. Number of days in culture at time of sample, date and number sampled (N) are indicated.

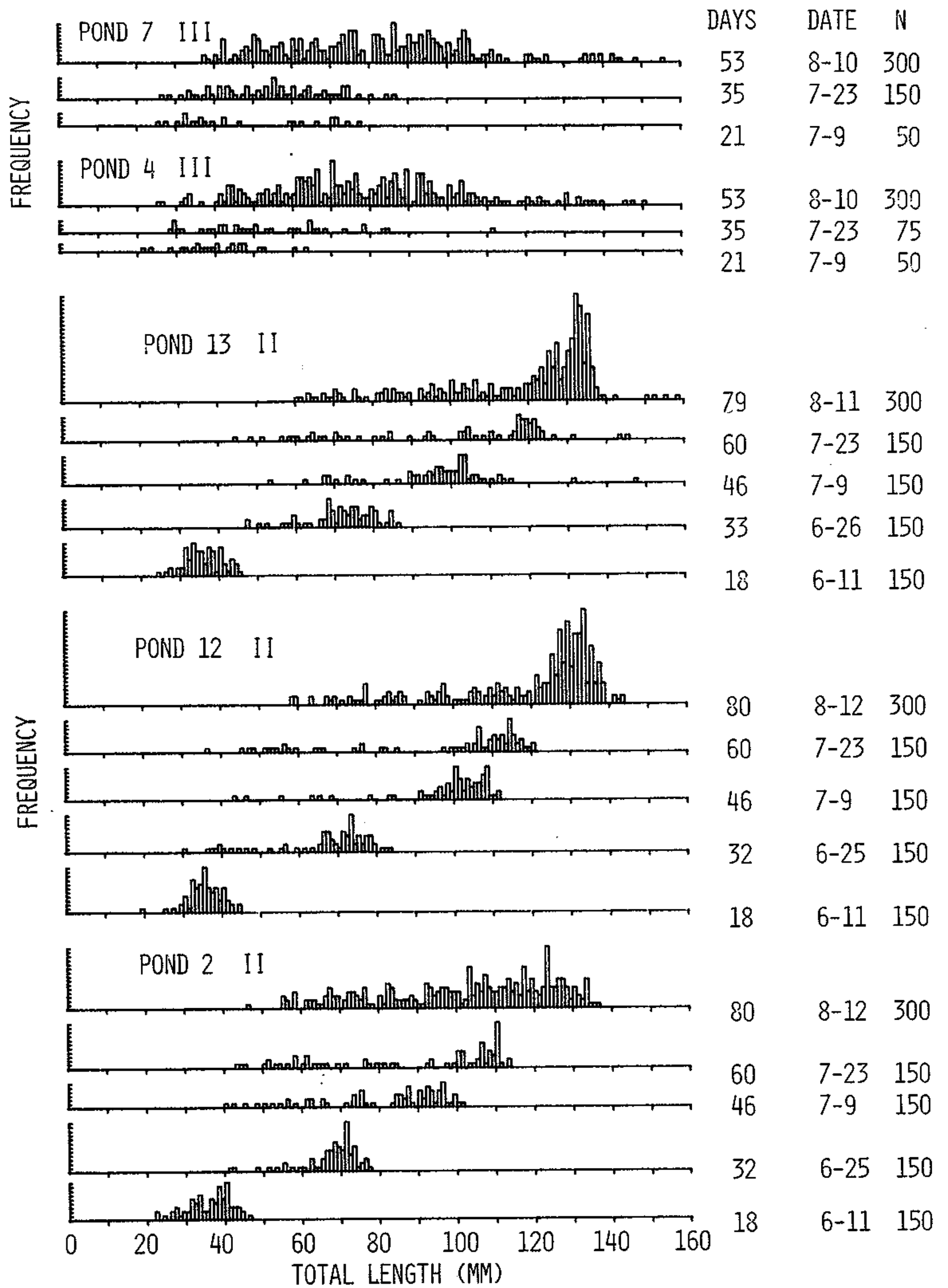

Figure 7. Length-frequency distributions of blue shrimp in control I and II ponds throughout the 1979 staggered stocking experiment. Treatment (I or II), number of days in culture at time of sample, date and number sampled (N) are indicated.

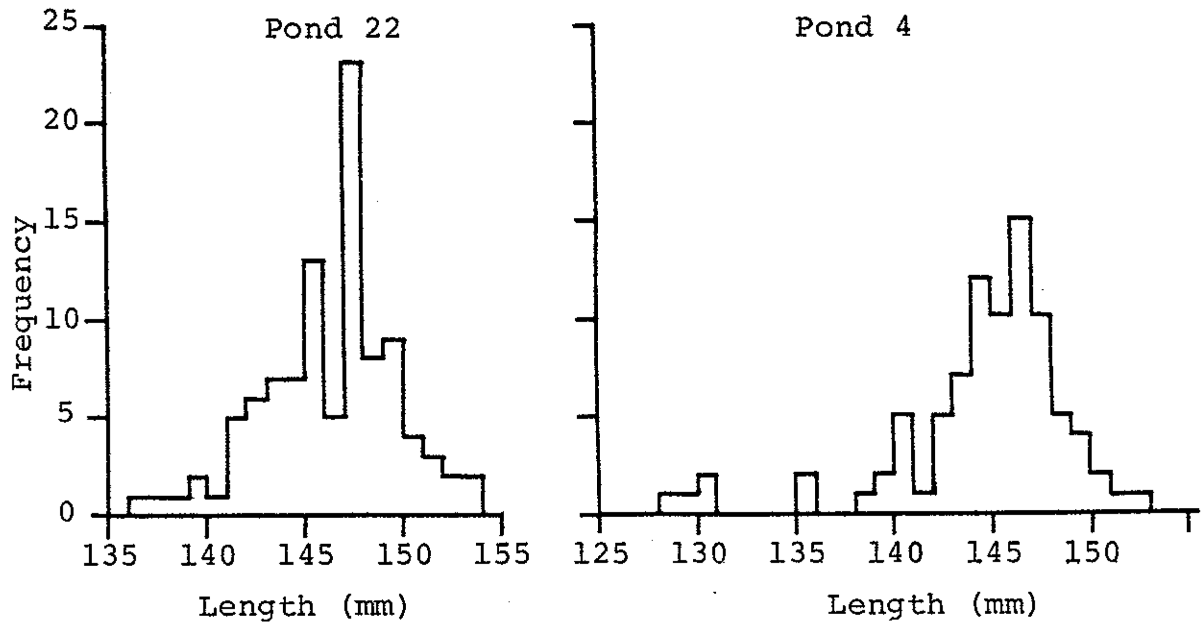

Figure 8. Length-frequency histograms at harvest for blue shrimp grown in the 1978 polyculture experiment.

The experiment indicates that staggered stocking gives greater yields than conventional stocking methods. Observed yields in the staggered stocked ponds were about 30% higher than the expected yield (Table 7). Survivals in the staggered stocked ponds were as good as or better than the expected survival (Table 7). These results show no evidence that smaller shrimp experienced a higher mortality due to cannibalism by larger animals, thus indicating that cannibalism is no more of a problem in the staggered stocking method than in conventional stocking, at least at the stocking densities I used. The greater-than-expected yields indicate a positive effect of staggered stocking on growth of blue shrimp.

Even though the staggered stocking method increased shrimp yields above the calculated expected value, the ear-

Table 7. Observed and expected yields and survivals for the staggered stocked ponds in the 1979 experiment.

Pond	Expected Yield (kg/ha)	Observed Yield (kg/ha)	Expected Survival (%)	Observed Survival (%)
5	225	335	32.2	40.9
9	225	311	32.2	32.6

liest stocked control ponds had a greater mean yield than the staggered stocked ponds. However, this difference was not statistically significant (Table 8). In addition, the shrimp in the staggered stocked ponds were larger, and thus worth more money than those in the control I ponds (Table 9). At 1980 Texas prices, the mean value of the harvest from the staggered stocked ponds was $190.39. The mean value of the control I pond harvest was $157.75. Again, the 2 mean values are not significantly different (Student's t test, $P > .05$).

Table 8. Mean yields and survivals from the 4 treatments. Means bearing the same superscript do not significantly differ when compared by analysis of variance and Duncan's new multiple range test (P=.05).

Treatment	Mean yield (kg/ha)	Mean survival (%)
Control I	370^{a}	49.4^{a}
Control II	195^{bc}	21.4^{b}
Control III	37^{c}	25.2^{b}
Staggered	323^{ab}	36.8^{ab}

Growth in the 1979 experiment was in general much slower than in the 1978 experiment (Appendix Table C4, Appendix

Table 9. Summary of harvest data from the 1979 staggered stocking pond experiment.

Pond	Treatment	# Days stocking-harvest	wt. (g) ± S.D.	Instantaneous growth** (g/g/day X 10^{-2})	Instantaneous growth** (mm/mm/day X 10^{-2})	Recovered # stocked	% Survival	F.C.R.	Yield (kg/ha)
3	Control I	105	7.84 ± 2.05	4.66	1.57	3104/7800	39.4	6.10	243
8	Control I	105	9.13 ± 2.13	4.92	1.66	4927/7800	63.2	3.66	450
14	Control I	105	11.86 ± 2.96	5.05	1.70	3528/7800	45.2	5.50	418
2	Control II	80	8.93 ± 4.35	5.77	1.86	1436/7800	18.4	8.87	128
12	Control II	80	12.78 ± 4.51	6.10	1.94	1739/7800	22.3	7.28	222
13	Control II	79	12.89 ± 4.76	6.08	1.96	1831/7800	23.5	6.75	236
4	Control III	53	5.91 ± 4.95	5.79	1.77	567/2435	23.3	2.62	33
7	Control III	53	6.19 ± 4.92	5.84	1.79	660/2435	27.1	3.16	41
5	Staggered	104,78,53	10.75 ± 5.22			3120/7635	40.9	4.01	335
9	Staggered	106,80,55	12.49 ± 5.66			2488/7635	32.6	4.45	311
15*	Staggered	106,80	13.19 ± 3.18			2079/5200	40.0	5.58	274

* Pond 15 was not included in statistical analyses among treatments.

** Number of days for which growth was calculated were initial 59 days for control I, 60 days for control II and 53 days for control III.

Figures C13-C33). Survivals and pond yields were also much lower than in the previous year (Table 9). This poor performance was probably due to the extremely low salinities experienced throughout most of the 1979 study. Huang (1983) has demonstrated that salinities below 5 ppt decrease growth and increase mortality of P. stylirostris in laboratory conditions. Salinities encountered by my blue shrimp were near 2 ppt for most of the culture period.

Survival in 1979 was much poorer in control II and III ponds than in control I ponds (Table 9). In the case of stock II, this may be due to the smaller initial size of the postlarvae stocked (6.7 mm vs 9.3 mm for stock I). Biesiot (1975) found that salinity tolerance was size-dependent in postlarval brown shrimp (Penaeus aztecus); smaller ones had a narrower tolerance range than larger ones. Mair (1980) found that 6.0 mm blue shrimp postlarvae preferred much higher salinities than did 16.9 mm ones. Thus the stock II shrimp may have experienced a higher mortality than stock I due to the low salinity. Stock III postlarvae were about the same size (9.1 mm) as stock I, but they may not have been of as high quality. About 75% of the stock III shrimp were dead on arrival in the shipping cartons. At that time hatchery personnel reported that there were temporary problems in their water supply system, exposing the postlarvae to some unknown toxic substance. There may have been continuing mortalities in the ponds because of that exposure. Also, stock III shrimp were transported from the hatchery at a stressfully low salinity (0.9 ppt) which probably affected their survival.

Comparisons of growth rates among the ponds were made on the instantaneous growth rates (g/g/day and mm/mm/day) over similar time periods; the first 59 days of culture for control I, the first 60 days for control II and 53 days for control III (Table 9). As in the 1978 white shrimp experiment, a fairly high degree of correlation between growth rate and density at harvest was found for control I and II ponds (Figure 9). In general, control I shrimp grew less rapidly than control II, but experienced higher densities. Control III shrimp did not follow the same pattern. Even though they had the lowest stocking and harvest densities, they grew less well than did control II shrimp, especially when growth is expressed as mm/mm/day (Figure 9). These patterns are also evident from comparisons of the growth curves in Appendix Figures C13-C20. The poor performance of stock III shrimp may be related to their stressful postlarval history.

As in the 1978 staggered stocking study, several of the growth curves show apparent spurts in growth between the last sample and harvest (Appendix Figures C13, C17 and C20-C22). The jump is most pronounced in the 2 staggered stocked ponds containing small stock III shrimp as well as larger shrimp. This phenomenon indicates small shrimp may be more likely to be caught by the sampling gear (in this case a bag seine) than larger shrimp. Some supplementary data taken from the

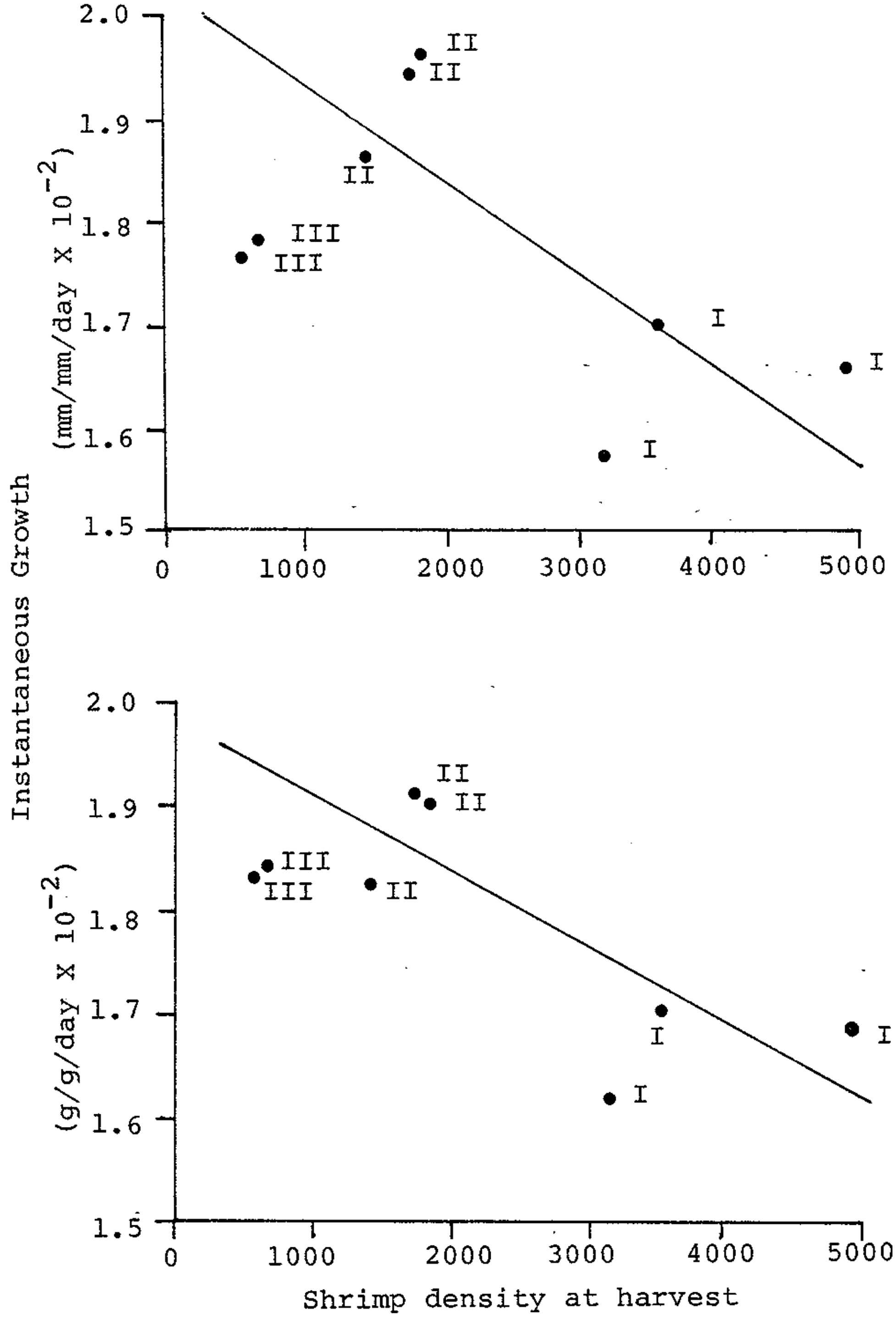

Figure 9. Relationship between instantaneous growth rate (g/g/day and mm/mm/day) and shrimp density at harvest of blue shrimp in the 1979 staggered stocking experiment control ponds. Regression lines are calculated only with data from control I and II ponds. Treatment (control I, II or III) is indicated for each point.

1978 polyculture experiment ponds tend to support this hypothesis. As part of a class laboratory project (WFS 615, Mariculture), an attempt was made to estimate the numbers of shrimp in the ponds using a 1.22-m radius, 5-cm stretch mesh castnet made of thin monofilament plastic line. On October 8, 2 weeks before harvest, 30 casts were taken into each pond at equidistant points around the perimeter during the day (1300-1600 hrs) and again during the night (2030-2330 hrs). The number of each species of shrimp caught per cast was recorded. The method proved unsatisfactory for population estimation, and will not be dealt with here, but those data allowing comparison of the mean numbers of blue and white shrimp caught per cast from the same ponds are presented.

The mean number of blue shrimp caught per cast was consistently much lower than the mean number of white shrimp caught in the same 30 casts, even though the numbers of each species present were almost the same (Table 10). This difference is significant ($P<.025$) when the means are compared by a paired t test.

Table 10. Mean number of blue and white shrimp caught per cast of 30 casts taken in each blue shrimp/white shrimp polyculture pond during the day and at night.

		Mean # of shrimp/cast		# shrimp in pond	
Time	Pond	White	Blue	White	Blue
Day	4	1.50	.77	1577	1614
Day	22	3.37	1.40	1536	1502
Night	4	2.60	1.13	1577	1614
Night	22	2.60	1.80	1536	1502

No such study was performed using a seine, but it was noted throughout the culture period that more effort was required to catch 30 blue shrimp than to catch 30 white shrimp from the same pond when sampling for growth. That is, the complement of 30 white shrimp was usually reached first, and extra seine hauls had to be made to reach the complement of blue shrimp.

Since in each pond the blue shrimp were somewhat larger than the white shrimp, it cannot be determined whether this difference in catchability is due to some difference in the behavior of the species, or to a greater ability of larger shrimp to escape the sampling gear. In my 1979 pond study with blue shrimp, the ponds contained a wide range of shrimp sizes. The sudden jumps in size at harvest on some growth curves indicate that large shrimp may be more successful in avoiding the sampling gear. The shape of some length-frequency distributions also show a higher proportions of large shrimp at harvest, where a truly random sample of the whole pond could be taken, than was found in the previous samples, where shrimp were seined from the ponds (Figure 5, ponds 5 and 9). Thus, while a species difference cannot be ruled out, there is considerable evidence that relatively large shrimp are less likely to be caught by the sampling gear than smaller shrimp.

This could be an important consideration in mixed size ponds when sampling for growth to determine feeding rate. If relatively more small shrimp were caught, feeding rate would be underestimated, resulting in underfeeding of shrimp and less-than-maximum growth rates. It would also be an important consideration in population estimations. If fewer shrimp per area sampled are caught as growth progresses, more mortality may be assumed than has actually occurred, again resulting in underfeeding and restricted growth rates. These considerations underline the need for more studies to develop a body of knowledge about shrimp behavior and movement in ponds, and to develop a reliable technique for pond population estimation. Staggered stocking may create more problems than conventional stocking methods in pond population estimates and growth sampling because of the presence of different sizes of shrimp in the same ponds.

Food conversion ratios during the experiment were poor (Table 9). The much lower than anticipated survival resulted in overfeeding of the ponds. The best (lowest) food conversion ratios are from the control III ponds, where overfeeding occurred for the shortest period.

Pond bottom softness data are presented in Table 11. Furness and Aldrich (1979) found a significant positive correlation between increasing pond bottom softness and growth of brown shrimp. No correlation between pond bottom softness and growth (instantaneous growth rate or initial growth rate) or survival of blue shrimp in the present experiment was found. The values for pond bottom softness recorded in the present study are generally smaller than reported by Furness (1978) from the same ponds. My method was similar, but I used a 1.5 kg weight while Furness used

Table 11. Pond bottom softness (cm penetration).

	Pond										
	2	3	4	5	7	8	9	12	13	14	15
Shallow end	2.0	3.2	1.0	1.9	1.0	3.0	2.0	2.8	2.7	5.1	6.0
	3.0	3.2	1.0	3.2	0.5	8.0	2.3	2.5	2.8	2.2	3.5
	5.8	2.8	0.5	6.0	1.0	3.0	1.7	1.0	2.4	1.8	3.7
	5.7	3.3	0.5	2.9	1.0	6.0	3.1	2.1	3.6	5.1	3.0
Mean	4.13	3.13	0.75	3.50	0.88	5.0	2.28	2.10	2.88	3.55	4.05
Middle	4.5	3.1	2.4	4.7	1.8	7.8	4.3	2.2	3.8	5.8	2.5
	6.5	4.3	3.0	7.8	5.1	6.7	3.1	1.5	3.5	8.2	2.2
	4.9	5.3	2.0	4.0	3.4	6.8	1.9	3.3	2.8	8.0	6.0
	5.7	3.0	2.0	4.5	1.5	7.1	3.2	2.3	4.0	6.2	2.8
Mean	5.40	3.93	2.35	5.25	2.95	7.10	3.13	2.33	3.53	7.05	3.38
Deep end	5.8	3.4	2.9	3.9	1.5	6.0	10.5	3.3	4.1	5.9	3.8
	9.0	3.9	4.9	11.0	2.8	11.5	4.5	5.8	4.0	2.5	2.0
	9.0	4.0	2.9	10.5	4.0	7.8	3.5	3.0	3.5	2.5	2.2
	8.0	2.3	2.6	6.3	2.0	6.0	6.5	2.1	3.2	2.4	3.2
Mean	7.95	3.40	3.33	7.93	2.58	7.83	6.25	3.55	3.70	3.33	2.80
Overall mean	5.83	3.48	2.14	5.56	2.13	6.64	3.88	2.66	3.37	4.64	3.41

a 1.7 kg weight to drive the post into the mud, which accounts for the difference. Seasonal environmental variations and the species of shrimp in the ponds may also influence the degree of pond bottom softness.

The staggered stocking method certainly deserves further investigation. Under better growing conditions, better growth and survival should result, and possibly the trend I observed of increased value of yields from staggered stocking would be shown to be significant. Higher populations densities would be of particular interest in this context.

Shrimp Distribution Study

Introduction

In an attempt to elucidate blue shrimp movements within ponds, a distribution study was carried out in the ponds used in the 1979 staggered stocking experiment. The study was designed to provide answers to the following questions:

1) Are sizes of shrimp distributed homogeneously throughout the ponds or do the shrimp tend to separate into size groupings?

2) Do the relatively larger or smaller shrimp tend to favor any particular area (shallow, middle or deep) of the ponds?

3) Can differences of the relative size distribution pattern be detected between day and night?

4) Are numbers of shrimp distributed equally in the shallow, middle and deep areas of the ponds?

5) Can differences of the distribution pattern with respect to numbers be detected between day and night?

6) Are shrimp more easily caught during the day or at night?

7) Can differences in distribution patterns or shrimp movements be detected between ponds with mixed age groups of shrimp and ponds with uniform age groups?

Materials and Methods

A series of systematic seine hauls was carried out in the 11 study ponds of the staggered stocking experiment in 1979. A 6.1-m bag seine with a .64-cm bag mesh size was used to sample the shrimp. To make the seine hauls as consistent as possible, a 6.0-m guideline was tied between the seine poles, near the top. By keeping this line taut, and the poles in a vertical position, variation in cross-sectional area during seine hauls was minimized. Three seining stations were marked by stakes on the banks of each pond, in the shallow, middle and deep sectors. The deep and shallow stations began about 6 m from either end of the pond. The middle station was located halfway between the pond ends (about 41 m from each end). Seine hauls were made straight across the ponds, a distance of about 12.2 m, thus covering an area of about 73.2 m^2. The marking stakes were placed on both sides of the pond and were painted white to be visible at night.

Each pond trial consisted of one seine haul at each of the 3 stations within a pond. One person made sure the bag was untangled and open before each haul, and observed the tautness of the guideline and straightness of the seine poles, giving directions to the 2 people pulling the seine. The shrimp from each seine haul were placed in a bucket of water, then measured individually to the nearest millimeter by a fourth person. Estimates of length were made when shrimp had broken rostra. A fifth person recorded the lengths, calling back the numbers to the one doing the measuring. The shrimp were returned to the pond at the station from which they had been removed.

Two pond trials on different dates were made during the day (between 1000 and 1500 hrs) in each of the 11 study ponds, one on July 6, another on either July 27, 28 or 30. In addition, at least one trial was made at night (between 2200 and 0100 hrs) in each pond on the same date as one of the day trials. Hydrological data (salinity, temperature and dissolved oxygen) were taken in the ponds, near the surface and bottom of the deep ends, within about one hour before sampling began (except on July 28, when they were taken immediately after the day trials). Air temperature, cloud cover, wind direction and velocity, and the approximate phase of the moon were also recorded.

Other studies have found shrimp distribution in ponds to be patchy (Furness and Aldrich, 1979; Chamberlain et al., 1980; Hutchins et al., 1980; Hardin, 1981). For this reason, only non-parametric statistical procedures were used to treat the data, thus avoiding any assumptions about the distribution patterns. All the tests used were taken from Conover (1971), and were considered to show significant differences or patterns (i.e. the null hypothesis was rejected) at the 95% level of confidence, or P=.05 level.

The mean (and median) sizes of shrimp among the 3 samples of each pond trial were compared by the Kruskal-Wallis test. Significance obtained thus would indicate that within a given pond trial, at least one of the samples tended to yield larger sized shrimp than at least one of the others; that is, the shrimp tended to separate into size groupings.

In order to look at size distribution patterns in the different sectors of the ponds, the data were reduced to relative size categories. This was done because of the wide variation of shrimp sizes among the ponds. Within each pond trial, the samples were categorized as yielding the smallest, medium or largest median shrimp length. The median rather than the arithmetic mean was used because it is not affected by extreme values, and so may be more typical of all the obsevations (Ostle and Mensing, 1975). To compare the incidence of shrimp in each size category in the different pond sectors, the chi-square test for homogeneity was used. A significant χ^2 value would indicate that at least one category of shrimp was not distributed equally among the 3 pond sectors; i.e. there was a non-uniform size distribution pattern. The chi-square test for homogeneity was made on the combined 38 pond trials, then separately on data from only the day trials (excluding those that had no paired night trial on the same date in the same pond) and only the night trials. Finally, the data from the staggered stocked ponds were considered separately from those from the control ponds for the paired day/night trials. In cases where the level of significance almost, but not quite, reached the P=.05 level, the chi-square goodness-of-fit test was used to test the distribution of observations within one particular size category. Significance would indicate that the shrimp in that category were not distributed uniformly among the 3 pond sectors, but favored or avoided a particular sector.

Differences in actual size of the shrimp caught during the day and at night were tested by the Wilcoxon signed ranks test, using the 16 pairs of day/night trials. Significance would indicate that the night samples tended to yield larger or smaller shrimp than the day samples. The data tested were the median size values from each sample, and pond trial median size values obtained by pooling all the observations from the 3 samples of each trial and finding the median shrimp length for the whole pond. The test was used to compare the sizes of shrimp caught during the day and at night, for the pond as a whole and separately for each pond sector. The 16 pairs of day/night trials were considered together, and also the 11 control pond trials were considered separately from the 5 staggered stocked pond trials.

The distribution patterns of numbers of shrimp among the 3 pond sectors were evaluated in the same manner as the relative size distribution patterns. The samples were categorized as most, medium, and fewest shrimp caught within each pond trial. Like the relative size categories, the relative number categories were tested by the chi-square test for homogeneity and the chi-square test for goodness-of fit. The actual numbers of shrimp caught during the day and night were compared by the Wilcoxon signed ranks test. The data were grouped for testing exactly as they were for the size distribution tests.

Results and Discussion

Meteorological conditions varied among the different sampling dates, particularly the degree of cloud cover (Table 12.) Wind direction and velocity and the phase of the moon were similar on July 27, 28 and 30. On July 6, the moon was fuller, and the wind, while its direction was similar, was weaker.

Hydrological conditions were similar among the ponds on any given sampling date (Table 13). Temperature ranged from 26.0 C to 34.0 C on the surface and near the bottom. Salinity ranged from 1.7 ppt to 4.1 ppt on the surface and near the bottom. Dissolved oxygen ranged from 3.6 to 15.9 ppm on the surface and from 3.3 to 12.8 ppm near the bottom. There were no obvious differences in the trends seen on different sampling dates that could be related to hydrological or meteorological conditions.

The median length and number of shrimp caught in the 3 pond sectors for all 38 pond trials are given in Table 14. Of the 38 trials, 14 showed statistically significant differences in length of shrimp caught among the 3 pond sectors when tested by the Kruskal-Wallis test (Table 15). Thus it seems clear that some segregation of shrimp by size occurs within the ponds. A significant difference of shrimp size among the 3 pond sectors was found at least once in every pond, but occurred most frequently in the staggered stocked ponds (in 6 of 11 trials). This is easily explained by the greater numbers of relatively small shrimp present in the staggered stocked ponds. If small shrimp occur in

Table 12. Meteorological parameter values on the dates the ponds were sampled for the distribution study. D = day, N = night.

DATE	AIR TEMPERATURE (C)	CLOUD COVER (%)	WIND DIRECTION	WIND VELOCITY (KPH)	MOON PHASE	TIME (HRS)
7-6-D	26.5	90	SW	1.7-3.3		0845
7-6-N	26.0	60	SW	1.7-3.3	2/3 full	2120
7-27-D	26.0	100	SW	16.7		0805
7-27-N	26.0	50	S	8.4-10.0	crescent	2100
7-28-D	31.0	50	S	8.4		1200
7-28-N	25.0	10	S	6.7-8.4		2145
7-30-D	27.0	35	S	8.4		0830
7-30-N	26.0	10	S	8.4	1/4 full	2140

Table 13. Hydrological parameter values in the ponds on the days they were sampled for the distribution study.

DATE	POND	TEMPERATURE SURFACE	TEMPERATURE BOTTOM	CONDUCTIVITY SURFACE	CONDUCTIVITY BOTTOM	DISSOLVED O_2 SURFACE	DISSOLVED O_2 BOTTOM
7-6-D	2	31.5	32.0	3.7	3.7	6.7	6.7
	3	31.0	31.0	3.4	3.4	5.8	5.7
	4	31.0	31.5	3.4	3.4	7.1	7.0
	5	32.0	32.0	3.8	3.7	5.4	5.2
	7	30.0	30.0	3.6	3.6	5.2	5.1
	8	31.5	32.0	3.6	3.6	5.0	4.8
	9	31.5	31.5	3.3	3.3	5.6	5.5
	12	31.5	31.5	3.3	3.3	5.1	4.9
	13	31.5	32.0	3.6	3.5	5.8	5.6
	14	31.0	31.5	3.4	3.4	3.6	3.3
	15	31.0	31.5	3.4	3.4	4.6	4.5
7-6-N	2	34.0	33.0	4.1	3.6	10.6	10.2
	3	33.0	33.0	3.7	3.5	10.2	9.6
	4	33.5	32.0	3.8	3.4	11.0	7.4
	5	34.0	34.0	4.1	4.1	9.8	9.8
	9	33.5	33.0	3.6	3.5	9.5	8.2
7-27-D	13	26.0	26.0	7.4	7.4	6.3	6.4
	14	26.0	26.0	7.1	7.1	9.3	9.3
	15	26.0	26.0	6.0	6.0	7.3	7.1
7-27-N	13	28.5	28.5	6.3	6.3	6.9	7.3
	14	28.5	28.5	7.0	7.0	7.0	6.9
	15	28.5	28.5	6.3	6.3	6.9	7.3
7-28-D	7	31.0	29.5	7.0	6.9	11.2	10.6
	8	31.5	28.5	6.8	6.7	11.0	6.3
	9	32.0	29.0	5.8	5.6	15.9	7.6
	12	31.5	29.0	5.6	6.0	6.7	5.7
7-28-N	7	31.0	29.5	7.0	6.9	10.0	11.4
	8	30.5	29.5	6.7	6.6	12.4	9.2
	9	31.5	29.0	5.7	5.9	15.4	8.9
	12	31.0	30.5	5.8	5.9	7.0	6.9
7-30-D	2	30.0	30.0	6.8	6.9	9.1	8.7
	3	30.0	30.5	6.7	6.7	7.8	6.7
	4	30.5	30.5	7.4	7.4	8.3	8.4
	5	30.0	30.0	6.3	6.2	7.0	7.2
7-30-N	2	31.5	31.5	6.8	6.8	11.4	10.7
	3	32.0	32.0	6.7	6.7	12.8	12.8
	4	31.5	31.5	7.4	7.4	9.5	9.5
	5	31.5	31.5	6.3	6.3	9.6	9.6

patches, the greater the relative number of small shrimp, the more likely one is to encounter a patch of them in any given seine haul. Also, the area I sampled per seine haul was fairly large, and may have overlooked small patches. At time I may have mixed patches of large and small shrimp, thus getting similar mean or median sizes in all 3 sectors.

The chi-square test for homogeneity on the categorized median lengths showed that overall, the sample with the smallest median length of shrimp was most likely to come from the shallow sector; the sample with the largest median length was least likely to come from that sector (Table 15). The size distribution pattern differed from day to night (Table 15). During the day, the smallest shrimp were most likely to be found in the shallow sector and the largest were most likely to be found in the middle sector. At night the sizes were distributed much more homogeneously, but with some tendency for the largest shrimp to be found in the deep sector (although the night pattern as a whole is significant only at the P=.055 level, slightly larger than my P=.05 cut-off point, the largest category when considered alone shows a distribution pattern among the sectors significantly different from a uniform one).

When the relative size distribution data are further divided into the staggered stocked and control ponds, the same pattern is seen in the control ponds as in the combined data during the day, while there is no significant pattern at

Table 14. Median lengths and numbers of shrimp caught in the 3 pond sectors, deep (D), middle (M) and shallow (S), and in the pond as a whole (TOTAL) in the 38 pond trials of the 1979 distribution study. * indicates that the lengths of shrimp in the 3 pond samples of a trial differ significantly when compared by the Kruskal-Wallis test. D = day, N = night.

			MEDIAN LENGTH (mm)				NUMBER CAUGHT			
TREATMENT	POND	DATE	D	M	S	TOTAL	D	M	S	TOTAL
Staggered stocked	5*	7-6-D	94	92	84	88	44	41	37	122
	5*	7-6-N	90	56	43	86.5	42	20	34	98
"	5*	7-30-D	66	112	83	101	20	28	41	89
"	5	7-30-N	101	72	67	73.5	27	13	28	68
"	9	7-6-D	112.5	115	113	115	24	52	31	107
"	9	7-6-N	111	41	103	98	21	19	17	57
"	9*	7-28-D	122	121	68	117	22	34	45	101
"	9	7-28-N	98	118	101	102	53	26	19	98
"	15*	7-6-D	91	115	82.5	86.5	33	33	60	126
"	15*	7-27-D	113	125.5	121.5	121	27	12	18	57
"	15	7-27-N	122	113	110	115	9	17	15	41
Control I	3*	7-6-D	95	97	92	95	70	50	27	147
"	3	7-6-N	95	94	94.5	94	9	54	24	87
"	3	7-30-D	101.5	96	98	100	16	9	26	51
"	3	7-30-N	104	101.5	103	103	50	16	23	89
"	8	7-6-D	103	102	101.5	102	76	56	42	174
"	8	7-28-D	108	109.5	107.5	108	33	32	28	93
"	8*	7-28-N	111	109	100	109	60	32	36	128
"	14*	7-6-D	93	107	110	106	36	48	43	127
"	14	7-27-D	115.5	115	112.5	115	50	39	26	115
"	14	7-27-N	115	114	118	117	25	15	16	56
Control II	2	7-6-D	81	81.5	84.5	82	29	34	48	111
"	2	7-6-N	87.5	80	81	86.5	40	7	23	70
"	2*	7-30-D	87.5	110	92.5	105	18	22	12	52
"	2	7-30-N	105.5	86.5	92	92	20	14	19	53
"	12	7-6-D	93	94	96	94	76	75	39	190
"	12*	7-28-D	118	103	79.5	99	15	29	22	66
"	12	7-28-N	111	104.5	103	104	7	14	22	43
"	13*	7-6-D	91	58	54	84	44	21	10	75
"	13	7-27-D	107	113	91.5	99	13	17	32	62
"	13	7-27-N	76	94	119	94.5	13	10	19	42
Control III	4	7-6-D	33	36.5	30.5	33	21	14	6	41
"	4*	7-6-N	34	44	31	35	4	8	15	27
"	4	7-30-D	72	77.5	60	69	6	2	13	21
"	4	7-30-N	73	75	57	66.5	8	7	9	24
"	7*	7-6-D	48	28	42.5	31	10	29	12	51
"	7	7-28-D	54.5	57	54	54.5	4	7	9	20
"	7	7-28-N	48	57	63	57.5	9	5	8	22

Table 15. Tables showing how many samples fell into the categories of smallest (SM), medium (MD) and largest (LG) sample median shrimp length in the 3 pond sectors for the combined and paired day/night data. * indicates a significant relative size distribution trend when the data are tested by the chi-square test for homogeneity.

COMBINED DATA (38 pond trials)

Pond Sector	Size Category SM	MD	LG	
Shallow	20	13	5	$\chi^2 = 13.09^*$, d.f. = 4,
Middle	8	14	16	$P < .025$
Deep	10	11	17	

PAIRED DAY/NIGHT DATA (16 pairs of pond trials)

DAY ONLY

Pond Sector	Size Category SM	MD	LG	
Shallow	10	5	1	$\chi^2 = 18.4^*$, d.f. = 4,
Middle	1	4	11	$P < .005$
Deep	5	7	4	

NIGHT ONLY

Pond Sector	Size Category SM	MD	LG $^\psi$	
Shallow	7	6	3	$\chi^2 = 9.38$, d.f. = 4,
Middle	6	7	3	$P \doteq .055$
Deep	3	3	10	

$^\psi$Numbers of samples within this category show a distribution significantly different from a uniform one at the $P = .05$ level, by the chi-square goodness-of-fit test.

night (Table 16). In the staggered stocked ponds, no significant pattern occurred during the day, but there was a significant tendency for the largest shrimp to be caught in the deep sector at night.

Overall, there was a significant tendency for the greatest numbers of shrimp to be caught in either the shallow or deep sectors of the pond, with more being caught in the deep sector (Table 17). Furness (1979) and Hardin (1981) also found more shrimp to be caught in the ends of the ponds compared to the middle. When only my paired night/day trials were considered, a change in the pattern of catch sizes was detected. During the day small and large catches were distributed fairly homogeneously; the only tendency found is for the medium-numbered catch to be made in the middle pond sector. However, at night, it was most likely for the largest number to be found in the deep sector and the fewest in the middle sector. This appears to indicate some movement of shrimp from the middle to the deep sector. When the data are considered by treatment (staggered stocked or control) the only statistically significant pattern found is in the control ponds at night, essentially the same pattern seen for the combined data (Table 18).

I hesitate to draw conclusions from the differences in significant patterns of relative size and numbers distributions between the control and staggered stocked ponds. Because of the very small number of pond trials from the latter, a lack of significant patterns is not surprising. The

Table 16. Tables showing how many samples fell into the categores of smallest (SM), medium (MD) and largest (LG) sample median shrimp length in the 3 pond sectors for the paired day/night staggered stocked and control pond data. * indicates a significant relative size distribution trend when the data are tested by the chi-square test for homogeneity.

STAGGERED STOCKED POND DATA (5 pairs of pond trials)

DAY ONLY

Pond Sector	Size Category SM	MD	LG	
Shallow	2	3	0	$\chi^2 = 8.4$, d.f. = 4,
Middle	0	2	3	$P \cong .08$
Deep	3	0	2	

NIGHT ONLY

Pond Sector	Size Category SM	MD	LG	
Shallow	3	2	0	$\chi^2 = 9.6$*, d.f. = 4,
Middle	1	3	1	$P < .05$
Deep	1	0	4	

CONTROL POND DATA (11 pairs of pond trials)

DAY ONLY

Pond Sector	Size Category SM	MD	LG	
Shallow	8	2	1	$\chi^2 = 20.18$*, d.f. = 4,
Middle	1	2	8	$P < .001$
Deep	2	7	2	

NIGHT ONLY

Pond Sector	Size Category SM	MD	LG	
Shallow	4	4	3	$\chi^2 = 3.8$, d.f. = 4,
Middle	5	4	2	$P > .25$
Deep	2	3	6	

Table 17. Tables showing how many samples fell into the categories of fewest, medium and most shrimp caught in the 3 pond sectors for the combined and paired day/night pond trials. * indicates a significant relative catch size distribution trend when the data are tested by the chi-square test for homogeneity.

COMBINED DATA (38 pond trials)

Pond Sector	Number Category FEW	MED	MOST	
Shallow	12	13	13	$\chi^2 = 10.58$*,
Middle	12.5	18.5	7	d.f. = 4,
Deep	13.5	6.5	18	$P < .05$

PAIRED DAY/NIGHT DATA (16 pairs of pond trials)

DAY ONLY

Pond Sector	Number Category FEW	MED$^{\psi}$	MOST	
Shallow	6	3	7	$\chi^2 = 9.38$,
Middle	3	10	3	d.f. = 4,
Deep	7	3	6	$P \doteq .055$

NIGHT ONLY

Pond Sector	Number Category FEW	MED	MOST	
Shallow	3	8	5	$\chi^2 = 10.87$*,
Middle	9	5	2	d.f. = 4,
Deep	4	3	9	$P < .05$

$^{\psi}$Numbers of samples within this category show a distribution significantly different from a uniform one at the $P = .05$ level, by the chi-square goodness-of-fit test.

Table 18. Tables showing how many samples fell into the categories of fewest, medium and most shrimp caught in the 3 pond sectors for the paired day/night staggered stocked and control pond data. * indicates a significant relative catch size distribution trend when the data are tested by the chi-square test for homogeneity.

STAGGERED STOCKED POND DATA (5 pairs of pond trials)

DAY ONLY

Pond Sector	Number Category FEW	MED	MOST	
Shallow	1	2	2	$\chi^2 = 7.64$, d.f. = 4,
Middle	1	3	1	$p > .25$
Deep	3	0	2	

NIGHT ONLY

Pond Sector	Number Category FEW	MED	MOST	
Shallow	2	2	1	$^2 = 2.4$, d.f. = 4,
Middle	2	2	1	$P > .25$
Deep	1	1	3	

CONTROL POND DATA (11 pairs of pond trials)

DAY ONLY

Pond Sector	Number Category FEW	MED	MOST	
Shallow	5	1	5	$\chi^2 = 7.64$, d.f. = 4,
Middle	2	7	2	$p > .1$
Deep	4	3	4	

NIGHT ONLY

Pond Sector	Number Category FEW	MED	MOST	
Shallow	1	6	4	$\chi^2 = 10.9$*, d.f. = 4,
Middle	7	3	1	$P < .05$
Deep	3	2	6	

only significant pattern seen in the staggered stocked ponds was for relatively larger shrimp to be caught in the deep end at night. This pattern, while not statistically significant, is also present in the control ponds.

Much more striking are the differences between the staggered stocked and control ponds in the changes in actual numbers and sizes of shrimp caught during the day and at night. In the staggered stocked ponds, the whole pond median size of shrimp caught at night was smaller in every case than that of those caught during the day (Table 19). There was no significant change between day and night in the size of shrimp caught in the control ponds, but it more often occurred that larger shrimp were caught at night. When the different pond sectors were considered separately, there was no significant difference in the median size of shrimp caught in the control ponds in any sector. In the staggered stocked ponds, the trend in all sectors was for smaller shrimp to be caught at night. This difference was statistically significant only in the middle sector, indicating that the change was most pronounced here, and was least pronounced in the deep sector.

Smaller shrimp may be more catchable at night for some mechanical reason, but if this were so, I would expect to see at least a trend, if not statistical significance, of smaller shrimp caught at night in the control ponds where there were small shrimp as well, but no such trend occurred. Another possible explanation is that the smaller shrimp are relatively more active at night than the larger ones in the

Table 19. Comparisons of the numbers of times the median size of shrimp caught differed from day to night. The data are considered for the ponds as a whole and separately by pond sector. * indicates that the observed trend is significant when the data are tested by the Wilcoxon signed ranks test.

	Median Size Differences (#)	
	Night < Day	Night > Day
WHOLE POND DATA (1 median/trial)		
Combined data	9	7
Staggered stocked ponds*	5	0
Control ponds	4	7
BY POND SECTOR (3 medians/trial)		
DEEP		
Combined data	6	9
Staggered stocked ponds	3	2
Control ponds	3	7
MIDDLE		
Combined data*	12	3
Staggered stocked ponds*	5	0
Control ponds	7	3
SHALLOW		
Combined data	7	9
Staggered stocked ponds	4	1
Control ponds	3	8

staggered stocked ponds. This could be a mechanism by which some cannibalism and intraspecific aggression is avoided and efficiency of pond utilization increased in cultures of mixed size classes.

The actual numbers of shrimp caught declined from day to night, but the difference was significant only in the staggered stocked ponds and the combined data, especially in the shallow sector, but never in the control ponds (Table 20). The overall decline in numbers caught probably indicates a decrease in activity at night rather than a decrease in catchability. Other penaeid species, P. aztecus and P. vannamei have been found to be more easily caught at night than during the day, presumably because of increased activity (Furness, 1979; Hutchins et al., 1980). However, Aquacop (1979) stated that their broodstock blue shrimp were active day and night. The interesting point in my study is that the decrease in activity is much more pronounced in the staggered stocked than in the control ponds. Since the relatively smaller shrimp were more likely to be caught at night in the staggered stocked ponds, the decrease in activity is apparently primarily of the larger shrimp.

It is possible that competition within size classes may explain why the same decrease in activity was not observed in the control ponds. If larger shrimp feed on different natural food items than smaller shrimp, the amount of natural food available to each shrimp would be greater in the staggered stocked ponds than in the control ponds, since the latter contained shrimp of only one age group. The larger

Table 20. Comparisons of frequency of catch size differences between day and night. The data are considered for the ponds as a whole and separately by pond sector. * indicates that the observed trend is significant when the data are tested by the Wilcoxon signed ranks test.

	Catch Size Differences (#)	
	Night < Day	Night > Day
WHOLE POND DATA (1 number/trial)		
Combined data*	11	5
Staggered stocked ponds*	5	0
Control ponds	6	5
BY POND SECTOR (3 numbers/trial)		
DEEP		
Combined data	7	8
Staggered stocked ponds	3	2
Control ponds	4	6
MIDDLE		
Combined data*	11	4
Staggered stocked ponds	4	1
Control ponds	7	3
SHALLOW		
Combined data*	12	3
Staggered stocked ponds*	5	0
Control ponds	7	3

shrimp may prefer to feed during the day and become less active at night. In the control ponds where less natural food is available, the shrimp may continue feeding longer in order to obtain more. Such a mechanism could be operating even though artificial food was present, since shrimp have been shown to strongly prefer natural food items to artificial rations similar to the one used in this study (Quarberg, 1974).

To summarize the results, a definite pattern of shrimp distribution in the ponds can be seen. There is strong evidence for some segregation by size, especially during the day. The relatively smaller shrimp tended to favor the shallow sector of the pond during the day but were distributed fairly homogeneously at night. The larger shrimp favored the middle sector by day, and tended to move toward the deep sector at night. In the staggered stocked ponds, there was a decrease in activity at night, but the relatively smaller shrimp either did not decrease their activity, or did so to a lesser extent than the larger shrimp.

All these patterns show how contact between the larger and smaller shrimp in ponds containing different size groups may be reduced, thus reducing cannibalism and competition problems. The underlying reasons for the patterns are not clear. The movement of shrimp may be related to the movement or availability of natural food organisms in the different pond areas. Gould (1973) and Quarberg (1974) found differences in numbers and types of potential food organisms present in the different sectors of ponds at this site. The preferred prey of the smaller shrimp might be most concentrated in the shallow sector and that of the larger shrimp in the middle sector during the day. If the prey move or become unavailable at night, or if the shrimp no longer feed, that could explain the change in the smaller shrimp distribution pattern. The larger shrimp may follow their prey to the deep sector at night, or they may prefer that sector for other reasons. Hutchins et al. (1980) found that P. vannamei became concentrated in the deep ends of ponds during their least active periods.

Temperature may be a driving factor. As the ponds heat up during the day from the sun shrimp may tend to move away from the otherwise preferred shallower areas into the deeper, cooler areas. Furness (1978) showed that the Cedar Bayou research ponds tend to be warmer at the shallow end, and progressively cooler toward the deep end. Marty Ordonez (1972) found blue shrimp averaging 130 mm in length to consistently prefer the lowest available temperatures in gradient tanks where temperatures ranged from about 10-35 C. In a similar study Arosamena (1976) reported that juvenile blue shrimp (no size given) preferred temperatures of 10-15 C. However, both these studies used gradient tanks where the lowest temperature was also at the deepest level; the shrimp may have been seeking the deepest rather than the coldest level. They may also have become trapped by inactivity induced by low temperatures.

Another possible explanation is that the distribution of smaller shrimp depends on that of larger shrimp. The smaller ones may actively avoid the larger ones by concentrating in patches, especially in the shallow end, during the day when they are most visible and the larger shrimp most active. As the larger shrimp retreat toward the deep end and reduce their activity at night, the smaller shrimp may take the opportunity to feed relatively unmolested throughout the pond.

Whatever the underlying reasons may be, I have demonstrated that there are mechanisms in ponds that reduce contact between the different sizes of shrimp. This explains why cannibalism, so often a problem in uniform-environment raceways, was not found to be any more of a problem in the staggered stocked ponds than in the control ponds. I have also shown that different relative sizes of shrimp make differential use of the pond space resources, and therefore possibly the food resources. This may explain why the yield from the staggered stocked ponds was greater than expected; it could be due to more efficient utilization of pond resources by mixed size classes compared to only one size class.

Aquarium Study

Introduction

In an attempt to further elucidate the effects of staggered stocking on shrimp, an aquarium experiment was designed to study the effects of relatively large shrimp on relatively small ones in mixed-size culture at stocking densities similar to those in the culture ponds. The objectives were to answer the following questions:

1) Does the physical presence of large shrimp affect the growth of small ones?

2) Does the presence of large shrimp without the possibility of physical contact or food competition affect the growth of small ones?

3) Does the presence of large shrimp affect the survival of small ones?

4) Is there a difference in feeding behavior patterns be-between large and small shrimp, and between small shrimp in culture with large ones and small shrimp alone?

Materials and Methods

Eight 0.38-m^3 Plexiglas aquaria with bottoms of polyester-coated plywood were used. The bottoms measured approximately 120 cm X 80 cm, an area of about .96 m^2. The aquaria were equipped with bottom filters covered with a layer of crushed oyster shell and topped with one of sand. They were covered by screens to prevent shrimp jumping out of the tanks. Two aquaria were divided into 2 equal compartments by a vertical screen made of PVC pipe, fiberglass windowscreen and silicone. All tanks were visually isolated from eachother by the use of black plastic screens.

The tanks were filled with 10 ppt water and allowed to clear for 2 weeks before introduction of shrimp. Occasional addition of small amounts of fresh water maintained this salinity throughout the experiment. Temperature was checked daily and ranged from 26.5 C to 31.0 C. The tanks were always within 1.1 C of eachother.

"Large" shrimp, mean length 108.1 mm and mean weight 8.44 g, were taken from pond 8 (stock I, stocked April 28.) "Small" shrimp, mean length 52.0 mm and mean weight 1.17 g, were taken from pond 7 (stock III, stocked June 18). They were stocked into the 8 tanks according to the following design: 2 tanks each of 8 large shrimp, 2 tanks each of 8 small shrimp, 2 tanks each of 4 large and 4 small shrimp in physical contact, and 2 tanks each of 4 large and 4 small shrimp separated by a barrier. After several days of acclimation, all shrimp were weighed to the nearest .01 g and measured to the nearest millimeter on July 27.

Shrimp were fed whole frozen brine shrimp (<u>Artemia salina</u>), which were first thoroughly washed and thawed with fresh water, then weighed. Shrimp were fed once per day at rates calculated from the following table.(Table 21):

Table 21. Shrimp feeding rate regime.

Shrimp weight (g)	% body wt fed/day
< 1.5	10.0
1.5-1.99	8.0
2.0-2.5	6.25
> 6.0	2.5

These rates were one-half the then-current rates of feeding for shrimp in pond culture at the Texas A&M Mariculture facility at Corpus Christi (George Chamberlain, Associate Mariculture Specialist, personal communication). The rates were probably less than the satiation level; there was never any leftover food visible in the tanks on the following day.

All the shrimp were again weighed and measured on Aug. 8 (day 12), Aug. 17 (day 21) and Aug. 23 (day 27, termination). Mean instantaneaous growth rate (g/g/day) for each size category was calculated for each tank over all 3 sampling periods. Occasionally a shrimp died between samples. If it could be recognized to correspond to a particular shrimp weight from the previous sample, it was dropped from the data to give a more accurate mean growth rate for the tank. When feasible, replacement shrimp were added at sampling times to maintain the shrimp density in the tank. These came from the original stock animals which had been held in separate tanks.

At the end of the experiment, mean instantaneous growth rate was calculated for each tank and size category over the entire growth period. In tanks where no shrimp had been replaced, this was done simply by using the mean final weight on day 27 and the mean initial weight on day 0. Where replacements had been made, the weighted mean of the growth rates calculated for the 3 sampling periods was used. It was necessary to weight the mean since the sampling periods were of unequal length. The formula for instantaneous growth is:

$$\text{Instantaneous growth} = \frac{\log(wt_f/wt_i)}{\#\text{ of days}}$$

where wt_f and wt_i are the final and initial mean weights of the shrimp and # of days is the number of days in the sample period.

Final mean survival and growth rates were compared between treatments by Student's t test. In addition, the mean instantaeous growth rates calculated as of day 12, 21 and 27 were compared by the Mann-Whitney test, a non-parametric equivalent of the t test (Conover, 1971). A t test would have tested for differences in the non-weighted final mean for each treatment, inappropriate in this case; the Mann-Whitney procedure tests for the tendancy of one treatment to give lower values for growth than another.

Shrimp feeding behavior observations were made on 3 separate occasions. Each tank was observed for 10 minutes before the addition of food and for 10 minutes after. At one-minute intervals each shrimp was classified into one of the following categories: 1) feeding without locomotion, 2) feeding and walking, 3) feeding and swimming, 4) no feeding, no locomotion and 5) no feeding, swimming. Because of the very small number of observations in category 5 (5 out of 3540), it was combined with category 4 and relabeled no feeding. It must be emphasized that these classifications were made on the basis of observable behavior rather than actual ingestion of food. If shrimp were observed moving their chelipeds to their mouth parts, they were classified as feeding. Since shrimp frequently sift through the substrate for particulate matter and "taste" as they go while walking, all walking shrimp were classified as feeding.

The number of observations in each category was summed separately over the 10 minutes before and 10 minutes after the addition of food, giving a total number of observations in each category both before and after feeding for each tank. These results were then pooled for each treatment (2 replicate tanks on 3 occasions) to give a grand total number of observations in each category before and after addition of food for each treatment. These totals could then be compared between treatments by a chi-square test for homogeneity.

Results and Discussion

There was no significant difference in survival of the small shrimp among the 3 treatments, nor was there any trend indicating lower survival of small shrimp cultured with large ones (Table 22). Thus the presence of large shrimp had no adverse effect on survival of small ones at this stocking density. Likewise, the presence of small shrimp had no effect on the survival of large ones (Table 23). In general, large shrimp had better survival rates than the small ones, an average of 93.9% vs 76.7% respectively. However, this difference is statistically significant only at the 92% level of confidence (Students t test). This trend may reflect differences in the inherent viability of the 2 shrimp stocks. At harvest, stock I shrimp (the large shrimp source) had 49.3% mean survival; stock III shrimp (the small shrimp source) had only 25.2% mean survival.

Table 22. Survival (%) of small shrimp over the 27-day experiment. The treatments were 1) small shrimp cultured with large, without a barrier, 2) small shrimp cultured with large, with a barrier, and 3) small shrimp alone (control). Each treatment had 2 replicate tanks. Means bearing the same superscript are not significantly different (P<.05).

Treatment	Rep 1	Rep 2	Mean
1 no barrier	100	43	71.5[a]
2 with barrier	100	75	87.5[a]
3 control	75	67	71.0[a]

Table 23. Survival (%) of large shrimp over the 27-day experiment. The treatments were 1) large shrimp cultured with small, without a barrier, 2) large shrimp cultured with small, separated by a barrier, and 3) large shrimp alone (control). Each treatment had 2 replicate tanks. Means bearing the same superscript are not significantly different (P<.05).

Treatment	Rep 1	Rep 2	Mean
1 no barrier	100	100	100[a]
2 with barrier	100	100	100[a]
3 control	100	63.6	81.8[a]

The growth rate of small shrimp was not affected by the presence of large shrimp separated from them by a barrier (Table 24), thus there was no evidence of a growth inhibiting substance such as that known in frogs (West 1960). The growth rate of small shrimp was, however, apparently decreased by culture in physical contact with large ones. Final mean growth was consistently lowest in that treatment. There was too much variation in the final mean growth for a t test to show significant differences at the 95% level of confidence, but the Mann-Whitney test did show a significant (P<.05) tendency for small shrimp in physical contact with large ones to have a lower growth rate than the control shrimp.

The large shrimp in contact with small ones grew better than did the large shrimp in the barriered and control tanks (Table 25). It seems obvious they were competing with the small shrimp for food. They got more than their "share" of the calculated feeding rates, while the small shrimp got less, reflected in the growth rates of both. Thus where food is limited, as in this experiment, the presence of large shrimp appears to have a detrimental effect on the growth rate of small ones, apparently by direct competition for food. If the animals were fed to satiation there might be no effect of large shrimp on the growth of small ones. There is no evidence from the pond study, where food was abundant, that large shrimp had any detrimental effect on growth or yield of small ones. However, this hypothesis requires further testing.

Table 24. Mean instantaneous growth rate (g/g/day X 10^{-3}) of small shrimp over the 27-day experiment. Individual sample means, and the weighted means over the whole period for each replicate and treatment are shown. The treatments were 1) small shrimp cultured with large, without a barrier, 2) small shrimp cultured with large, with a barrier, and 3) small shrimp alone (control). Means with the same superscript indicate treatments that do not show significant ($P<.05$) tendencies to give different values for growth, tested by the Mann-Whitney test.

Treatment	Day 12 Rep 1, Rep 2	Day 21 Rep 1, Rep 2	Day 27 Rep 1, Rep 2	Weighted mean Rep 1, Rep 2	Weighted treatment mean
1 no barrier	5.90, 3.24	5.48, 1.89	5.61, 8.97	5.69, 4.06	4.88 [a]
2 with barrier	4.99, 9.32	11.04, 12.32	4.39, 3.87	6.87, 9.10	7.99 [ab]
3 control	3.88, 10.88	9.04 10.89	7.81, 10.78	6.47, 10.85	8.63 [b]

Table 25. Mean instantaneous growth rate (g/g/day X 10^{-3}) of large shrimp over the 27-day experiment. Individual sample means, and the weighted means over the whole period for each replicate and treatment are shown. The treatments were 1) large shrimp cultured with small, without a barrier, 2) large shrimp cultured with small, with a barrier, and 3) large shrimp alone (control). Means bearing the same superscript are not significantly different (P<.05), tested by Students t test.

Treatment	Day 12 Rep 1, Rep 2	Day 21 Rep 1, Rep 2	Day 27 Rep 1, Rep 2	Weighted mean Rep 1, Rep 2	Weighted treatment mean
1 no barrier	1.63, .817	-0.88, 1.18	4.43, 3.48	1.41, 1.53	1.47 [a]
2 with barrier	-0.092, -1.66	0.792, -0.245	1.35 1.28	0.522 -0.534	-0.006 [b]
3 control	-0.419, 0.168	0.224 2.62	1.82 -0.868	0.294 0.754	0.524 [b]

As the best single indicator of shrimp interest in feeding, the proportion of shrimp in each treatment either feeding or not feeding after the addition of food to the tank was examined (Fig. 10). These patterns were paired in all possible combinations of treatments (15) and tested against eachother by a chi-square test for homogeneity. While the data were converted to percentages for ease of visual comparisons, the statistical tests were done with the actual numbers of observations (Table 26.) The analysis shows that there was no difference in the feeding pattern (or degree of interest in feeding) after addition of food between the large shrimp control, and the large shrimp

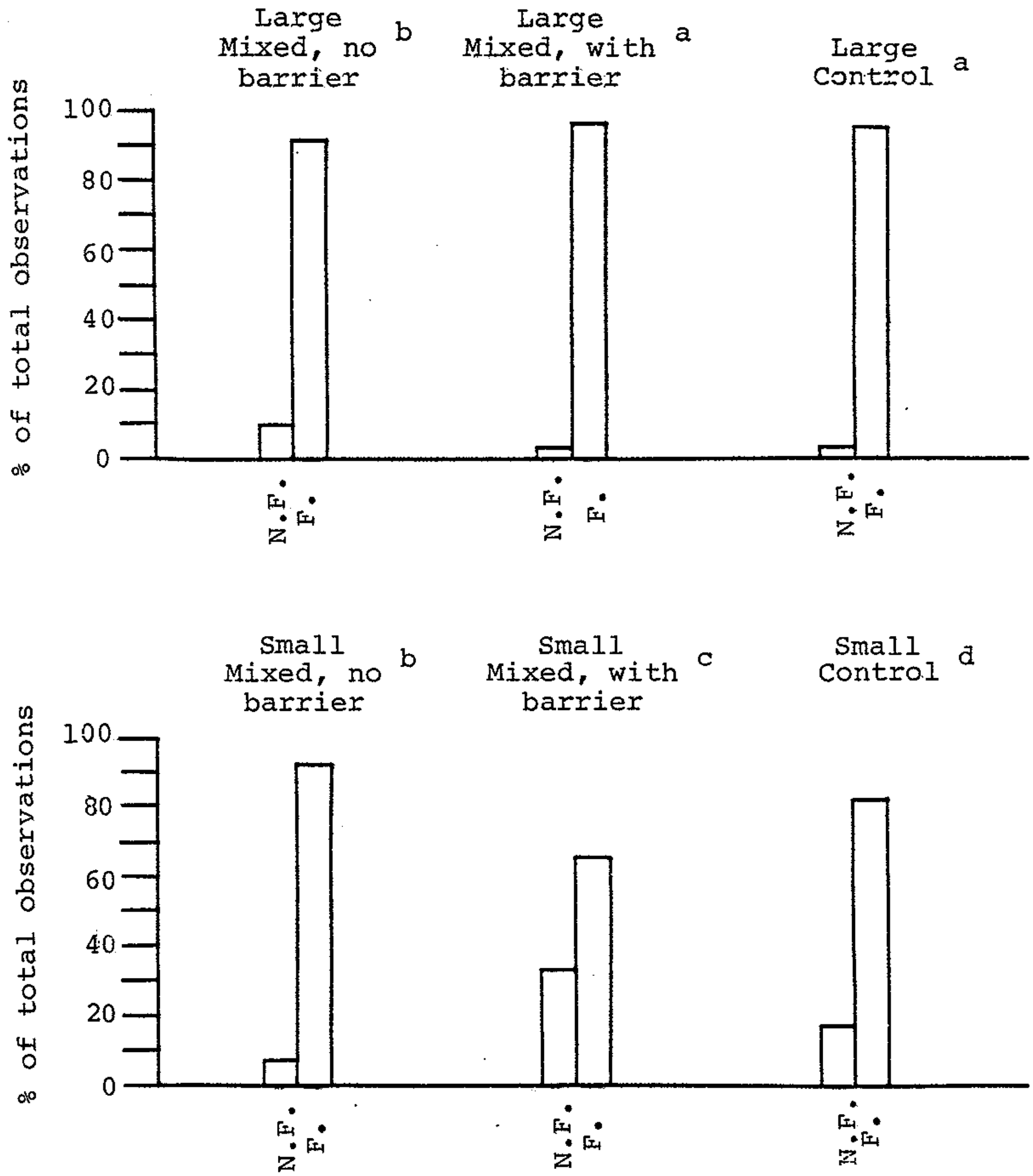

Figure 10. Percentages of total observations in either the feeding (F.) or not feeding (N.F.) categories after the addition of food to the tanks for all treatments. Treatments bearing the same superscript do not have significantly different feeding patterns (chi-square test, $P > .05$).

Table 26. Numbers of observations of shrimp in each feeding category before and after addition of food to the tank for all treatments. Each number represents data pooled from 6 trials.

Treatment		Feeding, no locomotion	Feeding, walking	Feeding, swimming	Not feeding	Total
Small, mixed with barrier	Before	39	23	6	152	220
	After	115	23	9	73	220
Small, mixed without barrier	Before	64	52	4	90	210
	After	141	23	30	16	210
Small control	Before	97	112	12	199	420
	After	201	103	42	74	420
Large, mixed with barrier	Before	31	23	3	183	240
	After	157	48	28	7	240
Large, mixed without barrier	Before	48	10	0	182	240
	After	134	56	28	22	240
Large control	Before	104	97	41	198	440
	After	244	113	68	15	440

separated from small ones by a barrier (Figure 10, Table 27). They show significantly greater interest than all the other treatments, probably because they were the hungriest. The percentage of body weight per day fed to the small shrimp was apparently well above the maintenance level since all tanks achieved positive mean growth rates (Table 24). The ration of the large shrimp was apparently closer to the maintenance level since overall growth rate of those not in contact with small ones was low, and was negative for at least one sample period in all 4 tanks (Table 25). Thus one would expect them to be hungrier and show greater interest in feeding than the small shrimp.

Table 27. Numbers of observations of shrimp either feeding or not feeding after addition of food to the tank for all treatments. Each number represents data pooled from 6 trials. Treatments bearing the same superscript do not show significant differences in the proportions of observations in each category (chi-square test, P=.05).

Treatment	Feeding	Not feeding
Large control [a]	425	15
Large, mixed with barrier [a]	233	7
Large, mixed without barrier [b]	218	22
Small, mixed without barrier [b]	194	16
Small, mixed with barrier [c]	147	73
Small control [d]	346	74

The large shrimp physically mixed with small ones showed slightly, but significantly less interest in feeding than the other large shrimp treatments. Since they were successfully competing with the small shrimp for food, reflected in the comparative growth rates for large shrimp, they were probably less hungry than their counterparts whose food was more limited.

Likewise the small shrimp physically mixed with large ones showed an interest in feeding significantly greater than that of the small shrimp control. The pattern they exhibit is closer to that shown by the large shrimp, and indeed was no different than that of the large shrimp they were competing with. Since they were getting comparatively less food than the other small shrimp, as shown by their lower growth rate, they were probably hungrier, and thus more likely to feed.

Of particular interest is the pattern shown by the small shrimp separated by a barrier from large ones. These shrimp showed the least interest in feeding of any treatment. They were significantly much less likely to feed immediately after addition of food than the small shrimp control; 33.2% of the observations made after the addition of food were in the not feeding category, compared to only 17.6% of the observations in the small shrimp control. Those shrimp that were feeding in the barriered treatment were significantly more likely to be feeding without locomotion and less likely to be walking or swimming that the small shrimp feeding in the control treatment. This was also true of the small shrimp feeding in physical contact with large ones. Shrimp in both categories mixed with large ones were significantly less likely to be feeding with locomotion than without locomotion compared to the large shrimp they were in contact with, but small control shrimp were no different than large control shrimp (Figure 11).

This marked inhibition of activity is apparently due to the presence of large shrimp. The stimulus may be visual, or may be due to some other means of perception of large shrimp by the small ones. Since there was no difference in growth between the small control shrimp and those in the barriered tanks, the latter must have consumed the food eventually, possibly increasing their activity as the large shrimp decreased theirs. There is some evidence that small shrimp in culture with large ones in ponds show somewhat different temporal activity patterns than the large ones (see Distribution Study). This may be a mechanism whereby small shrimp avoid aggressive encounters and possible injury by actively feeding large shrimp.

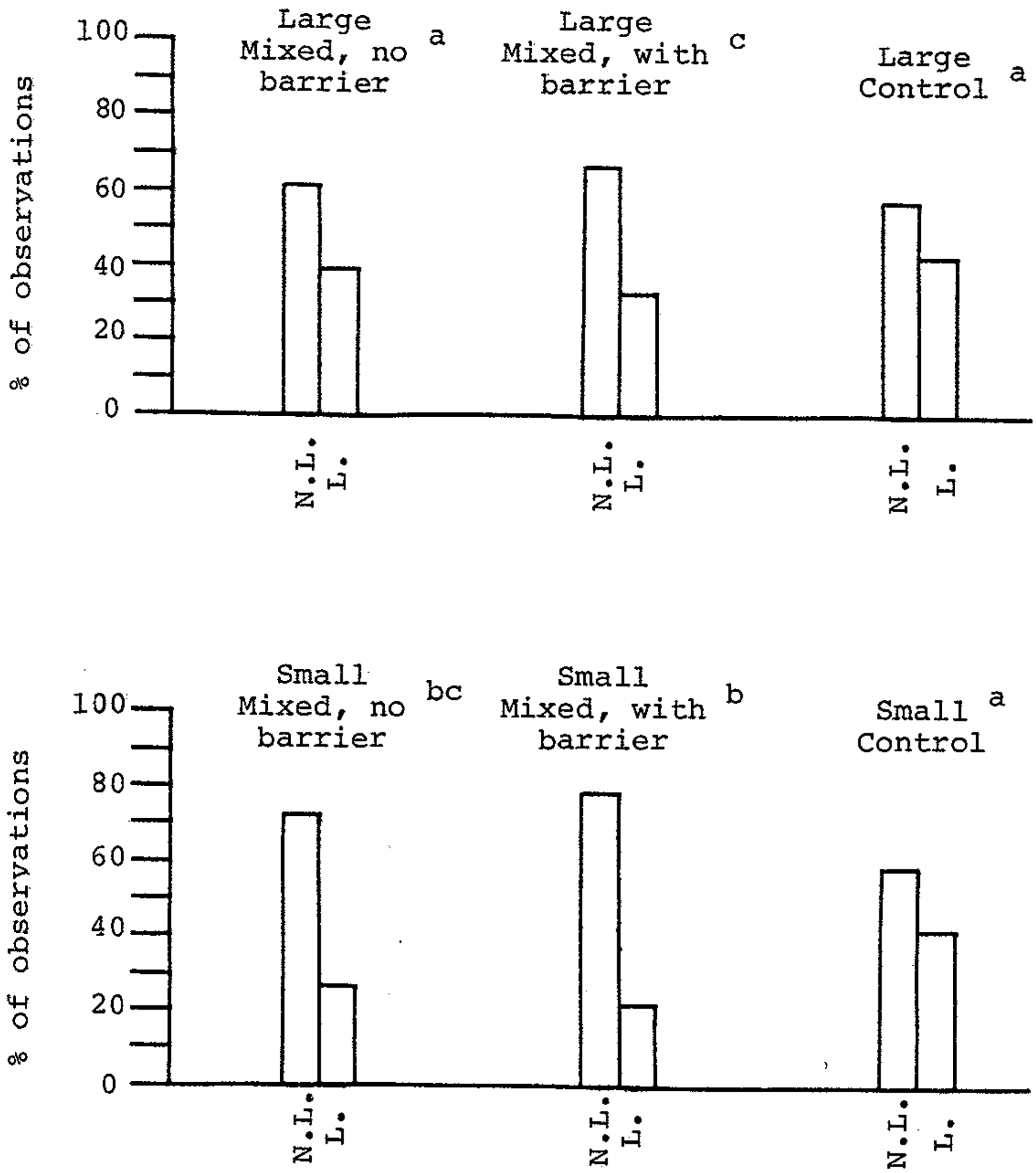

Figure 11. Percentages of shrimp that were feeding after the addition of food to the tank that fell into either the feeding and walking or swimming (L.) categories or the feeding without locomotion (N.L.) category. Treatments bearing the same superscript do not have significantly different feeding patterns (chi-square test, $P > .05$).

The small shrimp in the mixed non-barriered tanks fed promptly, but still showed inhibited activity while feeding. Perhaps their degree of hunger was enough to partially override the inhibiting stimuli from the large shrimp. The fact that their growth rate was depressed may be a result of their less active feeding compared to the large shrimp, allowing the large shrimp to capture more of the food.

In the pond study, food was probably abundant; shrimp density was fairly low, and feeding rates were calculated for assumed survival rates higher than those actually achieved. Thus since food was not limited, small shrimp in the ponds may have behaved more like the small shrimp in the barriered tanks, rather than those in physical contact with large shrimp. Results from the distribution study indicate that some segregation of shrimp by size occurred in the ponds, and that small shrimp were relatively more active at night than large shrimp.

Further work in this area would be of interest. Use of different sizes of shrimp and stocking densities might give different results. Such studies using shrimp of 2 species should give insights to suitable species combinations for polyculture of shrimp in ponds.

LENGTH-WEIGHT RELATIONSHIPS

The condition coefficient (K) derived by Lagler (1956) and modified by Wheeler (1967) has been used by researchers as a measure of relative well-being of shrimp (Gould, 1973; Quarberg, 1974; Reitsema, 1975; Fredieu, 1978). Other workers, while avoiding the use of K, still describe pond shrimp populations with relatively greater weight per unit length as being in better condition than those with relatively less weight per unit length (Furness, 1978; Hardin, 1981). Results of analyses of length-weight relationships from my blue shrimp studies indicate this may not always be valid.

In my staggered stocking pond study, there was a considerable proportion of very slow-growing shrimp. The length-frequency data at harvest for control I and control II shrimp typically show a modal portion of the curve approximating a normal curve with a long tail of small, slow-growing shrimp to the left of it (Figures 6 and 7, pages 67-68). Size range at harvest was between 70 and 100 mm in these ponds, compared to a maximum of 25 mm for blue shrimp during the 1978 polyculture study (Figure 8, page 69). I compared the individual K values from random samples of 15 shrimp from each pond from the modal portion at harvest, the tail portion at harvest, and the modal portion of an earlier sample whose size range corresponded to the tail portion at harvest, using the Mann-Whitney test (Conover, 1971). I found that these slow-growing, or stunted shrimp from the tail portions of the curves typically gave mugh higher values of

K than shrimp from the modal portion of the curve at harvest. The difference is not simply due to size; shrimp from the tail portion of the curve at harvest always gave much higher K values than shrimp of the same size from the modal portion of the curve of earlier samples (Table 28).

Table 28. Comparisons of condition factor values (K) among samples of shrimp within each pond. Each mean represents 15 shrimp. Means within each pond bearing the same superscript do not differ significantly when tested by the Mann-Whitney test (P=.05). No comparisons were made between ponds.

Treatment	Pond	Date / Sizes (mm)	K	Date / Sizes (mm)	K	Date / Sizes (mm)	K
Control I	3	8-11-79 / 100-120	6.63[a]	8-11-79 / 60-80	8.06[b]	6-12-79 / 60-80	6.40[a]
"	8	8-11-79 / 110-130	6.40[a]	8-11-79 / 70-90	7.47[b]	6-12-79 / 70-90	6.26[a]
"	14	8-11-79 / 115-135	6.74[a]	8-11-79 / 80-100	7.91[b]	6-12-79 / 80-100	6.64[a]
Control II	2	8-12-79 / 110-130	7.37[a]	8-12-79 / 60-80	8.74[b]	6-25-79 / 60-80	6.79[c]
"	12	8-12-79 / 120-140	7.09[a]	8-12-79 / 60-80	8.67[b]	6-26-79 / 60-80	7.00[a]
"	13	8-12-79 / 120-140	7.02[a]	8-12-79 / 60-80	8.83[b]	6-26-79 / 60-80	7.04[a]

It is ludicrous to state that the apparently stunted shrimp in the tail portion of the curve at harvest have a higher state of "well-being" than the much faster growers in the modal portion of the curve. Their greater weight per unit length may be the result of some inablility to molt normally, or may be due to some other abnormality. Thus it appears that higher K values, or greater wight per unit length may sometimes be an indicator of relative lack of well-being, and sometimes may indicate the reverse.

Rather than make comparisons of K, I opted to compare length-weight relationships in my studies by analysis of covariance. Since shrimp growth is not isomorphic, it is important to make such comparisons over the same general size range of animals. In the polyculture experiment, I combined the data for all samples within each pond and compared the length-weight relationships for white shrimp among all the ponds. There were no significant differences within or among treatments for white shrimp. Nor was there a significant difference between the 2 pond populations of blue shrimp. Blue shrimp tended to have a greater weight per unit length than white shrimp in the same ponds, but the difference was not significant.

The length-weight relationships of shrimp in my polyculture study compare well with other relationships available for the same species (Table 29). Hutchins et al. (1979) give relationships for pond cultured white and blue shrimp. Fontaine and Neal (1971) give a relationship for wild white shrimp. The predicted value of white shrimp weight at 50 mm is smaller in my study than predicted by Hutchins et al., but that for 100 mm is somewhat higher, indicating white shrimp nearing harvest size in my study reached a slightly higher degree of plumpness than has typically been found at the Corpus Christi Texas A&M Mariculture facility. White shrimp in my study were also typically plumper at 100 mm than wild shrimp. The equation for blue shrimp in my study gives about the same predicted weight for a 100 mm shrimp as Hutchins et al. and a somewhat higher value for 130 mm shrimp, indicating shrimp condition values at harvest were at least as high as those normally found at the Corpus Christi facility.

Table 29. Comparisions of predicted weights at selected lengths for blue and white shrimp by equations found in my 1978 polyculture study, and equations reported by Hutchins et al., 1979, and Fontaine and Neal, 1971.

Species	Source	Equation	Predicted weight(g) 50 mm	100 mm	130 mm
White	Present study	$W=4.38X10^{-6}\ L^{3.100}$	.81	6.95	*
White	Hutchins et al.	$W=1.072X10^{-5}L^{2.893}$	.88	6.55	*
White	Fontaine & Neal	$W=2.163X10^{-6}L^{3.247}$	*	6.75	
Blue	Present study	$W=5.035X10^{-6}L^{3.074}$	.84	7.08	15.86
Blue	Hutchins et al.	$W=9.311X10^{-6}L^{2.940}$	.92	7.06	15.28

* Outside of range covered by equation.

No analyses of length-weight relationships were made in the 1978 staggered stocking study due to the lack of replicates. In the 1979 staggered stocking study, I first compared the ponds and treatments at harvest. There was no significant difference in length-weight relationships at harvest among ponds within any treatment, but the control III treatment gave significantly heavier shrimp per unit length than all the other treatments, which did not differ significantly from eachother (Table 30). Since control III shrimp reached a smaller mean size than control II shrimp over a similar time period even though their density was much lower, and because they were not as high quality postlarvae, I conclude that the greater degree of plumpness in control III shrimp does not indicate a greater degree of well-being, but rather the reverse. They appear to have experienced some degree of stunting, like shrimp in the tail portions of the control I and II length-frequency curves.

Table 30. Length-weight relationships at harvest for each pond in the 1979 staggered stocking study. Treatments bearing different superscripts have significantly different length-weight relationships.

Treatment	Pond	Equation	Predicted weight (g) 50 mm	Predicted weight (g) 100 mm
Control I [a]	3	$W=4.721X10^{-5}L^{2.581}$	1.15	6.85
"	8	$W=5.338X10^{-5}L^{2.556}$	1.17	6.91
"	14	$W=3.424X10^{-5}L^{2.664}$	1.15	7.29
Control II [a]	2	$W=3.955X10^{-5}L^{2.643}$	1.22	7.64
"	12	$W=4.149X10^{-5}L^{2.635}$	1.24	7.73
"	13	$W=3.561X10^{-5}L^{2.669}$	1.22	7.75
Control III [b]	4	$W=2.344X10^{-5}L^{2.793}$	1.30	9.04
"	7	$W=2.380X10^{-5}L^{2.797}$	1.34	9.34
Staggered [a]	5	$W=3.370X10^{-5}L^{2.676}$	1.19	7.58
"	9	$W=3.241X10^{-5}L^{2.686}$	1.19	7.63

Since the tail portions of the curves in control I and control II tend to give plumper shrimp, I divided each sample in all the control I and II ponds into a tail portion and a mode portion (Table 31). This was done by picking the most reasonable cut-off point from the length-frequency data in figures 6 and 7 (pages 67 and 68). I then combined all the modes for each treatment and compared the resulting length-weight relationships between the 2 treatments. The process was repeated

Table 31. Size class divisions of the length-frequency data throughout the 1979 staggered stocking experiment for control I and II ponds. Data are divided into tail and mode portions by the indicated cut-off point.

Treatment	Pond	Date	Tail<Cutoff point(mm)≥ Mode	
Control I	3	5-17-79		All mode
		5-29-79		All mode
		6-12-79	60	
		6-26-79	80	
		7-10-79	85	
		7-24-79	90	
		8-11-79	100	
Control I	8	5-17-79		All mode
		5-29-79	40	
		6-12-79	70	
		6-26-79	80	
		7-10-79	80	
		7-24-79	100	
		8-11-79	110	
Control I	14	5-17-79		All mode
		5-29-79	50	
		6-12-79	75	
		6-26-79	90	
		7-10-79	100	
		7-24-79	110	
		8-11-79	120	
Control II	2	6-11-79		All mode
		6-25-79	61	
		7-9-79	80	
		7-23-79	95	
		8-12-79	110	
Control II	12	6-11-79		All mode
		6-25-79	60	
		7-9-79	90	
		7-23-79	95	
		8-12-79	120	
Control II	13	6-11-79		All mode
		6-26-79	60	
		7-9-79	80	
		7-23-79	100	
		8-11-79	120	

for the tail portions. I found that control II modes gave significantly plumper shrimp than Control I modes (Table 32). since control II modal shrimp grew faster than control I (probably due to their lower density) this appears to be a case in which it can be stated the the fastest-growing control II shrimp were in better condition than the fastest-growing control I shrimp. There was no significant difference between the tail portions of the data (Table 32).

The modal portions of both treatments give lower predicted weights than Hutchins et al. (1979) or my 1978 polyculture study relationship for blue shrimp. This probably indicates poorer condition in general in 1979, possibly due to the low salinity throughout the study period. This conclusion is consistent with the poorer growth and survival experienced in 1979 compared to 1978.

Table 32. Comparisons between control I and control II length-weight relationships of modal and of tail portions of the length-frequency data throughout the culture period. Treatments bearing the same superscript within the same portion of the curve do not have significantly different length-weight relationships.

Treatment	Portion of curve	Equation	Predicted weight (g) 50 mm	Predicted weight (g) 100 mm
Control I[a]	Modes	$W=7.993X10^{-6}L^{2.958}$	.85	6.59
Control II[b]	Modes	$W=6.900X10^{-6}L^{3.001}$	.87	6.93
Control I[a]	Tails	$W=7.580X10^{-6}L^{2.986}$	.90	7.11
Control II[a]	Tails	$W=9.939X10^{-6}L^{2.942}$	.99	7.61
Hutchins et al.		$W=9.311X10^{-6}L^{2.940}$	.92	7.06
1978 Polyculture		$W=5.035X10^{-6}L^{3.074}$	.84	7.08

In an attempt to determine whether staggered stocking influences shrimp condition, I compared the mode at harvest from the best-growing control I pond (14) and the best-growing control II pond (12) with the modes ($\geq$ 120 mm) of the 2 staggered stocked ponds. While the control I and control II ponds had significantly different length-weight relationships from eachother, neither differed significantly from the staggered stocked ponds (Table 33), indicating neither better nor poorer condition of shrimp in the staggered stocked ponds compared to control ponds.

Table 33. Comparisons of length-weight relationships of modes at harvest from ponds 5 and 9 (staggered stocked), pond 14 (control I) and pond 12 (control II). Ponds with the same superscript do not have significantly different length-weight relationships.

Pond	Equation	Predicted weight (g) at 120 mm
5[ab]	$W=2.977X10^{-3}L^{1.752}$	13.08
9[ab]	$W=1.132X10^{-3}L^{1.959}$	13.04
12[a]	$W=5.416X10^{-4}L^{2.107}$	13.02
14[b]	$W=2.994X10^{-3}L^{1.738}$	12.30

Finally, I compared the tail portions of the data at harvest (< 120 mm for staggered stocked and control III ponds, see Table 31 for control I and II pond cut-offs) among all the treatments. The staggered stocked treatment was not significantly different from control II, but gave heavier shrimp than control I and lighter shrimp than control III. Control III gave significantly heavier shrimp than all other treatments (Table 34). Interpretation of these results is difficult.

Table 34. Comparisons among treatments of length-weight relationships for tail portions of the length-frequency data at harvest in the 1979 staggered stocking study. Treatments bearing the same superscript do not have significantly different length-weight relationships.

Treatment	Equation	Predicted wt(g) 50 mm	100 mm
Staggered[ac]	$W=2.737X10^{-5}L^{2.724}$	1.16	7.68
Control I[b]	$W=1.571X10^{-5}L^{2.831}$	1.01	7.22
Control II[c]	$W=3.546X10^{-5}L^{2.668}$	1.21	7.69
Control III[d]	$W=2.098X10^{-5}L^{2.823}$	1.31	9.28

The staggered stocked tails are most similar to those of control II ponds, which are intermediate between control I and III. This would be expected, since the staggered stocked ponds were a mixture of stock I, II and III shrimp. Control I tails gave lighter shrimp than control II tails. In addition, only 37% of control I shrimp at harvest were in the tail category compared to 56% of control II shrimp. This appears to indicate that stock I shrimp suffered a lesser degreee of stunting than stock II shrimp. Their much higher survival and yield also indicate that they experienced less stress, or were a stronger stock to begin with.

I have concluded that control III shrimp suffered some degree of stunting, but certainly as far as growth rate, they performed better than the tails at harvest of control I and II ponds. Thus their greater plumpness in this comparison may indeed indicate greater well-being. They appear to be somewhat stunted, but relatively well-fed. This may sound paradoxical, but serves to illustrate the care with which interpretations of length-weight relationships must be made in shrimp populations exhibiting abnormal growth patterns.

Overwintering of White and Blue Shrimp

Introduction

An attempt was made to utilize the power plant heated effluent to overwinter white and blue shrimp in one pond.

Materials and Methods

Pond 7 was drained and harvested on October 21, 1978, then refilled the following day. On October 23, 1000 white shrimp harvested from pond 6 (white shrimp monoculture) were placed in pond 7. Twenty shrimp were held for 24 hours in a cage in pond 7 to estimate the mortality due to handling. On November 22, 1473 blue shrimp (mean length) were added to the pond. These animals had been held for approximately 2 months in concrete troughs in a greenhouse.

The shrimp in this pond were not fed. Hydrological data were taken about 6 times per week, and the pond received a continuous flow of water. A castnet was used, once in January and once in March, to check for the presence of shrimp in the pond.

On April 14, 1979, the pond was drained and all the shrimp removed and counted. A sample of 30 shrimp was taken for individual weights and measurements. Most of the shrimp (190) were transferred alive to a newly-prepared pond (10). Sixty-five of them were held in cages for 24 hours to estimate the mortality due to handling. Other large animals found in pond 7 were identified and counted. Where large numbers of fairly small organisms were involved, the total mass of organisms was weighed, and a subsample taken. The proportion by weight of each component in the subsample and the number of individuals in each were determined; these numbers were extrapolated to give estimates of the numbers of each species present in the total.

Pond 10 was maintained as pond 7 had been until July 2, 1979 when it was drained and harvested. This was done to maintain some native species shrimp as biological monitors since all experimental animals in 1979 were the exotic _P. stylirostris_. Again, all the shrimp were counted at harvest, as sample of 30 was individually weighed and measured, and other animals found in the pond were identified and counted.

Results and Discussion

The white shrimp increased in length, weight and condition from October 1978 to July 1979, but their survival over the winter was poor (Table 35). Only 217 (21.7%) of the white shrimp were recovered in the April inventory. Of these, an estimated 58% had black spots or lesions of the chitin. Twenty-one of the 30 sampled shrimp died while being weighed and measured. Of the cage-held shrimp, 20% died at stocking in October. Mortality of the cage-held shrimp moved from pond 7 to pond 10 in April was 50.8%.

No blue shrimp were found at any time after they were stocked in November. Other organisms were found in the pond both at the April inventory and the July harvest (Table 36).

Table 35. Mean length, weight, growth, condition (K) and survival of white shrimp in the monitoring study.

Date	# Days	Length (mm)	± S.D.	Weight (g)	± S.D.	Growth (g/day)	K	Survival (%)
11-23-78	0	133.30	3.60	17.06	1.29		7.20	
4-14-79	173	160.50	5.02	33.58	3.16	.095	8.12	21.7
7-2-79	252	171.20	7.46	42.46	5.35	.112	8.46	54.2

The pond water pump broke down in December and was not repaired until the following April, so that only gravity flow was available to the pond. This catastrophe resulted in no beneficial use by the shrimp of the heated effluent, indicated by the temperature pattern in the pond (Appendix Figure B28). It was very similar to that of the intake area, and had much lower temperatures than the heated discharge canal. The exposure to very low temperatures probably accounts for the death of all the blue shrimp and the low survival and poor physical condition of the white shrimp.

In general temperature decreased to January, then increased to July. Salinity was variable, but in general decreased throughout the culture period. Extremely low surface values were caused by heavy rainfall. Oxygen was variable throughout the culture period. Values below 2 ppm were recorded on several occasions, twice when very low salinity surface water created a layering effect in the pond. Values of Ph (Appendix Figure B29) also fluctuated throughout the period. In general, the lowest pH values were

Table 36. Organisms other than shrimp found in the monitor pond at inventory (April 14) and harvest (July 2).

Date	Species	Number	Approximate Size (mm)
4-14-79	*Palaemonetes sp.*	7417*	
"	*Callinectes sapidus*	19	40-100
"	*Anchoa mitchilli*	95	70
"	*Brevoortia patronus*	121	70
"	*Cyprinodon variegatus*	555	25
"	*Gobiosoma bosci*	4	41-61
"	*Micropogon undulatus*	193	90-120
"	*Mugil cephalus*	1	94
"	*Paralichthys sp.*	1	127
7-2-79	*Callinectes sapidus*	3	
"	*Palaemonetes sp.*	19,096*	
"	*Gambusia sp.*	3,751*	
"	*Menidia beryllina*	34*	

* Estimate

associated with the lowest dissolved oxygen values. There are no pH data for the last 3 months of the period because of equipment failures.

Biological Monitoring of Water Quality: Heavy Metals and Pesticides

Introduction

All organisms used in the pond experiments also served as biological monitors of water quality. In addition to simply demonstrating that the animals could survive and grow in the power plant effluent, tissue samples were taken of the animals and analyzed for the presence of heavy metals and pesticides.

Materials and Methods

At each harvest, samples of culture animals were taken for analysis for the presence of selected heavy metals and pesticides. Animals from replicate ponds were pooled to give one sample per treatment in each experiment. In the multi-species polyculture experiment, the different species were sampled separately.

For sampling, shrimp were headed and peeled, and fish were filleted and skinned using a stainless steel knife and a wooden cutting board. For each heavy metal sample, a total of 50 g of shrimp tail meat or fish fillet, from at least 10 animals, was chopped with a stainless steel knife, placed in a plastic bag and labeled. For pesticide analysis, samples of 150 g, again from at least 10 animals, were wrapped in aluminum foil and labeled. The samples were all immediately frozen until they could be delivered to the laboratory for analysis.

The analyses were made by the Department of Agricultural Analytical Services, Texas A&M University, College Station, Texas. The heavy metals analyzed for were arsenic, mercury, copper, manganese, iron, cobalt, zinc, chromium, cadmium, nickel and lead. The pesticides analyzed for were toxaphene, Arochlor 1254 (PCB), dieldrin, and DDE.

Results and Discussion

There were no detectable levels of the pesticides analyzed for in any of the samples. The concentrations of heavy metals detected are shown in Table 37. These concentrations were compared with those found in organisms occurring locally in the wild (Hall et al., 1978). Arsenic, cobalt, mercury, cadmium, iron, manganese, zinc, nickel and lead were below those levels reported. Small quantities of mercury were detected in my shrimp (.20 ppm or less), but were below acceptable levels. The only heavy metal found in concentrations higher than in previous years at the Cedar Bayou Generating Station was chromium, whose values were also higher than those encountered in nature. There is no set limit for chromium in food organisms by the Environmental Protection Agency.

Table 37. Heavy metal concentrations of cultured organisms during 1978 and 1979 at the Cedar Bayou Mariculture Facility.

EXPERIMENT	TREATMENT	SPECIES (DATE)	HEAVY METAL CONCENTRATIONS IN CULTURED ANIMALS (PPM)										
			Hg	As	Co	Cu	Cr	Cd	Fe	Mn	Zn	Ni	Pb
Multi-species polyculture	White shrimp/ striped mullet	White shrimp (10-21-78)	<0.01	<1.0	<0.6	4.0	3.0	<0.5	3.5	<0.5	9.7	<1.0	<0.15
"	White shrimp/ blue shrimp	White shrimp (10-23-78)	<0.01	<1.0	<0.6	4.0	2.9	<0.5	2.1	<0.5	9.3	<1.0	<0.15
"	White shrimp monoculture	White shrimp (10-23-78)	<0.01	1.1	<0.6	4.1	3.0	<0.5	5.3	<0.5	8.9	<1.0	<0.15
"	White shrimp/ striped mullet	Striped mullet (10-21-78)	<0.01	1.3	<0.6	0.5	3.2	<0.5	9.8	0.6	4.3	<1.0	<0.15
"	White shrimp/ blue shrimp	Blue shrimp (10-23-78)	<0.01	<1.0	<0.6	4.1	3.2	<0.5	3.7	<0.5	10.3	<1.0	<0.15
Staggered stocking (1978)	Control	Blue shrimp (11-28-78)	<0.01	<1.0	<0.6	3.1	3.0	<0.5	3.4	<0.5	10.0	<1.0	0.20
"	Staggered stocked	Blue shrimp (11-28-78)	<0.01	<1.0	<0.6	3.1	3.2	<0.5	7.2	<0.5	9.6	<1.0	<0.15
Overwintering		White shrimp (7-2-79)	0.14	<0.6	<0.6	5.0	2.0	<0.5	1.2	<0.5	17.5	<1.0	0.40
Staggered stocking (1979)	Control I	Blue shrimp (8-11-79)	0.05	<0.6	<0.6	3.6	7.4	<0.5	4.9	<0.5	14.0	<1.0	0.41
"	Control II	Blue shrimp (8-12-79)	0.12	<0.6	<0.6	2.3	7.3	<0.5	4.7	<0.5	12.8	<1.0	<0.15
"	Control III	Blue shrimp (8-10-79)	0.20	<0.6	<0.6	5.0	7.4	<0.5	9.6	<0.5	14.4	<1.0	<0.15
"	Staggered stocked	Blue shrimp (8-12-79)	0.07	<0.6	<0.6	3.0	7.5	<0.5	4.6	<0.5	17.5	<1.0	<0.15

SUMMARY

Polyculture of white shrimp *Penaeus setiferus* with blue shrimp *Penaeus stylirostris* or striped mullet *Mugil cephalus* was found to have no effect on survival or yield of white shrimp, indicating culture with either species is not detrimental to white shrimp. Blue shrimp had slightly lower survival, but significantly greater yields than white shrimp in the same ponds; it may be a better species for culture than white shrimp at this facility. Total pond yields were increased by polyculture with both species.

The staggered stocking method gave greater blue shrimp yields than expected yields calculated from the control pond yields. The mean value of the staggered stocked pond yields was greater (but not significantly) than the best control pond yields, thus showing promise as a method for improving economic returns from shrimp ponds. There was no detrimental effect of the staggered stocking method on shrimp survival.

Survival, growth and yield of blue shrimp were poorer in 1979 than in 1978, probably due to the low (near 2 ppt) pond salinities in 1979. A marked tendency was found for smaller blue shrimp to be more likely caught by sampling gear than larger shrimp. This could make sampling for growth and population estimations more difficult in staggered stocked ponds compared to conventionally stocked ponds.

It was found that shrimp in ponds with a wide range of sizes show a significant tendency to segregate by size. Lar-

ger shrimp tended to favor the middle pond sector by day, and the deep sector by night, while small shrimp favored the shallow sector by day and were fairly homogeneously distributed at night. In the staggered stocked ponds there was a decrease in shrimp activity at night, but small shrimp apparently did not decrease activity, or did so to a lesser extent than large shrimp. These are mechanisms whereby contact between large and small shrimp may be reduced, explaining the fact that survival was as good as or better than in the stagered stocked ponds. Cannibalism and aggresive encounters may be avoided in this manner by small shrimp.

A laboratory study showed that growth of small shrimp in contact with large ones where food was limited did not grow as well as small shrimp alone, while small shrimp separated by a barrier from large shrimp grew as well as the controls. Small shrimp in the barriered tanks were significantly less likely to feed than control shrimp after the addition of food to the tanks. Both small shrimp categories in mixed culture with large ones showed significant tendencies to reduce locomotion while feeding compared to small control shrimp, and to the large shrimp they were in culture with. This further clarifies the mechanisms by which contact between large and small shrimp may be reduced in mixed size cultures.

Blue shrimp in the staggered stocking study had a very wide size range compared to the blue shrimp in the 1978 polyculture study, even in those ponds stocked conventionally.

Analyses of length-weight relationships of these shrimp indicate that a high condition factor, generally associated with increased shrimp well-being, may also be an indicator of stunting, or lack of well-being in shrimp.

Overwintering of shrimp was unsuccessful due to lack of sufficient heated water flow. Survival for blue shrimp from October 1978 to April 1979 was 0%. White shrimp survival was 21.7%, but the shrimp were severely stressed. There were no dangerously high levels of heavy metals or pesticides in any of the animals cultured.

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APPENDIX A - FEED COMPOSITION

Table A1. Composition of the commercial shrimp ration used in the experiments.

PURINA EXPERIMENTAL MARINE RATION 25
(Ralston Purina Co., St. Louis, MO)

Guaranteed analysis

Crude protein not less than	25.0%
Crude fat not less than	10.0%
Crude fiber not more than	5.0%

INGREDIENTS

Fish meal, soybean meal, meat and bone meal, animal fat preserved with BHA, ground yellow corn, ground wheat, wheat middlings, corn gluten meal, dried whey, isolated soy protein, vitamin A supplement, D activated animal sterol (source of vitamin D-3), menadione sodium bisulfite (source of vitamin K activity), DL methionine, vitamin E supplement, vitamin B-12 supplement, biotin, dicalcium phosphate, folic acid, pyridoxine hydrochloride, thiamin, niacin, calcium pantothenate, riboflavin supplement, copper oxide, manganous oxide, calcium iodate, iron carbonate, calcium carbonate, cobalt carbonate, zinc oxide.

APPENDIX B - HYDROLOGICAL DATA

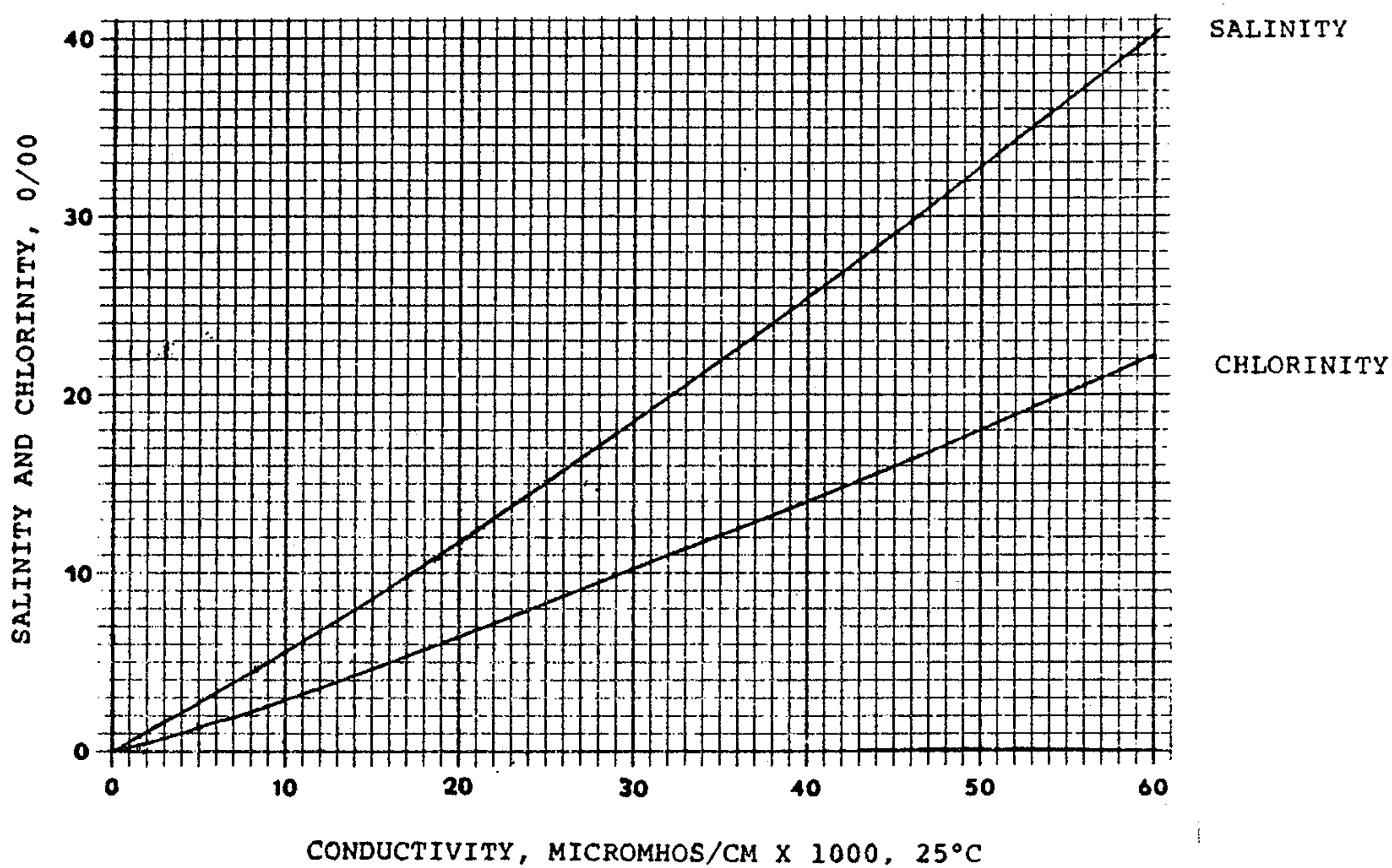


Figure B1. Salinity and chlorinity vs conductivity.

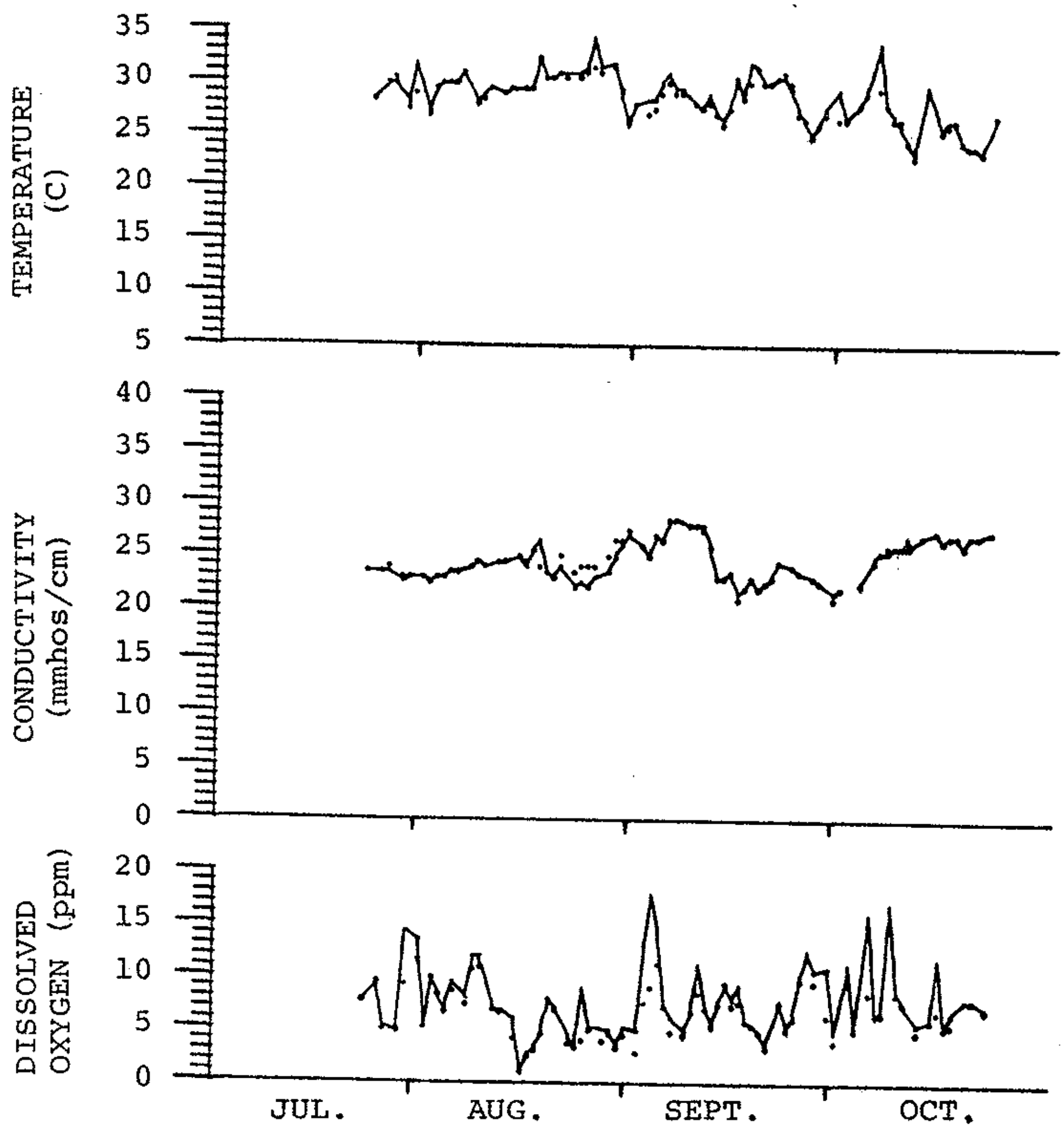


Figure B2. Temperature, conductivity and dissolved oxygen levels for Pond 4 (blue shrimp/white shrimp polyculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.

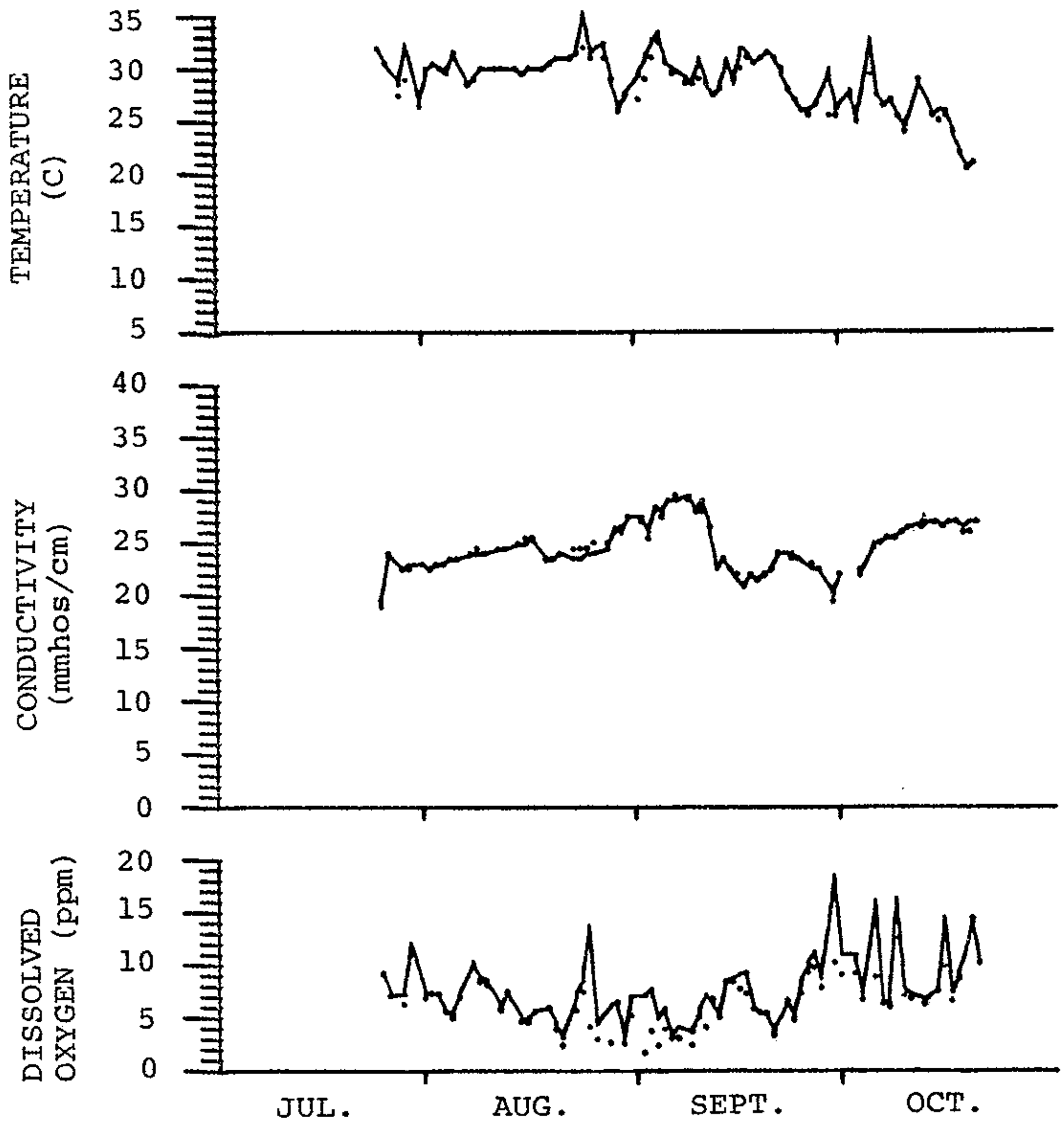


Figure B3. Temperature, conductivity and dissolved oxygen levels for pond 22 (blue shrimp/white shrimp polyculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.

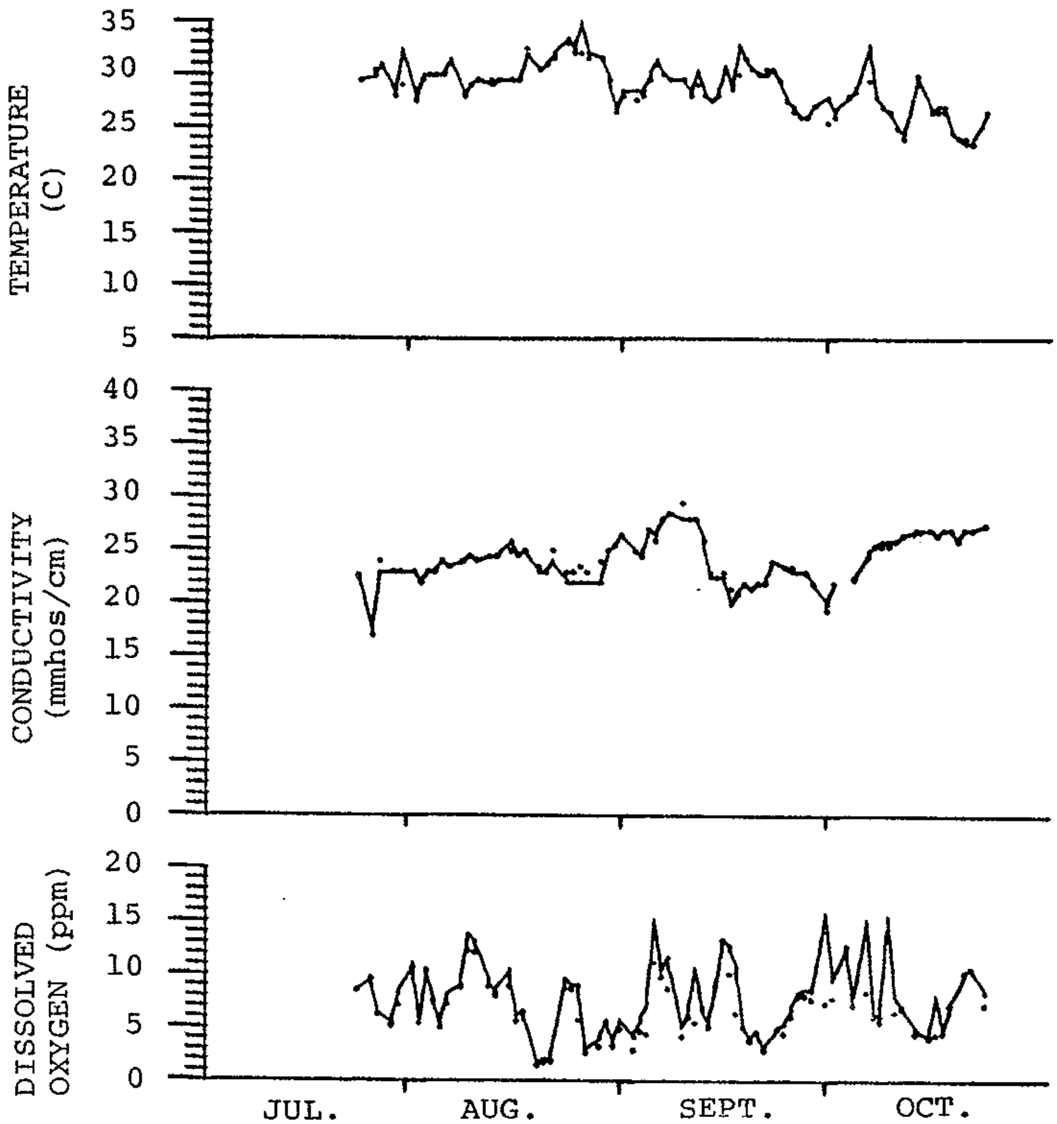


Figure B4. Temperature, conductivity and dissolved oxygen levels for pond 6 (white shrimp monoculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.

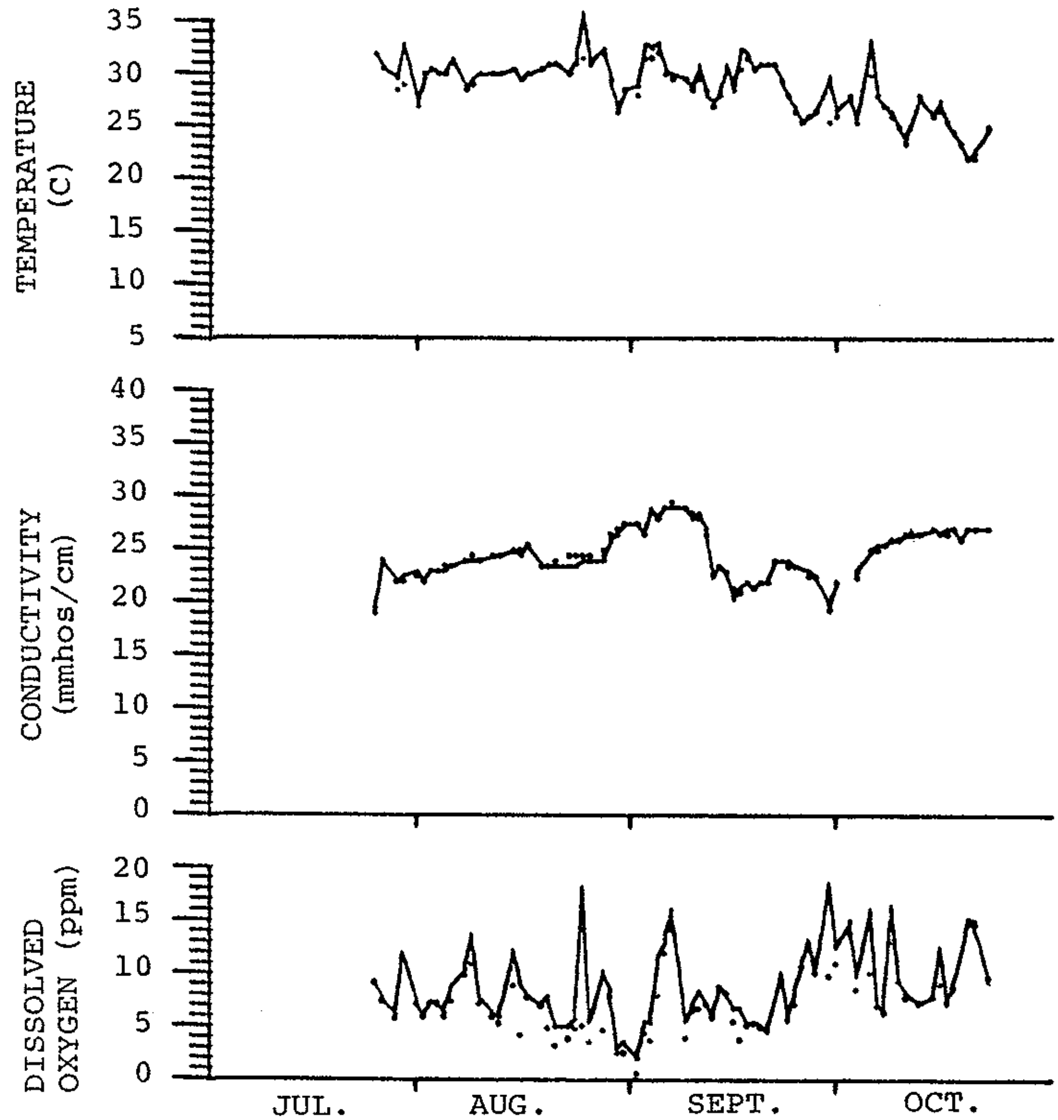


Figure B5. Temperature, conductivity and dissolved oxygen levels for pond 21 (white shrimp monoculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.

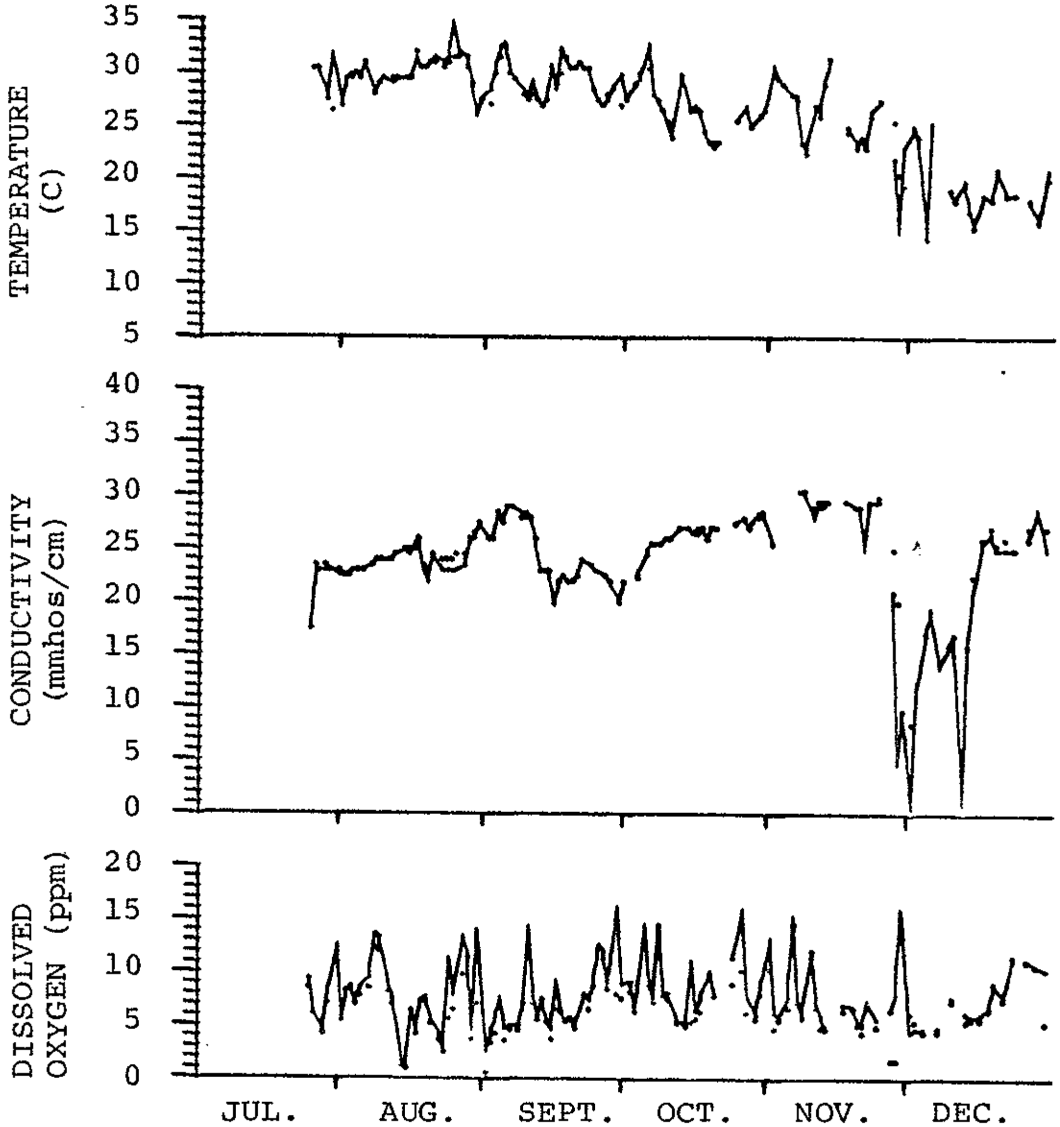


Figure B6. Temperature, conductivity and dissolved oxygen levels for pond 7 (white shrimp/striped mullet polyculture and monitor pond) throughout the 1978 polyculture experiment and through Dec. 31, 1978. Solid line indicates surface values; dots represent bottom values.

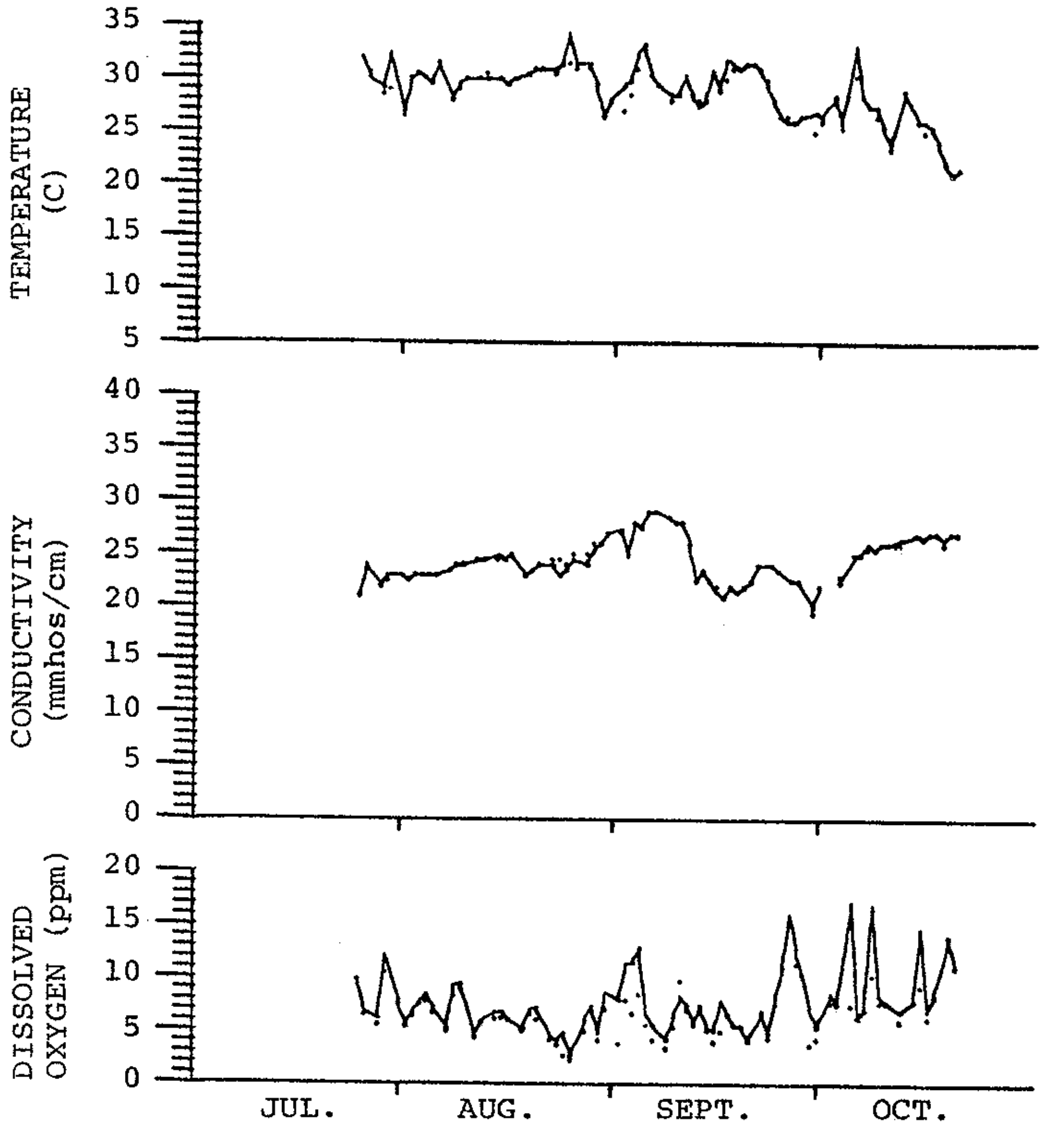
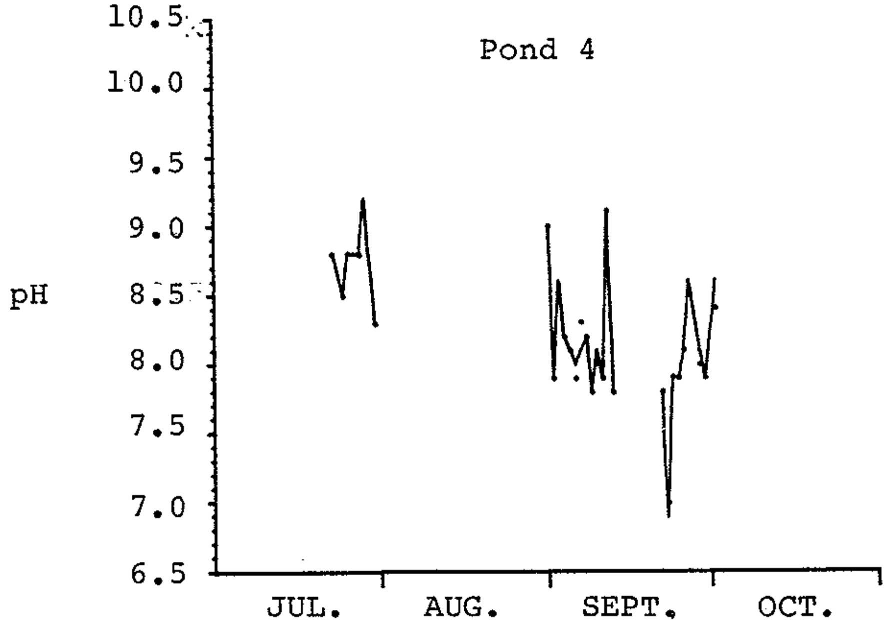


Figure B7. Temperature, conductivity and dissolved oxygen levels for pond 23 (white shrimp/striped mullet polyculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.



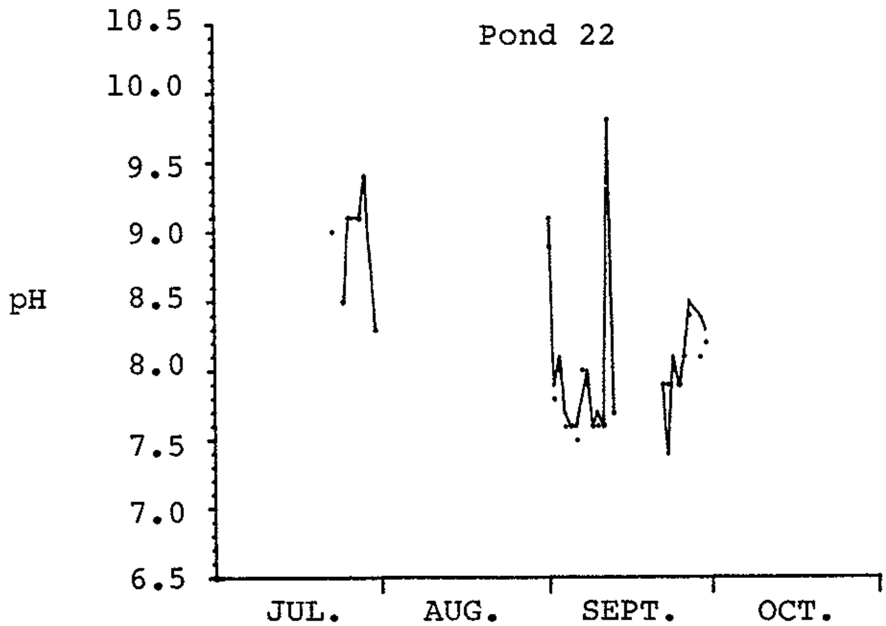
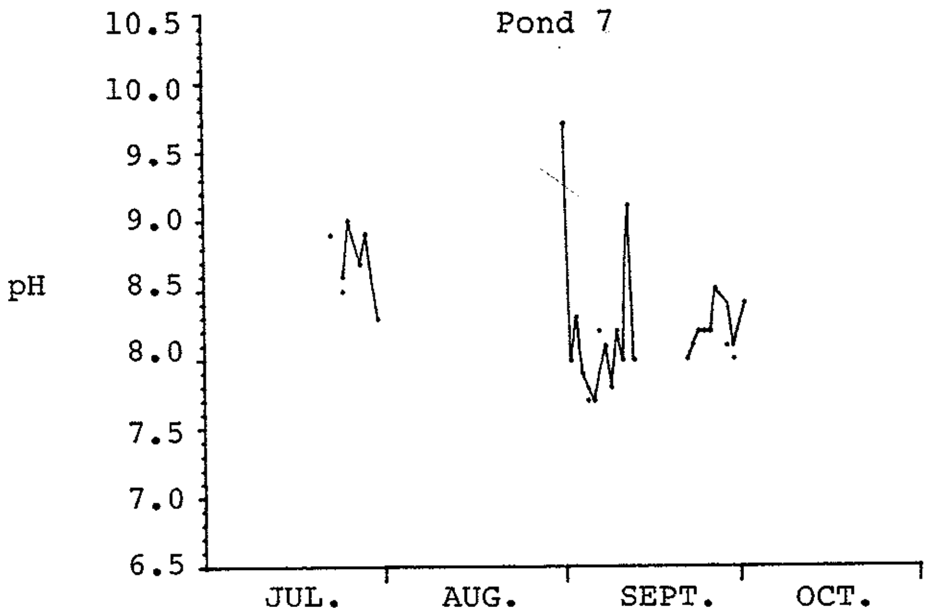


Figure B8. pH levels for ponds 4 and 22 (blue shrimp/ white shrimp polyculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.



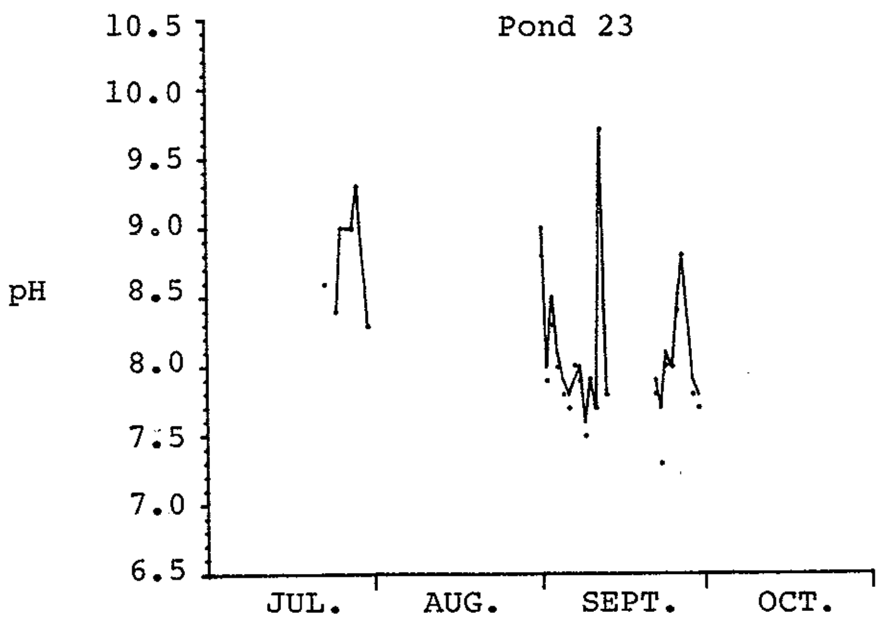


Figure B9. pH levels for ponds 7 and 23 (white shrimp/striped mullet polyculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.

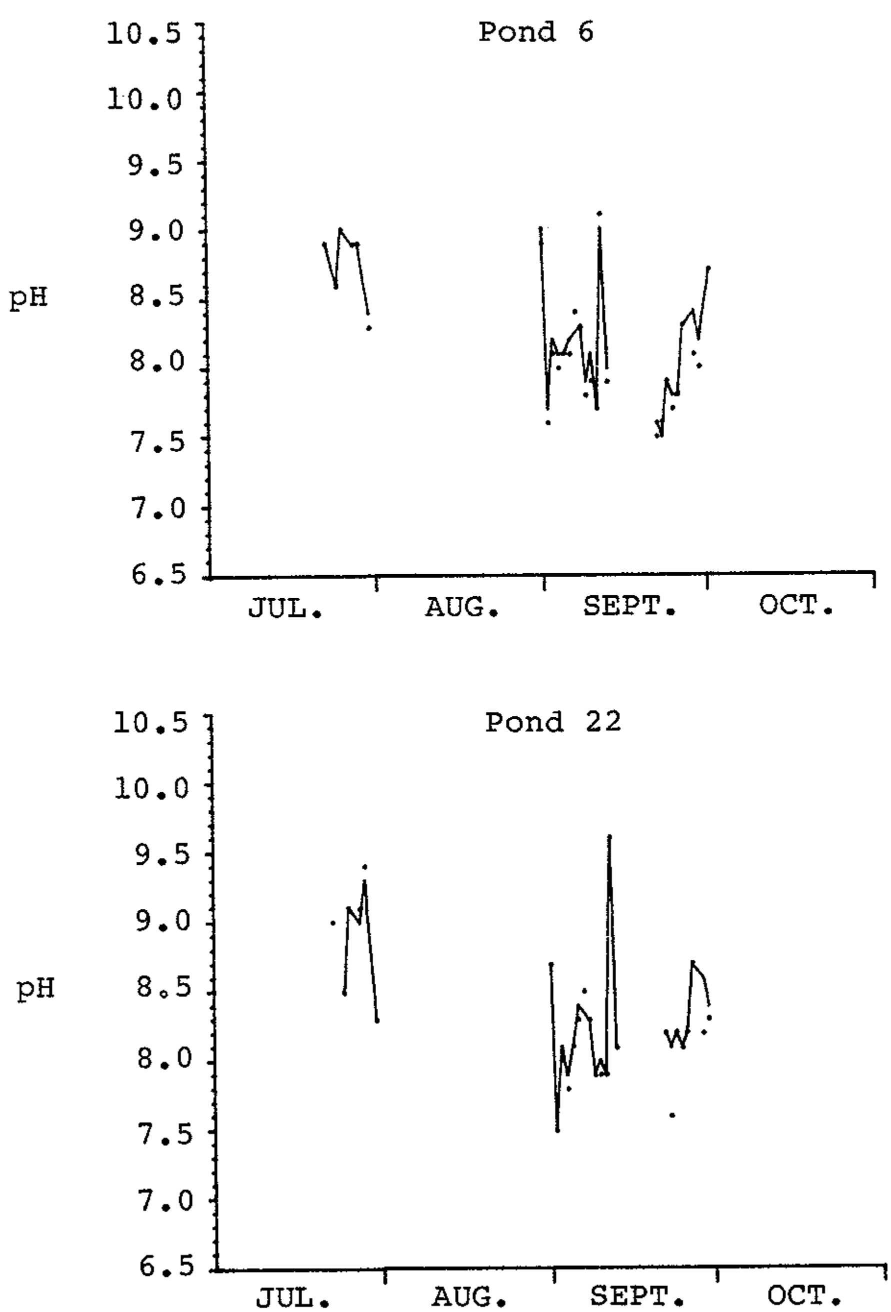


Figure B10. pH levels for ponds 6 and 21 (white shrimp monoculture) during the 1978 polyculture experiment. Solid line indicates surface values; dots represent bottom values.

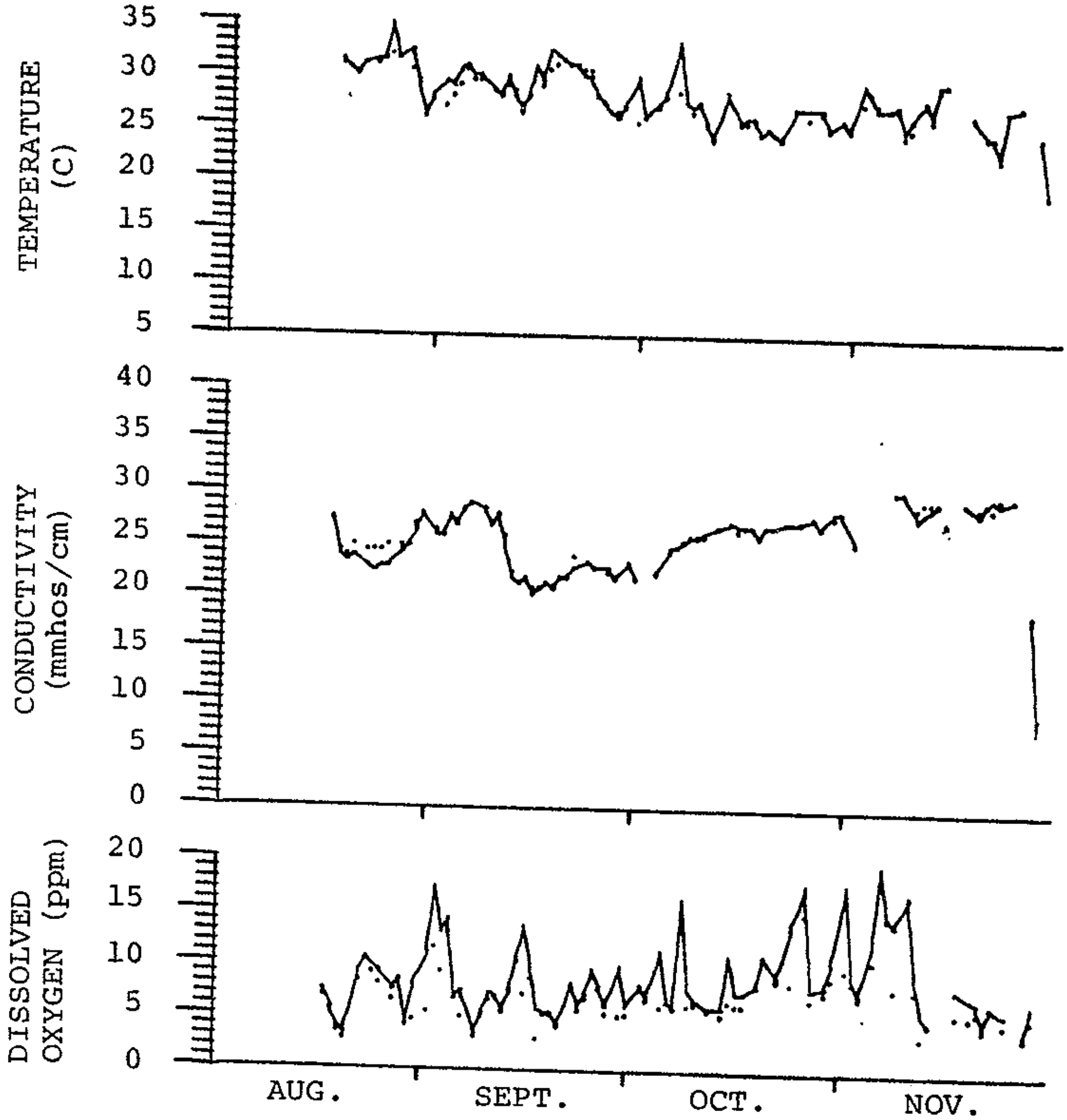


Figure B11. Temperature, conductivity and dissolved oxygen levels for pond 2 (control pond) during the 1978 staggered stocking experiment. Solid line indicates surface values; dots represent bottom values.

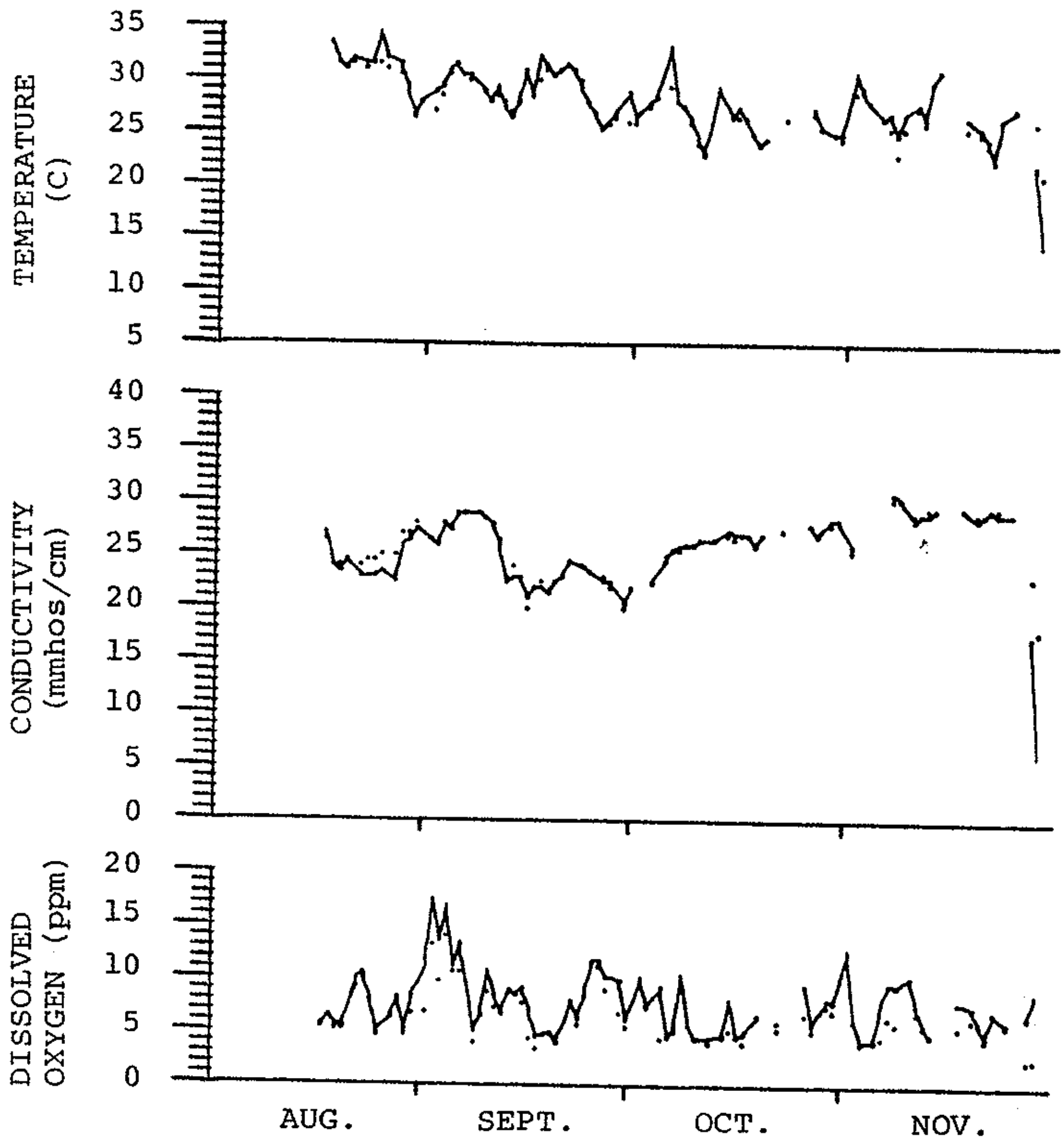


Figure B12. Temperature, conductivity and dissolved oxygen levels for pond 5 (control pond) during the 1978 staggered stocking experiment. Solid line indicats surface values; dots represent bottom values.

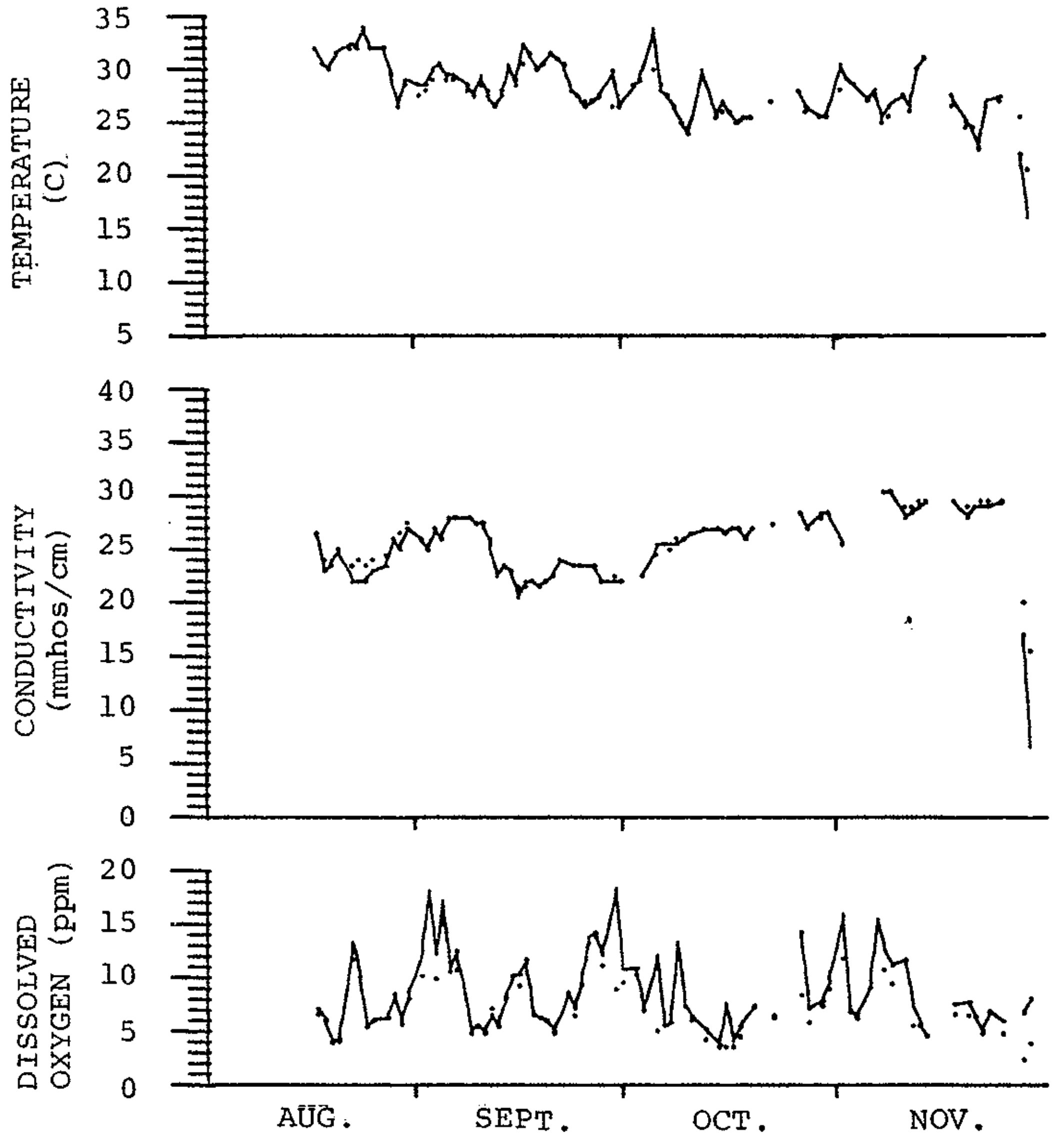


Figure B13. Temperature, conductivity and dissolved oxygen levels for pond 2 (staggered stocked pond) during the 1978 staggered stocking experiment. Solid line indicates surface values; dots represent bottom values.

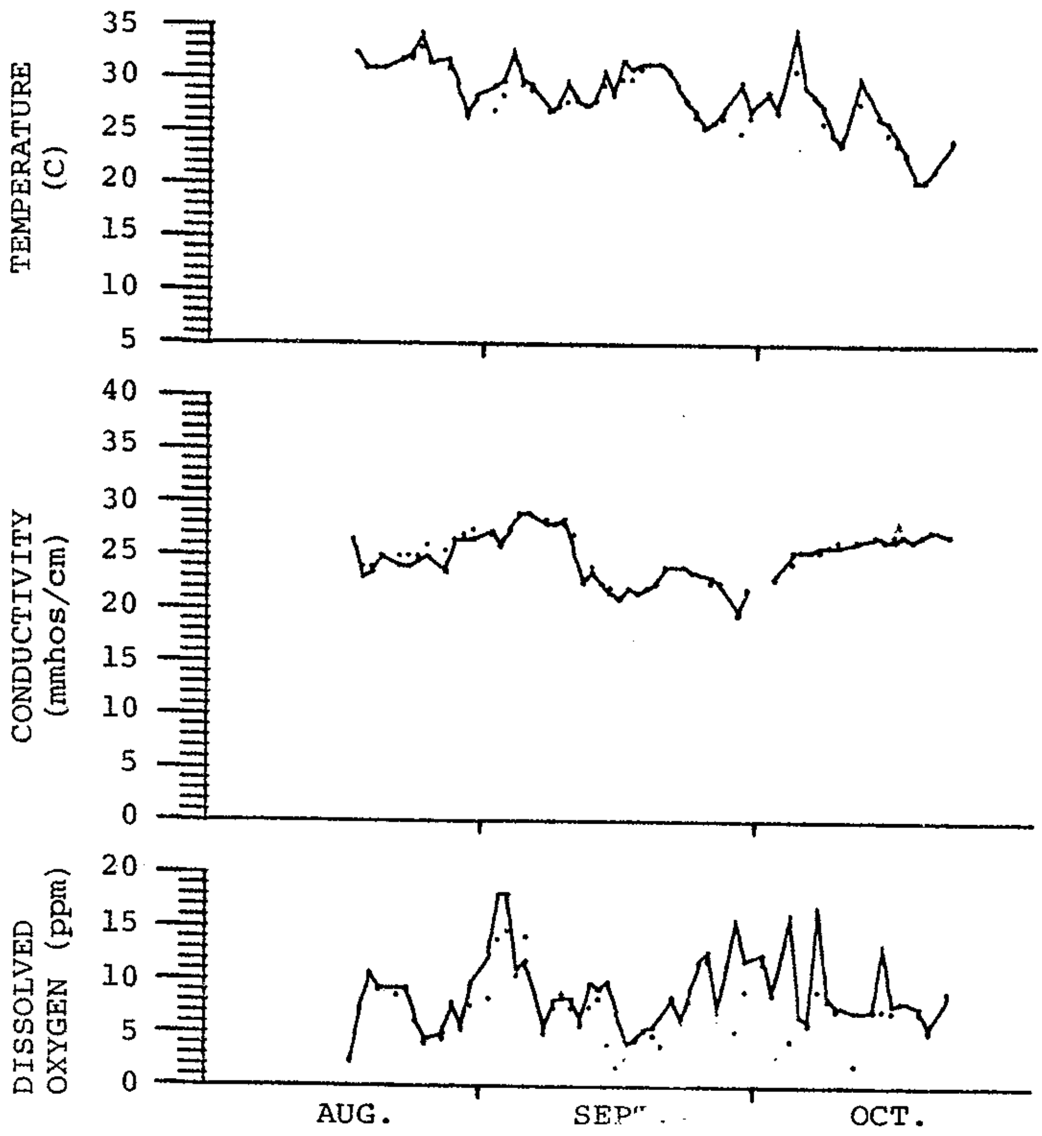
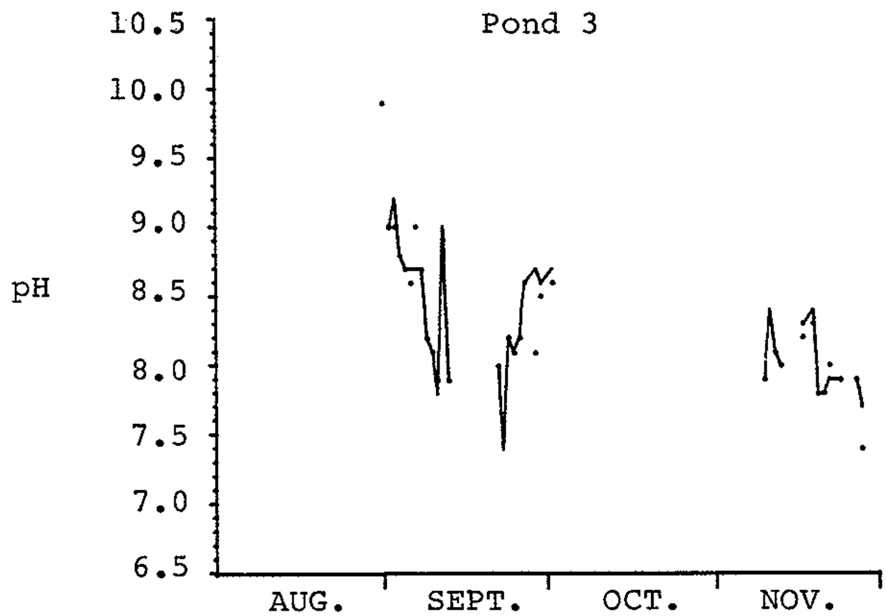


Figure B14. Temperature, conductivity and dissolved oxygen levels for pond 24 (staggered stocked pond) during the 1978 staggered stocking experiment. Solid line indicates surface values; dots represent bottom values.



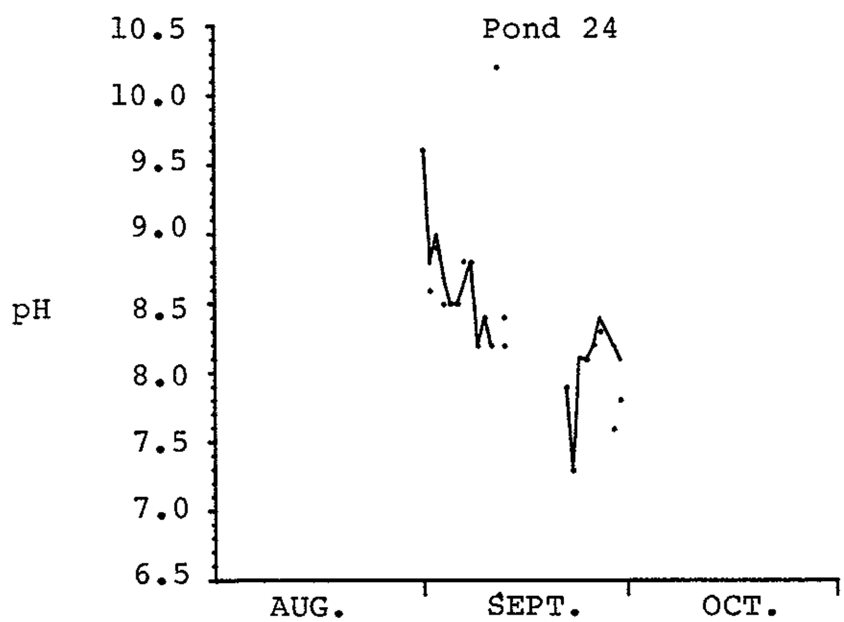
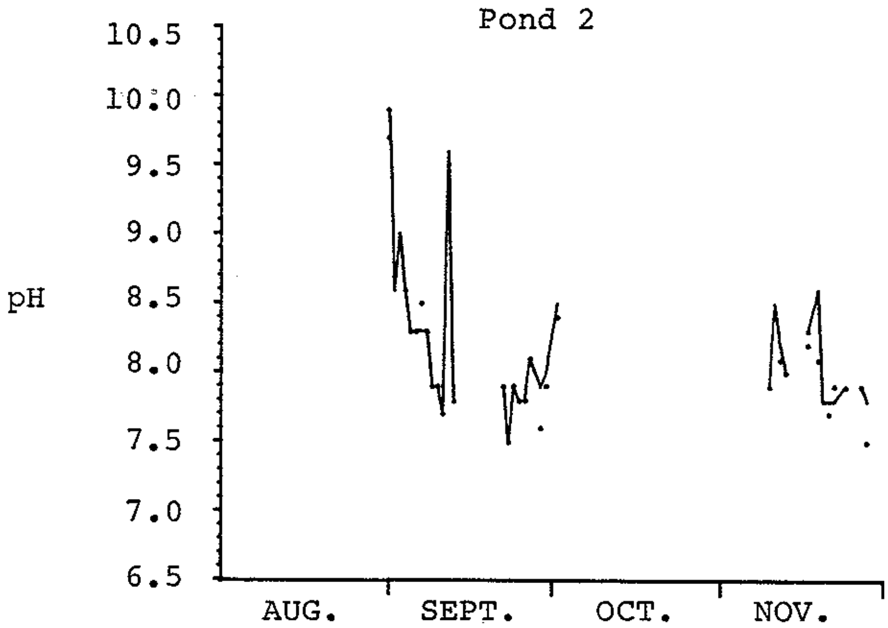


Figure B15. pH levels for ponds 3 and 24 (staggered stocked ponds) during the 1978 staggered stocking experiment. Solid line indicates surface values; dots represent bottom values.



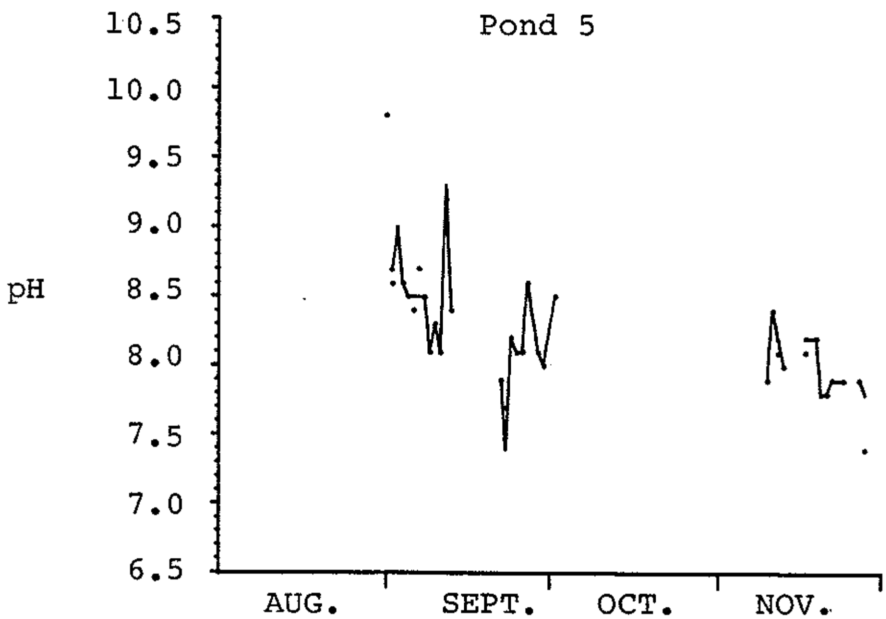


Figure B16. pH levels for ponds 2 and 5 (control ponds) during the 1978 staggered stocking experiment. Solid line indicates surface values; dots represent bottom values.

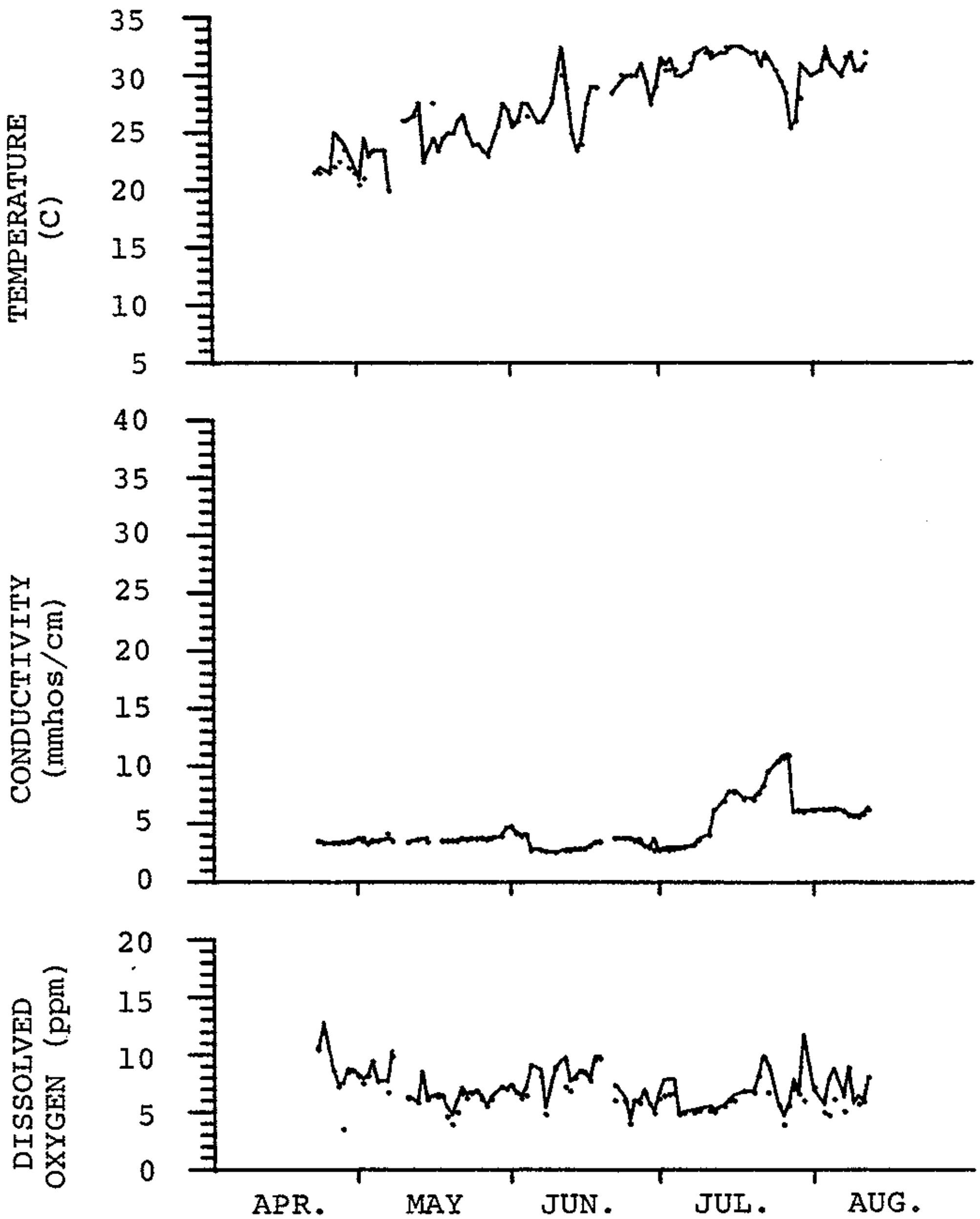


Figure B17. Temperature, conductivity and dissolved oxygen levels for pond 5 (staggered stocked pond) from April 24 to August 10, 1979. Solid line indicates surface values; dots represent bottom values.

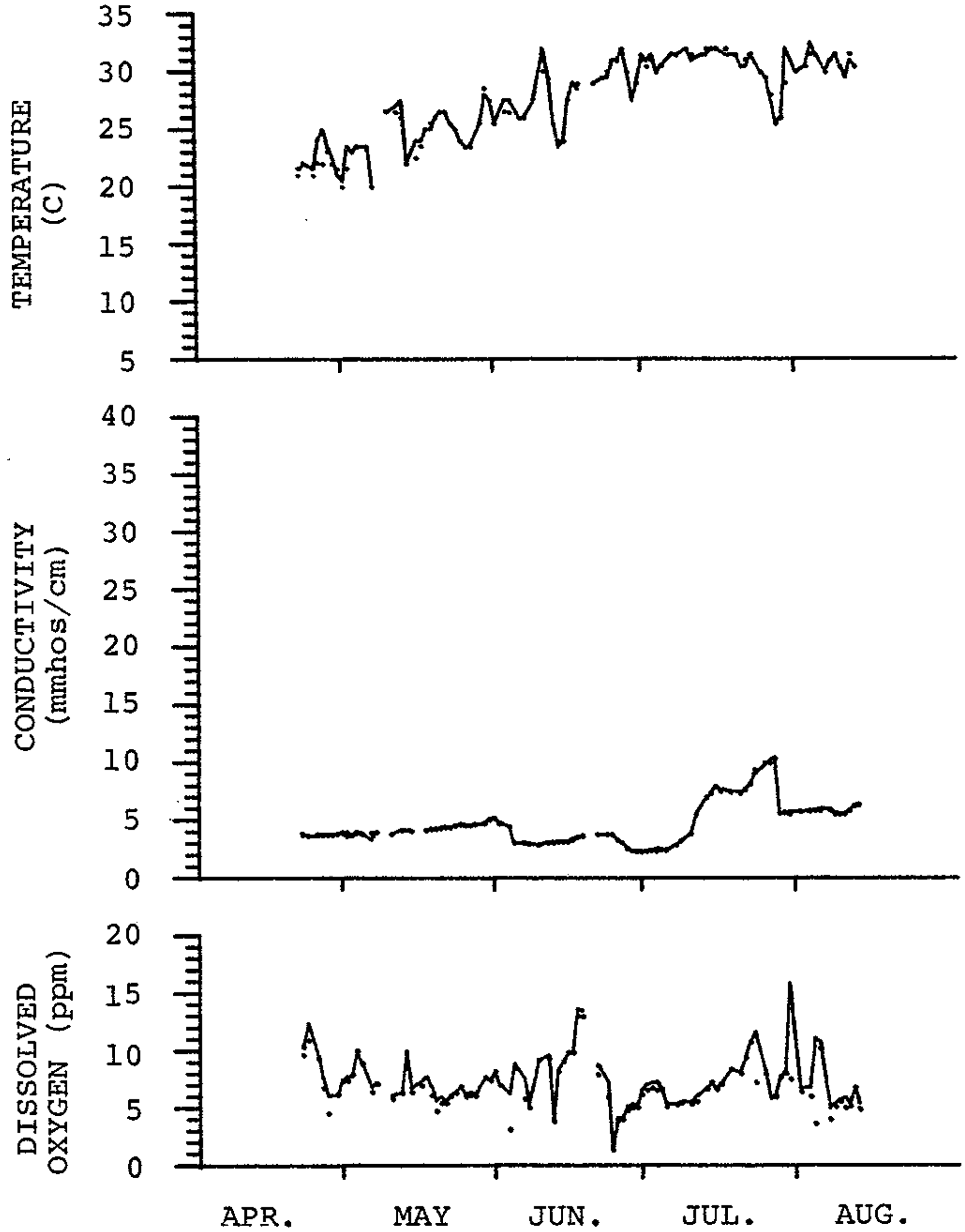


Figure B18. Temperature, conductivity and dissolved oxygen levels for pond 9 (staggered stocked pond) from April 24 to August 12, 1979. Solid line indicates surface values; dots represent bottom values.

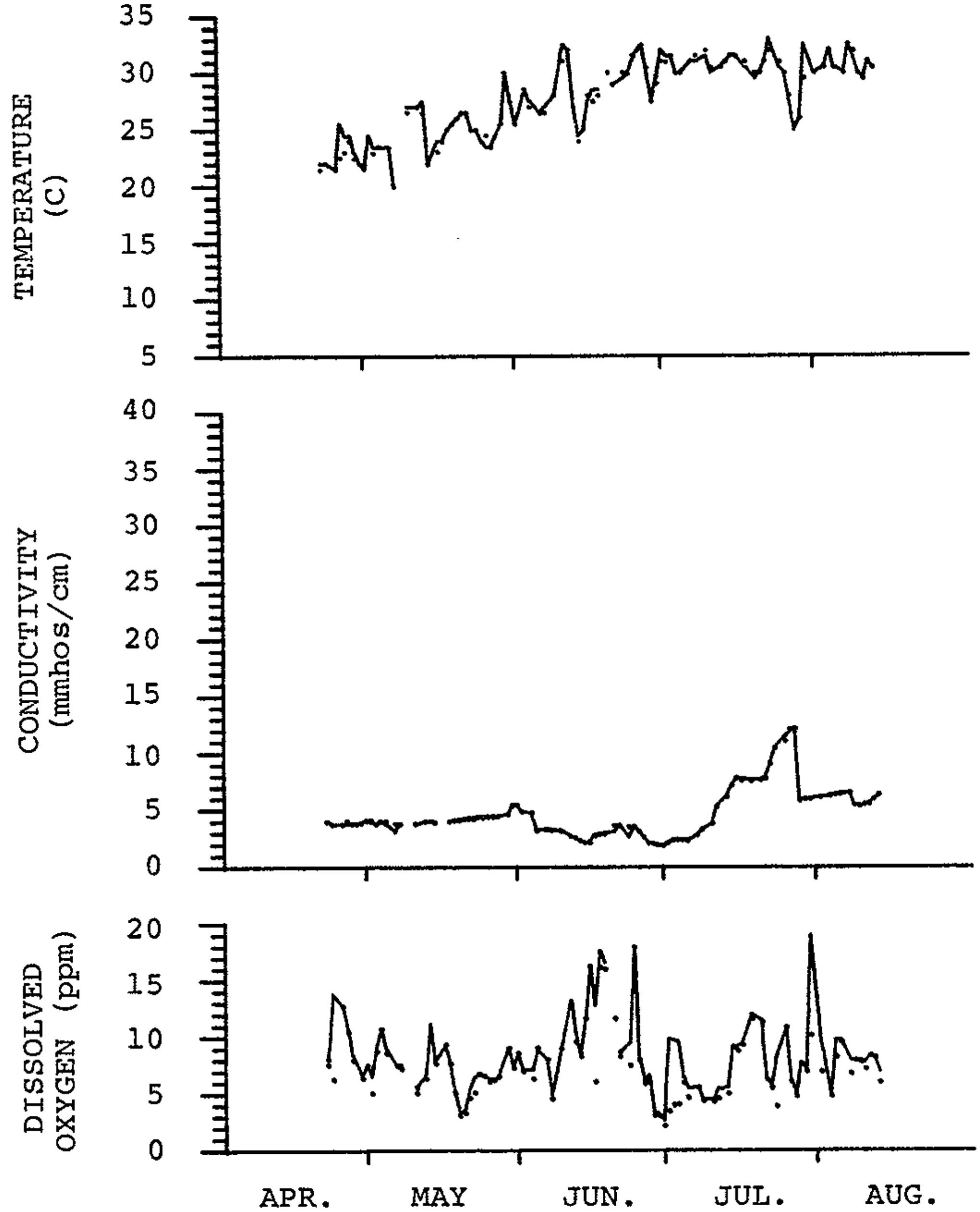


Figure B19. Temperature, conductivity and dissolved oxygen values for pond 15 (staggered stocked pond) from April 24 to August 12, 1979. Solid line indicates surface values; dots represent bottom values.

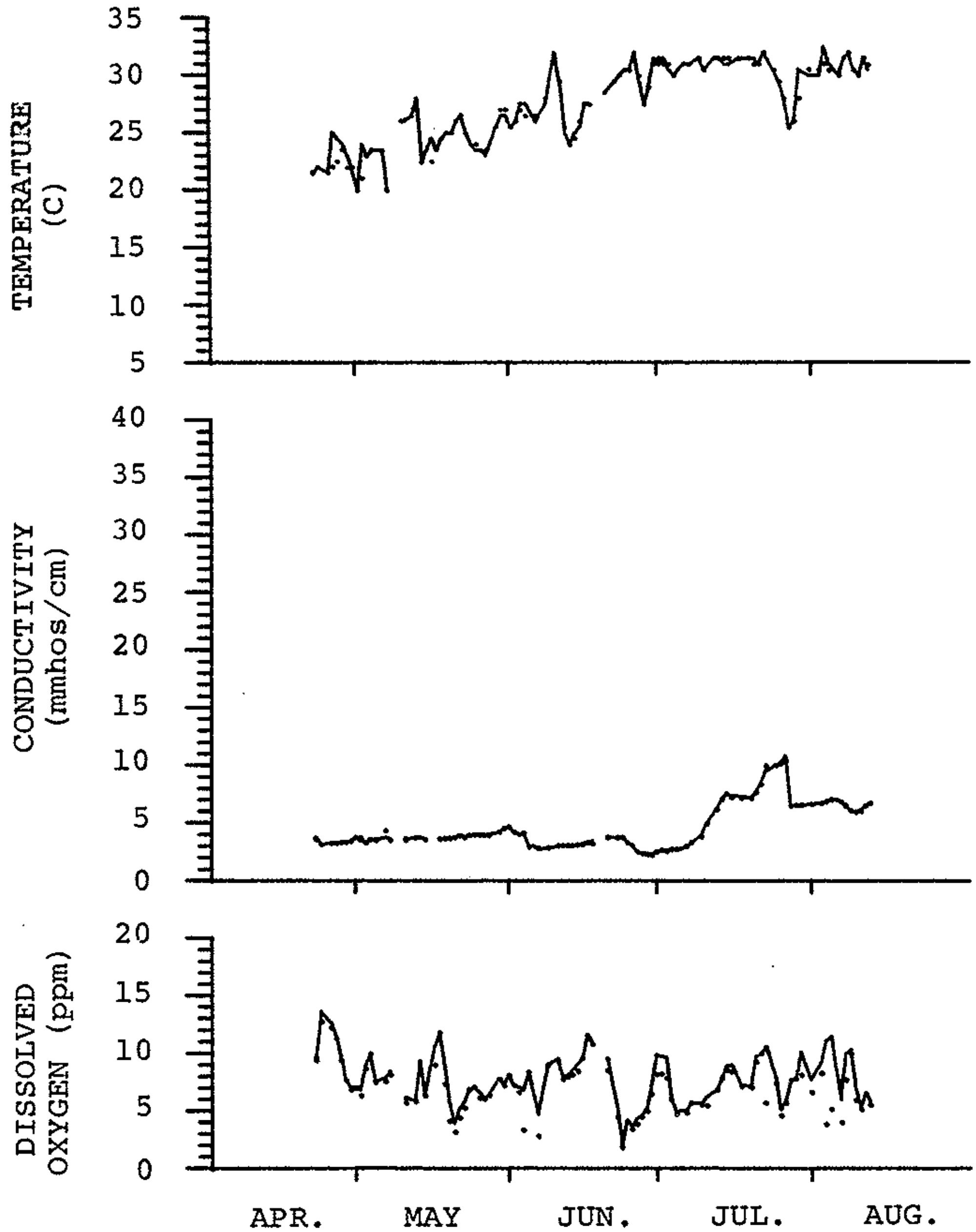


Figure B20. Temperature, conductivity and dissolved oxygen levels for pond 3 (control I pond) from April 24 to August 11, 1979. Solid line indicates surface values; dots represent bottom values.

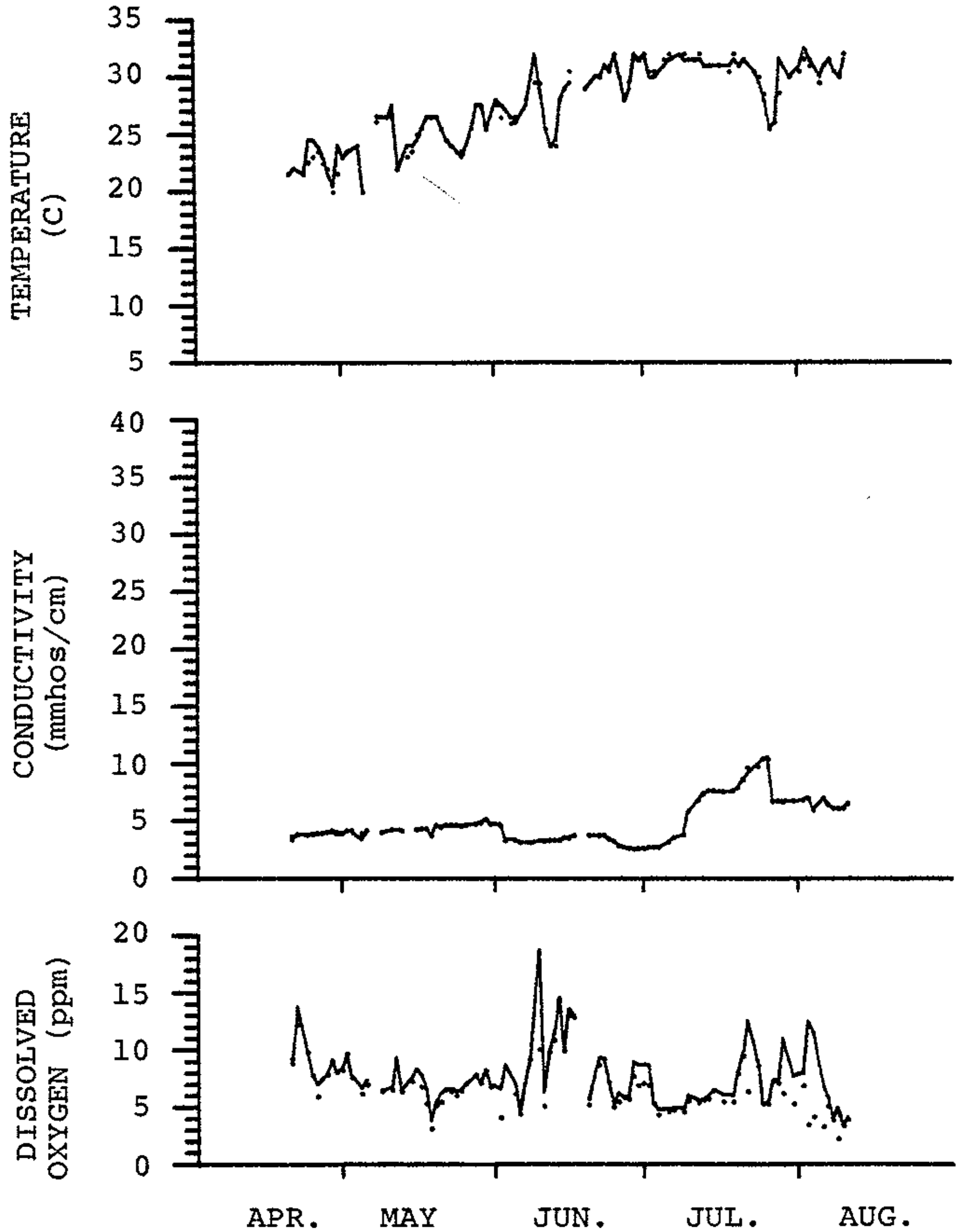


Figure B21. Temperature, conductivity and dissolved oxygen levels for pond 8 (control I pond) from April 24 to August 11, 1979. Solid line indicates surface values; dots represent bottom values.

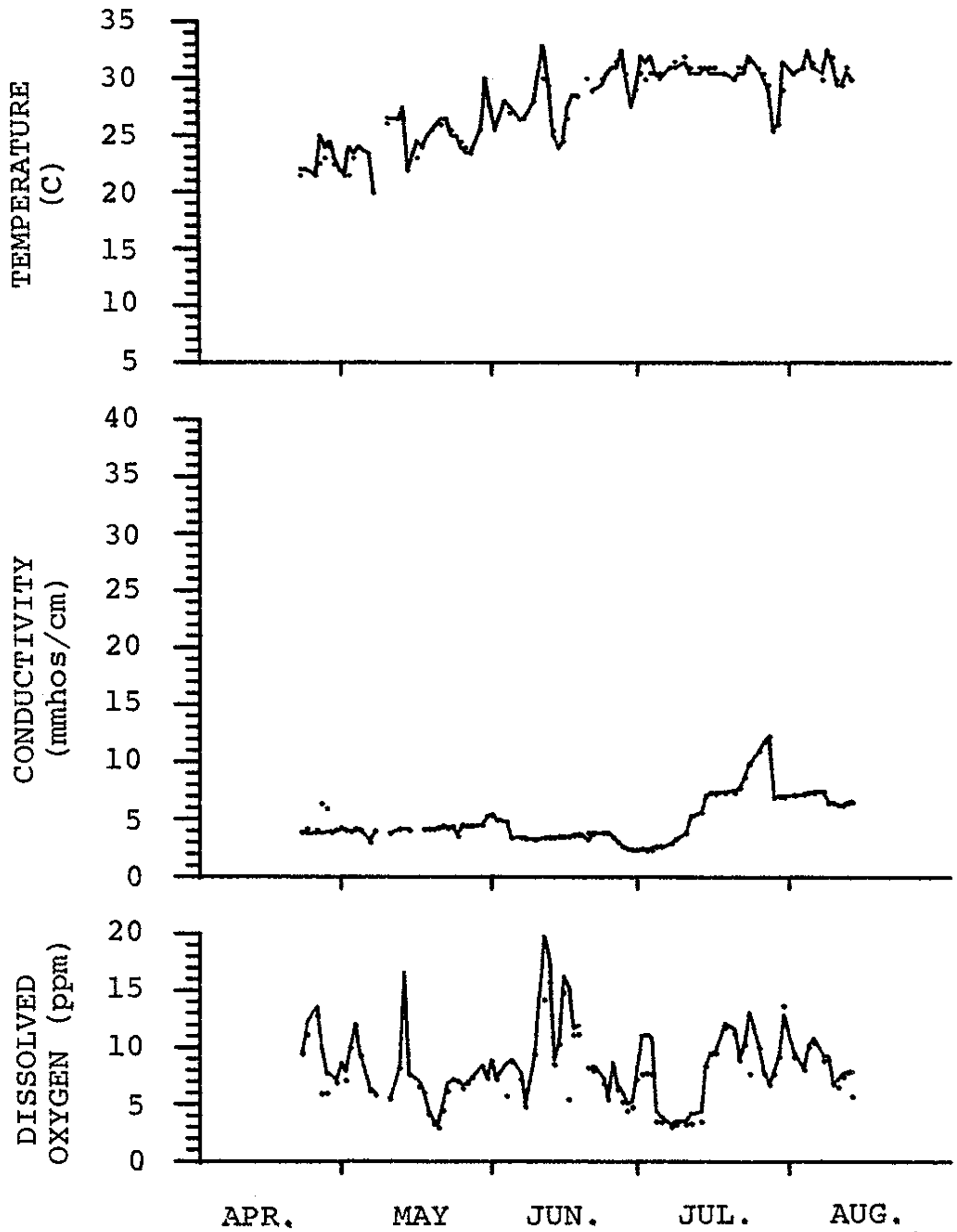


Figure B22. Temperature, conductivity and dissolved oxygen levels for pond 14 (control I pond) from April 24 to August 11, 1979. Solid line indicates surface values; dots represent bottom values.

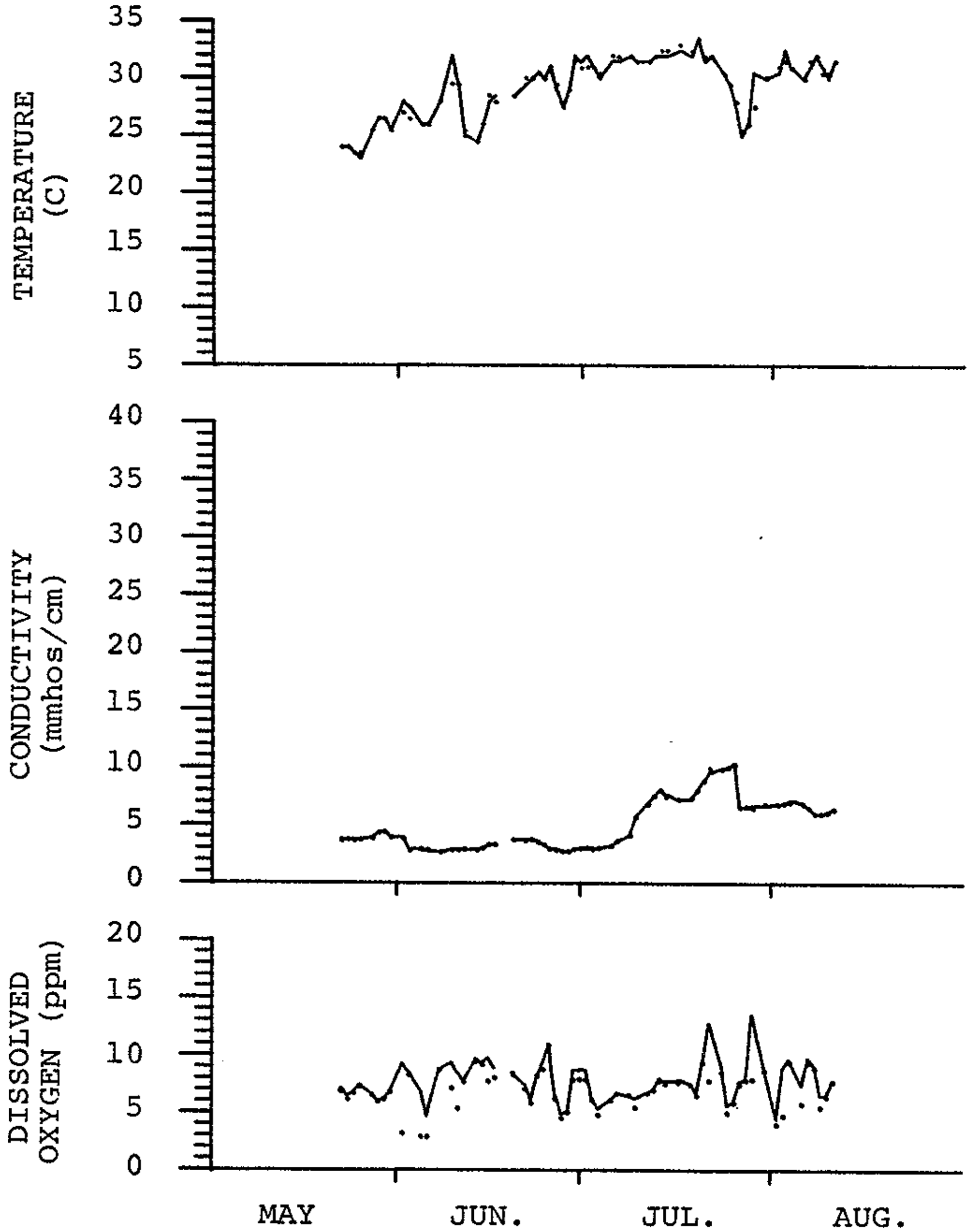


Figure B23. Temperature, conductivity and dissolved oxygen levels for pond 2 (control II pond) from May 28 to August 12, 1979. Solid line indicates surface values; dots represent bottom values.

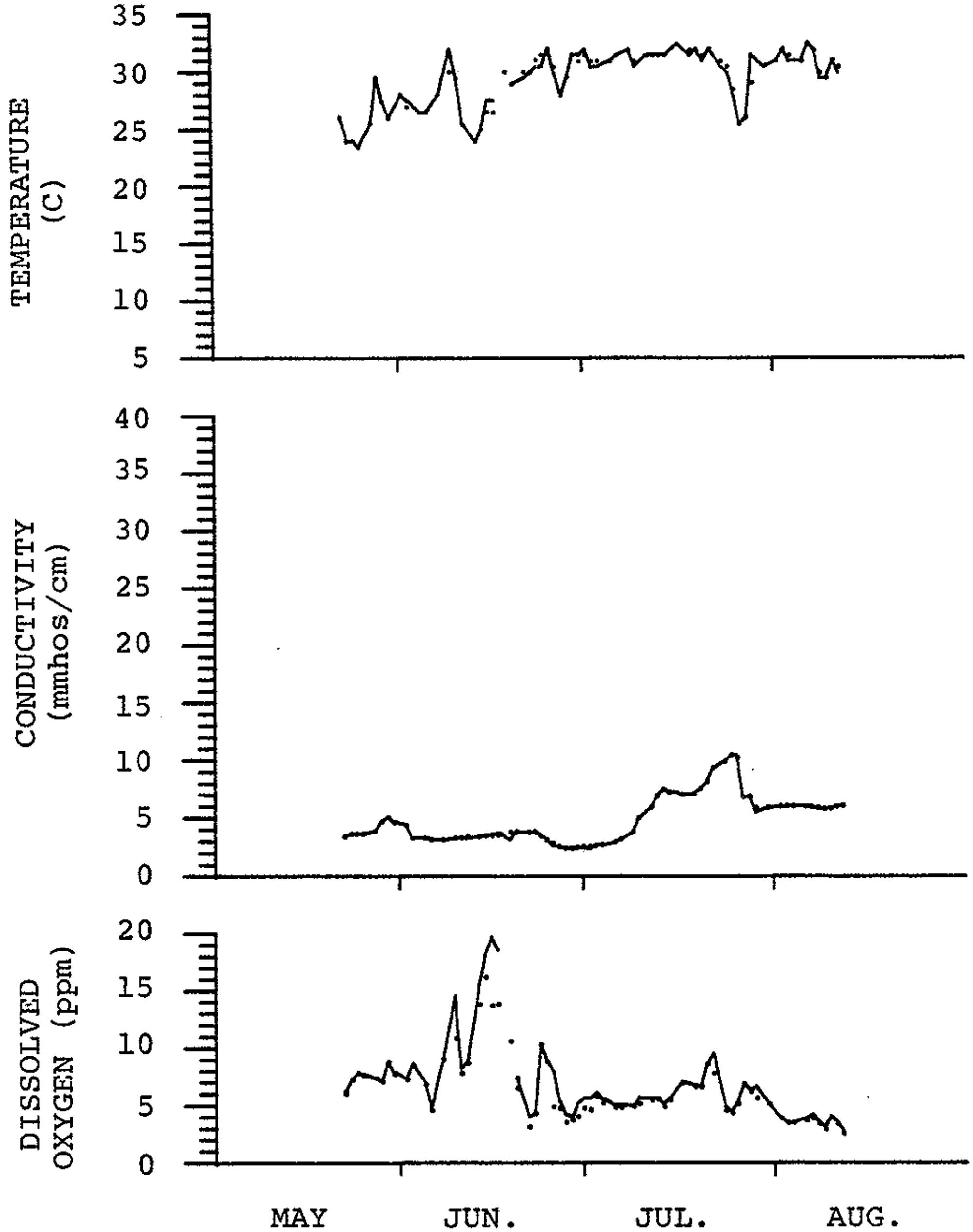


Figure B24. Temperature, conductivity and dissolved oxygen levels for pond 12 (control II pond) from May 28 to August 12, 1979. Solid line indicates surface values; dots represent bottom values.

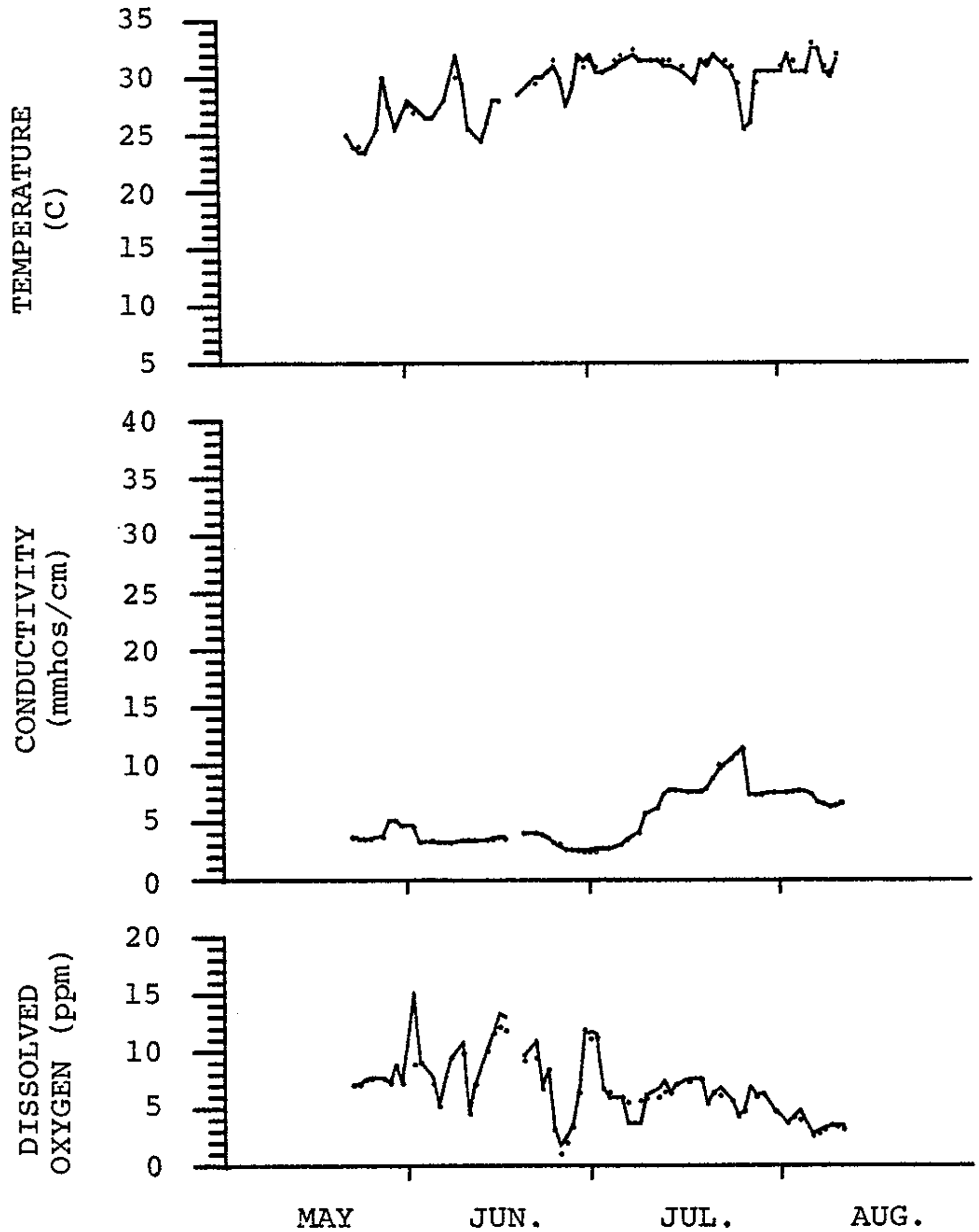


Figure B25. Temperature, conductivity and dissolved oxygen levels for pond 13 (control II pond) from May 28 to August 11, 1979. Solid line indicates surface values; dots represent bottom values.

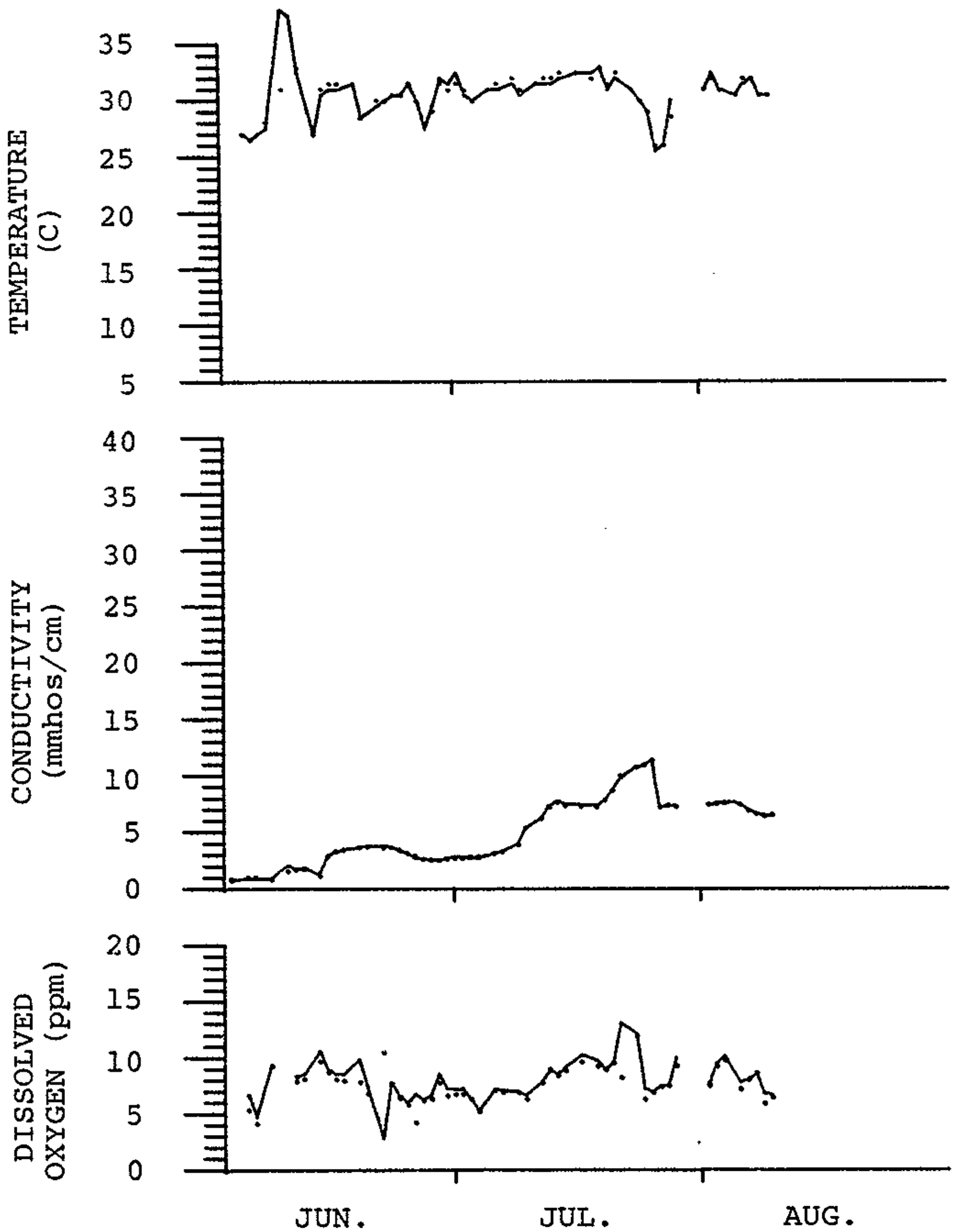


Figure B26. Temperature, conductivity and dissolved oxygen levels for pond 4 (control III pond) from June 18 to August 10, 1979. Solid line indicates surface values; dots represent bottom values.

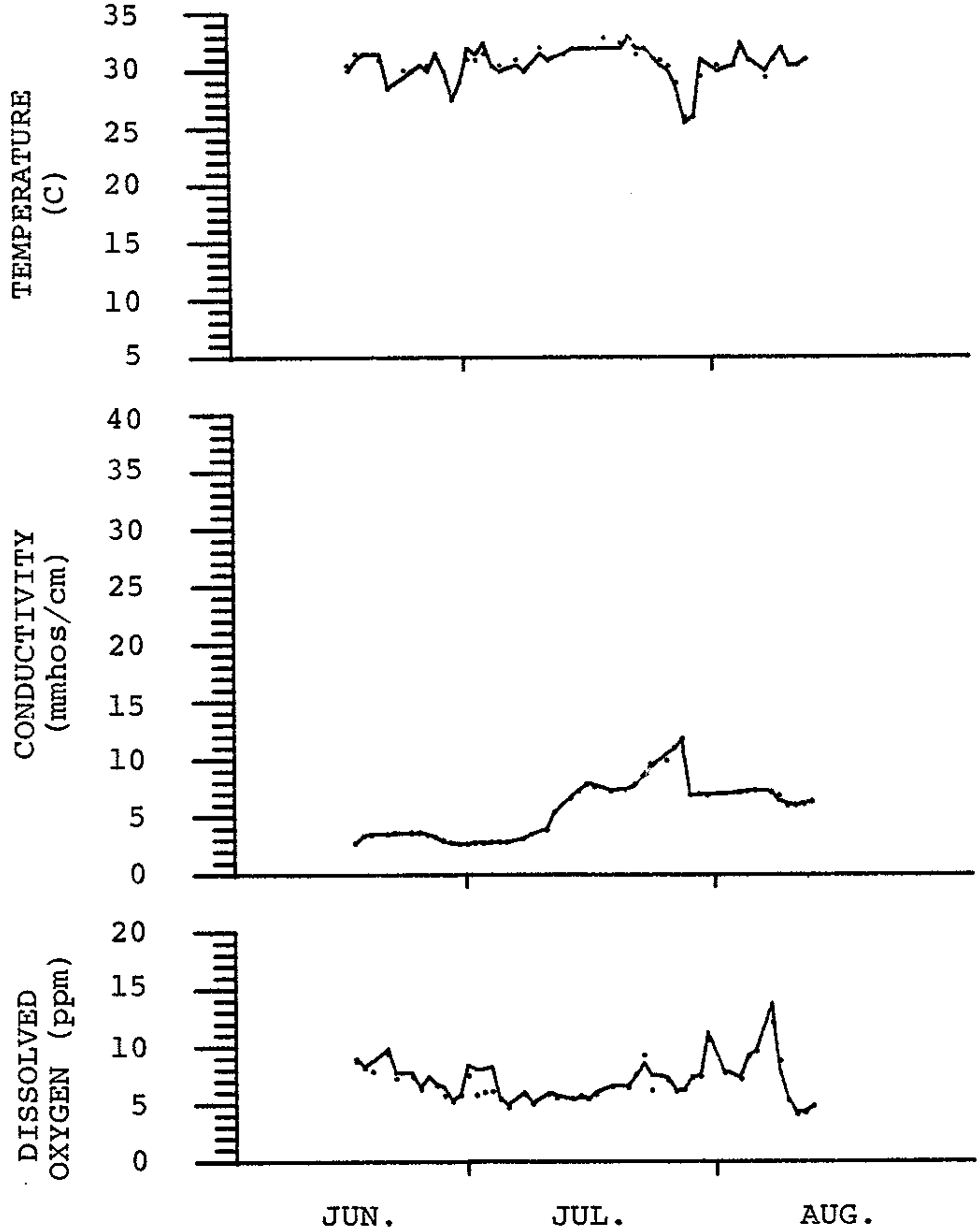


Figure B27. Temperature, conductivity and dissolved oxygen levels for pond 7 (control III pond) from June 18 to August 10, 1979. Solid line indicates surface values; dots represent bottom values.

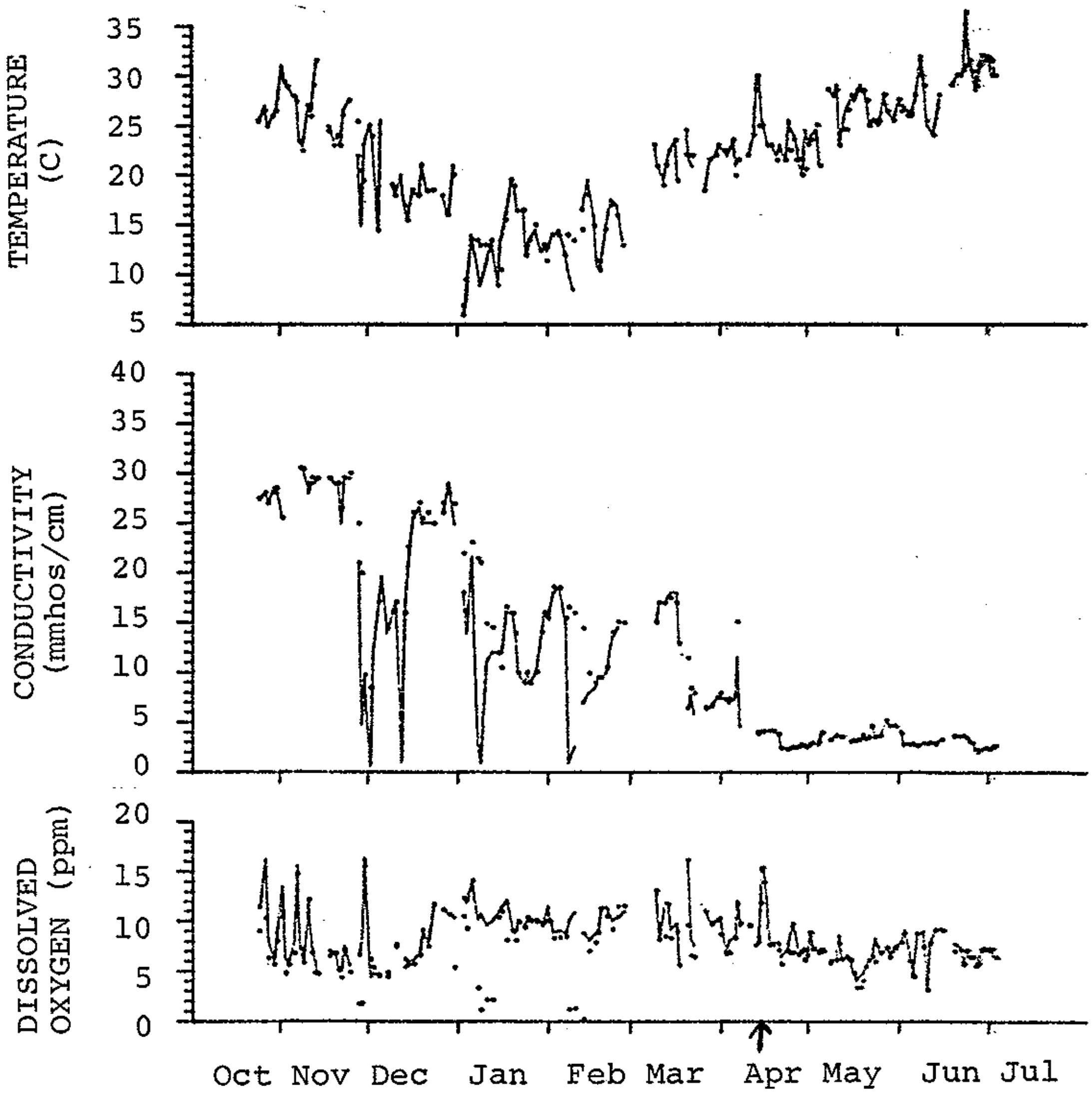


Figure B28. Temperature, conductivity and dissolved oxygen levels for the overwintering study (pond 7 pond 10) from October 23, 1978 to July 2, 1979. Solid line indicates surface values; dots represent bottom values. Arrow indicates when shrimp were moved from pond 7 to pond 10.

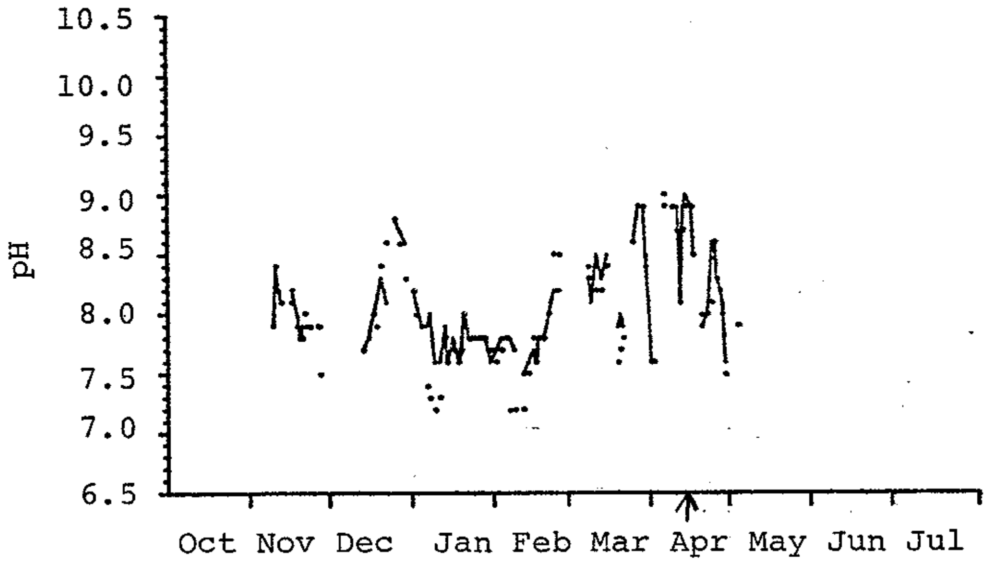


Figure B29. pH levels for the overwintering study (pond 7 pond 10) from October 23, 1978 to July 2, 1979. Solid line indicates surface values; dots represent bottom values. Arrow indicates when shrimp were moved from pond 7 to pond 10.

APPENDIX C - BIOLOGICAL DATA

Table C1. Mean length, weight, condition and number sampled of white shrimp and blue shrimp during the polyculture experiment.

Pond	Date	Species	Sample size	Length mean ± std. dev.	Weight mean ± std. dev.	Condition
4	8-24-78	white shrimp	30	73.5 ± 5.4	2.67 ± 0.59	6.72
"	9-9-78	"	30	103.7 ± 4.6	7.41 ± 0.83	6.64
"	9-23-78	"	30	114.4 ± 3.9	10.46 ± 1.03	6.99
"	10-9-78	"	30	122.5 ± 2.8	13.38 ± 0.92	7.28
"	10-23-78	"	100	128.8 ± 3.7	14.94 ± 1.21	6.99
4	8-24-78	blue shrimp	30	82.1 ± 8.1	3.98 ± 0.95	7.19
"	9-9-78	"	30	113.0 ± 4.8	9.78 ± 1.19	6.78
"	9-23-78	"	30	121.9 ± 8.3	12.76 ± 2.29	7.04
"	10-9-78	"	30	136.6 ± 3.2	18.65 ± 1.29	7.32
"	10-23-78	"	100	144.8 ± 4.8	21.80 ± 2.45	7.18
6	8-24-78	white shrimp	30	70.3 ± 7.1	2.40 ± 0.63	6.91
"	9-9-78	"	30	110.0 ± 4.7	9.60 ± 1.26	7.21
"	9-23-78	"	30	122.8 ± 3.3	13.27 ± 1.18	7.17
"	10-9-78	"	30	125.9 ± 3.2	14.82 ± 1.20	7.43
"	10-23-78	"	100	133.2 ± 3.6	17.07 ± 1.30	7.22
7	8-22-78	white shrimp	30	72.7 ± 5.9	2.74 ± 0.62	7.13
"	9-9-78	"	30	96.0 ± 6.7	6.08 ± 1.22	6.87
"	9-23-78	"	30	113.5 ± 4.3	10.40 ± 1.30	7.11
"	10-9-78	"	30	124.9 ± 3.9	14.30 ± 1.39	7.34
"	10-21-78	"	100	130.1 ± 3.3	16.38 ± 1.24	7.44
21	8-22-78	white shrimp	30	71.7 ± 4.8	2.56 ± 0.53	6.95
"	9-9-78	"	30	95.2 ± 7.7	6.05 ± 1.10	7.01
"	9-23-78	"	30	109.6 ± 2.3	9.40 ± 0.75	7.14
"	10-9-78	"	30	120.3 ± 2.5	12.72 ± 0.88	7.31
"	10-23-78	"	100	123.9 ± 3.3	14.04 ± 0.98	7.38

Table Cl. (continued).

Pond	Date	Species	Sample size	Length mean ± std. dev.	Weight mean ± std. dev.	Condition
22	8-24-78	white shrimp	30	85.2 ± 4.9	4.38 ± 0.79	7.08
"	9-9-78	"	30	107.8 ± 4.6	8.80 ± 1.17	7.02
"	9-23-78	"	30	117.3 ± 3.8	11.65 ± 1.21	7.22
"	10-9-78	"	30	125.3 ± 3.5	14.30 ± 1.15	7.27
"	10-21-78	"	100	129.2 ± 4.1	15.60 ± 1.35	7.23
22	8-24-78	blue shrimp	30	92.8 ± 7.2	5.87 ± 1.21	7.35
"	9-9-78	"	30	122.4 ± 6.4	13.22 ± 1.83	7.21
"	9-23-78	"	30	129.7 ± 4.9	16.40 ± 1.98	7.52
"	10-9-78	"	30	139.8 ± 4.1	20.17 ± 1.73	7.38
"	10-21-78	"	100	145.8 ± 3.4	22.99 ± 1.57	7.42
23	8-22-78	white shrimp	30	77.7 ± 5.5	3.24 ± 0.67	6.91
"	9-9-78	"	30	105.2 ± 5.1	8.14 ± 1.22	6.99
"	9-23-78	"	30	114.0 ± 4.0	10.58 ± 1.14	7.14
"	10-9-78	"	30	119.1 ± 3.5	12.22 ± 0.98	7.23
"	10-21-78	"	100	123.3 ± 3.8	13.37 ± 1.23	7.13

Table C2. Mean standard length, total length, weight and condition of striped mullet stocked (first 4 dates) and harvested (final date) in the polyculture experiment.

Pond	Date	Sample size	Std. length (mm) mean ± std. dev.	Tot. length (mm) mean ± std. dev.	Weight (g) mean ± std. dev.	Condition
7	8-09-78	62	66.4 ± 6.2	79.5 ± 7.7	6.03 ± 1.93	2.05
"	8-11-78	30	85.3 ± 20.7	103.3 ± 25.9	14.47 ± 10.23	2.33
"	8-12-78	30	91.9 ± 27.2	112.0 ± 33.1	18.58 ± 14.66	2.39
"	8-29-78	13	101.7 ± 15.3	127.9 ± 19.0	23.90 ± 12.67	2.27
"	10-21-78	129	177.5 ± 15.1	225.8 ± 21.6	121.6 ± 38.0	2.17
23	8-09-78	62	67.9 ± 7.8	81.7 ± 9.4	6.40 ± 2.49	2.04
"	8-11-78	30	82.1 ± 19.8	99.0 ± 24.0	12.52 ± 9.14	2.20
"	8-12-78	30	93.6 ± 30.4	113.8 ± 36.9	20.15 ± 17.00	2.45
"	8-29-78	13	97.0 ± 9.2	122.8 ± 12.0	20.46 ± 5.48	2.24
"	10-21-78	135	181.7 ± 16.8	231.0 ± 20.7	122.3 ± 42.2	2.03

Table C3. Mean length, weight, and condition, number sampled and days in culture at the time of sample for blue shrimp during the fall 1978 staggered stocking experiment.

Pond	Date	Days in culture	Sample size	Length mean ± std. dev.	Weight mean ± std. dev.	Condition
2	9-20-78	32	30	67.7 ± 16.63	2.39 ± 1.21	7.70
	10-6-78	48	100	76.6 ± 22.68	3.81 ± 2.50	8.48
	10-18-78	60	60	83.8 ± 22.13	4.96 ± 3.11	11.04
	11-3-78	76	100	102.4 ± 23.44	8.54 ± 4.52	7.95
	11-18-78	91	90	108.4 ± 20.59	10.44 ± 5.11	8.20
	11-28-78	101	300	127.8 ± 18.19	16.25 ± 5.26	7.79
5	9-20-78	32	30	69.8 ± 13.41	2.47 ± 0.94	7.26
	10-6-78	48	100	75.6 ± 23.31	3.75 ± 2.78	11.03
	10-18-78	60	60	93.0 ± 23.80	6.80 ± 3.92	8.45
	11-3-78	76	100	103.1 ± 25.17	9.02 ± 5.39	8.23
	11-18-78	91	90	103.1 ± 19.80	9.17 ± 5.01	8.36
	11-28-78	101	300	124.0 ± 21.20	15.43 ± 6.32	8.09
3	9-20-78	32,14	60	67.9 ± 25.38	3.12 ± 2.35	9.97
	10-6-78	48,30,10	100	86.2 ± 29.05	6.07 ± 4.42	9.48
	10-18-78	60,42,22	90	79.7 ± 28.85	5.22 ± 4.95	10.31
	11-3-78	76,58,35	100	92.7 ± 25.56	6.97 ± 5.18	8.75
	11-18-78	91,73,53	90	97.2 ± 28.39	8.87 ± 7.63	9.66
	11-28-78	101,83,63	300	120.7 ± 24.95	15.66 ± 7.88	8.91
24	9-20-78	32,14	60	50.4 ± 23.49	1.65 ± 2.06	12.89
	10-6-78	48,30,10	100	87.0 ± 32.14	6.88 ± 6.30	10.45
	10-18-78	60,42,22	90	109.3 ± 26.93	11.60 ± 7.35	8.88
	10-23-78	65,47,27	100	67.4 ± 15.12	2.73 ± 1.69	8.92
	"	"	100	104.0 ± 8.98	8.48 ± 2.40	7.54
	"	"	100	141.3 ± 9.33	20.93 ± 2.90	7.42
	"	"	300*	109.0*	11.81*	

* weighted means

Table C4. Mean length and weight, number sampled and days in culture at the time of sample for blue shrimp during the spring 1979 staggered stocking experiment.

Pond	Treatment	Days in culture	Length mean ± std. dev.	Weight mean ± std. dev.	# In sample
3	Control I	19	34.7 ± 3.31	.29 ± .08	50
		31	57.7 ± 5.09	1.32 ± .30	150
		45	67.7 ± 13.19	2.14 ± .86	150
		59	78.2 ± 17.70	3.49 ± 1.62	150
		73	93.4 ± 10.79	5.23 ± 1.30	150
		87	91.4 ± 15.37	5.44 ± 1.94	150
		105	104.2 ± 12.63	7.84 ± 2.05	300
8	Control I	19	30.9 ± 3.78	.22 ± .08	50
		31	57.3 ± 8.84	1.38 ± .49	150
		45	75.2 ± 13.34	2.86 ± 1.08	150
		59	88.9 ± 15.40	4.93 ± 1.66	150
		73	95.4 ± 12.48	6.62 ± 1.82	150
		87	98.8 ± 17.51	6.85 ± 2.57	150
		105	110.5 ± 11.89	9.13 ± 2.13	300
14	Control I	19	30.2 ± 4.42	.21 ± .08	50
		31	60.6 ± 8.56	1.63 ± .55	150
		45	72.4 ± 18.87	2.96 ± 1.49	150
		59	93.4 ± 17.30	5.91 ± 2.20	150
		73	101.6 ± 20.17	8.53 ± 3.41	150
		87	112.6 ± 15.12	10.28 ± 2.94	150
		105	118.8 ± 13.28	11.86 ± 2.96	300

Table C4. (continued)

Pond	Treatment	Days in culture	Length mean ± std. dev.	Weight mean ± std. dev.	# In sample
2	Control II	18	35.1 ± 6.03	.33 ± .15	150
		32	66.0 ± 7.85	1.98 ± .56	150
		46	79.9 ± 16.38	3.72 ± 1.67	150
		60	87.6 ± 22.09	5.49 ± 3.00	150
		80	102.3 ± 21.42	8.93 ± 4.35	300
12	Control II	18	34.5 ± 4.44	.33 ± .12	150
		32	66.3 ± 13.03	2.25 ± .97	150
		46	96.3 ± 14.85	6.51 ± 1.97	150
		60	97.1 ± 23.16	8.63 ± 3.99	150
		80	118.4 ± 19.79	12.78 ± 4.51	300
13	Control II	18	36.5 ± 4.85	.34 ± .13	150
		33	70.2 ± 10.96	2.59 ± .95	150
		46	94.0 ± 16.22	6.71 ± 2.70	150
		60	100.8 ± 23.96	8.45 ± 4.50	150
		80	118.3 ± 20.17	12.89 ± 4.76	300
4	Control III	21	40.5 ± 12.35	.64 ± .63	50
		35	53.1 ± 17.72	1.65 ± 1.87	75
		53	78.5 ± 24.08	5.88 ± 4.91	300
7	Control III	21	47.4 ± 16.61	1.10 ± 1.00	50
		35	53.6 ± 14.39	1.69 ± 1.31	150
		53	81.2 ± 24.05	6.19 ± 4.92	300

Table C4. (continued)

Pond	Treatment	Days in culture	Length mean ± std. dev.	Weight mean ± std. dev.	# In sample
5	Staggered	19	30.2 ± 4.26	.21 ± .08	50
		31,5	58.2 ± 8.28	1.44 ± .47	150
		45,19	72.4 ± 22.13	3.13 ± 1.75	150
		59,33,8	76.9 ± 24.26	3.87 ± 2.87	150
		73,47,22	88.5 ± 25.57	6.28 ± 3.67	150
		87,61,36	89.7 ± 27.65	6.27 ± 4.05	150
		104,78,53	109.2 ± 26.18	10.75 ± 5.22	300
9	Staggered	19	31.7 ± 4.88	.24 ± .10	50
		31,5	63.3 ± 12.14	1.86 ± .76	150
		45,19	77.6 ± 27.68	4.22 ± 2.83	150
		59,33,8	94.4 ± 28.39	7.07 ± 4.08	150
		73,47,22	88.0 ± 36.77	7.08 ± 5.16	150
		87,61,36	85.2 ± 31.44	7.00 ± 5.45	150
		106,80,55	115.7 ± 25.91	12.49 ± 5.66	300
15	Staggered	19	29.9 ± 3.96	.25 ± .37	50
		31,5	59.8 ± 7.22	1.56 ± .47	150
		45,19	88.9 ± 19.85	5.18 ± 2.08	150
		58,32	97.8 ± 20.80	6.91 ± 3.03	150
		73,47	100.2 ± 24.67	8.63 ± 4.52	150
		87,61	105.5 ± 18.82	10.25 ± 3.93	150
		106,80	123.7 ± 12.75	13.19 ± 3.18	300

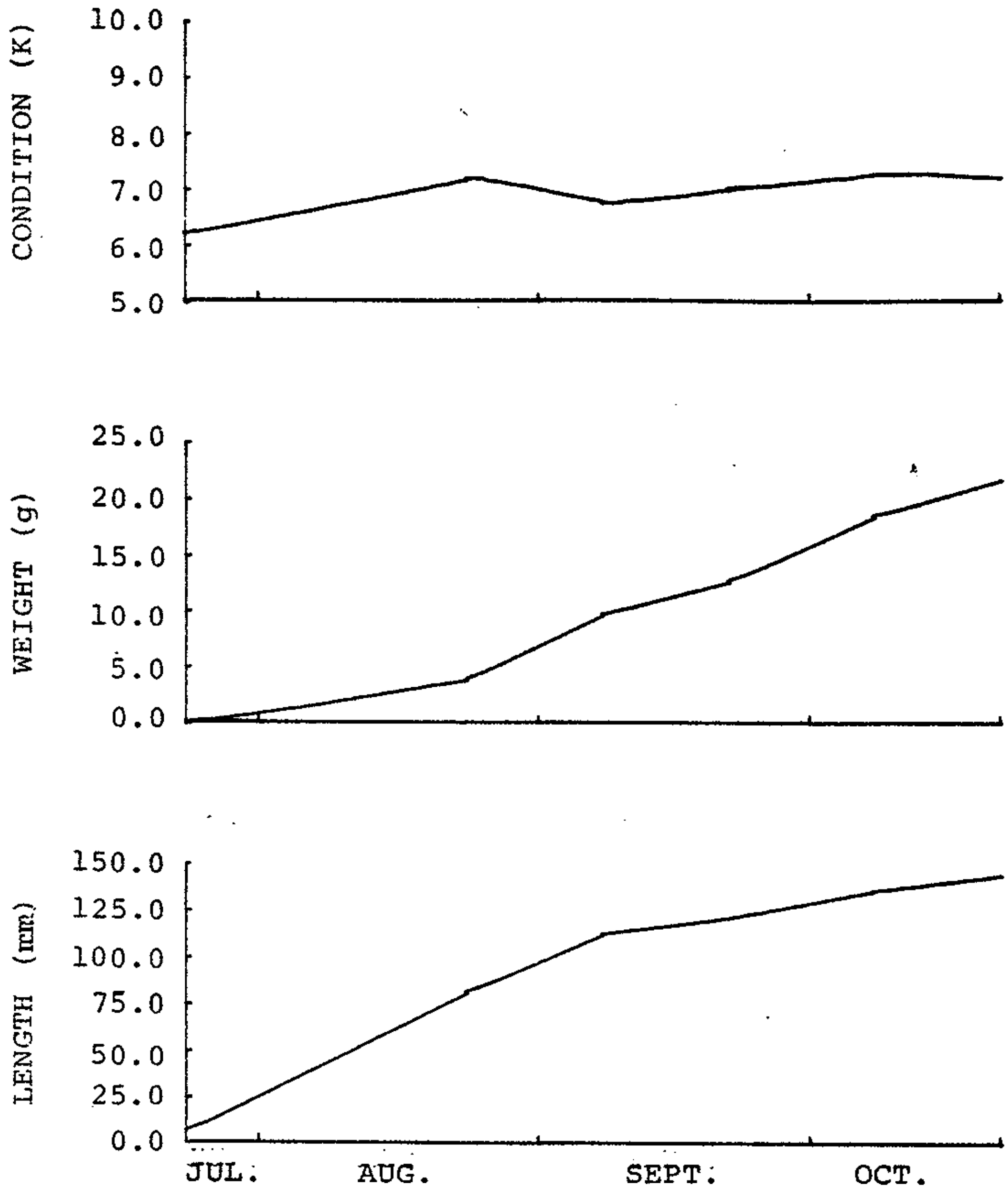


Figure Cl. Mean length and weight of blue shrimp in pond 4 (blue shrimp/white shrimp polyculture) during the 1978 polyculture experiment.

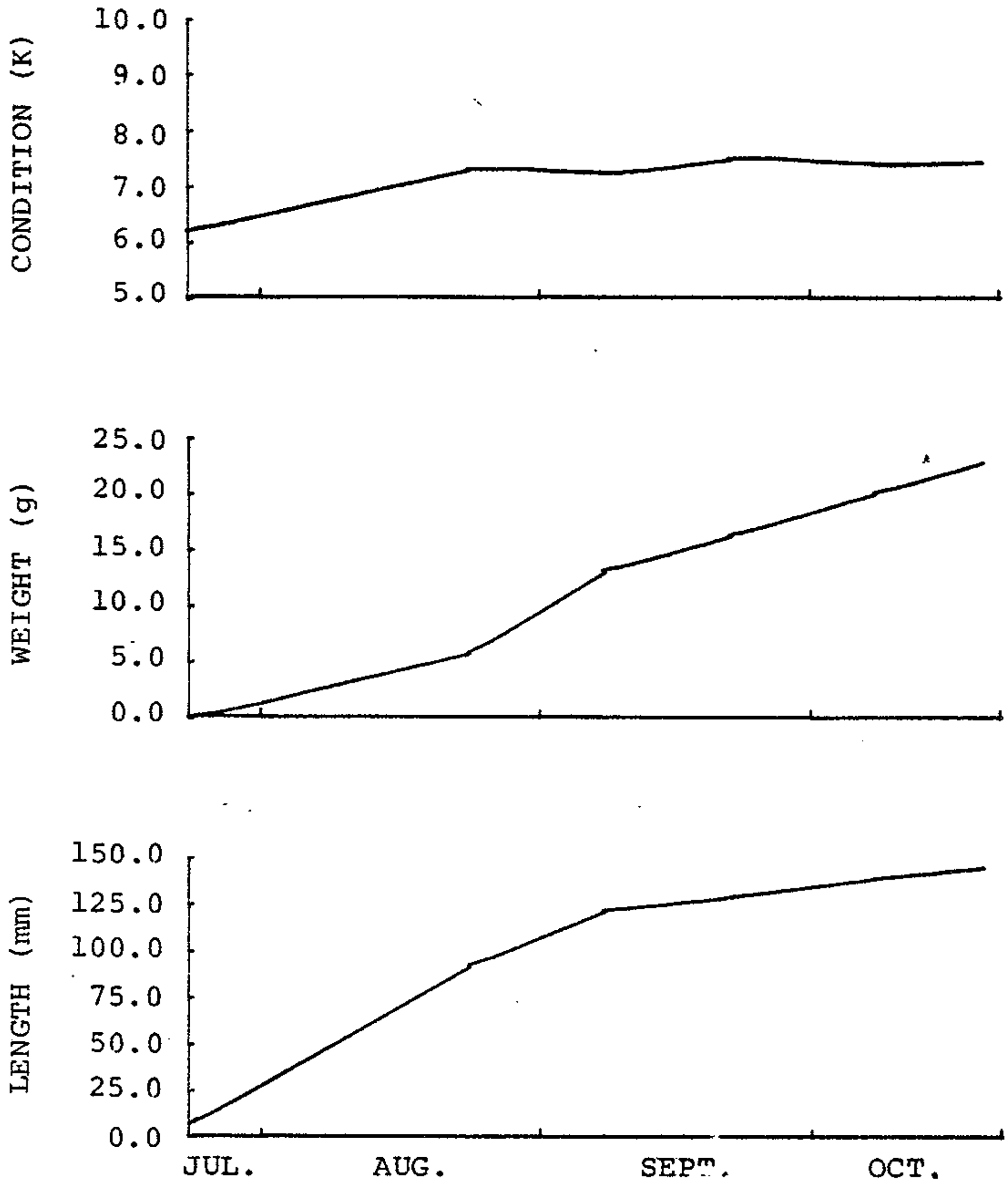


Figure C2. Mean length and weight of blue shrimp in pond 22 (blue shrimp/white shrimp polyculture) during the 1978 polyculture experiment.

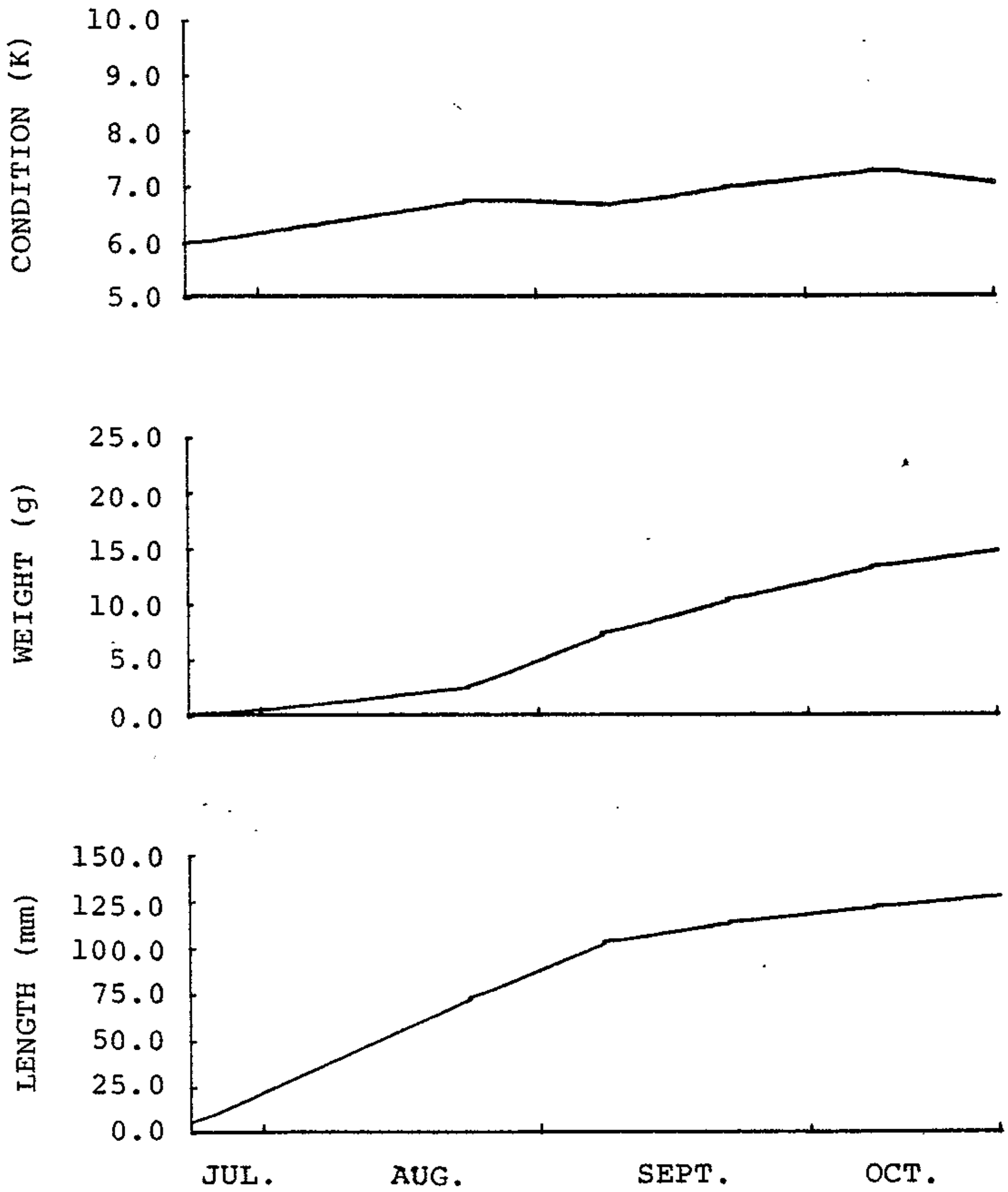


Figure C3. Mean length and weight of white shrimp in pond 4 (blue shrimp/white shrimp polyculture) during the 1978 polyculture experiment.

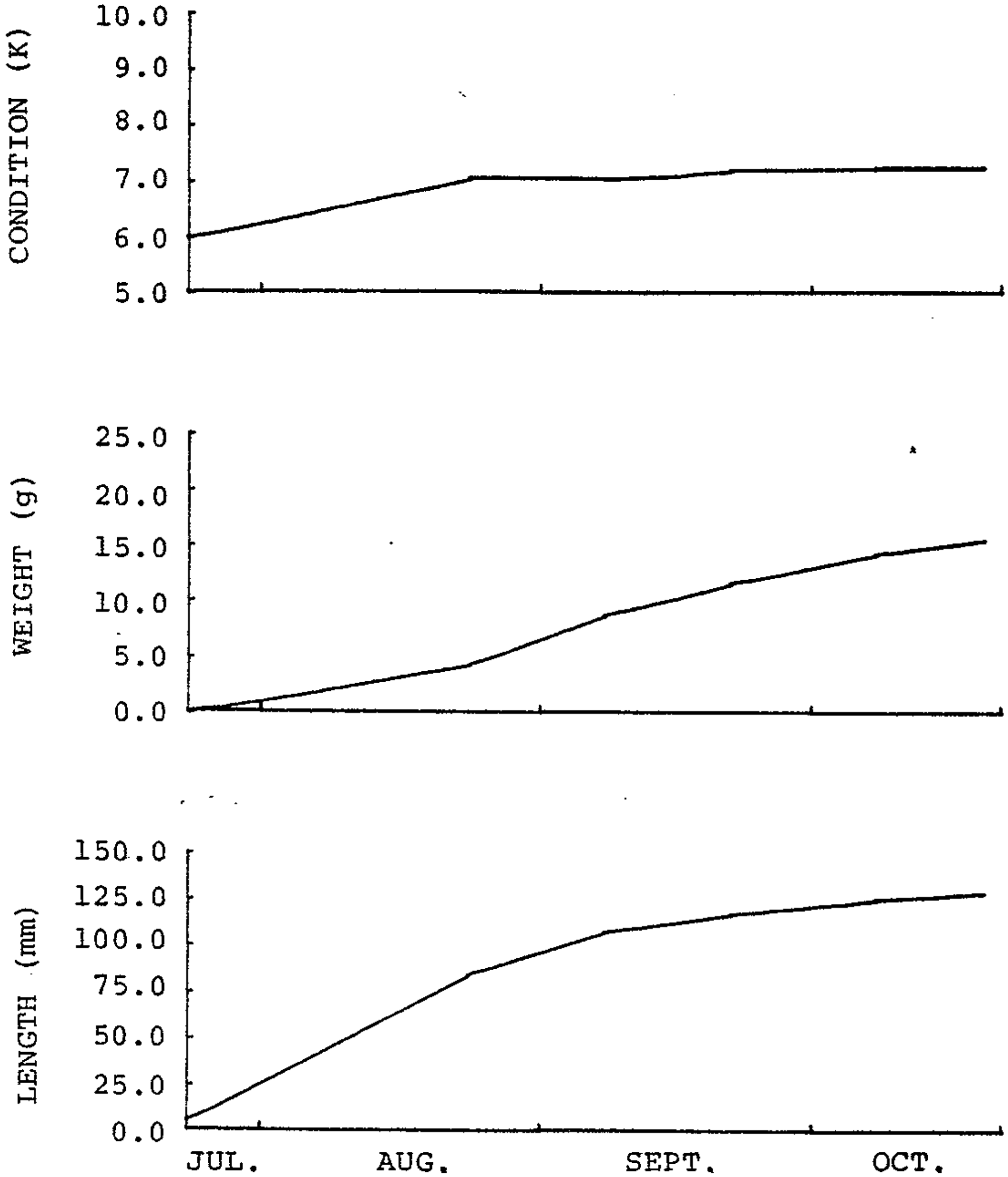


Figure C4. Mean length and weight of white shrimp in pond 22 (blue shrimp/white shrimp polyculture) during the 1978 polyculture experiment.

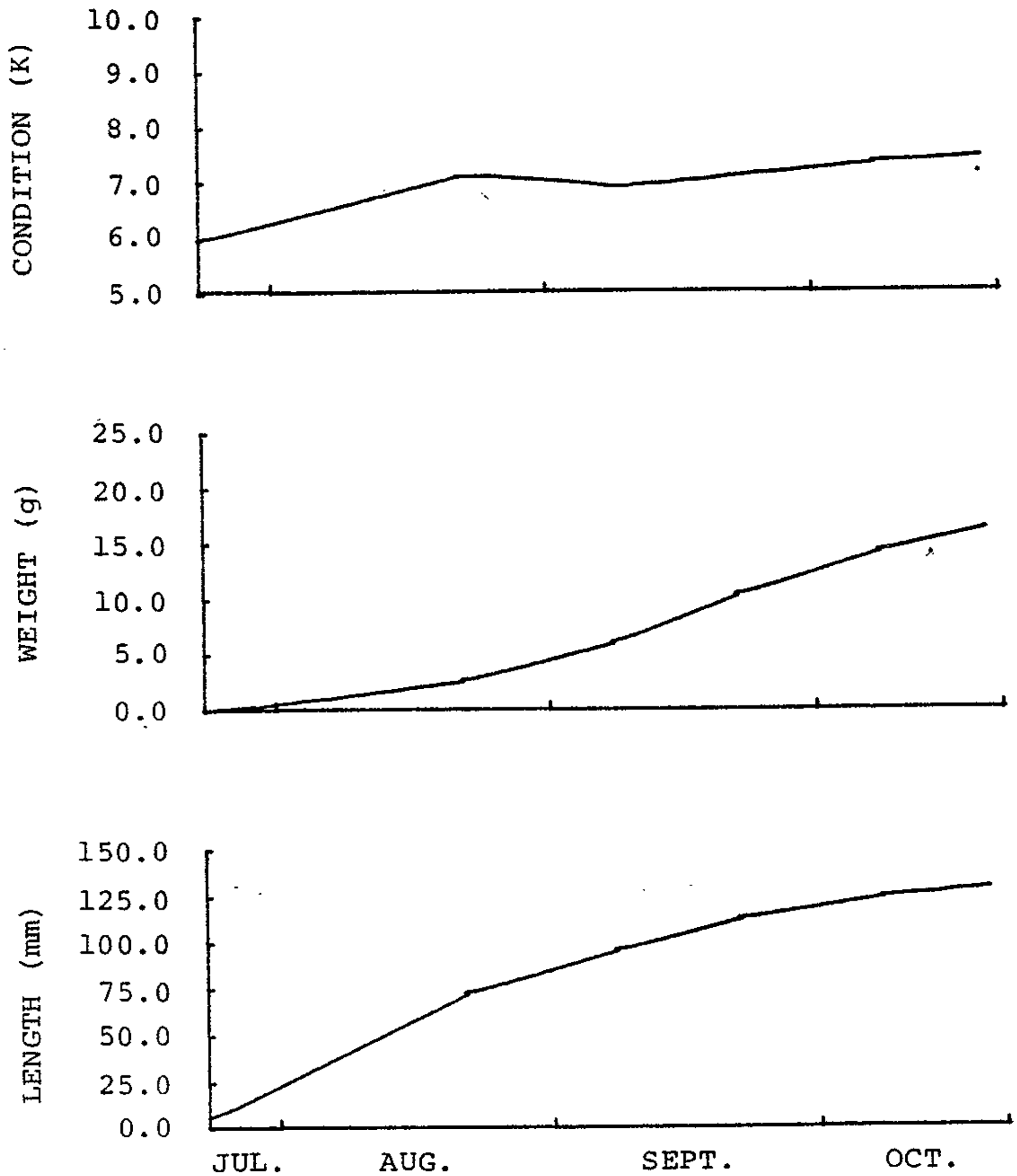


Figure C5. Mean length and weight of white shrimp in pond 7 (white shrimp/striped mullet polyculture) during the 1978 polyculture experiment.

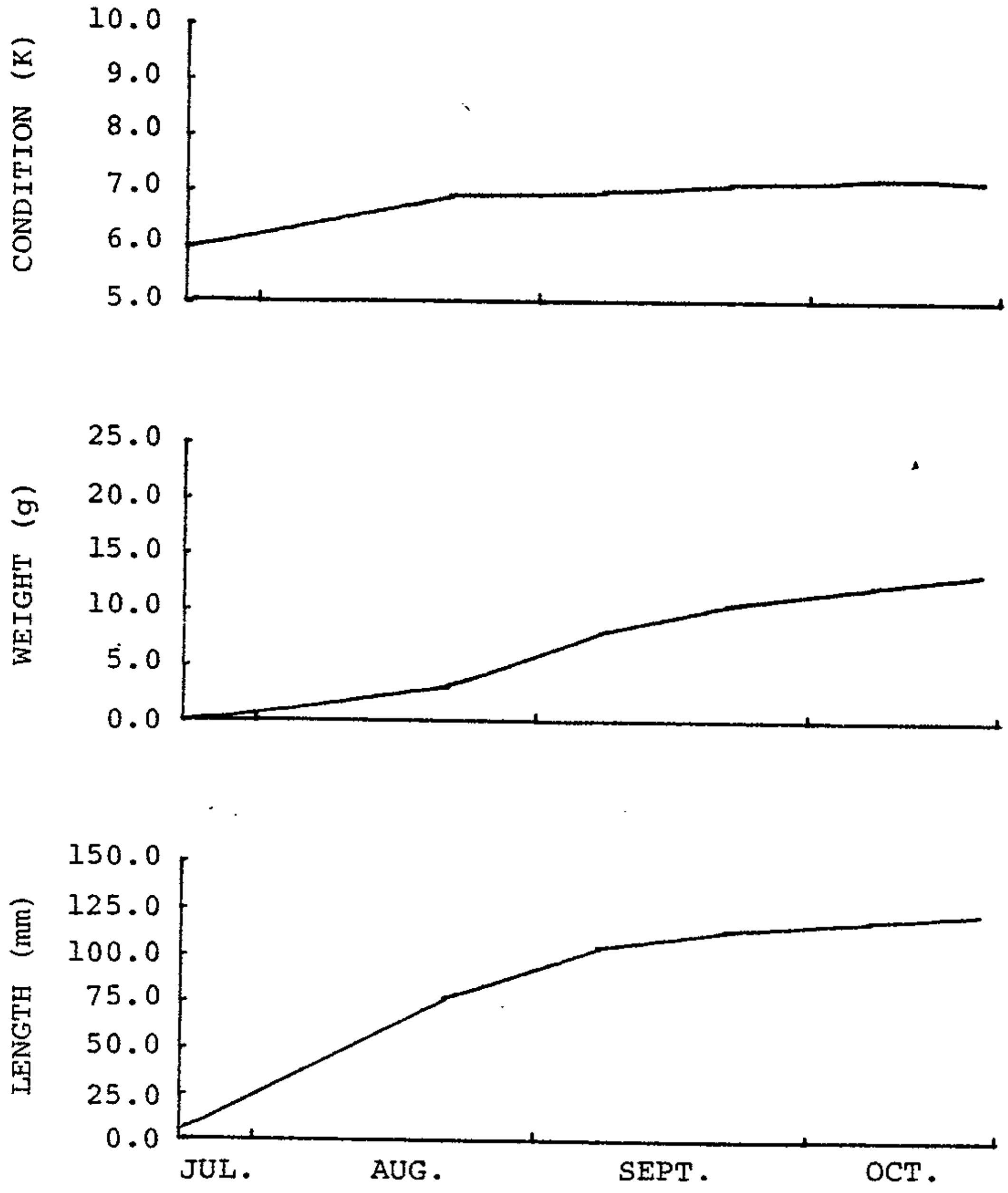


Figure C6. Mean length and weight of white shrimp in pond 23 (white shrimp/striped mullet polyculture) during the 1978 polyculture experiment.

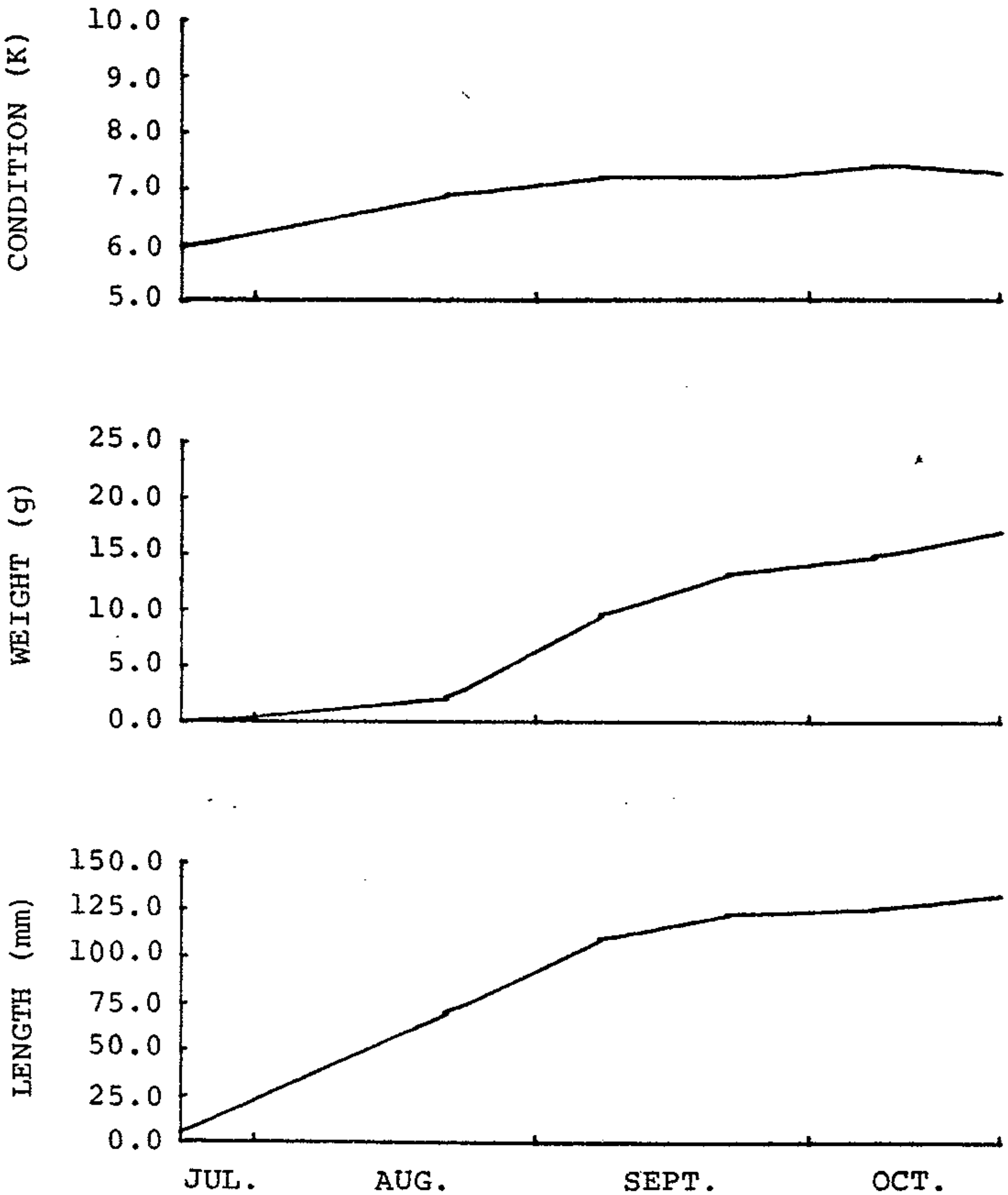


Figure C7. Mean length and weight of white shrimp in pond 6 (white shrimp monoculture) during the 1978 polyculture experiment.

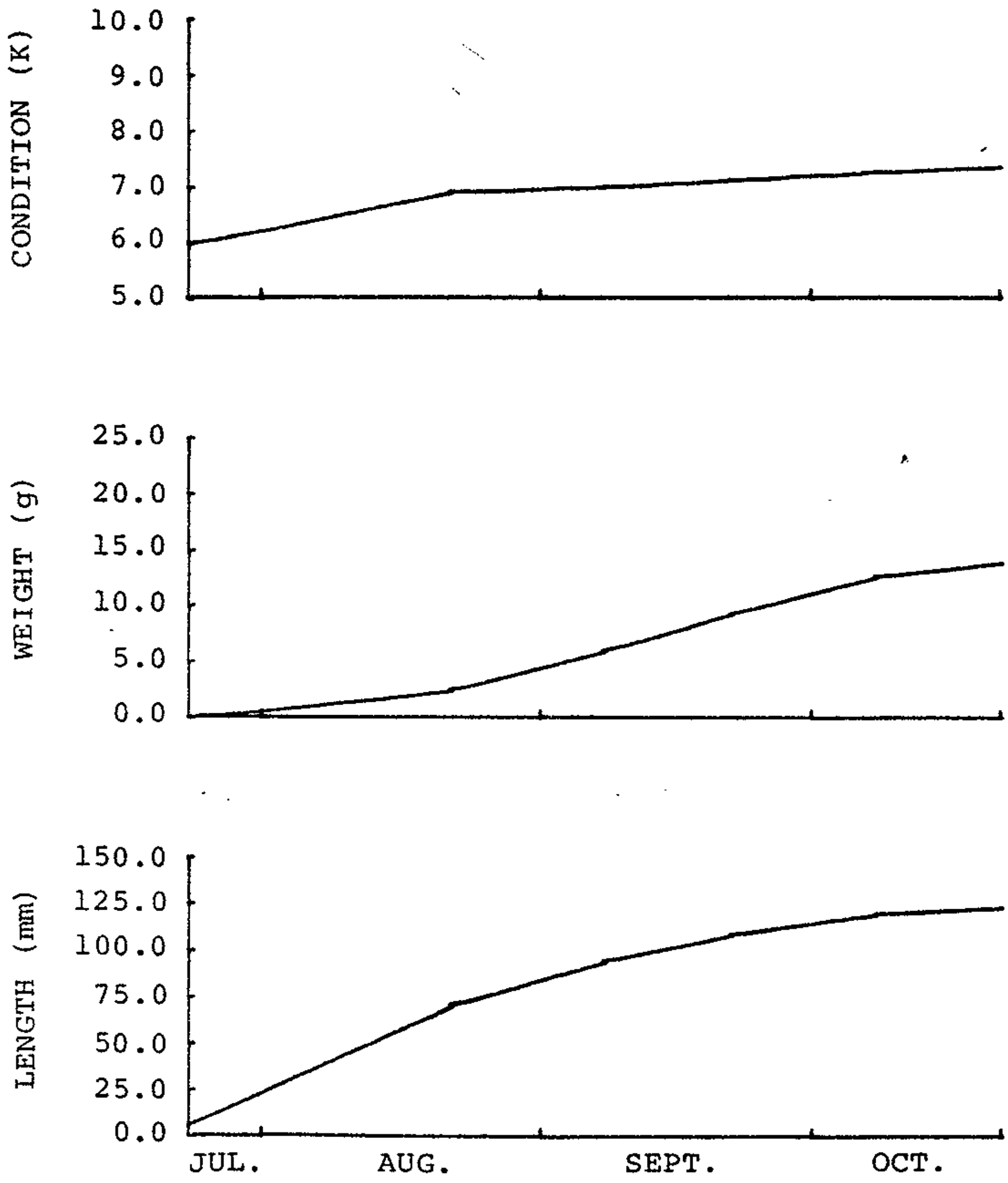


Figure C8. Mean length and weight of white shrimp in pond 21 (white shrimp monoculture) during the 1978 polyculture experiment.

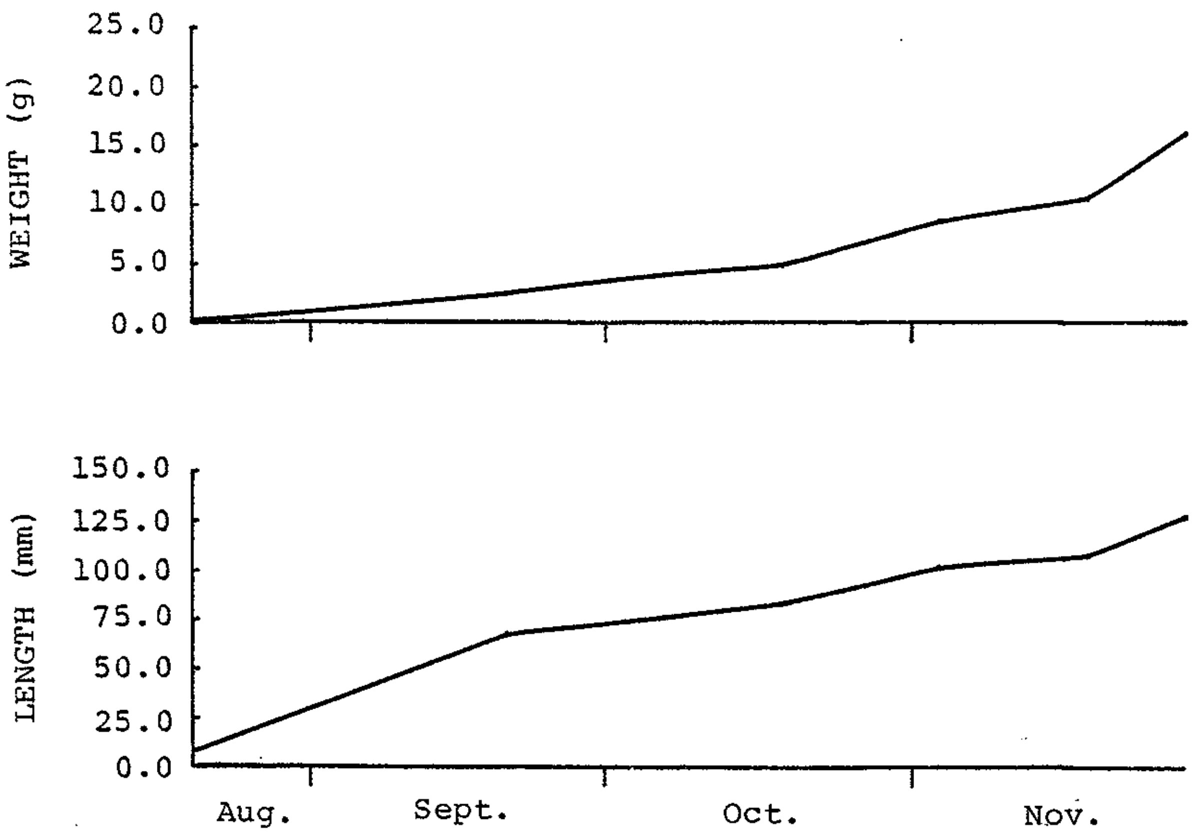


Figure C9. Mean length and weight for blue shrimp in pond 2 (control pond) during the 1978 staggered stocking experiment.

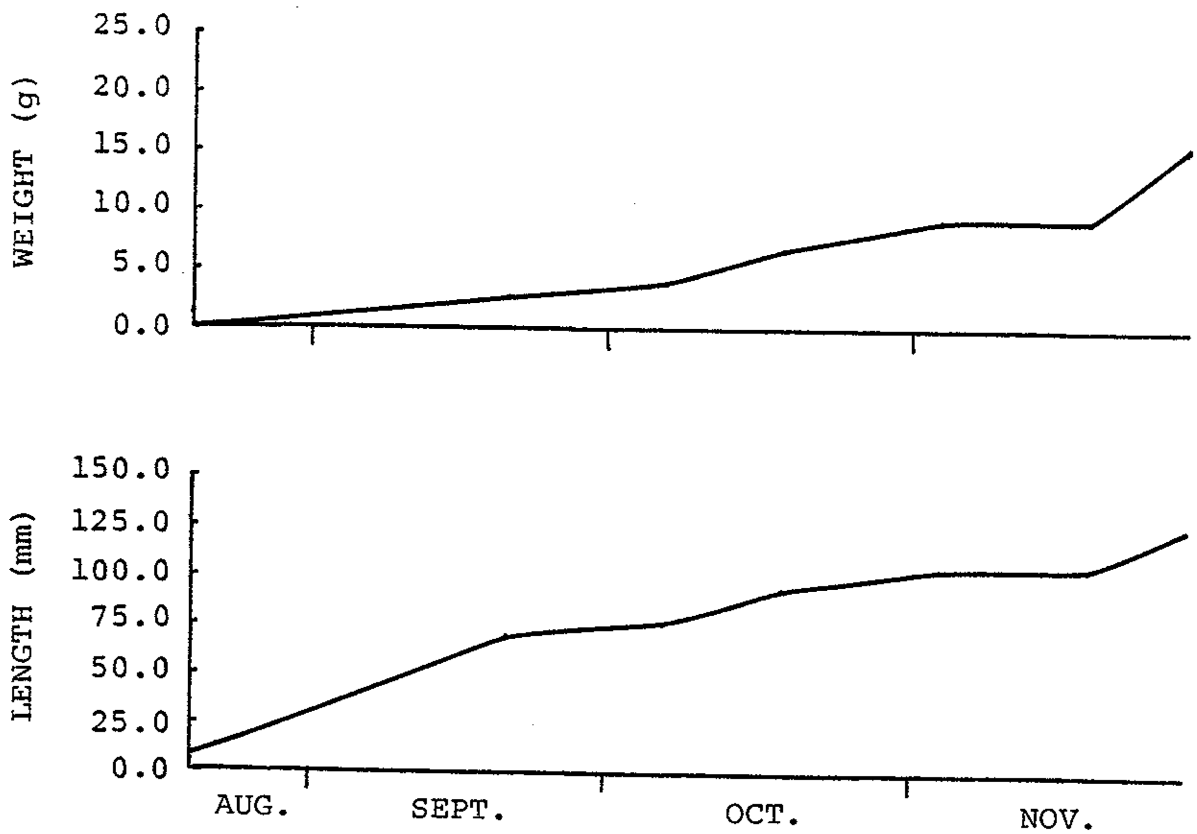


Figure C10. Mean length and weight for blue shrimp in pond 5 (control pond) in the 1978 staggered stocking experiment.

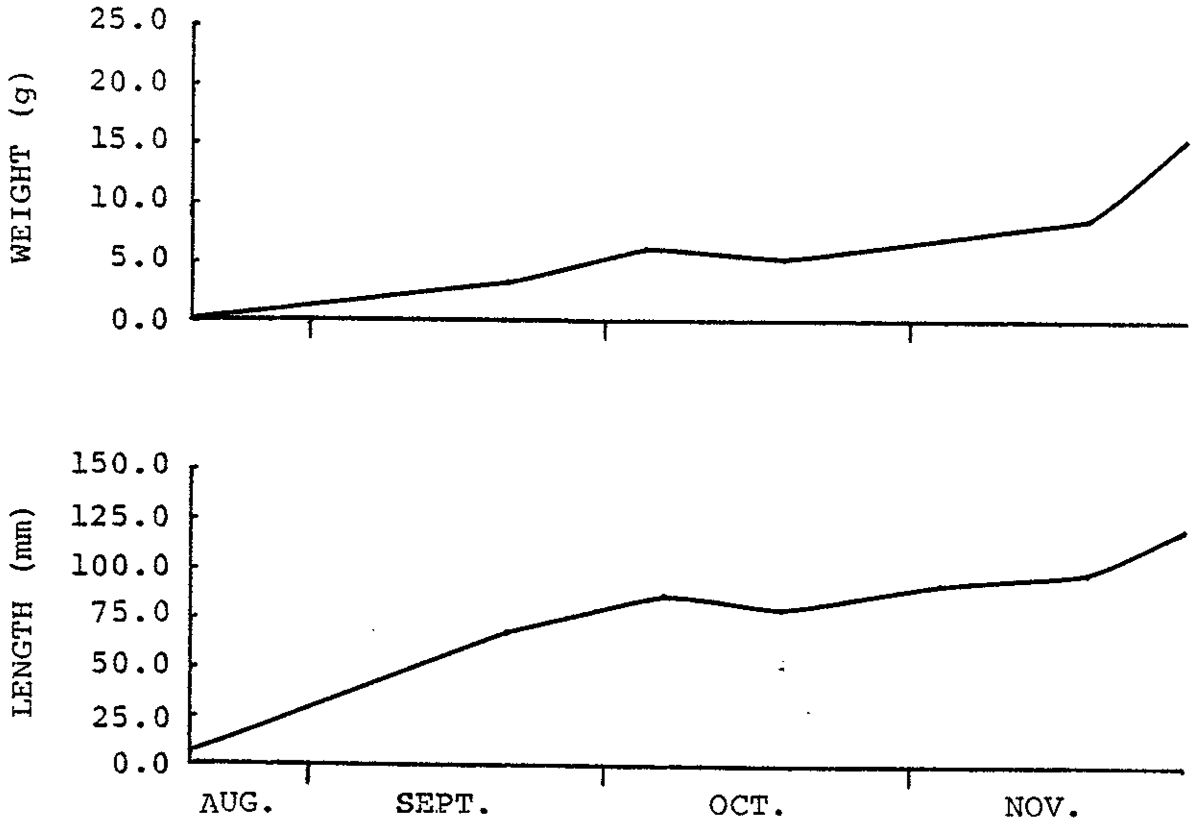


Figure C11. Mean length and weight for blue shrimp in pond 3 (staggered stocked pond) during the 1978 staggered stocking experiment.

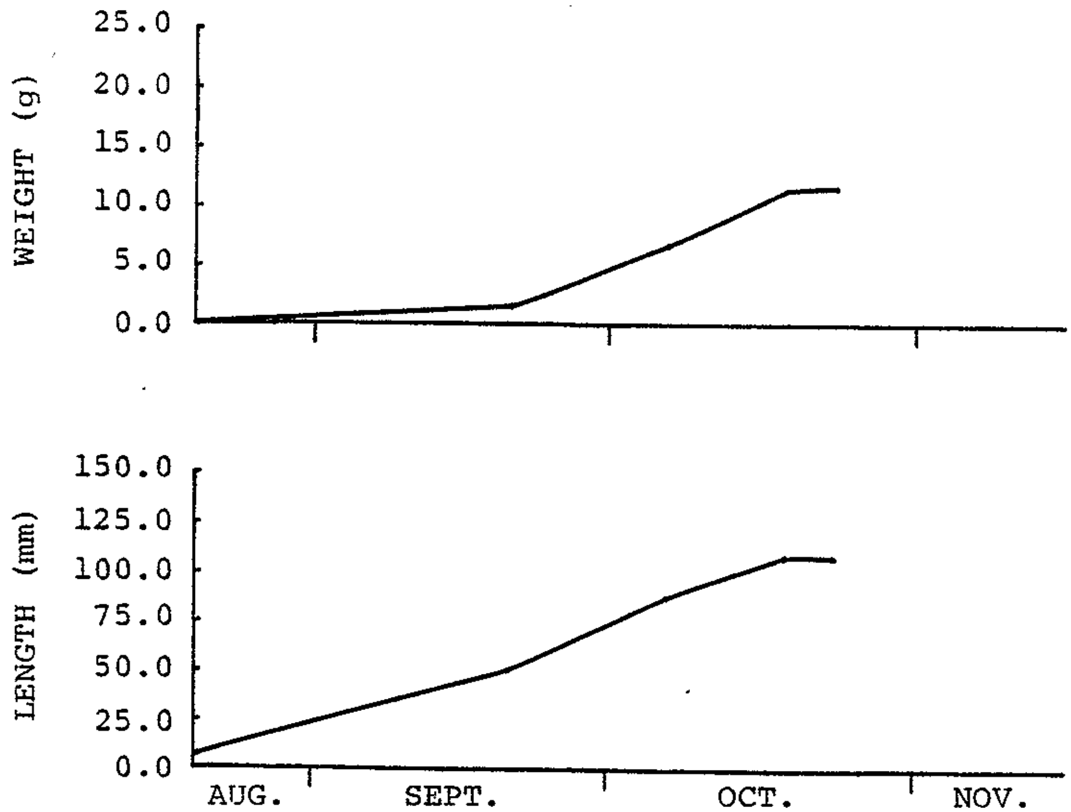


Figure C12. Mean length and weight for blue shrimp in pond 24 (staggered stocked pond) during the 1978 staggered stocking experiment.

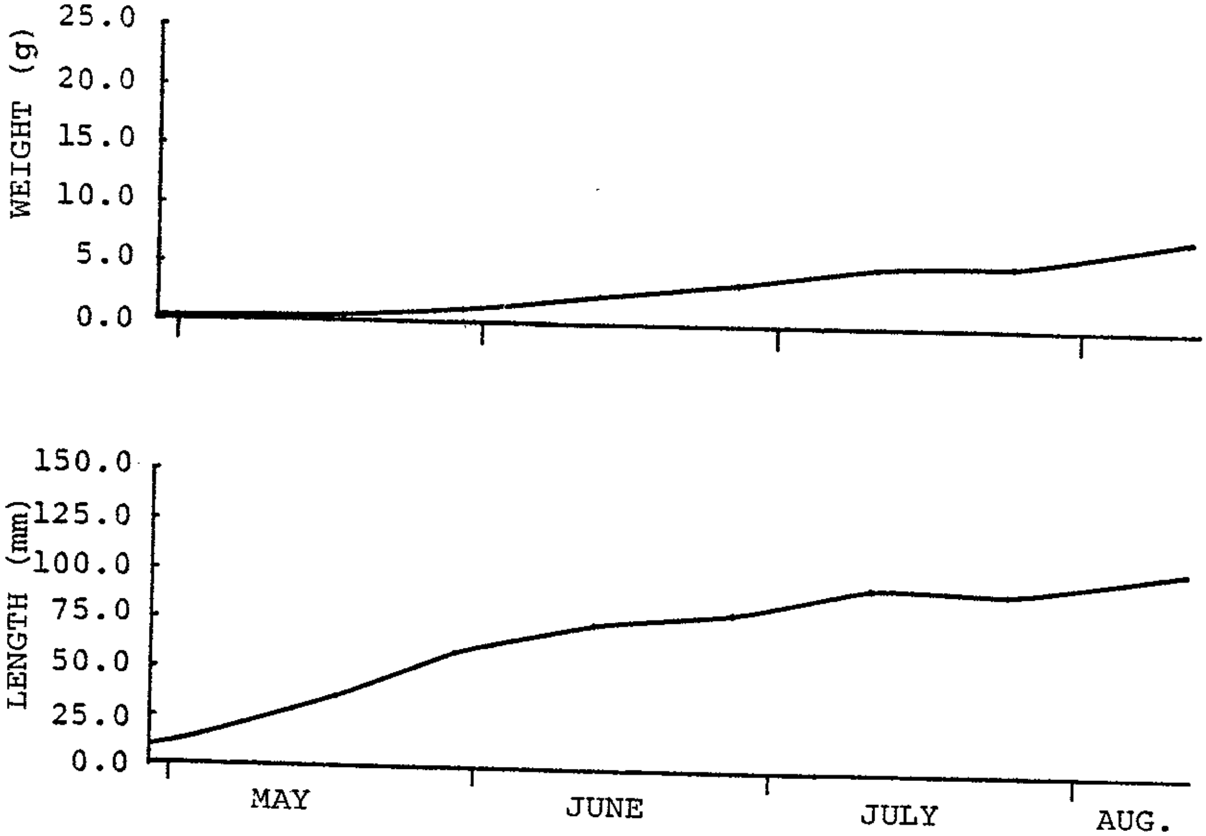


Figure C13. Mean length and weight for blue shrimp in pond pond 3 (control I pond) during the 1979 staggered stocking experiment.

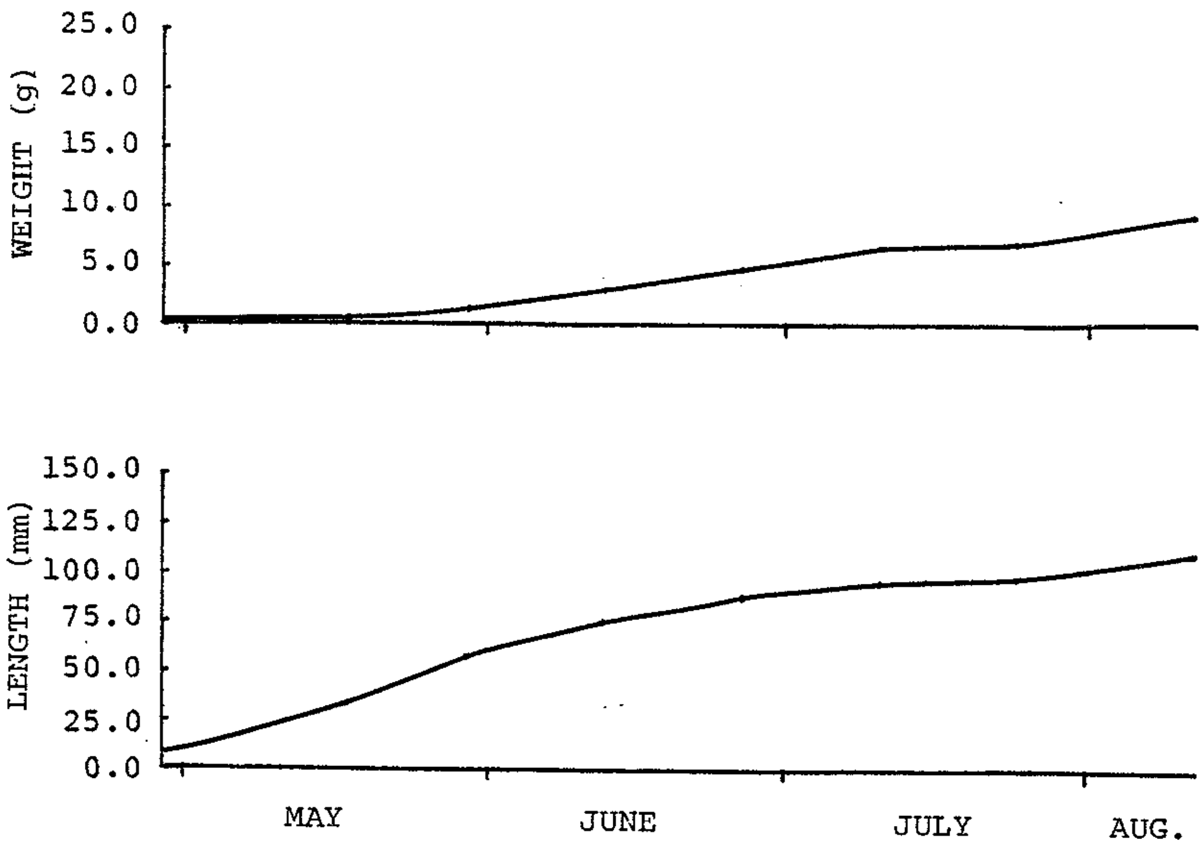


Figure C14. Mean length and weight for blue shrimp in pond 8 (control I pond) during the 1979 staggered stocking experiment.

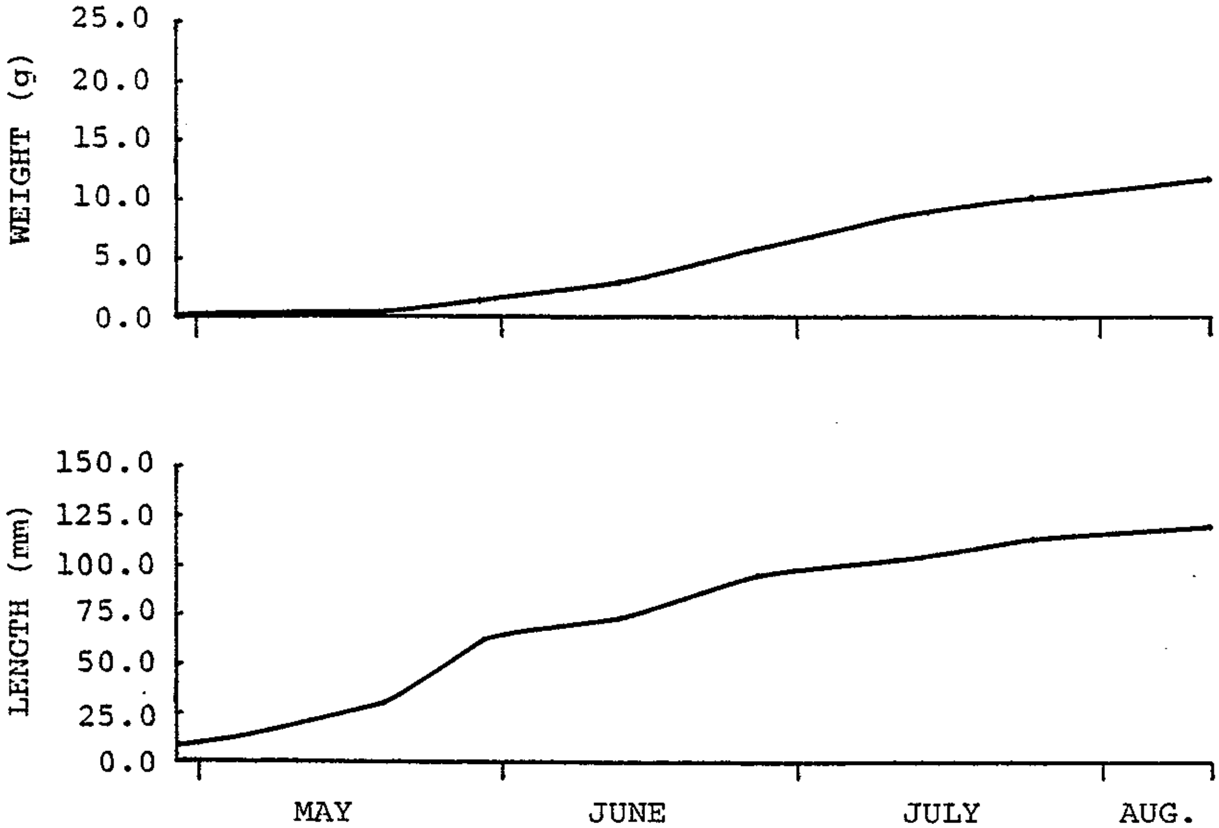


Figure C15. Mean length and weight for blue shrimp in pond 14 (control I pond) during the 1979 staggered stocking experiment.

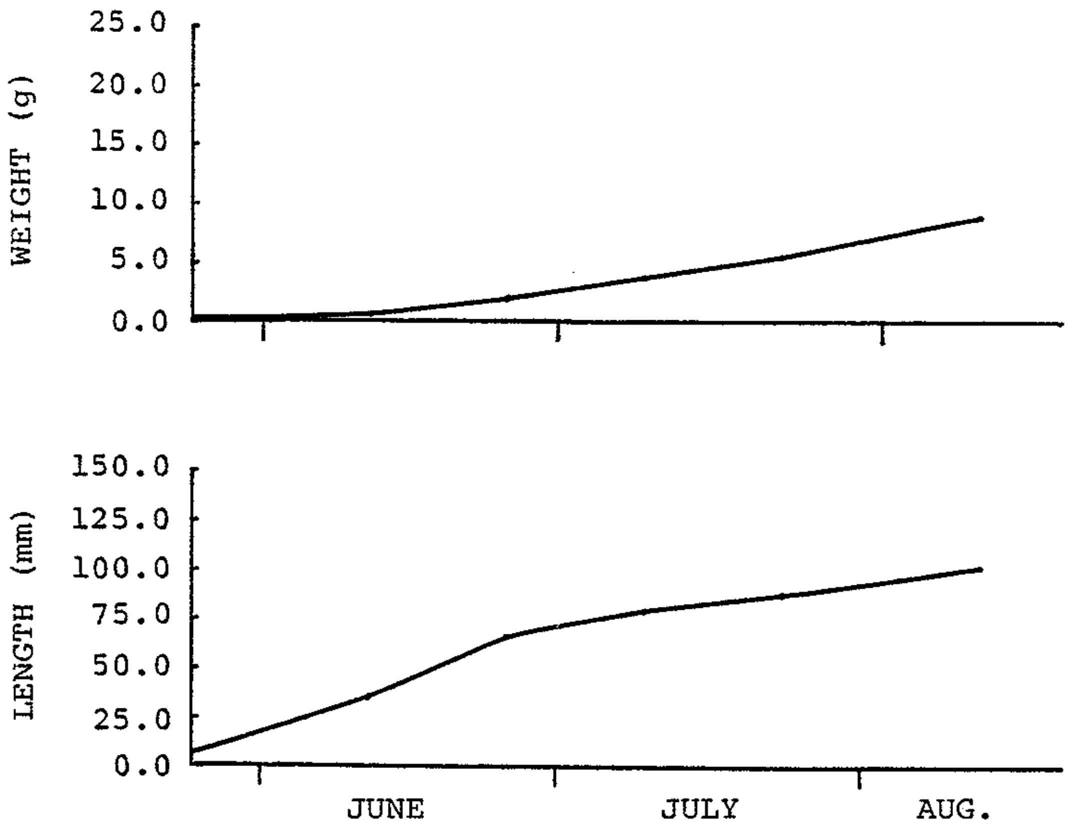


Figure C16. Mean length and weight for blue shrimp in pond 2 (control II pond) during the 1979 staggered stocking experiment.

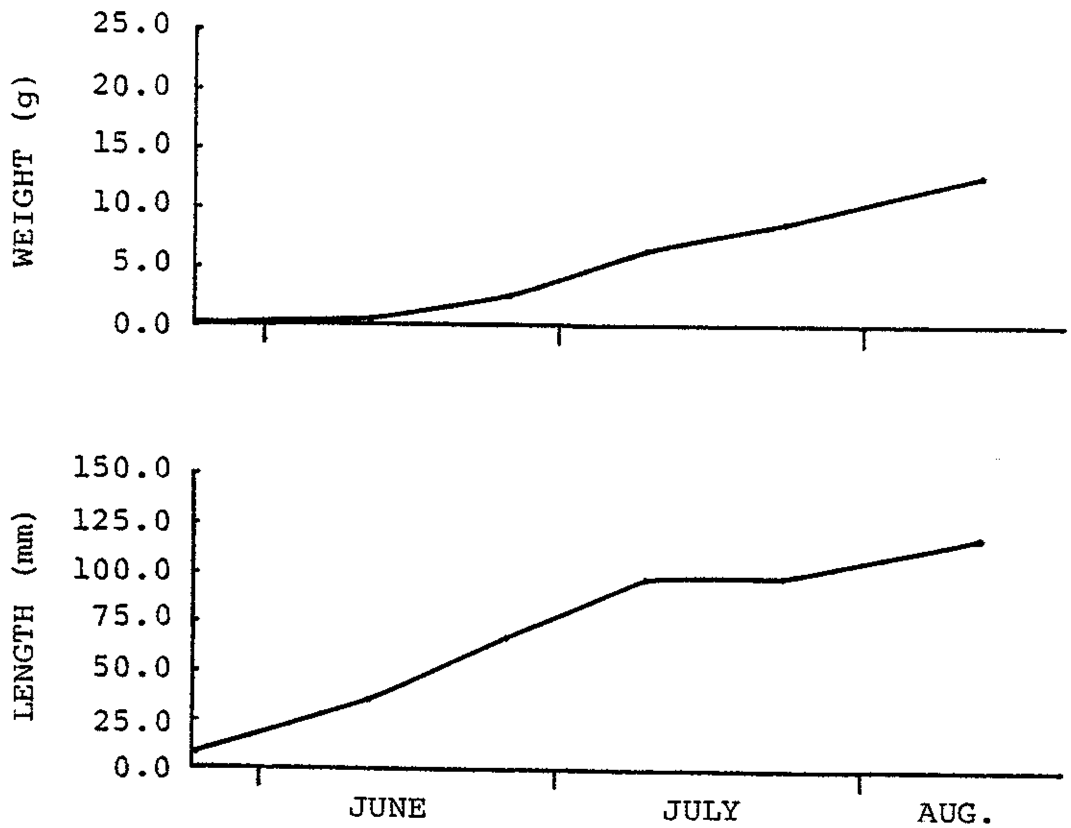


Figure C17. Mean length and weight for blue shrimp in pond 12 (control II pond) during the 1979 staggered stocking experiment.

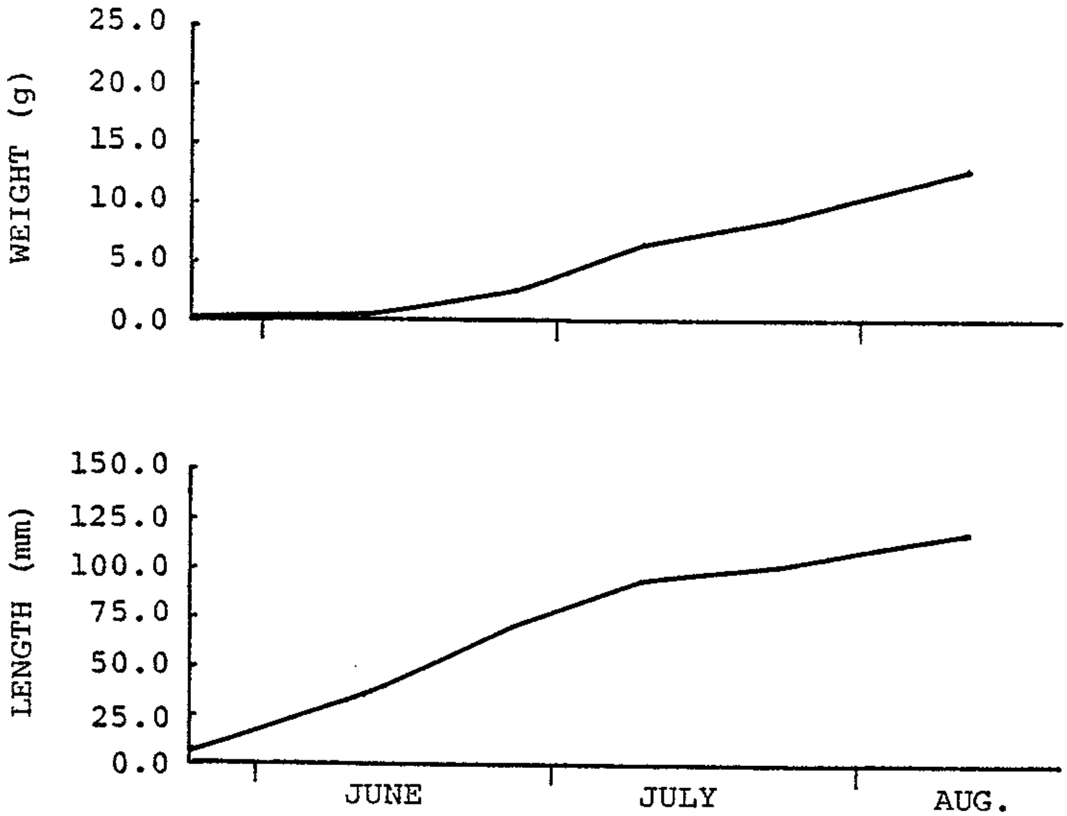


Figure C18. Mean length and weight for blue shrimp in pond 13 (control II pond) during the 1979 staggered stocking experiment.

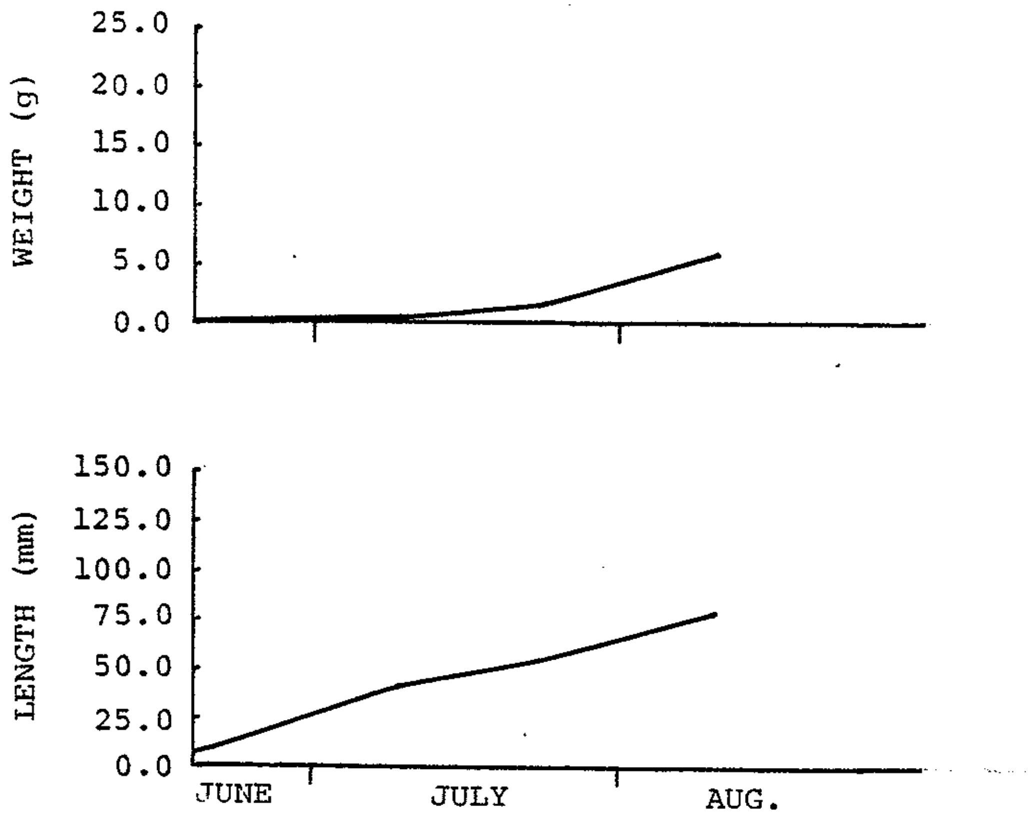


Figure C19. Mean length and weight for blue shrimp in pond 4 (control III pond) during the 1979 staggered stocking experiment.

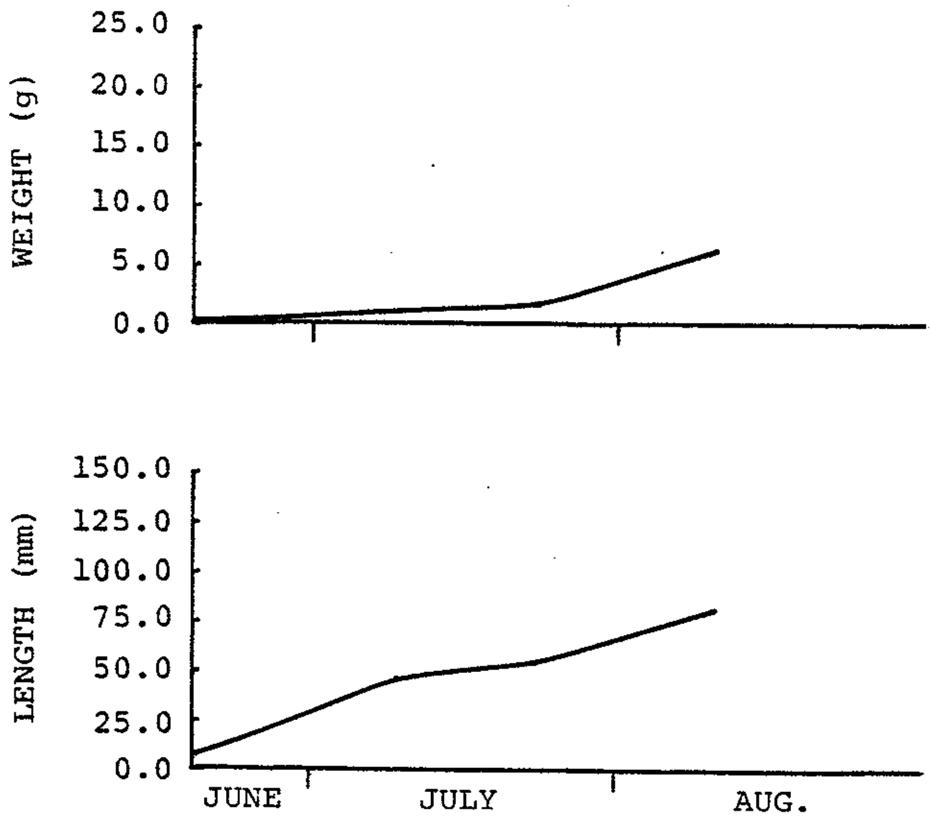


Figure C20. Mean length and weight for blue shrimp in pond 7 (control III pond) during the 1979 staggered stocking experiment.

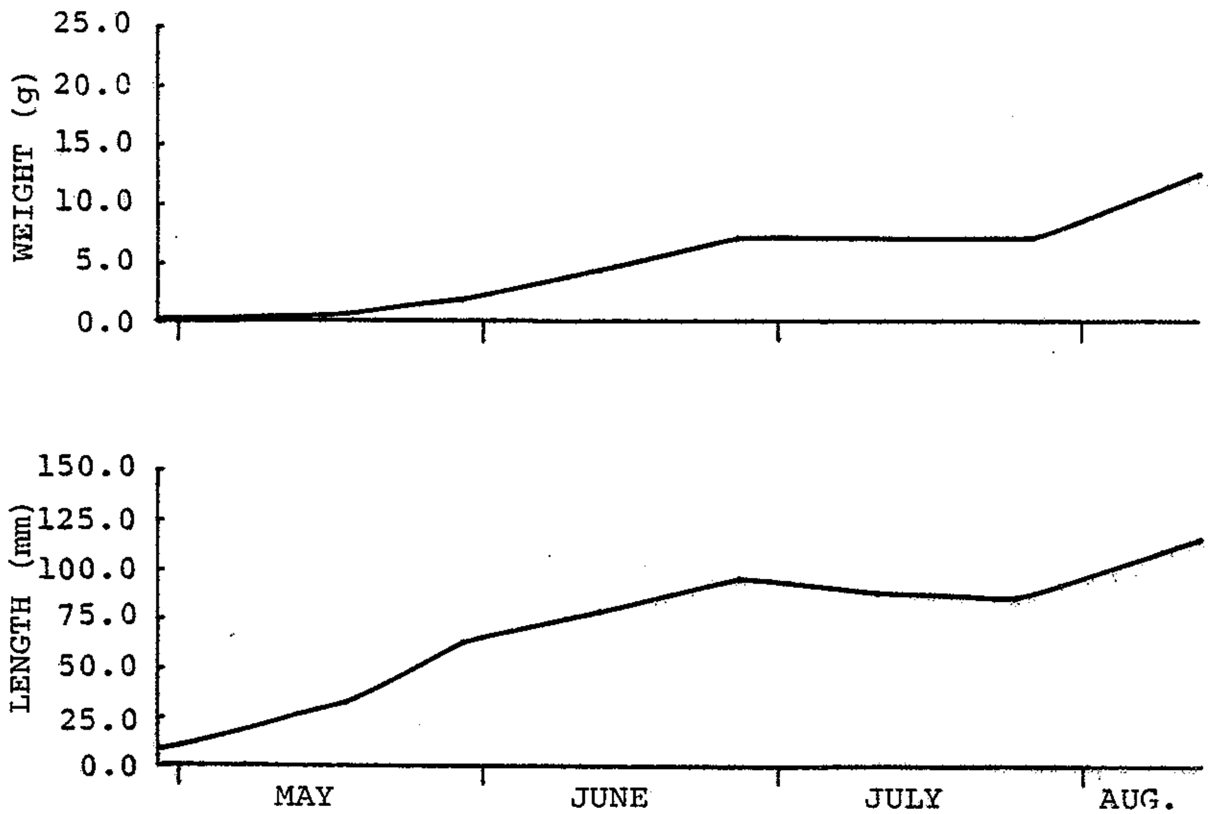


Figure C22. Mean length and weight for blue shrimp in pond 9 (staggered stocked pond) during the 1979 staggered stocking experiment.

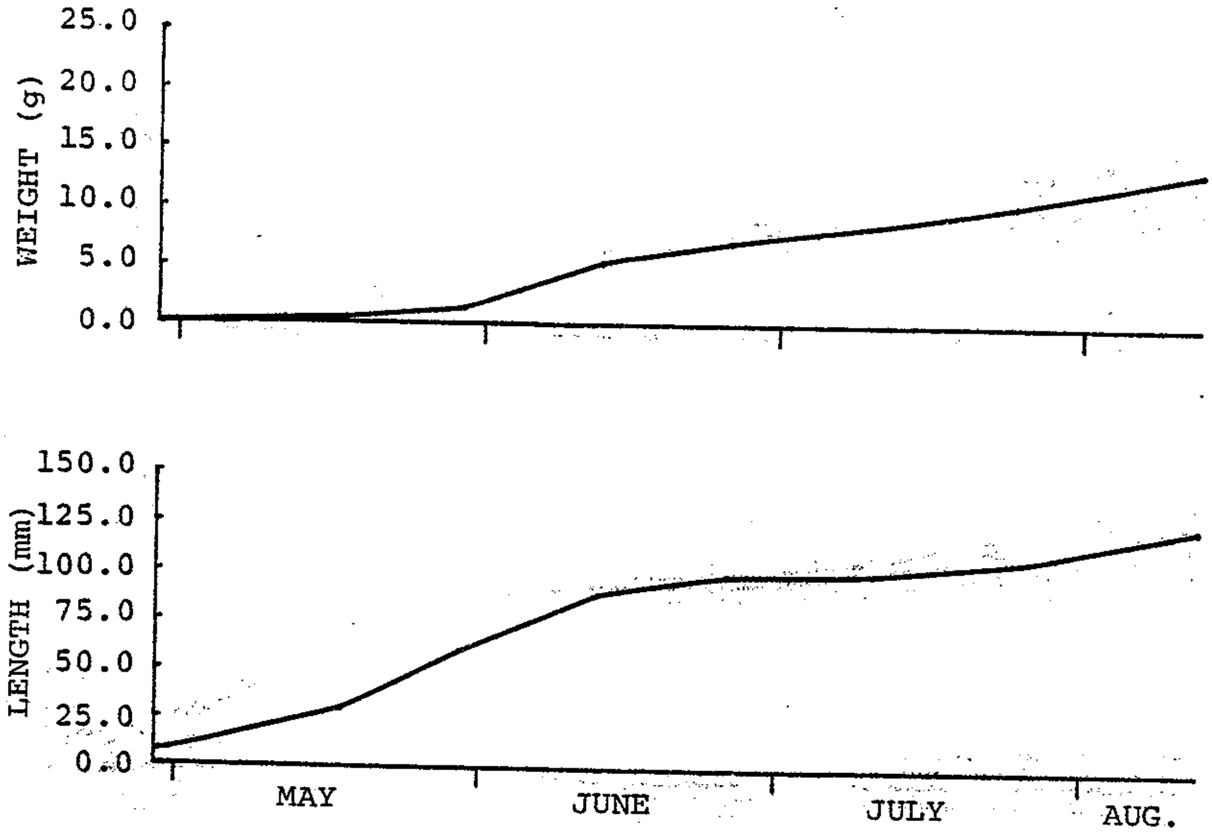


Figure C23. Mean length and weight for blue shrimp in pond 15 (staggered stocked pond) during the 1979 staggered stocking experiment.